RPWG
O

RESTORATION PROJECTS
PROGRESS REPORT
1991

experimental use permit is effective from June 6, 1991 to June 6, 1992. (George LaRocca, PM 15, Rm. 204, CM #2, (703-557-2400))

Persons wishing to review these experimental use permits are referred to the designated product managers. Inquires concerning these permits should be directed to the persons cited above. It is suggested that interested persons call before visiting the EPA office, so that the appropriate file may be made available for inspection purposes from 8 a.m. to 4 p.m., Monday through Friday, excluding legal holidays.

Authority: 7 U.S.C. 136.

Dated: July 21, 1991.

Anne E. Lindsay,

Director, Registration Division, Office of Pesticide Programs.

[FR Doc. 91-18106 Filed 7-30-91; 8:45 am]

BILLING CODE 6560-50-F

[WH-FRL-3979-6]

Availability of Study Plans; Exxon Valdez Oil Spill

AGENCY: Environmental Protection Agency and Alaska Department of Law.

ACTION: Notice of availability of study plans for 1991 restoration science studies and work plans for restoration implementation projects for the *Exxon Valdez* oil spill.

SUMMARY: This notice announces the availability of study plans for restoration science studies and work plans for restoration implementation projects that are in progress or may be carried out in 1991 and invites public comment. This notice is a follow-up to a prior notice, which announced the draft 1991 Restoration Work Plan (56 FR 8898, March 1, 1991).

DATES: Comments on this notice and requests for copies of the study and work plans for 1991 should be received no later than September 16, 1991.

ADDRESSES: All requests for copies of the study and work plans must be submitted in writing to the following address: Restoration Planning Work Group, c/o Oil Spill Public Information Center, 645 G Street, Anchorage, AK 99501.

FOR FURTHER INFORMATION CONTACT: Linda R. Comerci, Environmental Protection Agency, or Stanley E. Senner, Alaska Department of Fish and Game, at 907-271-2461.

SUPPLEMENTARY INFORMATION:

I. Introduction

On March 1, 1991 the Environmental Protection Agency (EPA), on behalf of the Federal Trustees (National Oceanic and Atmospheric Administration, Department of Agriculture, Department of the Interior), and the Alaska State Trustees (Department of Law, Department of Environmental Conservation, Department of Fish and Game) published in the **Federal Register** a draft 1991 Restoration Work Plan (56 FR 8898). It described restoration planning and implementation activities being considered by the Trustees for 1991. More details of these activities were to be described subsequently. Today's notice announces the availability of details about specific restoration activities in 1991 and provides additional opportunity for public comment.

The first part of this notice describes restoration science studies in 1991 and announces the availability of detailed study plans for these studies. The second part of this notice lists the titles of restoration implementation projects described in the March 1, 1991, **Federal Register** notice and announces the availability of detailed work plans for two of these projects. Many of the 1991 restoration science studies are being funded either by the State or the Federal government. Efforts are underway to authorize funds for the remaining science studies.

Some Trustee agencies have funds for implementation of restoration projects. Not all Trustee agencies, however, have been able to locate funding for the restoration implementation projects and funds may not be available for these projects in 1991. The Trustees agencies intend to seek costs for restoration projects from responsible parties.

II. Restoration Science Studies

Background

Restoration science studies provide information used to evaluate potential restoration implementation activities. There are three types of studies (individual studies may serve more than one purpose):

—*Feasibility studies* test the practicality and potential success of proposed restoration techniques;
—*Technical support studies* provide biological information or other information necessary to identify, evaluate, or conduct restoration activities;
—*Monitoring studies* document the extent, degree, and pace of natural recovery of an injured resource.

Each of the 12 studies described below and in the detailed study plans has been reviewed by agency staff and outside experts. The Trustee Council also has evaluated each study, taking into account the following factors:

a. Documentation of probable injury;
b. Estimated time needed for natural recovery;
c. Restoration activity or endpoint that may result from this study;
d. Need for the proposed study with respect to the ability to carry out future restoration activities;
e. Technical feasibility of the proposed study and the prospect for success;
f. Importance of conducting the study in 1991 (i.e., would delay beyond 1991 result in a lost opportunity); and
g. The cost of a proposed study relative to the degree of injury or to the cost of the potential restoration outcome.

The timing of this notice is such that all of the studies described below are now underway, with the exception of study number 11, "Pre-Spill and Post-Spill Concentrations of Hydrocarbons in Sediments and Mussels at Intertidal Sites in Prince William Sound". The Trustee Council however invites public review of the plans for all 12 studies. Any comments submitted by September 16, 1991 will be considered as the Trustee Council reviews the progress of these studies in 1991 and develops proposals for 1992. The detailed study plans for any or all of the studies may be obtained by written request to the address above.

Brief descriptions of each of the science studies follow:

1. Habitat Use, Behavior, and Monitoring of Harbor Seals in Prince William Sound

Lead agency: Alaska Department of Fish and Game.

This technical support and feasibility study will delineate habitats used by harbor seals and provide missing life history information. Satellite tagging methods will be tested. This study will identify possible opportunities for habitat protection and other management activities. Cost: $182,000.

2. Killer Whale Monitoring and Habitat

Lead agency: National Oceanic and Atmospheric Administration.

This technical support and monitoring study is designed to identify habitat needs and determine population trends for killer whales and other cetaceans in the spill area. In 1991 this study will analyze existing census and location data (1984 to present) to determine their adequacy in supporting decisions on habitat protection and other

MM 2

management activities. This study also will begin development of satellite tagging methods for year-round tracking of killer whales, although no tags will be applied in 1991. Cost: $44,000.

3. Population Assessment of the Prince William Sound Sea Otter Population

Lead agency: U.S. Fish and Wildlife Service.

This feasibility and technical support study will develop a technique for sea otter population census and will gather data on otter habitat use. Development of an efficient and reliable census technique is necessary for tracking the long-term recovery of this injured species. The habitat data will be used to identify opportunities for habitat protection and other management activities. Cost: $150,000.

4. Identification of Upland Habitats Used by Marbled Murrelets in Prince William Sound

Lead agency: U.S. Fish and Wildlife Service, U.S. Forest Service.

This technical support study will further document the presence or absence of marbled murrelets in selected upland habitats and characterize their nest habitats through vegetation mapping. This study may link an injured marine species with adjacent upland habitats and identify possible opportunities for habitat management and protection. Cost: $124,000.

5. Prince William Sound Harlequin Duck Breeding Habitat Analysis

Lead agencies: U.S. Fish and Wildlife Service, U.S. Forest Service, Alaska Department of Fish and Game.

This technical support study will attempt to locate nests of harlequin ducks and characterize their nest sites in relation to streams, vegetation, and other habitat features. This study may link the injured marine bird species with upland riparian habitats and identify possible opportunities for habitat management protection. Cost: $223,000.

6. Feeding Ecology and Reproductive Success of Black Oystercatchers in Prince William Sound

Lead agencies: U.S. Fish and Wildlife Service

This technical support and monitoring study will track the breeding productivity and analyze the feeding ecology of a shorebird species at Herring Bay. It will provide data on the status and recovery of an intertidal predator in relation to the recovery of key intertidal invertebrates. Cost: $60,000.

7. Dolly Varden and Cutthroat Trout Populations in Prince William Sound

Lead agency: Alaska Department of Fish and Game.

This technical support study will identify unoiled streams with Dolly Varden and cutthroat trout and estimate stock sizes. This will enable fisheries managers to redirect sport fishing from oiled to unoiled streams, where the stocks can better sustain harvest, allowing faster recovery of stocks in oiled streams. Cost: $147,000.

8. Salmon Coded-Wire Tagging in Prince William Sound

Lead agency: Alaska Department of Fish and Game.

In this technical support study coded-wire tags will be applied to juvenile wild salmon, which will be recovered as adults the following year, to enable greater separation of wild and hatchery stocks. Separation of wild and hatchery stocks, which are harvested together in an intercept fishery, will enable management actions focused on the restoration of stocks from oiled streams. Cost: $805,000.

9. Prince William Sound Pink Salmon Escapement Enumeration

Lead agency: Alaska Department of Fish and Game.

This technical support study will use weir counts to provide data on salmon escapements to compare with and "calibrate" aerial survey aerial. Streams will be walked to obtain additional information on intertidal spawners and stream enhancement opportunities. This study will provide information needed to determine management and enhancement alternatives to restore stocks from oiled streams. Cost: $230,000.

10. Monitoring Coastal Habitats at Herring Bay

Lead agency: U.S. Forest Service.

This monitoring study will track recovery of intertidal invertebrates and marine plants in oiled, unoiled, and cleaned areas at Herring Bay, Prince William Sound. It will provide information needed to understand the extent, degree, and pace of the natural recovery of the intertidal ecosystem on which many species depend for food and habitat. Cost: $246,000.

11. Pre-Spill and Post-Spill Concentrations of Hydrocarbons in Sediments and Mussels at Intertidal Sites in Prince William Sound

Lead agency: National Oceanic and Atmospheric Administration.

This study will monitor hydrocarbon levels in sediments and mussels at sampling sites for which there are historical data. Sampling supported by this study (a second late-summer sampling) will supplement early-spring sampling supported by the 1991 Natural Resource Damage Assessment Study, Coastal Habitat Intertidal Study 1B. A description of this study may be found in, "The 1991 State/Federal Natural Resource Damage Assessment and Restoration Plan for the Exxon Valdez Oil Spill" p.181–187, available from the Oil Spill Public Information Center whose address is given above. This study will provide a more complete history of exposure from releases of oil buried in intertidal sediments, particularly during biologically active summer months. The proposed second sampling will be conducted only if 1989 and 1990 sampling results indicate that seasonal factors affect levels of residual hydrocarbons in sediments and mussels. Cost: $84,000.

12. Survey of Injured Tidal Marshes in Prince William Sound and the Gulf of Alaska

Lead agency: U.S. Environmental Protection Agency.

This technical support study will review existing data on the extent, relative value of, and injury to marsh-wetland habitats. The review may be supplemented by field surveys. Pending the results of this study, there may be field studies to test the feasibility of using hydrological and transplanting techniques to restore oiled marshes. Cost: $15,000.

III. Restoration Implementation Projects

Four restoration implementation projects were described in the March 1, 1991 Federal Register notice (56 FR 8898). Work plans are now available for two of the four projects listed below, projects 2 and 3. Based on the results of the May Shoreline Assessment Program for Prince William Sound and the Gulf of Alaska, conducted by the U.S. Coast Guard, the State of Alaska and Exxon, the Trustees have decided that the need for the first project, "Restoration of the Beach Wild Rye Community, is limited. If any areas of Beach Rye are determined to need replanting, these activities will be carried out under the clean-up/response program.

The Restoration Planning Work Group is currently developing a process by which the fourth project, "Protection of Strategic Fish and Wildlife Habitats and Recreation Sites," could be implemented.

The proposed implementation projects are:

1. Restoration of the Beach Wild Rye Community

Lead agencies: Alaska Department of Environmental Conservation, U.S. Forest Service.

2. Public Information and Education for Recovery and Protection of Alaska's Marine and Coastal Resources

Lead agency: U.S. Department of the Interior.

3. Salmonid Stocks and Habitat Restoration

Lead agencies: Alaska Department of Fish and Game, U.S. Forest Service.

4. Protection of Strategic Fish and Wildlife Habitats and Recreation Sites

Lead agencies: Alaska Department of Fish and Game, Alaska Department of Natural Resources, U.S. Department of the Interior, U.S. Forest Service, U.S. Environmental Protection Agency.

Public comments are invited on all four implementation projects.

Dated: June 19, 1991.

LaJuana S. Wilcher,

Assistant Administrator, Office of Water, U.S. Environmental Protection Agency.

Dated: July 18, 1991.

Charles E. Cole

Attorney General, State of Alaska.

[FR Doc. 91-18107 Filed 7-30-91; 8:45 am]

BILLING CODE 6560-50-M

FEDERAL DEPOSIT INSURANCE CORPORATION

Statement of Policy Regarding Treatment of Collateralized Put Obligations After Appointment of the FDIC as Conservator or Receiver

AGENCY: Federal Deposit Insurance Corporation ("FDIC").

ACTION: Policy statement.

SUMMARY: The FDIC has adopted a Statement of Policy which sets forth procedures and guidelines as to how the FDIC, as conservator or receiver of an insured depository institution, will treat collateralized "put" options issued by the insured depository institution. This action is intended to cover collateralized put options issued in connection with capital markets financing transactions.

DATES: This Statement of Policy applies to (1) all collateralized put options originally issued prior to August 9, 1989 by insured depository institutions for which the FDIC is appointed as conservator or receiver and (2) collateralized put options issued on or after that date if the put option was issued in renewal, replacement, or extension of a put option issued prior to that date.

FOR FURTHER INFORMATION CONTACT: Linda L. Stamp, Counsel (202-736-0161), or Martin Roberts, Counsel (202-736-0180), Legal Division, Federal Deposit Insurance Corporation, 550 17th Street, NW., Washington, DC 20429.

SUPPLEMENTARY INFORMATION: The Board of Directors of the FDIC has adopted a Statement of Policy Regarding Treatment of Collateralized Put Options After Appointment of the Federal Deposit Insurance Corporation as Conservator or Receiver. The text of the Policy Statement follows:

Statement of Policy Regarding Treatment of Collateralized Put Obligations After Appointment of the Federal Deposit Insurance Corporation as Conservator or Receiver

This Statement of Policy sets forth the treatment that the Federal Deposit Insurance Corporation (FDIC) as the conservator or receiver of an insured depository institution will give collateralized "put" options issued by the insured depository institution.

Background

On August 9, 1989, the Financial Institutions Reform, Recovery, and Enforcement Act of 1989 (FIRREA) was signed into law. This statute amended the Federal Deposit Insurance Act (FDI Act) to clarify the FDIC's rights as conservator or receiver to repudiate contracts. With regard to secured contracts, the FDI Act provides that the repudiation provisions are not to be construed as permitting the avoidance of any legally enforceable or perfected security interest in any assets of the institution except where such interest is taken in contemplation of the institution's insolvency or with the intent to hinder, delay, or defraud the institution or the institution's creditors. 12 U.S.C. 1821(e)(11). Absent this provision for legally enforceable or perfected security interests, the conservator or receiver arguably could avoid such security interests and render any claim on the repudiated contract unsecured.

Reading these statutory provisions as a whole, it is clear that even secured contracts may be repudiated; that damages are limited to the extent set forth in the statute; and that legally enforceable or perfected security agreements must be honored to the extent of such damages but no further or otherwise. In other words, if there is a repudiation, the collateral securing the contract may be liquidated and the proceeds paid to or retained by the creditor up to the damages allowed by the statute, i.e. damages for actual direct compensatory losses measured as of the date of the appointment of the conservator or receiver. The remaining collateral or proceeds must then be remitted or returned to the conservator or receiver as property of the institution or its estate, or to a bona fide junior lienholder to the extent applicable.

While the preceding statement sets forth the existing law and is applicable to all contracts which have been or will be repudiated by a conservator or receiver after August 9, 1989, regardless of when the contract was entered into, certain issues have been raised regarding collateralized put options.

The FDIC has maintained a longstanding position that contingent obligations have no provable damages under the FDI Act's statutory damages limitation, if repudiated by the receiver or conservator, because the damages are not fixed and certain as of the date of the appointment of the receiver or conservator. As FIRREA has made this result more apparent, market certainty and stability have been affected.

Statement of Policy

The FDIC has considered a number of relevant policy factors, including its legal rights and powers under FIRREA; the assurances provided by the Federal Home Loan Bank Board prior to the enactment of FIRREA and market reliance on those assurances; the need for market certainty and stability; the potential long-term cost to the FDIC of outright repudiation of collateralized put options; and the potential for immediate acceleration of the issuer's obligations under these collateralized put options. Based on its consideration and balancing of such factors, the FDIC has determined to adopt and implement the following Policy with respect to the treatment of collateralized put options after its appointment as conservator or receiver of insured depository institutions having these types of obligations:

(1) This Policy will apply to collateralized put options in all respects where the collateralized put options were originally issued by insured depository institutions prior to August 9, 1989.

(2) It is recognized that the FDIC as conservator or receiver has the right to call, redeem or prepay any collateralized put options by repudiation or disaffirmance either directly by cash payment in exchange for release of the collateral or by the repudiation of the contract evidencing such borrowings followed by liquidation of the collateral

RESTORATION PROJECTS PROGRESS REPORTS

1. Habitat Use, Behavior, and Monitoring of Harbor Seals in Prince William Sound

2. Killer Whale Monitoring and Habitat

3. Population Assessment of the Prince William Sound Sea Otter Population

4. Identification of Upland Habitats Used by Marbled Murrelets in Prince William Sound

5. Prince William Sound Harlequin Duck Breeding Habitat Analysis

6. Feeding Ecology and Reproductive Success of Black Oystercatchers in Prince William Sound

7. Dolly Varden and Cutthroat Trout Populations in Prince William Sound

8. Salmon Coded-Wire Tagging in Prince William Sound

9. Prince William Sound Pink Salmon Escapement Enumeration

10. Monitoring Coastal Habitats at Herring Bay

11. Pre-Spill and Post-Spil Concentrations of Hydrocarbons in Sediments and Mussels at Intertidal Sites in Prince William Sound

12. Survey of Injured Tidal Marshes in Prince William Sound and the Gulf of Alaska

1. Habitat Use, Behavior, and Monitoring of Harbor Seals in Prince William Sound

#1

MEMORANDUM

STATE OF ALASKA
DEPARTMENT OF FISH AND GAME

TO: Mark Fraker
OSIAR
Anchorage

DATE: November 18, 1991

THRU:

TELEPHONE: 456-5156
FAX: 452-6410

FROM: Kathy Frost KJF
Marine Mammals Biologist
Wildlife Conservation
Fairbanks

SUBJECT: Harbor Seal
Progress Report-
Restoration Study

Enclosed is the annual progress report for the harbor seal restoration study entitled "Habitat use and behavior of harbor seals in Prince William Sound, Alaska." This report describes April and September 1991 field work during which satellite transmitters were attached to four harbor seals in Prince William Sound, and the results of preliminary analyses of data obtained from these PTTs.

I think the prognosis for future work is excellent. We have demonstrated that catching seals in PWS is possible, if not always predicatable or easy. We have a much better understanding of the personnel and logistics support that are necessary and of the capabilities and limitations of the netting technique. Some data were received from all four: three of the four remained near Seal Island where they were tagged; the other seal tagged in Herring Bay moved over 90 km away, and then returned to the original location.

The PTTs attached in early September were a simplified version of those that failed last April. They were reconfigured to transmit location and histograms of dive depth and duration on a single geolocational channel, in contrast to the more complex 5-channel configuration of the first two PTTs. Dive profiling features that required multiple data-only channels were eliminated.

By initiating this study with a two-phase pilot project that entailed only a few PTTs, we hope to have solved any major problems before we begin the full-scale study in 1992. This project has and will continue to benefit greatly from the fact that large numbers of similar PTTs are being attached to sea lions and fur seals this year and next. By the time we order the 20 PTTs for the 1992 field season, modifications based on sea lion and fur seal work should be in place. We have also benefited by having PTTs on four spotted seals in northern Alaska.

In summary, I am optimistic about the future of this project. I think that with what we learned in our first year pilot program and improvements that are being made in the PTTs, we will be able to make significant progress in our understanding of harbor seals during 1992. I think this project will provide us with valuable information about the movements and dive patterns of seals in Prince William Sound.

If you have any questions or want to discuss anything in the report, feel free to give me a call.

cc w/ enclosure: Don Calkins

Exxon Valdez Oil Spill Restoration Science Study
1991 Progress Report

<u>Title</u>: Habitat Use, Behavior, and Monitoring of Harbor Seals in Prince William Sound

<u>Project Leader</u>: Kathryn J. Frost

<u>Lead Agency</u>: Alaska Department of Fish and Game

<u>Cooperating Agencies</u>: NOAA/National Marine Fisheries Service
Texas A & M University
University of Alaska

19 November 1991

I. EXECUTIVE SUMMARY

Field work was conducted in April and September 1991 to attach satellite-linked transmitters (PTTs) to harbor seals (Phoca vitulina). Objectives were to investigate haulout use and at-sea behavior in order to identify important habitats as a guide to restoration activities.

Seals were captured by entangling them in specially constructed nets set near their haulouts. Nine animals were caught. PTTs were attached to three animals at Seal Island and one in Herring Bay. The length of time during which PTTs were received by the satellites ranged from 3 to 67 days. In spite of the premature failure of the PTTs, numerous locations and dive depths were obtained.

Two seals at Seal Island in April were equipped with VHF radiotags as well as PTTs. A combination of location data from the two sources indicates that the animals stayed in the vicinity of Seal Island at least through June. The seal tagged at Seal Island in September also stayed in the area for the short period that the PTT was functional. In contrast, the seal that was tagged in Herring Bay left that area and swam at least 100 km to spend a period of seven days near the Yale Glacier in College Fiord. It then returned to where it was tagged in Herring Bay.

Data on depth of dives showed that some harbor seals in Prince William Sound make dives deeper than 250 m, and therefore may do much of their feeding on the bottom. One seal concentrated its diving in the 51-150 m depth range. The sample size is currently too limited to say whether differences are individual or seasonal.

Continued development and testing of previous and new types of PTTs should produce units that will be more reliable and will provide longer records for each seal tagged. In 1992, PTTs should be attached to a larger sample of seals from more locations in order to gather data on harbor seal behavior, movements, and habitat use.

II. INTRODUCTION

The semi-enclosed waters of Prince William Sound (PWS) provide very good habitat for harbor seals and other marine mammals. Several thousand seals occur in PWS, where they are commonly seen hauled out on rocks, reefs, beaches, and glacial ice. Harbor seals are used for subsistence by residents of coastal communities such as Tatitlek, Chenega, and Cordova. Tourists and recreational users of PWS enjoy watching and photographing harbor seals. They, like other marine mammals, are protected by provisions of the Marine Mammal Protection Act. Because of a population decline that is going on in PWS and other parts of Alaska, it is possible that protective legislation may be invoked to provide for conservation and recovery of harbor seals.

Harbor seals were impacted by the Exxon Valdez oil spill (EVOS) in PWS. They encountered oil in the water and on haulouts. Early in the spill several fetuses, pups, and older animals were found dead in the impacted area. Studies conducted as part of the Natural Resources Damage Assessment (NRDA) program documented a substantial decline in the number of seals in oiled areas.

The number of seals in PWS had been declining prior to the EVOS. Twenty-five haulout sites in eastern and central PWS have been used to monitor trends in abundance since 1984. The mean number of seals in the trend count area during late summer surveys declined by 40% between 1984 and 1988, from 1,796 seals to 1,058 seals, a rate of about 10% per year (Pitcher 1989). Subsequent to the spill, the population decline continued at about the same rate at unoiled locations. However, at oiled sites the decline was much greater. From 1988 to 1990 harbor seals in the oiled portion of the trend count area declined 35%, compared to 13% in unoiled areas (Frost 1990).

Because of the decline in harbor seals, which was exacerbated in the area impacted by the EVOS, it is particularly important to understand what factors are limiting the population. Given the ongoing decline we cannot assume that the number of seals in oiled areas will return naturally to pre-spill levels. It is necessary both to continue monitoring population trends and to identify and appropriately manage areas of particular biological significance in order to augment recovery. Most of the information currently available on harbor seals in PWS consists of counts of animals on haulouts during pupping and molting. While these data are essential for monitoring changes in overall abundance, they are not adequate for determining what is causing the seal population to decline, or for designing conservation and management measures to facilitate recovery and ensure its future health. There is no information available on site fidelity, movements between haulout sites, seasonal changes in hauling out patterns, habitats used for feeding, or feeding behavior.

Recently developed satellite-linked telemetry can be used to gather information on these important aspects of harbor seal biology. Miniature platform transmitter terminals have created opportunities to monitor location and diving behavior of marine mammals (Mate 1986, 1989; Hill et al. 1987; Stewart et al. 1989; R. Merrick personal communication). The PTTs transmit to a satellite-based Doppler positioning system that calculates locations and tracks movements of animals with considerable accuracy. When combined with appropriate environmental sensors and microprocessor hardware and software, other information about an animal's environment and behavior can be transmitted to the satellite.

III. METHODS

Efforts in 1991 concentrated on developing techniques and equipment for live capture of seals. PTTs were attached to a small number of seals to evaluate tag performance and to determine baseline values for parameters such as depth of dive and dive duration. This information will be used to program tags with appropriate default values and threshold levels such that they will gather and store the maximum amount of useful data.

Field work was conducted during 15-19 April and 9-13 September. Personnel (Table 1) were transported to the study sites aboard a 10 m chartered vessel from Valdez and a 13 m volunteer vessel from Cordova. The primary area of operations included northern Knight Island, Seal Island, and Applegate Rocks.

Seals were caught by entanglement in nets set near their haulouts. Nets were approximately 100 m long and either 3.7 or 7.4 m deep with standard floats and lead lines. The size of openings ranged from 10 to 15 cm (20-30 cm stretch mesh). Nets were set from a 5 m Boston Whaler as close as possible to areas where seals were hauled out and where it was likely that seals would become entangled as they went in the water in response to the presence of people and boats. A 4 m Zodiac raft was used to help maneuver the net. Once the net was set it was tended by people in both the Whaler and the Zodiac. When seals became entangled they were brought into the boats or to shore, cut free from the tangle net, and put into hoop nets (large stockings made of 1 cm mesh soft nylon webbing).

In some cases seals could be physically restrained during handling and tagging. Larger animals were sedated with a mixture of ketamine and diazepam administered intramuscularly at standard doses (Geraci et al. 1981). Each seal was weighed, measured, and tagged in both hindflippers with individually numbered plastic tags. Approximately 50 cc of blood was drawn from the extradural intervertebral vein.

Larger seals were selected for attachment of satellite-linked PTTs. Transmitters (approximate size 15 cm x 15 cm x 3 cm) were attached to the mid-dorsal surface of the seal by gluing with epoxy resin (Fedak et al. 1984; Stewart et al. 1989). Some seals were also equipped with small (3 cm x 3 cm x 5 cm) VHF radiotags that were glued on the top of the head.

Data were acquired from the ARGOS satellite receiving system and analyzed using software provided by the manufacturer of the transmitters. Each PTT transmitted geographical locational information to a polar-orbiting satellite whenever it was hauled out or when it surfaced sufficiently long for transmission to occur and the satellite was positioned to receive the signal. Units were equipped with built-in programmable microprocessors that collected and summarized data for periods when animals were diving and stored it for later transmission, as has been done for crabeater seals (Lobodon carcinophagus) and Steller sea lions (Eumetopias jubatus) (Hill et al. 1987; R. Merrick, personal communication). These data were stored in six hour blocks and transmitted to the satellite once the six hour period was complete. Data from four periods were stored in memory providing at least a 24 hour window for transmission before the data were lost. Dive data were summarized as histograms in depth bins of 0-50 m, 51-100 m, 101-150 m, 151-200 m, 201-250 m, and over 250 m, and duration bins of 0-120 seconds, 121-240 seconds, 241-360 seconds, 361-480 seconds, 481-600 seconds and over 600 seconds. Temperature sensor data was also reported.

IV. RESULTS

During the April field work, weather was generally cold and windy, with rain and snow. Winds of 20-25 knots prevented any seal capture attempts on 15 and 16 April. On 17-18 April we attempted to catch seals in the short arm of Bay of Isles and at Seal Island and Applegate Rocks. On 19 April four seals were caught at Seal Island (Table 2). Flipper tags were attached to and blood samples were taken from all four seals. The two largest animals had PTTs and VHF tags attached to them. All animals were released in healthy condition.

Seals number 96 and 97 (PTT numbers 14096 and 14097) went back into the water at Seal Island at about 1420 hours Alaska Standard Time on 19 April. Signals from the head-mounted VHF tags were monitored from both animals for about 30 minutes as they dove and moved offshore.

Only two location fixes were received for seal 96. At 0649 hours on 21 April signals indicated that it was at Seal Island. A position obtained at 1114 hours on 8 May showed the seal to be at sea approximately 6 km west-northwest of Seal Island. Occasional transmissions were received from the PTT through 0916 hours on 25 June, but no other locations were determined. A total of 275 dive depths were received at intervals during 21 April-20 June (Table 3). Most of the dives were in the depth range from 51 to 100 m. No dives deeper than 200 m were recorded. Most dives were six minutes or less in duration; only 10 of 245 dives were 6-8 minutes long, two were 8-10 minutes long, and one was recorded as longer than 10 minutes.

After it was released, seal 97 was not located until 24 April. Eleven locations were obtained from 0615 hours on 24 April through 0731 hours on 26 April. All those fixes showed the animal to be on or within 0.9 km of Seal Island. The last transmission from the PTT was received at 0922 hours on 26 April. No dive depth data were received from seal 97. Dive durations were received for 31 dives on 20-21 April. Twenty-four dives were less than six minutes long, six were 6-8 minutes, and one was 8-10 minutes.

Because seals 96 and 97 were also equipped with VHF radio transmitters it was possible to verify their status and location from aircraft and boats. During the period from late April through late June they were regularly hauled out at Seal Island, especially at low tide (K. Frost, unpublished; S. Rainey, personal communication). They were not found anywhere else but Seal Island until late August when seal 97 was located at Port Chalmers. With the aid of the radio transmitters both seals were located and observed from boats on 23 May. At that time the satellite-linked PTTs were still attached properly and appeared undamaged.

Weather conditions were generally windy during September field operations. On 10 September we attempted to capture seals in Herring Bay. On 11 September four seals were caught at Seal Island (Table 2). Two small seals were blood sampled and released. One large seal was blood sampled, flipper tagged, and had a PTT attached. A fourth seal was accidentally drowned in the net, and blood and tissue samples were taken from it. On 12 September we caught one seal in Herring Bay (Table 2) and took blood samples, and attached flipper tags and a PTT. On 13 September we attempted to capture seals at Seal Island, but operations were terminated due to strong winds.

Seal number 66 (PTT number 11466) went back into the water at Seal Island at 1120 hours on 11 September. Eight location fixes were received from 0242 through 1820 hours on 12 September. Two of those locations show the seal on Seal Island while the other six indicate that the animal was 0.4-3.8 km from the island. No other fixes were obtained, although transmissions were received by the satellite until 0922 hours on 14 September. Dive data were received from seal number 66 during 12-14 September (Table 4). Of a total of 307 dives recorded, 89% were in the depth range of 0-150 m and 10% were to depths greater than 200 m. Most (89%) of the dives were six minutes or less in duration; six were longer than ten minutes.

Seal number 67 (PTT number 11467) was released into the water in Herring Bay at 2215 hours AST on 12 September. Five location fixes were received from 2338 hours on 12 September through 0913 hours on 13 September, three of them adjacent to the haulout where the seal had been captured and the other two approximately 1.8 km away. No other locations were obtained until 1347 hours on 15 September, at which time the seal was in College Fiord after having travelled a minimum distance of 90 km (Figure 1). Forty-nine location fixes were obtained from 1708 hours on 15 September through 1406 hours on 22 September, all of which showed the seal to be in the upper part of College Fiord, usually near the Yale Glacier. At 1546 hours on 22 September signals indicated that the seal had moved southward down College Fiord, traveling a distance of 26 km in 1 hour and 40 minutes. At 0848 hours on 24 September the seal was located in Herring Bay, and all subsequent location fixes showed it in the Bay. The last transmission was received at 0751 hours on 8 October. Dive data were obtained from seal 67 on 13-15 September while it was apparently feeding in the region between Knight Island and College Fiord (Table 5). Of a total of 429 dives, 98% were to depths of 0-150 m. Most (92%) of the dives were six minutes or less in length; one was longer than ten minutes.

V. DISCUSSION

Work conducted in April and September 1991 demonstrated that it is possible to live capture harbor seals in PWS. Nine seals were captured in seven days of actual capture operations. Poor weather prevented capture attempts on some days and made operations marginal on others.

The areas at which we worked were rocky and had very clear water, and it was difficult to set nets in such a way that there were no openings that the seals could find and escape through. Many seals were temporarily encircled but were able to swim around the end of the net or under it where the lead line left openings alongside boulders. Nonetheless, by selecting areas with specific characteristics and developing a detailed knowledge of those areas it was possible to catch seals with some regularity. Certain modifications to equipment and procedures as indicated in the recommendations section would result in greater capture success.

The procedures used for handling seals and attaching PTTs were very satisfactory. Animals that were handled did not seem unduly stressed and appeared to behave normally following release. The attachment of PTTs seemed very secure and there is no evidence that they were shed before the annual molt. Four PTTs were attached to spotted seals (Phoca largha) in the Chukchi Sea during 4-7 August 1991 using identical procedures. Three of the four transmitters were still providing data in mid-November, more than 100 days after attachment (K. Frost and L. Lowry, unpublished data).

The relatively short functional periods of the PTTs that we attached to harbor seals appear to have been due to equipment failure. Since the PTTs were not recovered it is not possible to determine exactly why they failed. Similar problems have occurred with PTTs attached to Steller sea lions. Two sea lion PTTs were recovered after they had stopped making contact with the satellite; one had a damaged antenna and the other had a battery leak (R. Merrick, personal communication). The tag manufacturer is continuing to evaluate PTT performance and problems. In addition, a new 0.5 watt circuit board has been developed, and is being packaged in a way that should eliminate some of the problems with prior tags. The new 0.5 watt PTTs have been tested in the laboratory and are currently deployed on Pribilof fur seals (Callorhinus ursinus) and Steller sea lions.

In spite of problems with PTT failures, the first year of this study demonstrated the utility of satellite-linked telemetry for studying harbor seals in PWS. Data from the satellite tags in conjunction with the VHF tags showed a high degree of haulout site fidelity during the spring-summer period for seals tagged at Seal Island. In contrast, the seal tagged in Herring Bay in September made a long distance movement and spent a period of seven days near the glaciers at the head of College Fiord, 100 km away from the location where it was tagged. Perhaps most remarkable was the fact that the seal then returned directly to Herring Bay. Dive depth information indicate that harbor seals are capable of diving in excess of 250 m, which means they can reach the bottom in most parts of PWS near their haulouts. The seal tagged at Seal Island in spring made fewer deep dives than the one tagged in the fall. This could be either an individual or a seasonal difference. The dives of the seal that moved from Herring Bay to College Fiord were mostly relatively shallow, but a few exceeded 200 m.

While most of the location fixes showed the seals to be relatively close to the haulouts, depth of dive information indicates that some feeding occurs farther away. For example, seal number 66 tagged at Seal Island made 23 dives in the 201-250 m depth range and 7 dives deeper than 250 m. According to bathymetry on charts, the nearest area where water depths exceed 200 m is 8 km to the east of Seal Island. To reach water deeper than 250 m the seal would have had to swim at least 21 km to the east, to an area very near the vessel traffic lanes used by tankers outbound from PWS. This demonstrates the utility of both location and depth of dive information for examining at-sea distribution and habitat use.

VI. RECOMMENDATIONS

In 1992 satellite-linked PTTs should be attached to more seals in more areas in order to gather data on movements within PWS and between PWS and adjacent areas. In addition to the Seal Island-Knight Island area, consideration should be given to capturing seals in eastern PWS (Port Gravina and Sheep Bay), northern PWS (College Fiord or Unakwik Inlet), southwestern PWS (Dangerous Passage and Icy Bay), and the Copper River Delta. A total of 20 PTTs should be attached, divided between spring and fall. Based on results with 0.5 watt PTTs that have recently been deployed on fur seals and sea lions and ongoing studies with 1 watt transmitters on spotted seals, a decision should be made as to what type of unit to deploy on PWS harbor seals in 1992.

Future capture operations should use three small boats. The boat used for setting the net should be a minimum of 6 m long so that it can carry two 100 m long sections of net. The other two boats should be used to assist in maneuvering the net and tending it to ensure that all captured seals are quickly detected and removed. Nets should be constructed of 20-25 cm stretch mesh and should have relatively light lead lines.

In addition to the studies described above, it is essential to continue tracking the trend in abundance of PWS harbor seals. Recovery, either natural or as a result of restoration efforts, should be monitored through annual fall counts of index sites as described in Pitcher (1989) and Frost (1990). Counts through 1991 have been conducted as part of the NRDA study program. Future surveys should be done annually in conjunction with the harbor seal restoration program.

VII. LITERATURE CITED

Fedak, M. A., S. S. Anderson, and M. G. Curry. 1984. Attachment of a radio tag to the fur of seals. Notes from the Mammal Society 46:298-300.

Frost, K. J. 1990. Marine Mammals Study Number 5: Assessment of injury to harbor seals in Prince William Sound, Alaska, and adjacent areas. State-Federal Natural Resource Damage Assessment for April 1989-December 1990. Unpubl. Prelim. Status Rep. ADF&G Fairbanks, AK. 22 pp.

Geraci, J. R. K. Skirnisson, and D. J. St. Aubin. 1981. A safe method for repeatedly immobilizing seals. J. Amer. Vet. Med. Assn. 179:1192-1193.

Hill, R. D., S. E. Hill, and J. L. Bengtson. 1987. An evaluation of the Argos satellite system for recovering data on diving physiology of Antarctic seals. Page 32 in: Abstracts of the Seventh Biennial Conference on the Biology of Marine Mammals, Miami, FL.

Mate, B. R. 1986. Tracking marine mammals by satellite: Identification of critical habitats. Whalewatcher, summer, pp 8-9.

Mate, B. R. 1989. Satellite monitored radio tracking as a method of studying cetacean movements and behavior. Rep. Intl. Whal. Commn. 39:389-391.

Pitcher, K. W. 1989. Harbor seal trend count surveys in southern Alaska, 1988. Final Rep. Contract MM4465852-1 to U.S. Marine Mammal Commission, Washington, D.C. 15pp.

Stewart, B. S., S. Leatherwood, P. K. Yochem, and M.-P. Heide-Jorgensen. 1989. Harbor seal tracking and telemetry by satellite. Mar. Mamm. Sci. 5:361-375.

Table 1. Participants in field activities conducted in Prince William Sound, April and September 1991.

Name	Affiliation
Kathryn Frost	ADF&G
Lloyd Lowry	ADF&G
Jon Lewis	ADF&G
Fred Weltz	Cordova resident and fisherman
Kate Wynne	University of Alaska Sea Grant Program (April only)
Brent Stewart	Hubbs Marine Research Institute (April only)
Pam Tuome	Alpine Veterinary Clinic (April only)
Randy Davis	Texas A & M University (September only)
Dennis McAllister	ADF&G (September only)

Table 2. Harbor seals captured during field activities conducted in Prince William Sound, April and September 1991.

Date	Location	Sex	Weight	PTT #	Flipper Tag #s
19 April	Seal Island	M	80 kg	14096	645/646 green
19 April	Seal Island	F	42 kg	14097	643/644 green
19 April	Seal Island	F	31 kg	none	639/640 green
19 April	Seal Island	F	32 kg	none	641/642 green
11 Sept.	Seal Island	M	89 kg	11466	178/179 green
11 Sept.	Seal Island	M	23 kg	none	none
11 Sept.	Seal Island	M	34 kg	none	none
11 Sept.	Seal Island	F	30 kg	none	none
12 Sept.	Herring Bay	F	70 kg	11467	176/177 green

Table 3. Diving pattern of harbor seal number 96 in the vicinity of Seal Island, Prince William Sound, 21 April through 20 June 1991.

Depth (m)	Number of dives in depth interval 0300-0900 hours	0900-1500 hours	1500-2100 hours	2100-0300 hours	Total	Percent
0-50	25	2	5	2	34	12
51-100	87	15	11	29	142	52
101-150	40	7	6	36	89	32
151-200	2	0	0	8	10	4
201-250	0	0	0	0	0	0
> 251	0	0	0	0	0	0

Table 4. Diving pattern of harbor seal number 66 in the vicinity of Seal Island, Prince William Sound, 12-14 September 1991.

Depth (m)	Number of dives in depth interval: 0300-0900 hours	0900-1500 hours	1500-2100 hours	2100-0300 hours	Total	Percent
0-50	85	12	25	58	180	59
51-100	9	8	22	15	54	18
101-150	0	24	4	8	36	12
151-200	0	6	0	1	7	2
201-250	0	0	21	2	23	7
> 251	0	0	5	2	7	2

Table 5. Diving pattern of harbor seal number 67 in northeastern Prince William Sound, 13-15 September 1991.

Depth (m)	Number of dives in depth interval 0300-0900 hours	0900-1500 hours	1500-2100 hours	2100-0300 hours	Total	Percent
0-50	41	84	60	94	279	65
51-100	0	19	36	1	56	13
101-150	0	22	61	1	84	20
151-200	0	2	3	0	5	1
201-250	0	0	3	0	3	<1
> 251	0	0	2	0	2	<1

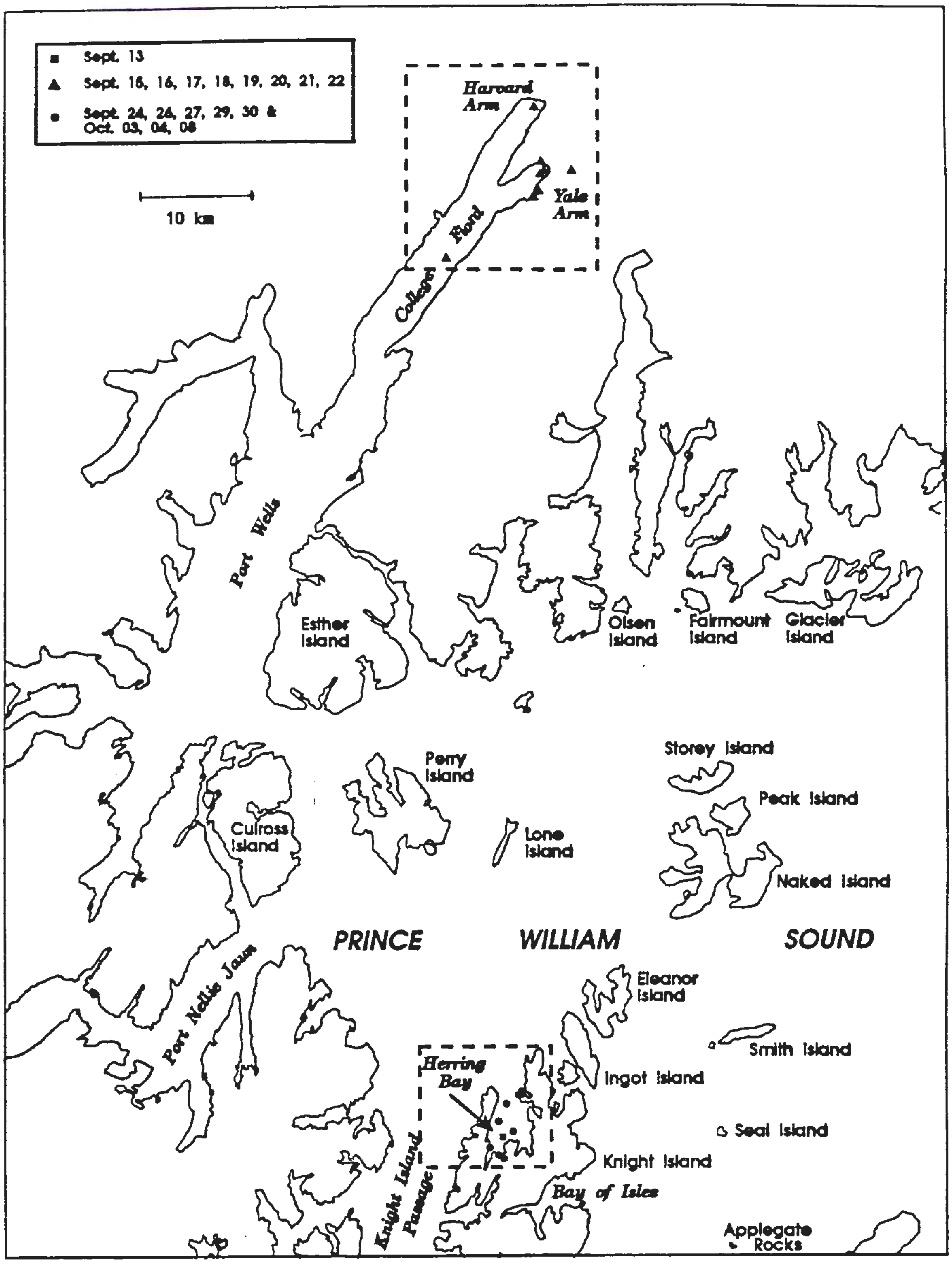


Figure 1. Map of Prince William Sound showing location fixes for seal number 67 in Herring Bay and College Fiord, 13 September-8 October 1991. Only one location per day is shown.

Progress Report

Habitat Use and Behavior of Harbor Seals
in Prince William Sound, Alaska
September 1991

Field work was conducted from September 9-13, 1991, in central Prince William Sound. The objective of this trip was to catch and attach satellite transmitters to three harbor seals in order to determine feasibility of a larger scale tagging project in 1992 and to provide preliminary data on distribution and movements of seals in autumn. This was the second of two tagging efforts to be conducted in 1991.

This was a cooperative effort among several agencies and individuals. The following personnel participated in field activities:

Personnel	Affiliation	Involvement
Kathy Frost	ADF&G	Principal investigator,project coordination, seal catching, tagging, logistics
Lloyd Lowry	ADF&G	Permits and coordination, seal catching and tagging
Jon Lewis	ADF&G	Seal catching and tagging, logistics
Dennis McAllister	ADF&G	Seal catching and tagging, logistics
Randy Davis	Texas A&M University	Seal catching, tagging, blood sampling
Fred Weltz	Cordova fisherman	Seal catching and tagging, logistics support

Other cooperators who contributed to the project but were not present in the field included: Tom Loughlin and Dick Merrick, National Marine Mammal Laboratory/National Marine Fisheries Service, who allowed ADF&G to use their permit to tag seals, contributed data acquisition time from Service ARGOS for the pilot project, and offered advice on methodology and PTT specifications; and Kate Wynne, Alaska Sea Grant Marine Advisory Program, who helped procure seal catching nets.

Frost and Lowry departed Valdez for Knight Island in central Prince William Sound on September 9th via the *F/V Inga Kristine*, a chartered 36-ft vessel. They were met there by Lewis and McAllister, who travelled from Whittier in a 17-ft ADF&G Boston Whaler. Davis and Weltz traveled from Cordova to Knight Island in the F/V *Dancing Bear* and met the *Inga Kristine* on the evening of September 9th in Louis Bay. Field activities were as follows:

Date	Location	Weather	Activity and Comments
9/9	Louis Bay	Windy, stormy	No activity; gale winds
9/10	Herring Bay	Windy, overcast; low tide at 0903	Reconnaissance; net deployed several times but unsuccessful
9/11	Seal Island	Light breeze; low tide at 0939	Ten seals hauled out; set net across cove; caught 4 seals, tagged 1 with PTT; blood from others
9/12	Seal Island, L. Smith, Applegate, Herring Bay	Calm, sunny, warm; low tide at 1016	No luck at any of haulouts, seals spooky; set net at twilight in Herring Bay; caught 1 seal and tagged with PTT
9/13	Seal Island	Windy, rough; low tide at 1052	< 10 seals hauled out, all went in water; set on seals in water, all got away; too rough to continue

Only two seals were tagged within the 5 days during which vessels and personnel were available, instead of the intended three. This was largely due to stormy weather on 2 of 5 days and the wary nature of the seals. We are still developing and refining capture techniques.

At Seal Island, seals were caught by setting a net near the haulout to block access to the water and entangle the seals as they tried to escape. The nets were deployed at high speed across the cove where the seals were hauled out, from a platform mounted over the stern of the Whaler. One net was 19-cm (7.5") stretch mesh, multifilament twine, 7.3 m (24 ft) deep x 91.4 m (300 ft) long with lead and cork lines. The other was 20.3 cm (8") stretch mesh, 3.7 m (12 ft) deep x 87.8 m (288 ft) long. Personnel jumped into the water and dragged the ends of the net to the shore. Three seals became tangled in the net. They were placed in stocking or "hoop" nets. All were measured, weighed, and blood was collected. The largest male was tagged with a satellite PTT. The other two seals were released without tags since they weighed 23 kg and 34 kg and were considered too small to easily carry the satellite package. One other small seal weighing 30 kg was entangled in the net and drowned. This seal was necropsied and samples taken for tissue hydrocarbon analysis and blood work. We believe that risk of future mortalities can be minimized by decreasing the weight of the lead line on the capture nets.

At Herring Bay, the shallow (3.7 m deep) net was deployed near the main haulout on a falling tide at twilight. Investigators departed the immediate area and obvserved the net from shore.

Approximately 15 minutes after deployment, an adult female swam into the net and became entangled. She was disentangled and, since it was rapidly becoming dark, taken to the *F/V Inga Kristine* for tagging. We believe that using stationary nets that are set at twilight and closely monitored promises to be an effective and efficient way to catch seals.

The seals selected for tagging were an adult male and adult female. Measurements (in centimeters), weights (pounds) and tag numbers were as follows:

Sex	Length	Weight	PTT #	Flipper tags
Male	161	88.6	11466	178,179 green
Female	139	70.5	11467	176,177 green

Blood was collected from both seals in EDTA, heparinized, and red-top tubes and centrifuged within a few hours after tagging. Blood or serum was provided to Randy Davis (Texas A&M University) and Mike Castellini (University of Alaska) for physiological analyses, Brendan Kelly (University of Alaska) for genetics studies, and Randy Zarnke (ADF&G) for virology studies.

The female was tagged without sedation. The male required sedation with ketamine and valium (diazapam). Satellite PTTs were attached to the middle of the back. The hair was first thoroughly dried and cleaned with acetone. Devcon 5-minute epoxy was used to glue nylon netting, which anchored a thin metal baseplate, to the pelage. The PTT was then bolted to the baseplate and the nuts secured with epoxy. Each seal required approximately one hour to tag.

Data were received from both PTTs during the 10 days following tagging. Through September 18th, multiple locations had been received for each seal. Both remained near the locations where they were caught; the male at Seal Island and the female in Herring Bay. For both seals, approximately 90% of their dives were to depths less than 100 m. Two to 6% of the dives were greater than 200 m.

Progress Report

Habitat Use and Behavior of Harbor Seals in Prince William Sound, Alaska April 1991

Field work was conducted from April 15-19, 1991, in central Prince William Sound. The objective of this trip was to catch and attach satellite and VHF transmitters to two harbor seals in order to determine feasibility of a larger scale tagging project in 1992. This was the first of two tagging efforts to be conducted in 1991. The second will be conducted in September.

This was a cooperative effort among several agencies and individuals. The following personnel participated in field activities:

Personnel	Affiliation	Involvement
Kathy Frost	ADF&G	Principal investigator, project coordination, seal catching, tagging, logistics
Lloyd Lowry	ADF&G	Permits and coordination, seal catching and tagging
Jon Lewis	ADF&G	Seal catching and tagging, logistics
Kate Wynne	AK Sea Grant Marine Advisory Program	Seal catching and tagging
Brent Stewart	Hubbs Sea World Research Institute	Seal catching, tag attachment, previous experience with PTTs
Pam Tuomi	College Village Animal Clinic	On-site veterinarian, seal sedation, blood collection
Fred Weltz	Cordova fisherman	Seal catching and tagging, logistics support

Other cooperators who contributed to the project but were not present in the field included: Tom Loughlin and Dick Merrick, National Marine Mammal Laboratory/National Marine Fisheries Service, who allowed ADF&G to use their permit to tag seals, contributed data acquisition time from Service ARGOS for the pilot project, provided two VHF radios, and offered advice on methodology and PTT specifications; Randy Davis, Texas A&M University, who interfaced with the PTT manufacturer and ordered and coordinated delivery of the PTTs; and Robin Brown, University of Oregon Marine Science Center, and Steve Jeffries, Washington Department of Wildlife, who provided seal-catching nets.

Frost, Stewart, and Tuomi departed Valdez for Bay of Isles in central Prince William Sound on April 15 via the F/V Inga Kristine, a chartered 36-ft vessel, accompanied by Lowry and Lewis in a 17-ft ADF&G Boston Whaler. Inclement weather delayed arrival at Bay of Isles until the afternoon of April 16. Wynne and Weltz traveled from Cordova to the Bay of Isles in the F/V

Dancing Bear and met the Inga Kristine on the evening of April 16. Field activities were as follows:

Date	Location	Weather	Activity and Comments
4/16	Bay of Isles (Short Arm)	Ice and slush in bay; cold (32-34 F)	Reconnaissance; few seals present; no good location to net seals
4/17	Bay of Isles (Short Arm)	Cold, windy, overcast; low tide at 0956	Only 4 seals present; poor location; net deployed but unsuccessful
4/18	Seal Island	Cold, foggy, rain, calm; low tide at 1044	Only 6 seals hauled out, all went in water; set on 1 seal in water, seal swam around end and got out
4/18	Applegate Rocks	Same as above	< 20 seals hauled out, all went in water; set on 10-12 seals in water, all got away
4/19	Seal Island	Calm, sunny, warm; low tide at 1137	35 seals hauled out in cove; set net across cove; caught 4 seals, tagged 2 with PTTs and VHF radios

Seals were caught by setting a net near the haulout to block access to the water and entangle the seals as they tried to escape. The net (8-12" stretch mesh, multifilament twine, 24 ft deep x 50 ft long with lead and cork lines) was deployed at high speed across the cove where the seals were hauled out, from a platform mounted over the stern of the Whaler. Personnel jumped into the water and dragged the ends of the net to the shore. Six or more seals were surrounded and/or tangled in the net. Four were placed in stocking or "hoop" nets (two for tagging and two as back-ups). The others were disentangled and released. The four seals that were retained were measured, weighed, and blood was collected. The two largest were tagged.

The seals selected for tagging were a subadult female and an adult male. Measurements (in centimeters) and tag numbers were as follows:

Sex	Length	Girth	PTT #	VHF #	Flipper tags
Female	122	87	14097	990	643,644 green
Male	158	113	14096	802	645,646 green

Blood from both seals was collected in EDTA tubes. Blood was centrifuged and smears were made approximately 4 hours after tagging.

The subadult female was tagged without sedation. The male required sedation with ketamine and valium (diazapam). Satellite PTTs were attached to the middle of the back. The hair was first thoroughly dried and cleaned with acetone. Devcon 5-minute epoxy was used to glue nylon netting, which anchored a thin metal baseplate, to the pelage. The PTT was then bolted to the baseplate and the nuts secured with epoxy. Small VHF transmitters were glued to the top of the head to serve as a backup for locating the seals. The entire operation, including catching and tagging, was completed in approximately four hours.

Since tagging, both seals have been observed visually. In early May, personnel associated with cleanup activities at Seal Island saw a "seal with an arrow on top of its head." It is unknown which of the two seals this was. On May 23, the female was seen hauled out at Seal Island by Don Calkins of ADF&G. He saw the male in the water near Seal Island the following day. Both PTTs were still attached and the antennas were intact. The VHF radios were also attached and transmitting strong signals. A Cordova fisherman reported seeing a seal "with a funny antenna" on its head near Seal Island in early June. The VHF signals of both seals have been heard on multiple occasions from April to June:

Date	Seal	Time	Tide	Location	Activity
4/26	Male	1120	High	Near Applegate	Diving
4/27	Male	1444	High	Near Applegate	Diving
4/30	Female	0803	Low	Seal Island	Hauled out
	Male	0805	" "	Seal Island	Hauled out
5/3	Female	1340	1/2 in	<1/2 mi S of Seal I	Diving
	Male	1345	" "	<1 mi W of Seal I	Diving
5/6	Female	1430	Low	Near Seal Island	Diving
	Male	1433	" "	Seal Island	Hauled out
5/12	Male	1730	Low	Seal Island	Hauled out
	Female	1736	" "	Near Seal Island	Diving
5/13	Female	0620	Low	Near Seal Island	Diving
	Male	0625	" "	Near Seal Island	Diving
5/22	Female	1300	Low	Seal Island	Hauled out
5/22	Male	1300	Low	Seal Island	Hauled out
5/23	Female	1700	Low	Seal Island	Hauled out
	Male	" "	" "	Near Seal Island	Diving
5/24	Male	0600	Low	Near Seal Island	Diving
6/1	Male	1100	Low	Near Seal Island	Diving
	Female	" "	" "	Near Seal Island	Diving

Data were received from both PTTs during the first few days following tagging. Through April 26, we had obtained a single location for the male. He was at Seal Island during the early morning of April 21. We obtained 11 locations for the female from April 24-26. All were at or near Seal Island. Data have not been received from ARGOS for the month of May. Dive profiling and dive summary features are not working for either seal. Some histogram data have been received and are being analyzed at this time.

2. Killer Whale Monitoring and Habitat

KILLER WHALE MONITORING AND HABITAT STUDIES

Study ID Number: Marine Mammals Study Number 6

Marilyn E. Dahlheim and Thomas R. Loughlin
Alaska Fisheries Science Center
National Marine Mammal Laboratory
7600 Sand Point Way N. E., Bin C15700
Seattle, Washington 98115

November 1991

TABLE OF CONTENTS

	Page
Executive Summary	3
Objectives.	4
Introduction.	4
Study Methodology	4
Study Results	7
Status of Injury Assessment	11

EXECUTIVE SUMMARY

Photographs of individual killer whales occurring in Prince William Sound were collected from May to September 1991 to assess the potential impacts of the Exxon Valdez oil spill on killer whale life history and ecology. Research vessels traversed over 7,000 nautical miles in search of whales or while photographing whales, reflecting 110 days of field research. An unusually high number of killer whales have been reported as missing from the spill area. Of particular concern are the fourteen missing whales from AB pod and ten missing whales from AT pod. In addition to missing whales, changes have occurred in the social structure of affected pods, an increase was documented in the rate of strandings, and unexplained anatomical changes were reported. Detailed results of our efforts to obtain information on killer whale abundance and whale reproductive rates are given in our 1991 annual report conducted under the NRDA Program (Marine Mammal Study Number 2 - Year 3).

To determine habitat use and overall distribution patterns of Prince William Sound killer whales we are in the process of reviewing all available sighting data. Published and unpublished data are being reviewed. Form letters, requesting sighting data on killer whales, were sent to various federal and state agencies. The National Marine Mammal Laboratory's Platforms of Opportunity Program currently contains approximately 30 years of sighting data. These sighting data are being plotted for the Prince William Sound area and adjacent waters. Unfortunately, effort is not consistent among months or years to provide quantitative data on whale seasonality or areas of whale concentrations. Once all data are collected, we will attempt to correlate sighting data with water depth and sea surface temperature. Review of fishery catch data may facilitate correlation of killer whale distribution with potential prey concentrations. The results of these studies will be available in March 1992.

We are also investigating the likelihood of success in placing satellite tags on killer whales to obtain critical information of whale habitats. Scientists with expertise in satellite tagging have been consulted and encourage this work. In addition, killer whale experts have been informed of these studies and agree that satelitte tagging will provide extremely useful information on killer whale movements and habitat preferences. Environmental agencies have been alerted to our future plans. The National Marine Fisheries Office in Washington, D. C., has been contacted and has provided valuable advice to facilitate obtaining needed federal permits to conduct this work. Discussions have also taken place with personnel from the Marine Mammal Commission. We will continue our investigations on tag deployment and attachment as well as continue discussions with our colleagues and environmental groups. A final report will be prepared and sumbitted by March 1992.

OBJECTIVES

1. To determine killer whale reproductive rates and trends in abundance within Prince William Sound and adjacent waters affected by the Exxon Valdez (NRDA).

2. To identify and describe habitat requirements for killer whales, a prerequisite to developing realistic restoration options for the species (Restoration).

INTRODUCTION

Since 1989, photographs of individual Prince William Sound killer whales have been collected to assess the potential impacts of the Exxon Valdez oil spill on killer whale life history and ecology. Field studies have been supported under the Natural Resource and Damage Assessment (NRDA) Program. Results indicate that an unusually high number of killer whales are missing from the spill area. In addition to the missing whales, changes occurred in the social structure of affected pods, an increase was documented in the rate of strandings, and unexplained anatomical changes were reported. Monitoring of the status and distribution of killer whales in Prince William Sound has continued for the last three years to obtain needed information on killer whale reproductive rates and trends in abundance.

To facilitate recovery of injured populations recovery plans must be implemented. Restoration of cetaceans can be enhanced by protecting sensitive habitats, minimizing fishery interactions, reducing or redirecting other human-use activities, and promoting public education. The designation of critical habitats has occurred in the United States to protect recovery of pinnipeds and also internationally to protect cetaceans. Unfortunately little or no quantitative information exists on habitat needs for killer whales in Prince William Sound and adjacent waters on which to base a recommendation to limit or otherwise change human-use activities.

In 1991, in addition to the NRDA studies, companion restoration science studies were initiated. The restoration studies were aimed at determining the adequacy of the damage assessment database to support decisions on habitat protection and other management activities.

STUDY METHODOLOGY

Personnel from the National Marine Mammal Laboratory (NMML), Seattle, Washington (Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA/DOC) developed and coordinated the killer whale damage assessment activities associated with the Exxon Valdez oil spill. Although NMML personnel participated in field studies, the majority of the field work was conducted by contractors that have recognized expertise in the study area of concern. Field studies were conducted under federal permits issued through the National Marine Mammal Protection Act (MMPA). The development and implementation of restoration studies on killer whales will be conducted by NMML personnel.

Sampling Methods

Killer Whale Reproductive Rates/Trends in Abundance

This work (Objective 1) will be conducted under the NRDA Program (Marine Mammal Study Number 2 - Year 3). The methods used to obtain censusing data are described briefly in this proposal and are reported on in more detail in the 1991 NRDA annual report on killer whales.

Killer whale reproductive rates and trends in abundance will be investigated by using ship surveys to obtain photographs of individual whales. When whales are sighted, researchers will stop to collect photo-identification information. To obtain a high-quality photograph, an approach within 30-60 meters is required. Photographs are taken of the left side of the whale's dorsal fin and saddle patch. In addition to photographs, data will be collected on the general condition of individual whales (e.g., observations of skin disease).

Daily vessel logs will be maintained each day which permits 1) quantification of the amount of time searching for whales versus photographing whales, 2) quantification of search effort under different weather conditions, 3) projection of daily trackline, and 4) the number of vessels/aircraft encountered in the study area.

Habitat Requirements

Initial assessment of habitat use for Prince William Sound killer whales (Objective 2) will include a review of all available sighting data. Federal and State agencies, as well as independent researchers, will be contacted and requested to supply sighting data on killer whales. Published and unpublished data will be reviewed. We will attempt to correlate sighting data with water depth and sea surface temperatures. Review of fishery catch data may facilitate correlation of killer whale distribution with potential prey concentrations. General behavior of killer whales and the presence of other marine mammals will be noted.

To more accurately determine habitat use and overall distribution and movements of killer whales, we will explore the feasibility of placing satellite transmitters on Prince William Sound killer whales. Recently, many successful deployments of satellite transmitters on cetaceans and pinnipeds have provided important ecological information and each year brings about major advances in technology. If feasible, and after extensive examination of existing technology, we will place satellite tags on at least three whales in Prince William Sound.

Year one investigations (1991) will involve a review of all information pertaining to satellite tagging and a determination of the likelihood of success in placing satellite tags on killer whales. Scientists with expertise in satellite tagging will be consulted. If the likelihood of success is considered high, year two (1992) would be devoted to the engineering of the satellite linked radio tag for placement on killer whales. If the necessary equipment is obtained in 1992 and we are satisfied with all aspects of the work (delivery system, attachment device, minimal disturbance to whales, etc.), we would propose to initiate satellite tagging during the 1993 field season (year three). The permit process for this activity would begin in mid-1992.

Data Analysis

Killer Whale Reproductive Rates/Trends in Abundance

All exposed film of killer whales collected during the 1991 field season would be analyzed for individual identification. Each negative (or prints as needed) is placed under a dissection microscope for identification and notes and sketches are made. Sub-standard photographs (not showing enough detail or improper angle/side) are discarded; reducing the probability of mis-matching photographs. Photographs are grouped by individuals. Each identified whale is visually compared to the historical photographic database available. Once all photographs are properly entered and evaluated, it is then possible to determine 1) if all members of the pod were present, and 2) if pod structure/integrity is similar to previous years. Missing animals are noted. The stability of resident pods over time is such that if an individual is listed as missing for at least one year; that missing whale is considered dead.

To avoid biases in data interpretation, it is important that the amount of effort in searching for and photographing whales is at least equal to (but not less than) that completed in previous years. For a large pod (>12 animals), the likelihood of obtaining photographs of all individuals are increased as the number of encounters are increased. Some individuals, and certain pods, are more likely to approach vessels making photographic documentation easier; while others keep a considerable distance away making for more difficult conditions. Whale behavior also plays a role when attempting to obtain photographs of individual whales. If the pod is resting (typically grouped together), it is easier to obtain photographs of all whales vs. when the pod is traveling (spread out through an area). General location of killer whales will be recorded each time photographs are taken, allowing comparisons of pod distributions among years.

Calves of the year will be noted and their mothers identified. Natality (number of calves per adult female) will be calculated for each pod for each year and comparisons made between resident and transient groups using descriptive statistics. Mortality rates will also be calculated for resident groups. Mortality for transient pods will be calculated when necessary data are available.

Habitat Requirements

Killer whale habitat usage will be investigated by plotting all observations of killer whales obtained from the various historical databases. A summary report (due March 1992) will be provided and will include any information collected on water depth, water temperatures, and potential prey species.

In addition to the report submitted on overall distribution of killer whales, a progress report will be written assessing the feasibility of placement of satellite transmitters on killer whales based upon the information obtained during 1991 investigations (due March 1992).

STUDY RESULTS

Objective 1. Between 16-24 May and 5 June to 13 September 1991, research vessels traversed 7,340 nautical miles in Prince William Sound in search of whales or while photographing whales. This coverage represents a total of 89 operable days of field research plus 21 days in which researchers were confined to camp due to weather. In 1991, seven resident pods and four transient pods were photographed. The objectives of our NRDA year 3 studies on killer whales were successfully met and detail results are found in the 1991 annual report.

Objective 2. To determine habitat use and overall distribution patterns of Prince William Sound killer whales we are in the process of reviewing all available sighting data. Published and unpublished accounts are being reviewed. Form letters, requesting information on killer whales, have been forwarded to appropriate sources (Figure 1). The National Marine Mammal Laboratory's Platform of Opportunity Program contains approximately 30 years of sighting data from the Prince William Sound area (Figure 2). Data will be reviewed to determined areas of whale concentrations. Unfortunately, the effort is not consistent among months or years to provide quantitative data on whale seasonality. Although a large body of information exists on sightings of killer whales, the

Alaska Fisheries Science Center
National Marine Mammal Laboratory
7600 Sand Point Way N.E., Bin C15700
Seattle, Washington 98115-0070

(206) 526-4045 FTS: 392-4045

October 7, 1991 F/AKC3:MED

Address Here

Dear xxx:

Since 1989, the National Marine Mammal Laboratory has been investigating the possible impact of the <u>Exxon Valdez</u> oil spill on Prince William Sound killer whales. As part of that investigation, we are interested in any sighting data on killer whales from Prince William Sound and the adjacent waters of the Gulf of Alaska as far as west as the Kenai Fjords, Seward, Homer, and Kodiak Island and southeast as far Yakutat.

If you have any killer whale sightings from these areas or know of anyone else who might have similar information, I would appreciate hearing from you. Useful information would include the date, time and location of a sighting, number of animals, and any other comments such as behavior or interactions with boats or other marine mammals. Copies of photographs would also be very helpful.

I hope to hear from you soon. Thank you for any information you might be able to provide.

Sincerely yours,

Marilyn E. Dahlheim, Ph.D.
Cetacean Task Leader
Alaska Ecosystem Program

Figure 1. Form Letter requesting killer whale sightings.

Killer Whale Sightings, all years, all seasons

(1958-1990)

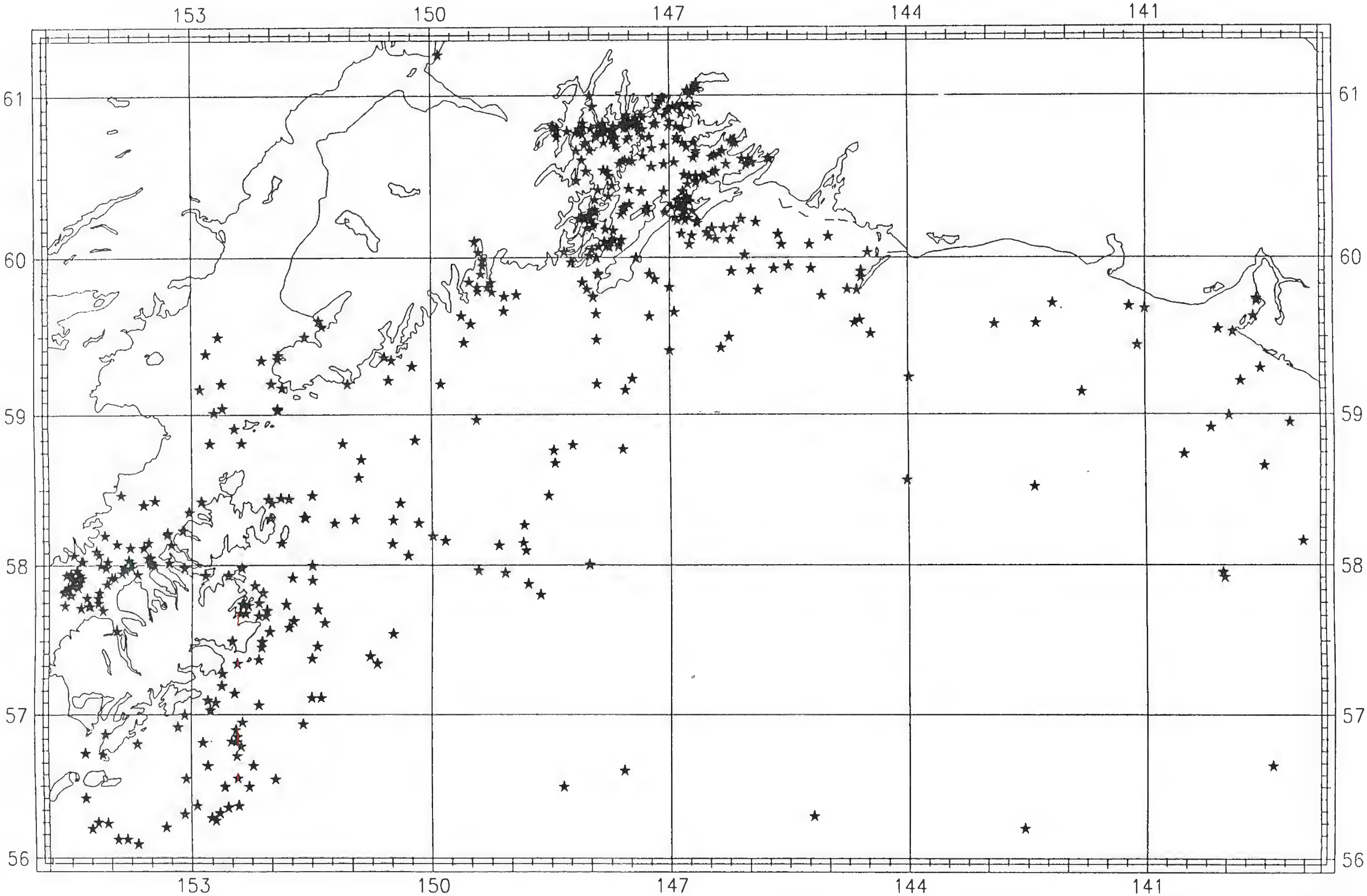


Figure 2. Killer whale sightings Prince William Sound and adjacent waters (1958-1990). Platforms of Opportunity Program (National Marine Mammal Laboratory).

information content is limited pertaining to seasonality, areas of concentrations or habitat requirements. Once all sighting data are collected and all literature is reviewed, we will attempt to correlate sighting data with water depth and sea surface temperatures. Review of fishery catch data may facilitate correlation of killer whale distribution with potential prey concentrations. The results of these efforts will be available in our report due March 1992.

We are currently investigating the likelihood of success in placing satellite tags on killer whales to obtain needed information on killer whale habitats and movement patterns. Scientists with expertise in satellite tagging have been consulted and have supported the continuation of this work. In addition, scientists with expertise on killer whales have been approached and have agreed that work of this type is needed on killer whales. Environmental agencies have been notified. In addition we have contacted our Washington D. C. permit office to obtain advice regarding permit procedures. Future meetings are planned with necessary experts in the field to discuss deployment and attachment of satellite tags to cetaceans. A final report will be prepared and submitted, as scheduled, in March 1992.

STATUS OF INJURY ASSESSMENT

We are currently only six months into our restoration studies. We are on schedule and plan to successful achieve our objectives and meet our deadlines listed in the study plan. Completed reports will be available in March 1992.

3. Population Assessment of the Prince William Sound Sea Otter Population

#5

NATURAL RESOURCES DAMAGE ASSESSMENT

DRAFT PRELIMINARY STATUS REPORT

US Fish and Wildlife Service

&

Alaska Fish and Wildlife Research Center

Study Title: Assessment of the Magnitude, Extent, and Duration of Oil Spill Impacts on Sea Otter Populations in Alaska.

Study ID Number: Marine Mammals Study Number 6

Project Leaders: B. E. Ballachey, J. L. Bodkin and D. Burn

Date Submitted: November 22, 1991

Preliminary Damage Assessment Report

Marine Mammal Study 6
20 November 1991

EXECUTIVE SUMMARY

Damages to sea otters resulting from the T/V Exxon Valdez oil spill can be categorized into two temporal components: 1) acute mortality, and 2) chronic damages.

Acute mortality was partially reflected in a total of about 1,000 sea otter carcasses collected during or shortly after the spill. It is probable that some additional number of sea otters became oiled and subsequently died, and that their carcasses were never recovered. Preliminary results of autopsies of intact carcasses indicate less than 5% of mortalities were clearly not spill related.

Three approaches were taken to estimate the total number of sea otter mortalities that resulted from acute exposure to oil. One method estimates the number of unrecovered carcasses based on the probability of carcass recovery. Available information suggests a about 75% of sea otter carcasses are not recoverable. Another method compares estimates of sea otter abundance before and after the spill. These comparisons suggest a large number of otters, relative to the number of carcasses retrieved, suffered acute mortality. A third method consists of an intersection model to estimate mortality based on potential exposure to oil and observed mortality rates dependent on degree of oiling. Simulations of this model indicate that about 52% of the Kenai Peninsula sea otter population was potentially exposed to oil. This model may be applied throughout the spill zone to provide an estimate of total mortality. A synthesis of these methods of loss estimates suggest between 3,500 and 5,500 sea otter may have died as a result of acute exposure to oil following the Exxon Valdez spill.

Chronic damages to sea otters may result from sub-lethal initial exposure and continued exposure to environmental hydrocarbons. Indirect damages, either chronic or acute, may result from affected sea otter prey populations. Preliminary findings of Coastal Habitat and Shellfish studies have identified elevated levels of hydrocarbons in intertidal and subtidal sediment samples collected within the spill zone. Additionally, hydrocarbon analysis of benthic marine invertebrates indicate that high levels of hydrocarbons persist in several species previously identified as sea otter prey in western Prince William Sound.

Preliminary results of several sea otter damage assessment studies indicate that sub-lethal, chronic exposure may be damaging sea otters at the biochemical, physiological and population levels.

Comparisons of pre- and post-spill estimates of sea otter abundance, based on boat surveys the shore, found non-oiled areas underwent a 13.5% increase in abundance, while oiled areas underwent a 34.6% decrease. In addition, the post-spill population in the oiled area is significantly lower than the best pre-spill estimate, indicating a real decline on the order of 1600 otters initially, and up to 2200 in subsequent years. No change in abundance was detected between July 1990 and July 1991 surveys.

Results of a 1991 field study evaluating sea otter prey selection and foraging success indicate sea otters have not altered their diet over the past decade and continue to rely primarily on clams and mussels as forage. Given hydrocarbon contamination in bi-valve mollusks, the prey study described a pathway for continued exposure of sea otters to environmental hydrocarbons. In addition, other damage assessment studies have documented decreases in abundance of mussels in oiled areas which may further impede recovery of sea otter population.

Analysis of age class composition of beach cast sea otters in western Prince William Sound from 1974-84, in 1989 and following the spill in 1990-91 detected significant differences between pre-spill and spill year distributions, and pre-spill and post-spill distributions. Spill year and post-spill distributions were not significantly different. The proportion of prime age animals dying in western Prince William Sound increased in both the spill year (1989) and post-spill years (1990 and 1991). The observed differences represent a shift from a pre-spill composition of principally young and aged animals to an increased proportion of prime-age animals during and following the spill. The observed changes in the age distributions of dying sea otters suggest a prolonged, spill-related affect on at least the western Prince William Sound sea otter population.

Results of clinical, hematologic and serum chemistry analyses of otters which died shortly (within the first 10 days) after entering the rehabilitation centers indicate that the majority of sea otters that died acutely appear to have succumbed to shock. Terminal signs generally included lethargy and hypothermia, often accompanied by anorexia, convulsions, and hemorrhagic diarrhea. The most common hematologic abnormalities included lymphopenia, leukopenia, and anemia. The most prevalent syndromes identified in these otters by clinical chemistry included azotemia, hyperkalemia, hypoglycemia, hepatocellular leakage, and hypoproteinemia/hypoalbuminemia.

Blood samples collected from wild caught otters in 1990 and 1991 identified significant differences in several blood parameters between eastern and western Prince William Sound. Hematologic and serum chemical analyses of adult male sea otters found significantly higher hematocrits and hemoglobins in the west. Western males had significantly higher eosinophil counts, suggesting systemic hypersensitivity reactions. Serum sodium and serum chloride were significantly higher and serum potassium lower in western males. Although there were no significant differences in hematologic parameters between east and west female otters, some chemistry changes were present which were consistent with changes observed in the males. However, the degree of difference was small so that data must be interpreted cautiously. As a group, western sea otter pup hematocrits, hemoglobins, and red cell counts were significantly lower than those of eastern pups, suggesting a mild anemia in the west pups. Hematologic and clinical chemistry differences between eastern pups were of equivocal biologic significance, and trends seen in adults were not present in the pups observed to date.

Over 400 sea otter tissue samples, predominatly liver, fat, and blood, have been analyzed for hydrocarbon contaminants. An exploratory data analysis has been initiated. Results will allow identification of linkages between exposure and effects observed in the population.

Results of a study on survival of sea otter pups demonstrate significantly higher post weaning mortality in western Prince William Sound, compared to controls in the east. In contrast, survival of adult females sea otters was significantly higher in western Prince William Sound compared to controls in the east. However, pupping rates of adult females and survival of those pups through weaning in 1990 and 1991 were similar between eastern and western Prince William Sound and were considered normal.

In conclusion, results of damage assessment studies to date suggest initial damages were extensive, killing between 3,500 and 5,500 sea otters. Additionally, results of several NRDA studies suggest chronic damages to sea otters are occurring which may preclude or delay recovery of affected populations. Although the conclusions presented here should be considered preliminary, evidence of persistent damages is compelling and warrants continued investigation.

ACKNOWLEDGEMENTS

During the last year, many people have contributed their time, knowledge and humor to help us accomplish the objectives of these studies. We extend our appreciation to the following individuals: Jack Ames, Barbara Boyle, Linda Browne, Dave Douglas, Carla Doroff, Mary Faustini, Bill Hughes, Tom Jennings, Kim Kloecker, Karen Laing, Carolyn McCormick, Dan Mulcahy, Linda Plovanich, Chris Robbins, Maria Sanchez, and many others. We thank Carol Cook, Larry Pank, Carol Gorbics, Paul Gertler, and Jon Nickles for exceptional support. Dana Bruden, Mike Fedorko and Kelly Modla should be recognized for making major contributions to these reports. We appreciate their endurance and cheerful assistance.

TABLE OF CONTENTS

Boat Surveys ....Section 1

Population Assessment............................Section 2

The Kenai Intersect Model........................Section 3

Prey Selection...................................Section 4

Age Distributions ....Section 5

Hydrocarbon Contamination of Sea Otter Tissue....Section 6

Hematology and Chemistry.........................Section 7

Appendix A. Histopathology (Lipscomb et al.)

Appendix B. Draft Juvenile Survival Report (PWSSC)

Appendix C. Draft Rehabilitation Report (PWSSC)

Appendix D. Draft Adult Female Study (PWSSC)

Section 1

BOAT-BASED SURVEYS OF SEA OTTERS IN PRINCE WILLIAM SOUND, ALASKA

Douglas M. Burn

SUMMARY

As part of the Natural Resources Damage Assessment (NRDA) studies conducted during spill year 3, boat-based surveys of sea otters in Prince William Sound were continued. The results of these third year surveys indicate that the otter population may have stabilized, but is still below pre-spill levels.

OBJECTIVES

The purpose of this study was to estimate post-spill sea otter population size in Prince William Sound, in order to determine initial and continuing damages related to the Exxon Valdez oil spill.

INTRODUCTION

Within the first few weeks of the Exxon Valdez oil spill, the sea otter quickly became the most vivid symbol of the damage to wildlife in Prince William Sound, Alaska. The fact that sea otters suffered injury by the spill cannot be refuted. It is only the magnitude of this injury that is in dispute. Various methods have been used to extrapolate the number of carcasses recovered to total mortality, based on carcass recovery rates. This study attempts to make direct comparisons between pre- and post-spill population estimates, in order to quantify the net change in the otter population.

STUDY METHODOLOGY

Study Area and Survey Strata

The study area consists of the waters of Prince William Sound (PWS), Alaska, exclusive of Hawkins Island Cutoff and Orca Inlet (Figure 1). Previously, the study area had been divided into 3 distinct survey strata: shoreline, coastal, and pelagic. The shoreline strata was based on shoreline transects surveyed by Irons, Nysewander and Trapp (1988) during the summers of 1984 and 1985, and is defined by the 200m-wide strip adjacent to the coastline. Areas outside of this 200m-wide strip were not systematically surveyed prior to the spill. In an attempt to quantify the PWS otter population as a whole, the areas greater than 200m from shore were divided into sampling "blocks" based on a 5-minute latitude/longitude grid system. The coastal stratum was comprised of those blocks that are immediately adjacent to 1km or more of shoreline. The pelagic stratum was comprised of those blocks that are adjacent to less than 1km of shoreline. Within each block, a number of 200m-wide strip transects were designated for sampling.

This original designation of coastal and pelagic strata was of little value to analysis of sea otter data (it must be emphasized that these data are collected as part of a joint seabird/marine mammal survey). Therefore, areas outside of the shoreline stratum were restratified, based on their distance to otter foraging habitat as defined by the 20m bathymetric contour. Those blocks whose mean distance is greater than 5km from foraging habitat are considered "offshore" blocks, while those whose average distance is less than 5km are considered "nearshore" blocks. While this new stratification still suffers from the artificial rigidity of the grid system, I feel it is an improvement over the original scheme.

Oiling Classification

The determination of oiled vs. non-oiled transects and blocks is of major importance in the estimation of damage to the sea otter population from these data. The pathways taken by the oil is a fundamental question in virtually all damage assessment studies. Ironically, it is one area of investigation that has been virtually ignored on a comprehensive basis, even though estimation of damages is extremely sensitive to these determinations.

Given the numerous sources of oiling information, with no means of evaluating the relative strengths and weaknesses of each, at this point in time any reasonable stratification of oiling seems as good as any other. The oiling classification presented in this report is based on Alaska Department of Environmental Conservation (ADEC) overflight data from the time of the spill. Aerial observations were used to create a GIS coverage depicting the movement of oil over the surface of the water. While it must be recognized that this interpretation of oiling has certain inconsistencies when compared to shoreline oiling and/or the National Oceanographic and Atmospheric Administration's (NOAA) HAZMAT model, it is the oiling picture most often used to depict the geographic extent of the spill.

Since sea otters are highly mobile animals, it is possible that otters inhabiting areas outside the pathway of the oil could have swam into the area of the slick and become oiled. For this reason, a buffer zone of 5km was added to the ADEC overflight data to represent an area within which otters might have been affected by oil. Shoreline transects, and nearshore and offshore blocks with any area located within 5km of the oil are therefore classified as oiled (Figure 2).

Survey Dates

Pre-spill data of Irons et al. (1988) were collected for shoreline transects during the summers of 1984 and 1985. These data serve as a baseline for comparison with post-spill surveys. For the purposes of this report, the pre-spill effort is referred to as survey 0. To date, 9 post-spill surveys have been completed. The dates of all surveys are listed below:

Survey 0	07/07/84 - 08/24/84
	05/22/85 - 08/31/85
Survey 1	06/15/89 - 07/06/89
Survey 2	07/12/89 - 07/26/89
Survey 3	08/07/89 - 07/26/89
Survey 4	03/12/90 - 03/22/90
Survey 5	06/08/90 - 06/23/90
Survey 6	07/06/90 - 07/30/90
Survey 7	08/06/90 - 08/22/90
Survey 8	03/07/91 - 03/23/91
Survey 9	07/03/91 - 07/22/91

Sample Size

The baseline survey of Irons et al. (1988) consisted of 718 shoreline transects, of which 708 are within the PWS study area (the remaining 10 transects are within the Orca Inlet and Hawkins Island Cutoff areas). The nearshore and offshore strata were not sampled by Irons et al. (1988).

Post-spill surveys were initially conducted during the summer of 1989 as a random sample of approximately 25% of available shoreline transects and the original coastal and pelagic blocks. Due to logistical constraints, only the shoreline stratum was sampled during survey 1. All three strata have been sampled in each survey since July 1989. Once the initial random sample of transects and blocks was chosen, each successive survey replicated the same sampling units to allow for comparison over time.

In order to complete winter surveys when weather conditions are often more constraining, only a subset of the summer transects and blocks (approximately 14% of all shoreline transects and nearshore and offshore blocks) were sampled.

Beginning with survey 5 in June 1990, an additional 25 transects were added to the shoreline sample, increasing the proportion sampled from 25% to 29%. These additional transects were randomly selected from both oiled and non-oiled western Prince William Sound. Sample sizes of the nearshore and offshore strata were not increased.

Analytical Methods

Sea otter density and abundance estimates are calculated using ratio estimator techniques (Cochran, 1977).

Shoreline sea otter density is calculated as a ratio:

$$R=\frac{\Sigma y}{\Sigma x}$$

where: R = shoreline sea otter density
y = number of sea otters within shoreline transect
x = area of shoreline transect in km^2

Standard error of this ratio is calculated as:

$$s(R)=\frac{1}{\bar{x}}\sqrt{\frac{\Sigma(y-Rx)^2}{n(n-1)}\frac{N-n}{N}}$$

where: s(R) = standard error of R
N = total number of shoreline transects
n = number of sampled shoreline transects

The ratio estimate of shoreline sea otter population:

$$\hat{Y}_R=RX$$

where: $\hat{Y}_R$ = ratio estimate of shoreline sea otter population
X = total area of all shoreline transects in km^2

Standard error of this estimate is calculated as:

$$s(\hat{Y}_R)=s(R)X$$

where: $s(\hat{Y}_R)$ = standard error of the ratio estimate $\hat{Y}_R$

Nearshore and offshore sea otter densities are calculated within each block as:

$$r_B=\frac{\Sigma y_t}{\Sigma x_t}$$

where: r_B = nearshore/offshore sea otter density for survey block
y_t = number of sea otters within nearshore/offshore transect(s) for survey block
x_t = area of nearshore/offshore transect(s) sampled

within survey block in km^2

Otter densities are calculated for the nearshore and offshore strata as:

$$R=\frac{\sum x_B r_B}{\sum x_B}$$

where: R = sea otter density in nearshore and offshore strata
x_B = total area of sampled survey block in km^2

Standard error of this ratio is calculated as:

$$s(R)=\frac{1}{\bar{x}_B}\sqrt{\frac{\sum(r_B x_B - R x_B)^2}{n(n-1)}}$$

where: s(R) = standard error of R
N = total number of nearshore/offshore blocks
n = number of sampled nearshore/offshore blocks

Estimate of nearshore and offshore otter population size:

$$\hat{Y}_R=RX$$

where: $\hat{Y}_R$ = ratio estimate of nearshore/offshore otter population
X = total area of all nearshore/offshore habitat in km^2

Standard error of the estimated population size:

$$s(\hat{Y}_R)=s(R)X$$

where: $s(\hat{Y}_R)$ = standard error of estimate $\hat{Y}_R$

STUDY RESULTS

Numbers of shoreline transects sampled and sea otters counted are presented in Table 1. Numbers of nearshore blocks sampled and otters counted are presented in Table 2. With the exception of one animal sighted during the July 1990 survey, no otters have ever been observed in the offshore stratum. Summary tables and estimates for this stratum are therefore omitted.

All estimates presented in this report are uncorrected for sightability. A pilot study conducted concurrently with the August 1990 survey estimated an overall sightability factor of 0.70. This value is based on a relatively small sample size of ground-truthing segments (n=21). While it is unclear how accurate this sightability value is, it is certain that these boat-based observations do miss some proportion of the otters within a transect. Abundance estimates presented here should be considered minimum values.

Sea otter density and abundance estimates for the shoreline stratum are presented in Table 3. In the non-oiled area, otter densities exhibited a modest increase (13.5%) between the pre-spill surveys of Irons et al. (1988) and the summer 1989 surveys. This would suggest that the otter population in these areas was increasing. Otter densities in the oiled area underwent a decline of approximately 34.6% during the same time period. Surveys conducted after summer 1989 show further declines in otter density in oiled areas, suggesting continuing injury to the population. However, otter density in non-oiled areas also exhibit a decline during the same time period. With the exception of the July 1990 survey, otter densities in the oiled area are consistently lower than those in the non-oiled area, which is exactly opposite the pre-spill pattern.

Otter density and abundance estimates for the nearshore stratum are presented in Table 4. Due to the relatively low level of sampling effort, abundance estimates for this stratum have low precision. In every survey, otter densities are much lower in the oiled area than in the non-oiled area. However, lacking pre-spill information on this stratum, it is unclear if this pattern is due to oil or some other factors. Of particular interest is the peak in otter density seen in all 3 July surveys for the non-oiled area. These fluctuations in otter densities have profound effects on the overall population estimates.

Ratios of nearshore to shoreline abundance were calculated for the 6 post-spill summer surveys in order to develop a correction factor to apply to the pre-spill shoreline estimate of Irons et al. (1988). For the non-oiled area, the mean nearshore/shoreline ratio is 1.855 (s.e. 0.363), and for the oiled area 0.852 (s.e. 0.187). The standard error of the mean of the 6 ratios was used to calculate an approximate 95% confidence interval around the adjusted pre-spill estimates. Adjustments for population growth during the period between 1984/85 and the moment of the spill have not been made. An increase in population during that time would logically result in larger estimates of damages. Total population estimates for the Prince William Sound study area are presented in Table 5. These data suggest that the current post-spill population size is approximately 6000 otters.

Population trends in non-oiled, oiled, and all areas are presented in Figures 3-5. For comparison, the pre-spill population estimate is also shown. In the non-oiled area, there is considerable overlap between pre- and post-spill population estimates. There is virtually no overlap in between estimates in the oiled area. These results would suggest that a real decline in sea otter abundance has occurred within the oiled area. The difference between point estimates is on the order of 1600 otters initially in summer 1989, and later 2200 otters in summer 1990 and 1991 (Figure 6). Adjusting these values for otters not seen, these loss estimates would be 2285 and 3143 otters, respectively. Given that approximately 500 oil-related otter carcasses were recovered at the time of the spill, these data suggest a carcass recovery rate of 21%.

STATUS OF INJURY ASSESSMENT

The task of estimating damages to sea otters is an extremely complicated one. Other sections of this report deal with physiological changes on the organismal level. The effect of low levels of hydrocarbon residues in blood and/or tissues of an individual otter may be insignificant on the population level. Conversely, population size may fluctuate over time for a variety of natural causes. Attempts to discern which population changes are directly related to the Exxon Valdez oil spill should only be made with a thorough understanding of the qualifying assumptions involved.

First, the geographic extent of the spill itself is not definitively known. Due to the mobility of sea otters, the actual extent of the oil effects on the sea otter population is also unknown. Results from this study suggest that the otter population in the Prince William Sound study area has undergone a decline relative to the 1984/85 surveys. The proportion of this decline attributable to oil is directly dependent upon classification of sampling units as oiled vs. non-oiled.

Second, pre- and post-spill comparisons are limited by the quality of the pre-spill data set. Results from post-spill surveys indicate that considerable numbers of sea otters frequent the waters greater than 200m from shore, and that proportions of otters within the shoreline and nearshore strata vary seasonally. Lack of pre-spill data from the nearshore stratum is a severe limitation to these comparisons. In addition, the 4-5 year period between pre- and post-spill surveys is problematic. The distribution and abundance of the population at the moment of the spill may or may not have been comparable to that of the 1984/85 survey.

Finally, the survey design for the waters greater than 200m from shore (i.e. the nearshore and offshore strata) is poor. Sampling units should be redesigned to increase precision, while still maintaining comparability with previous surveys. As a population monitoring tool, the current survey could only detect large population changes, primarily due to low precision in the nearshore stratum. The cooperative nature of this survey (seabirds and marine mammals are counted) dictates that the summer survey be conducted during July to minimize the influence of migratory bird species. In addition, we now have a period of 3 consecutive July surveys completed. Unfortunately, July also appears to be the summer month with the greatest number of otters moving into the nearshore stratum. This causes the July results to be the least precise of any summer survey.

Given these numerous assumptions and caveats, there remain several important results from this study. First, in direct comparisons between pre-and post-spill shoreline data, non-oiled areas underwent a 13.5% increase, while oiled areas underwent a 34.6% decrease. And second, the post-spill population in the oiled area is significantly lower than the best pre-spill estimate, indicating a real decline on the order of 1600 otters initially, and up to 2200 in subsequent years (estimates uncorrected for sightability). On the positive side, the population showed little change between July 1990 and July 1991 surveys, suggesting that perhaps the effects of the spill on a population level have subsided. However, this can not be determined conclusively without further monitoring of the population.

ACKNOWLEDGEMENTS

I wish to thank the following persons for their assistance in preparation of this report. Tom Jennings, Barbara Boyle, Roger Slothower, and Hans Buckholtz provided GIS support. Dave Bowden provided statistical advice. Greg Balogh, Larry Barnes, Tom Dietsch, Cris Dippel, Chris Elphick, George Esslinger, Thomas Evans, Jim Fuller, Janey Fadely, Greg Golet, Bonnie Gray, John Grosenbeck, Jody Gruber, David Irons, Susanne Kalxdorff, Steve Klosiewski, Tim Krumwiede, Karen Laing, Blair Leisure, Kelly Modla, Karen Oakley, Tina Odenbaugh, Jon Pohl, Gerry Sanger, Ben Schick, Anita Smith, Una Swain, Rick Turner, and Dave Wolfe served as observers. In addition, Karen Laing and Steve Klosiewski of the Office of Migratory Bird Management served as project coordinators, and were instrumental in getting this effort into the field.

LITERATURE CITED

Cochran, W.G. 1977. Sampling Techniques. John Wiley and Sons, Inc. New York, New York. 428pp.

Irons, D.B., D.R. Nysewander, and J.L. Trapp. 1988. Prince William Sound sea otter distribution in relation to population growth and habitat type. U.S. Fish and Wildlife Service. Unpubl. report. 31pp.

Table 1.1 Numbers of shoreline transects sampled and sea otters counted in Prince William Sound, Alaska.

	Non-Oiled Area			Oiled Area		
Survey Date	Sampled Transects	Area (km^2)	Count of Otters	Sampled Transects	Area (km^2)	Count of Otters
PWS Study Area	301	387.0	--	441	453.3	--
Summer 1984/85	285	367.6	1666	423	417.5	2191
June 1989	68	85.2	445	115	121.7	400
July 1989	69	86.7	460	118	125.4	414
August 1989	69	86.7	425	118	125.4	464
March 1990	38	49.6	216	61	66.6	173
June 1990	78	96.6	305	134	139.3	219
July 1990	78	96.6	253	134	139.3	384
August 1990	78	96.6	388	134	139.3	411
March 1991	38	49.5	195	61	66.6	123
July 1991	78	96.6	294	134	139.3	406

Table 1.2 Numbers of nearshore blocks sampled and sea otters counted in Prince William Sound, Alaska.

	Non-Oiled Area			Oiled Area		
Survey Date	Sampled Blocks	Area (km^2)	Count of Otters	Sampled Blocks	Area (km^2)	Count of Otters
PWS Study Area	118	2400.1	--	147	4573.8	--
Summer 1984/85	--	--	--	--	--	--
June 1989	--	--	--	--	--	--
July 1989	28	571.7	61	36	1140.3	31
August 1989	28	571.7	23	36	1140.3	19
March 1990	17	416.4	23	30	975.3	21
June 1990	27	543.6	44	34	1090.7	25
July 1990	28	571.7	62	36	1140.3	19
August 1990	28	571.7	42	36	1140.3	15
March 1991	17	416.4	21	30	975.3	9
July 1991	27	543.6	61	36	1140.3	18

Table 1.3 Summary of shoreline sea otter density and abundance estimates for Prince William Sound, Alaska.

	Non-Oiled Area			Oiled Area		
Survey Date	Density (otters/km^2)	Estimated Abundance	95% c.i	Density (otters/km^2)	Estimated Abundance	95% c.i.
Summer 1984/85	4.53	1754	±143	5.25	2285	±101
June 1989	5.22	2020	±586	3.29	1430	±362
July 1989	5.31	2053	±631	3.30	1438	±360
August 1989	4.90	1897	±635	3.70	1611	±460
March 1990	4.35	1685	±566	2.60	1130	±199
June 1990	3.16	1221	±511	1.58	690	±331
July 1990	2.62	1013	±291	2.76	1200	±397
August 1990	4.02	1554	±439	2.95	1284	±419
March 1991	3.94	1524	±510	1.85	804	±161
July 1991	3.04	1177	±362	2.91	1268	±287

Table 1.4 Summary of nearshore sea otter density and abundance estimates for Prince William Sound, Alaska.

Survey Date	Non-Oiled Area Density (otters/km^2)	Non-Oiled Area Estimated Abundance	Non-Oiled Area 95% c.i	Oiled Area Density (otters/km^2)	Oiled Area Estimated Abundance	Oiled Area 95% c.i.
Summer 1984/85	--	--	--	--	--	--
June 1989	--	--	--	--	--	--
July 1989	1.33	3204	±1865	0.31	1416	±1274
August 1989	0.49	1180	±735	0.18	838	±754
March 1990	0.67	1604	±886	0.24	1120	±879
June 1990	0.99	2370	±1784	0.26	1190	±890
July 1990	1.30	3126	±3094	0.18	846	±701
August 1990	0.86	2070	±1182	0.15	704	±473
March 1991	0.57	1368	±497	0.11	498	±414
July 1991	1.27	3050	±1861	0.18	801	±796

Table 1.5 Summary of sea otter abundance estimates for Prince William Sound, Alaska. Summer 1984/85 estimate based on shoreline/nearshore ratios from 6 post-spill summer surveys.

	Non-Oiled Area		Oiled Area		All Areas	
Survey Date	Estimated Abundance	95% c.i	Estimated Abundance	95% c.i.	Estimated Abundance	95% c.i.
Summer 1984/85	4992	±1248	4249	±846	9241	±1508
June 1989	--	--	--	--	--	--
July 1989	5257	±1969	2854	±1324	8111	±2373
August 1989	3077	±971	2449	±884	5526	±1313
March 1990	3289	±1051	2250	±901	5539	±1384
June 1990	3592	±1856	1880	±950	5471	±2084
July 1990	4140	±3107	2099	±813	6239	±3212
August 1990	3624	±1261	1988	±632	5612	±1411
March 1991	2892	±712	1301	±444	4194	±840
July 1991	4228	±1895	2069	±846	6297	±2076

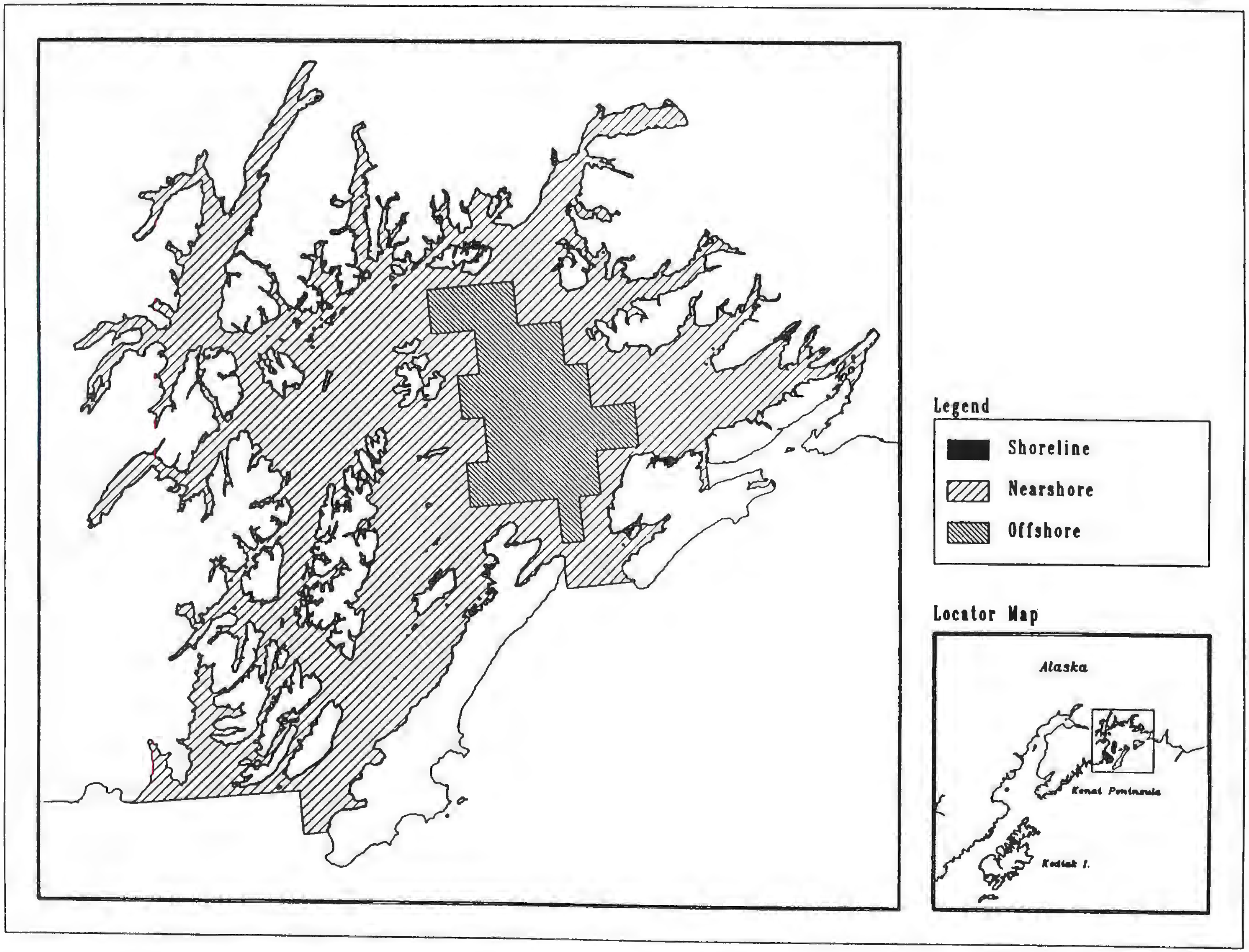


Figure 1.1   Prince William Sound study area, showing survey strata.

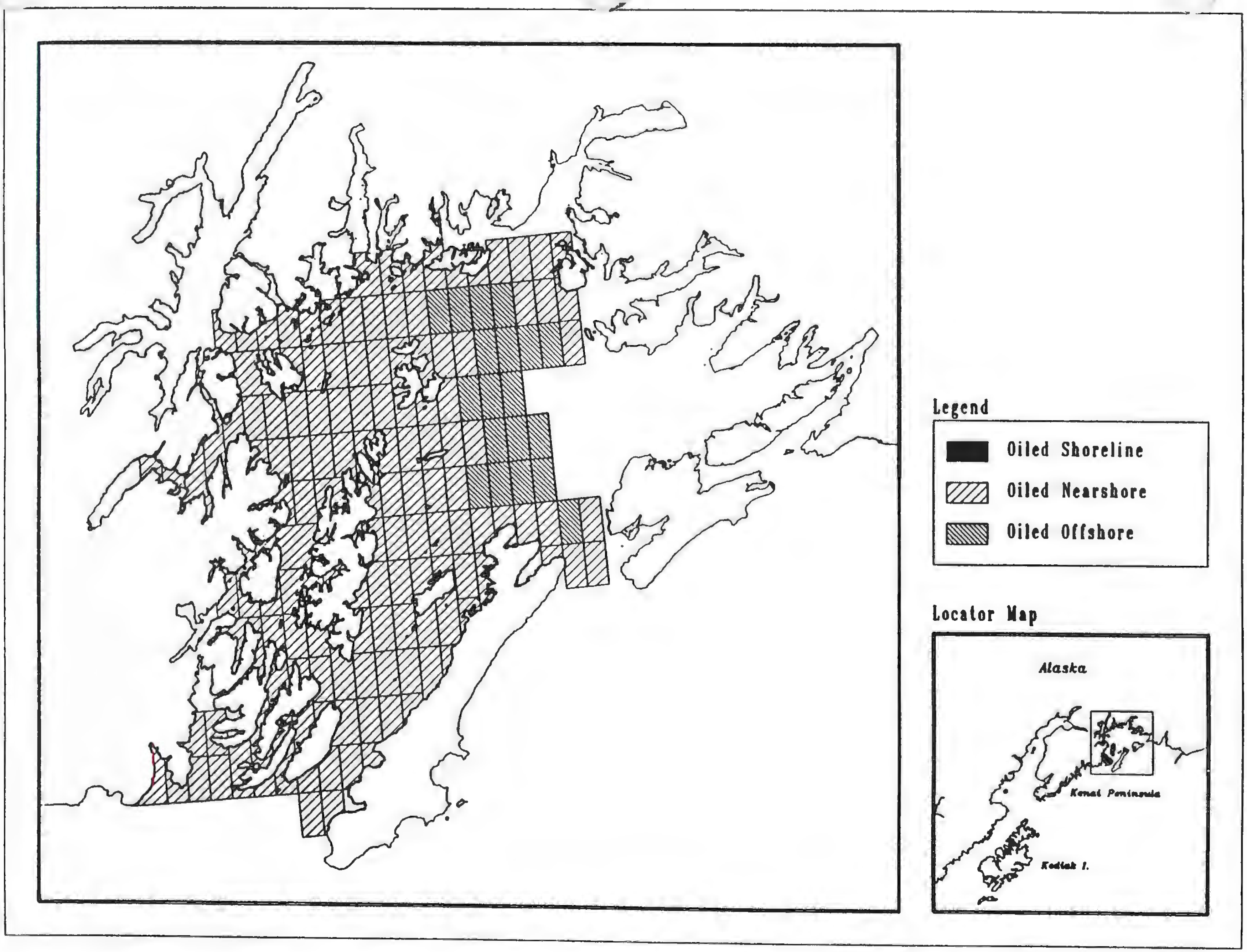


Figure 1.2 Oiling classification of sampling units within the Prince William Sound study area.

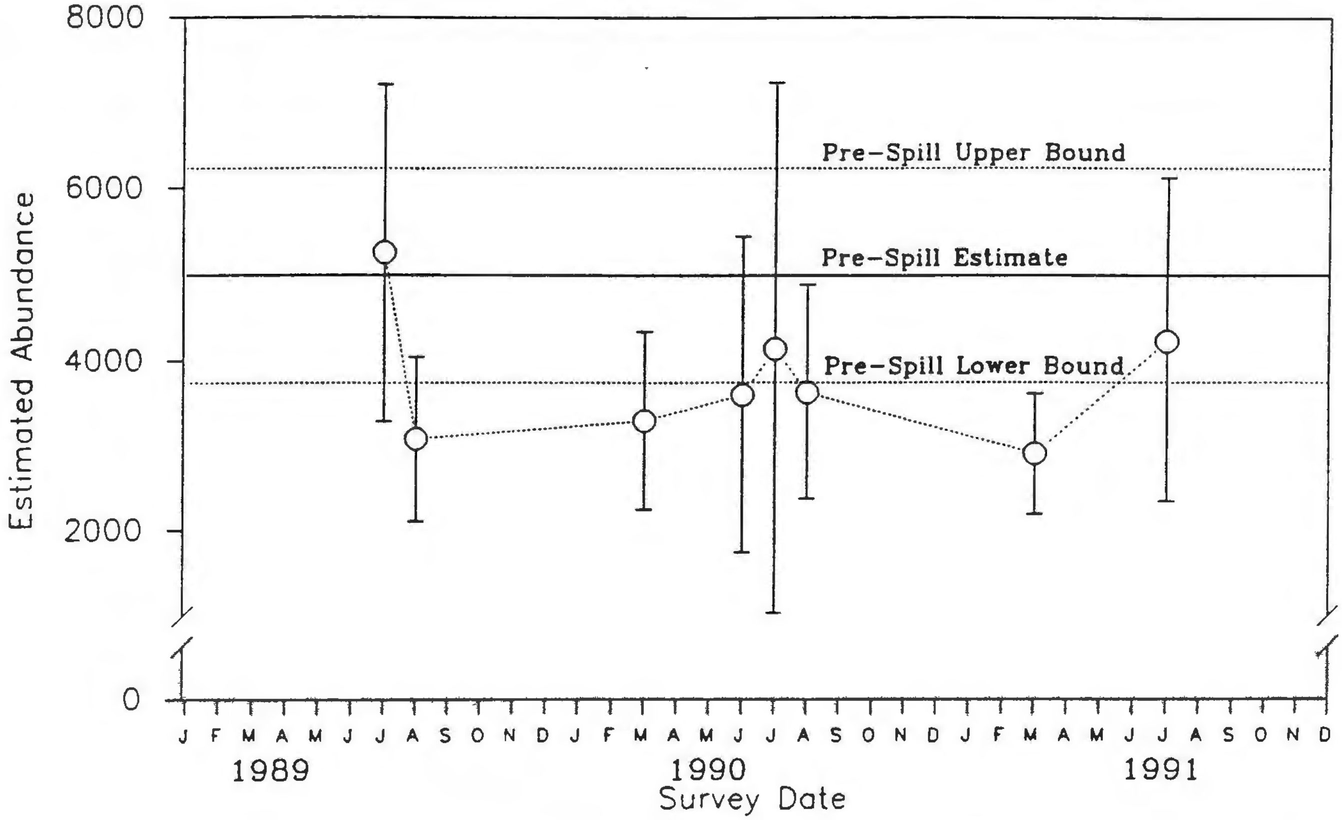


Figure 1.3. Post-spill sea otter population trend in the non-oiled areas of Prince William Sound, Alaska. Error bars represent 95% confidence intervals.

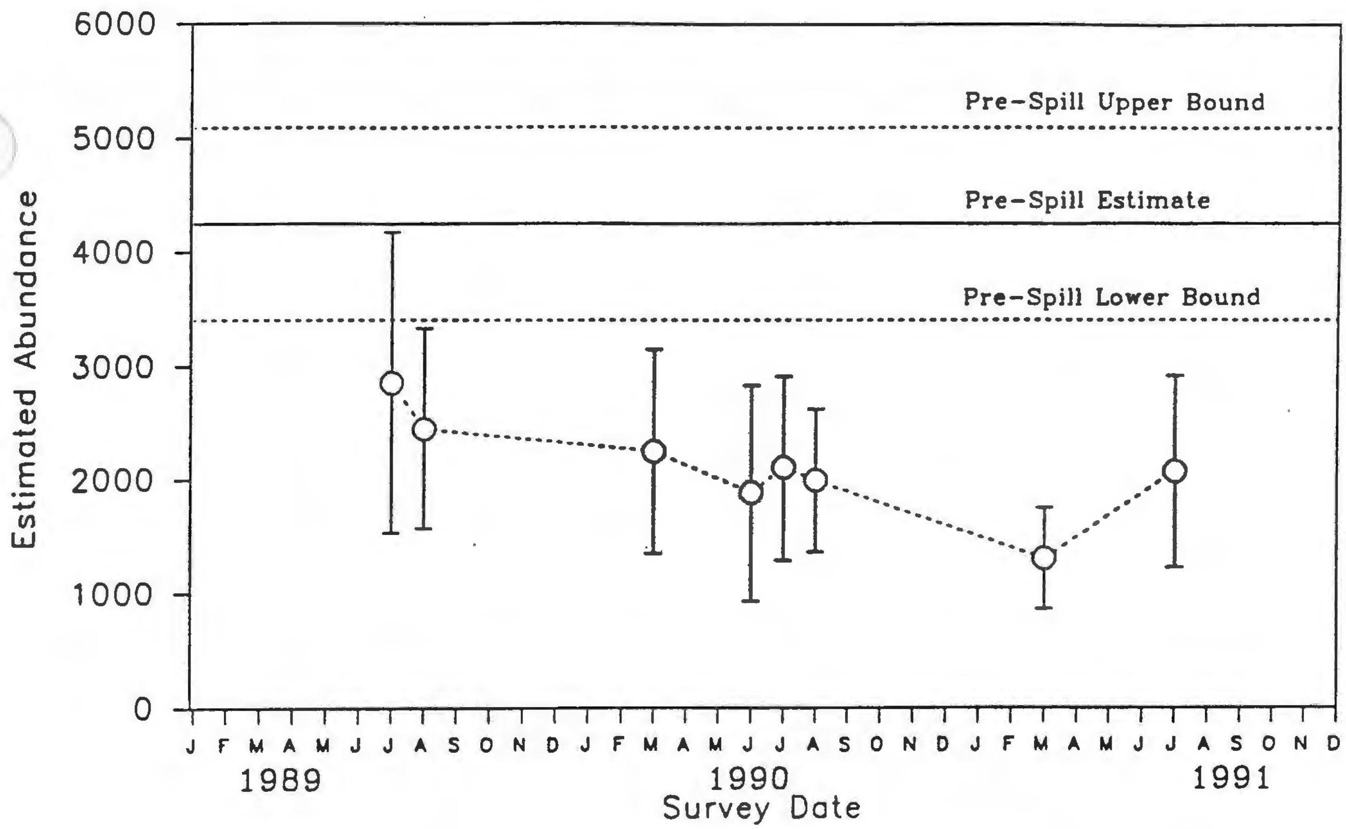


Figure 1.4. Post-spill sea otter population trend in the oiled areas of Prince William Sound, Alaska. Error bars represent 95% confidence intervals.

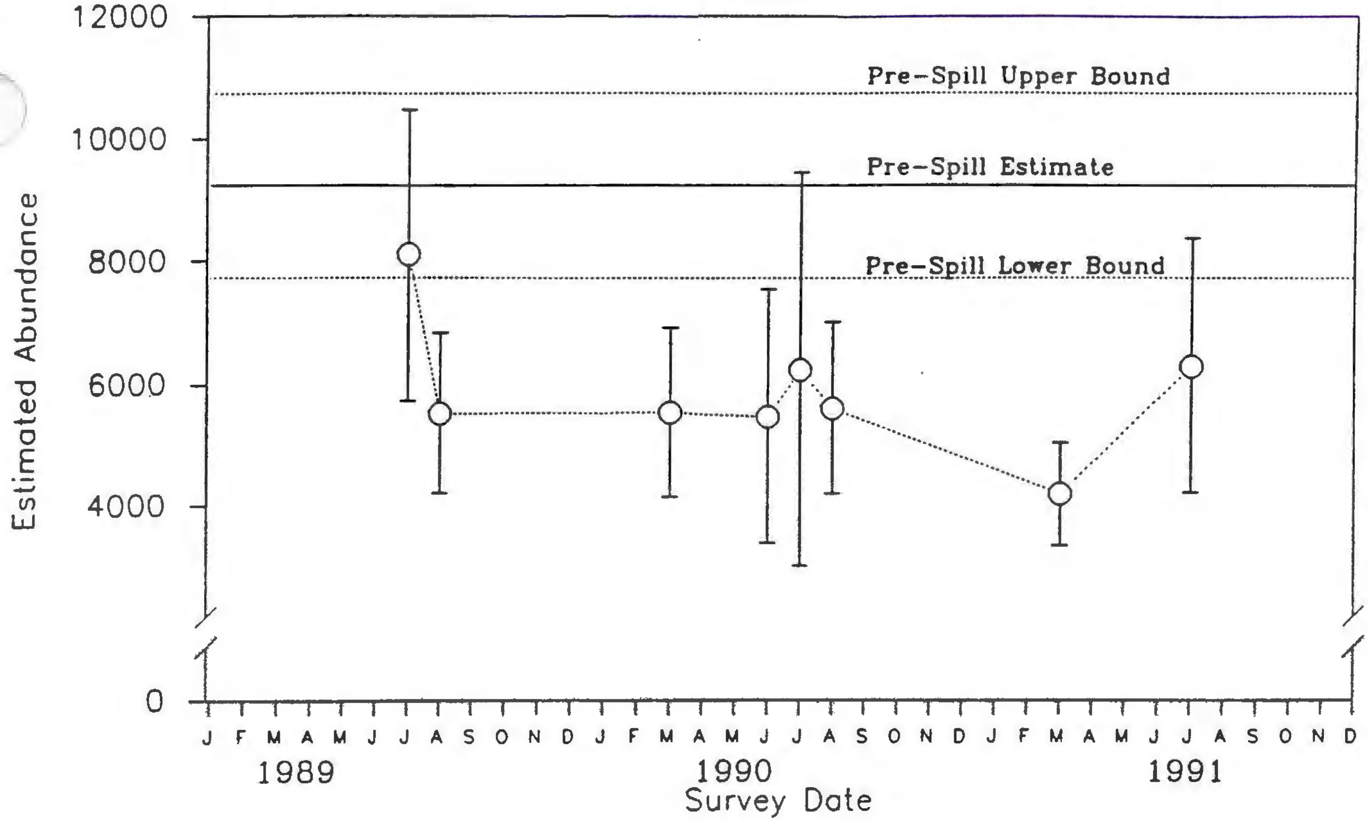


Figure 1.5. Post-spill sea otter population trend in the all areas of Prince William Sound, Alaska. Error bars represent 95% confidence intervals.

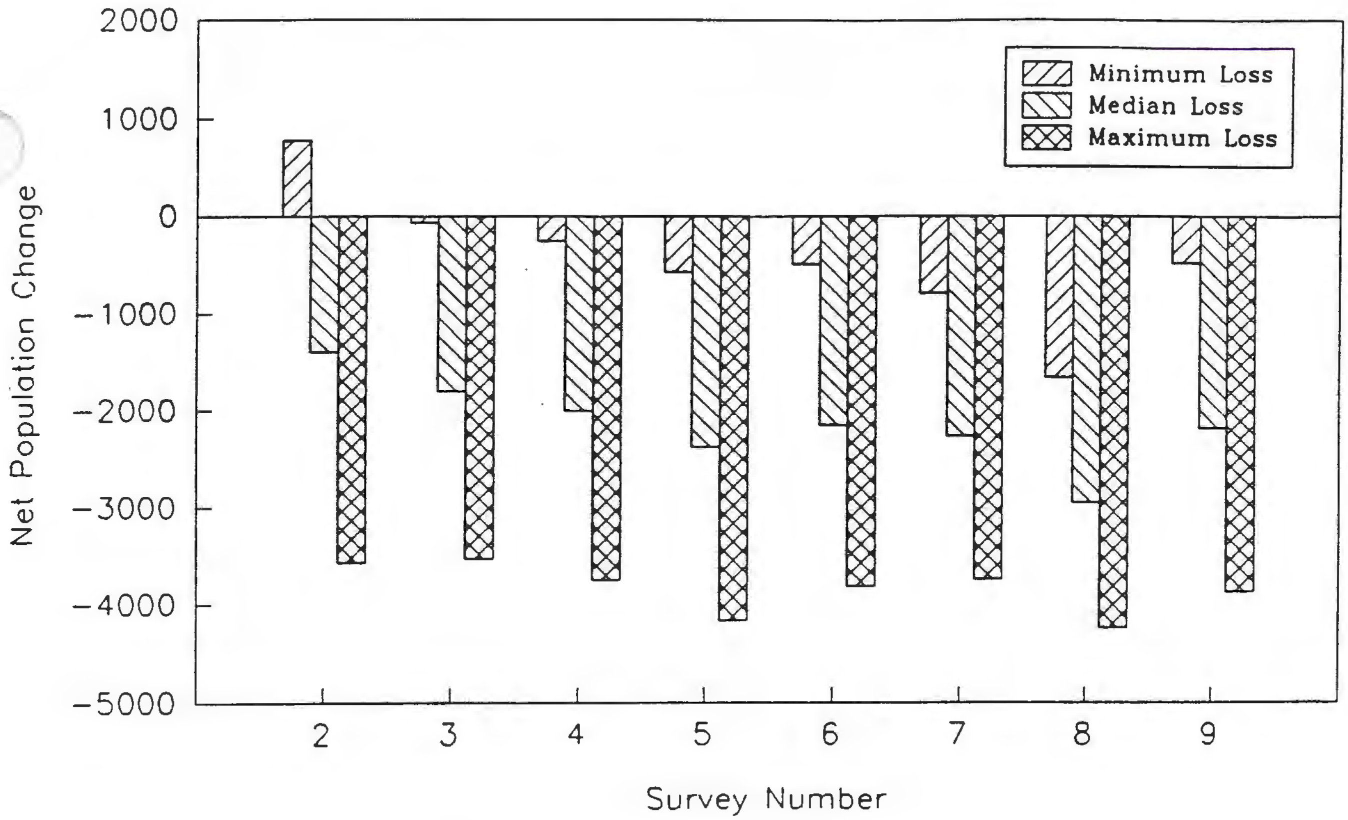


Figure 1.6 **Estimated net change in sea otter population in the oiled areas of Prince William Sound, relative to best pre-spill estimate.**

DEVELOPMENT OF SEA OTTER SURVEY TECHNIQUES

James L. Bodkin and Mark S. Udevitz

SUMMARY

Field trials were conduced in 1991 to evaluate the Piper PA-18 Super-Cub as a platform from which to estimate sea otter density. At least 90% of the sea otters observed in survey units by ground based observers were also detected by intensive aircraft searches at each of 3 altitudes using a fixed search pattern. The proportion of sea otters detected was also greater than or equal to .90 for intensive searches using each of 3 search patterns at a fixed altitude. Sea otter detectability increased and its rate of increase decreased with increasing search intensity. Results of these investigations suggest that additional work toward development of a Super-cub based sea otter survey technique is justified.

A boat-based survey was designed and implemented in 1991 to estimate ratios of independent to dependent sea otters and patterns of habitat use by sea otters in portions of Prince William Sound. The ratio of independent to dependent sea otters was similar among study areas along oiled and un-oiled shoreline in the western sound and along un-oiled shorelines in the eastern sound.

OBJECTIVES

1) Evaluate the feasibility of using the Piper PA-18 aircraft as platform for estimating sea otter density.

2) Design and implement a small boat survey to estimate ratios of dependent to independent sea otters and patterns of habitat use by sea otters in oiled and non-oiled portions of Prince William Sound.

INTRODUCTION

Initial damages to the sea otter population resulting from the T/V Exxon Valdez oil spill included lethal and sub-lethal levels of direct exposure. One method used to estimate the total immediate loss to the sea otter population in Prince William Sound was a comparison of estimates of sea otter abundance based on boat surveys conducted before and after the spill. Boat surveys were used to estimate sea otter density in 1989 and 1990 in order to be consistent with the method used before the spill. This consistency was necessary for assessing the immediate loss, but it has become evident that the boat survey methodology, as conducted, will not provide the accuracy or precision necessary to monitor the smaller annual changes that are likely to occur in the post-spill population (Burn 1990, Udevitz et al. 1990).

Several methods have been used in the past to obtain estimates of sea otter abundance and distribution. Most surveyors of sea otter abundance have acknowledged that some animals were probably missed (Kenyon 1969, Estes 1977) but have generally failed to quantify biases or estimate precision.

Counts of sea otters from the ground have been generally recognized as providing the most accurate estimates of nearshore sea otter abundance (Schneider 1971). Estes and Jameson (1988) estimated that the probability of sighting sea otters was 94.5% for standardized shoreside counts, using two experienced observers, high-resolution 10X binoculars and 50X Questar telescopes (New Hope, PA). This was the first study to rigorously evaluate the effect of activity, group size and distance from observer on sighting probability of sea otters. Their results provide a baseline, against which other methods might be evaluated. However, due to limited access and transportation along most coastlines, ground counts can not be used over the large geographic areas occupied by most sea otter populations.

Sea otter surveys have commonly been conducted from vessels of various sizes (Ebert, 1968, Jameson et al. 1986, Johnson 1987, Pitcher 1989). Pitcher (1989) suggested that applications of boat counts should be limited to assessing trends in abundance and geographic distribution. Schneider (1971) felt boat counts provided higher counts than aerial surveys. Johnson (1987) found that counts from boats were 1.7 times greater than helicopter counts in Prince William Sound. Udevitz et al. (1990) determined that detection of sea otters in boat-based surveys is reduced due to avoidance behavior of the otters as well as sightability problems. In addition to surveying sea otter abundance, boat surveys have been used to provide indices of reproductive rates in sea otter populations (Estes 1990).

Helicopters have occasionally been used to conduct surveys of sea otter populations (Estes 1971, Schneider 1971, Pitcher 1975). Schneider (1971) concluded that helicopters counts were two to four times higher than fixed-wing counts but that shore counts may be three times greater than helicopter counts. Johnson (1987) found helicopter counts inferior to boat counts. Preliminary, quantitative studies reported by Douglas et al. (1990) suggest that rotary-winged aircraft might be suitable as an observation platform. Cost and safety considerations of rotary-wing aircraft over water may preclude their wide spread use in sea otter surveys.

Aerial counts of sea otters from fixed-wing aircraft have been used for several decades throughout their range (Kenyon 1969, Wild and Ames 1974 and Simon-Jackson et al. 1986). Fixed-wing surveys have usually been based on single survey lines along a shoreline where sea otters may occur. Kenyon (1969) felt aerial surveys provided higher counts than those obtained from small boats, and estimated he observed 50-75% of the sea otters present from the air. Schneider (1971) felt only 10-25% of the sea otters were counted in a fixed-wing survey. Studies conducted by California Dept. of Fish and Game estimated that 25-40% of the sea otters are missed by fixed-wing counts (Wild and Ames 1974, Geibel and Miller, 1984). Traditionally, fixed-winged surveys have been conducted without standardized protocols. Many different types aircraft (e.g., DC-3, Grumman Goose, Cessna 185, Cessna 206, Piper PA-18) have been used, each with very different flight characteristics (e.g., speed, maneuverability, viewing attributes). Procedures commonly varied between surveys (e.g., airspeed, altitude, number of observers, weather conditions, flight patterns). While many of these survey attributes have been recognized as affecting counts, the magnitudes of these effects have not been previously quantified.

The objective of most sea otter surveys has been to describe changes that may have occurred in the abundance and distribution of the species over time or to provide a baseline against which future counts may be compared. Two factors have generally led to difficulty in interpreting survey data. First, with few exceptions (Estes and Jameson 1988, and Jameson et al. 1986) survey methodologies have not been standardized. Secondly, except for the ground counts described by Estes and Jameson (1988) and Jameson et al. (1986), survey methods have not been rigorously tested to determine the proportion of the animals actually observed or the effects of activity and environmental conditions on sightability.

The long term objective of this study is to develop and implement standardized survey methodologies that will provide improved estimates of sea otter density and reproductive rates and that are applicable throughout the species' range. The first phase of this work consisted of trials conducted in April and July, 1991 to evaluate the Piper PA-18 Super-Cub as a survey platform for estimating sea otter density. The Super-Cub has been selected repeatedly for wildlife survey work based on its slow stall speed and high degree of maneuverability (Erickson and Siniff 1964, LeResche and Rausch 1974, Gasaway et al. 1986). It seats one pilot and one passenger in tandem, an arrangement recommended by Erickson and Siniff (1964) as allowing navigation and observation to occur from the same spatial orientation in the plane. The second phase of this project was the development and implementation of a systematic boat survey in August and September, 1991 to document rates of reproduction in western Prince William Sound. Data analysis has not yet been completed, but we present preliminary results in this report.

METHODS

Aircraft Evaluation

Two series of trials were conducted to evaluate the Piper PA-18 aircraft as a platform for estimating sea otter density. All trials used ground based observers to quantify the proportion of animals detected from the air. The first series of trials was conducted in April 1991 to assess the effect of altitude (altitude evaluation) on sea otter detectability. The second series of trials was conducted in July 1991 to assess the effect of search pattern (pattern evaluation) on sea otter detectability.

Trials were conducted on areas of ocean (survey units) that did not contain canopy forming kelp, were large enough to contain a full search pattern, allowed unrestricted observation from an adjacent vantage point, and contained 1 or more otters immediately prior to arrival of the aircraft. Survey units were selected by ground crews based on previous reconnaissance and observation of the area immediately before ground crew deployment. All survey units for the altitude evaluation were located in Eastern Prince William Sound. Survey units for the pattern evaluation were scattered throughout Prince William Sound, though most were in the west.

Ground crews approached each selected survey unit after a thorough study of the area from offshore, taking care to minimize disturbance to sea otters. After deploying themselves at the vantage point, the ground crew defined the boundaries of the unit, established an orientation for the aerial search pattern within the unit and determined the position and activity of each otter within the unit. The ground crew then contacted the aircraft by VHF radio to begin the trial. Ground observations followed methods established by Estes and Jameson (1988). Immediately prior to arrival of the aircraft, the ground crew recorded the location, group size, number of dependent pups and activity of each otter or group of otters. Activity categories included swimming (changing location), resting (stationary on water surface) and diving (stationary and temporarily submerging). The ground crew also recorded the location and behavior of all otters observed outside the boundaries of the unit, observations regarding changes in sea otter activity associated with the approach of the aircraft, and the time the aircraft entered and departed the unit. Following the departure of the aircraft, the ground crew was transported by boat to the next survey unit.

Altitude evaluation trials were conducted at 46m, 92m and 137m observed by both crews (b_i), the number observed only by the ground crew (g_i), and the number observed only by the aerial observer (a_i) in the observation circle or strip were determined. The number of otters in the circle or strip before any response to the approaching aircraft was determined based on ground crew observations prior to the arrival of the aircraft.

Sea otter detection probabilities (detectabilies) for the aerial observer were estimated as

$$\hat{P}_d = \frac{\sum_{i=1}^{r} b_i}{\sum_{i=1}^{r} (b_i+g_i)}$$

where r is the number of trials. Detectabilities were also estimated separately for each trial as $b_i/(b_i+g_i)$. Kruskal-Wallis tests were used to evaluate differences in detection probabilities among altitudes and patterns. Fisher's exact test for contingency tables was used to evaluate the effect of altitude and pattern on the proportion of trials in which all otters were detected and the proportion of trials in which otters exhibited disturbance behavior. All statistical tests were conducted at the .05 significance level.

Reproduction

Estimates of annual reproduction, as indicated by ratios of independent to dependent sea otters and patterns of habitat use were obtained from small (<10m) boat surveys. Surveys were conducted from 13 August through 11 September 1991.

Sample units corresponded to the coastline transects established by Irons et al. (1988) and extended offshore out to the 100m depth contour or 1/2 the distance to the opposing shoreline, whichever was less. A subset of sample units was randomly selected to be surveyed in each of 3 strata. Strata consisted of heavily oiled and non-oiled nearshore habitat in western Prince William Sound and non-oiled habitat in eastern Prince William Sound.

The survey vessel maneuvered about 200 to 300m offshore, and out to the offshore boundry as necessary to observe and classify all otters within each selected sample unit. Boat speed was maintained at less than 15 mph. Surveys were conducted only when viewing conditions are considered good or better (calm to light winds, sea state less than Beaufort 2).

Surveys crews consisted of two observers, including the boat operator. Crews used high resolution binoculars and a Questar telescope. Otters were classified as either dependent or independent. Dependent otters were defined as sea otters smaller than, and in close association with, an adult. This definition included, but was not limited to, pups in close physical contact, nursing, receiving food from, swimming with or being groomed by an adult sea otter. Independents were defined as all other sea otters. Crews recorded the number of dependent and independent sea otters found in each sample unit.

Each sample unit was classified by coastline physiography and bathymetry into one of six categories. Coastline physiography was categorized as protected bay, open coast, or island. Bathymetry was categorized as either shallow (less than 31m deep for more than 50% of the sample unit's length, 200 to 300m offshore) or deep (greater than 31m deep for more than 50% of the sample unit length). Depth determinations were based on navigational charts and fathometer readings taken during the survey.

Ratios of independent to dependent sea otters were obtained for each stratum and for each habitat type by summing over all sample units within each stratum or habitat type. Proportion of dependent sea otters was calculated for each transect. Kruskal-Wallis tests were used to evaluate differences in proportions among areas. Statistical tests were conducted at the .05 significance level.

RESULTS

Aircraft Evaluation

We conducted 98 trials, observing 329 groups of one or more sea otters for a total of 741 animals in our preliminary evaluation of the Piper Super-cub as a survey platform. Intensive searches resulted in detectability estimates greater than or equal to .90 for all patterns and altitudes investigated (Tables 3.1 and 3.2). All otters were detected in over half of the samples (Tables 3.1 and 3.2). The type of avoidance behavior observed in boat surveys (Udevitz et al. 1990), in which otters leave the search area before the survey platform arrives, was not observed in response to the aircraft. However, on some occasions it was apparent that otters were disturbed and began diving, swimming out of the area, or swimming erratically within the search area in response to the aircraft after it arrived.

For a fixed search pattern, detection probability and proportion of samples in which all otters were detected tended to decrease slightly with altitude, but differences were not significant (Table 3.1). The proportion of samples in which otters appeared to be disturbed by the aircraft was higher at 150 ft than for 300 or 450 ft., but again the difference was not significant (Table 3.1).

Detectability estimates for initial strip counts ranged from .52 to .72 (Figure 1). Detectability increased sharply with the first 2 to 3 circles or ovals after the strip count and continued to increase slightly for the next 3 to 4 circles or ovals. No new otters were ever detected after the 7th circle or oval.

Detection probability and proportion of samples in which all otters were detected tended to increase with decreasing pattern size, but differences were not significant (Table 3.2). There were no significant differences in the amount of disturbance resulting from the search patterns (Table 3.2).

Reproduction

We surveyed 17 transects in non-oiled eastern Prince William Sound, 48 in non-oiled and 54 in oiled habitat in western Prince William Sound, observing 547 independent and 249 independent sea otters. Ratios of independent to dependent sea otters were 72:28, 68:32 and 68:32 in the eastern, western non-oiled and western oiled areas, respectively. Differences in proportions of dependent sea otters among areas were not significant. Dependent to independent ratios for each habitat type represented by 10 or more transects varied from 68:32 to 72:28 (Table 3.3).

DISCUSSION

Aircraft Evaluation

We were not able to detect any effect of altitude on detectability over the narrow range of altitudes we considered. We would expect detectability to decrease substantially at altitudes much greater than those we considered. In general, safety is expected to increase with altitude (for altitudes up to at least 164m). Forty-six meters was considered the minimum altitude safe enough for conducting this type of survey work. We selected an altitude of 92m for conducting the pattern evaluation because it could provide an added margin of safety without appreciably decreasing detectability.

We were also not able to detect any differences in detectability among the intensive search patterns we considered. In the absence of strong differences in detectability, selection of a search pattern could be based on the probability of encountering otters in each search. We hypothesize that this probability decreases with decreasing the size of the search pattern, thus increasing the number of replicated searches necessary to obtain a detection probability estimate with a given level of precision.

Sea otters occasionally exhibited behaviors in response to the aircraft that may have made them more difficult to detect. All of these behaviors have also been observed in response to boats in boat surveys (Udevitz et al. 1990). These behaviors occurred after the arrival of the survey platform at the search area and included diving and swimming away from the platform. In boat surveys, however, some otters were able to leave the search area before the survey platform arrived and thus avoid any possibility of detection. The aircraft approached search areas more quickly and disturbed otters were not able to leave before the aircraft arrived. This suggests that reductions in detectability due to disturbance by the survey platform may be less of a problem for aircraft than for boats.

Detectabilities were unacceptably low for uncorrected strip counts, but these were substantially improved by subsequent intensive searches using any of the investigated patterns. The data suggest that the most efficient search intensity might consist of 3 circles or ovals after an initial strip count. Almost all of the additional otters are detected during the first 3 circles or ovals. The time and fuel required for more than 3 circles or ovals would probably not justify the slight increase in detectability estimates they would provide. Even with intensive searches, however, not all of the otters were detected. Population size estimates based on correction factors derived from these types of intensive counts can be expected to be negatively biased on the order of 10%. This amount of bias may represent a substantial improvement over previously used methods, but probably cannot be considered negligible for most applications.

Results presented here are based on a preliminary analysis of data from the 1991 field season. We are in the process of refining the analyses reported here and conducting additional analyses, including investigations of

1) the possibility of over-counts by the air crew due to otters entering the area during the intensive search,

2) the effects of otter activity, group size, and viewing conditions on detectability,

3) sightability as a function of distance from the aircraft and otter group size (based on line transect data),

4) the number of systematically (or randomly) located intensive searches required to obtain detectability estimates of a given precision (based on simulations from sea otter distribution data),

5) differences in detectability of independent and dependent sea otters, and

6) the power of these analyses.

Additional work will be required to integrate the results of this study into a survey technique. Such a technique might employ counts of sea otters within strips of sea otter habitat and adjustments to account for missed otters based on intensive searches over portions of the strips. We anticipate designing a trial survey in Prince William Sound and continuing the evaluation of detectability from a Super-Cub in other habitat types in 1992.

Reproduction

Preliminary analysis of data from the reproduction survey suggests that any differences in ratios of independent to dependent sea otters among stratum or habitat types must be small. These ratios may serve as indices of pup production. However, care must be used in interpreting comparisons of these ratios obtained from different areas (e.g., zones or habitat types) because the proportion of sexually mature females may also vary among areas.

Results presented here are based on a preliminary analysis of data from the 1991 field season. We are in the process of completing analyses of

1) statistical differences in independent to dependent ratios among habitat types

2) the patterns of habitat utilization in relation to the availability of habitat types, and

3) the power of these analyses.

LITERATURE CITED

Burn, D.M. 1990. Boat-based surveys of sea otters in Prince William Sound, Alaska. 1 in: Assessment of the magnitude, extent, and duration of oil spill impacts on sea otter populations in Alaska. Natural Resources Damage Assessment Draft Preliminary Status Report, Marine Mammals Study No. 6. US Fish and Wildlife Service, Anchorage, AK.

Cochran, W.G. 1977. Sampling techniques. John Wiley and Sons, New York, 428pp.

Douglas, D.C., D.H. Monson, C. Robbins and L.F. Pank. 1990. Helicopter Surveys. in: Assessment of the magnitude, extent and duration of oil spill impacts on sea otter populations in Alaska. Natural Resources Damage Assessment Draft Preliminary Status Report, Marine Mammals Study No. 6. US Fish and Wildlife Service, Anchorage, AK.

Ebert E.E. 1968. California sea otter-census and habitat survey. Bulletin of the American Littoral Society, Underwater Naturalist. Winter pp.20-23.

Erickson, A.W. and D. B. Siniff. 1964. A statistical evaluation of factors influencing aerial survey results on brown bears. Trans. N. American Wildl. Conf. 28:391-409.

Estes, J.A. and R.J. Jameson. 1988. A double-survey estimate for sighting probability of sea otters in California. J. Wildl. Manage. 52(1):70-76.

Estes, J.A. 1971. Arizona Cooperative Wildlife Research Unit. Quaterly report.

Estes, J.A. 1977. Population estimates and feeding behavior of sea otters. Pp. 526-571 in: M.C. Merritt and R.G. Fuller (eds.), The Environment of Amchitka Island, Alaska. Springfield Virginia.

Estes, J.A. 1990. Growth and equilibrium in sea otter populations. Journal of Animal Ecology. 59:385-401.

Gasaway, W.C., S.D. DuBois, D.J. Reed, and S. Harbo. 1986. Estimating moose population parameters from aerial surveys. Biological papers of the University of Alaska, Institute of Arctic Biology. No. 22. 108pp.

Geibel, J.J. and D.J. Miller. 1984. Estimation of sea otter, *Enhydra lutris*, population, with confidence boundds, from air and ground counts. Calif. Dept. Fish and Game. 70(4): 225-233.

Irons, D. B., D. R. Nysewander and J. C. Trapp. 1988. Prince William Sound sea otter distribution in relation to population growth and habitat type. unpubl. rept. U.S. Fish and Wildlife Service, Anchorage, Alaska. 31 pp.

Jameson, R.J., K.W. Kenyon, S. Jeffries and G.R. VanBlaricom. 1986. Status of a translocated sea otter population and its habitat in Washington. Murrelet 67:84-87.

Johnson, A.M. 1987. Sea Otters of Prince William Sound, Alaska. unpub. report. US Fish and Wildlife Service, Alaska Fish and Wildlife Research Center, Anchorage, AK.

Kenyon, K. W. 1969. The sea otter in the eastern Pacific ocean. U.S. Fish and Wildlife Service. North American Fauna No. 68. 352 pp.

LeResche R.E. and R.A. Rausch. 1974. Accuracy and precision of aerial moose censusing. J. Wildl. Manage. 38(2):175-182.

Pitcher, K.W. 1975. Distribution and abundance of sea otters, Stellar sea lions and harbor seals in Prince William Sound, Alaska. unpub. report. Alaska Dept. of Fish and Game, Anchorage, AK.

Pitcher, K.W. 1989. Studies of Southeastern Alaska sea otter populations: Distribution, abundance, structure, range expansion, and potential conflicts with shellfisheries. Final Report Part I. U.S. Fish and Wildlife Service Cooperative Contract No. 14-16-0009-954, Anchorage, AK. pp.42

Schneider, K. 1971. An evaluation of sea otter survey techniques. unpubl. report. Alaska Dept. of Fish and Game, Anchorge, AK.

Simon-Jackson, T., M. Vivion, and D. Zwiefelhofer. 1986. Sea otter survey, Kodiak Archipelago, Alaska-1985. unpubl. rept. U.S. Fish and Wildlife Service, Anchorage, Alaska. 11pp.

Udevitz, M. S., J. L. Bodkin and D. P. Costa. 1990. Boat survey detection probability. in: Assessment of the magnitude, extent, and duration of oil spill impacts on sea otter populations in Alaska. Natural Resources Damage Assessment Draft Preliminary Status Report, Marine Mammals Study No. 6. US Fish and Wildlife Service, Anchorage, AK.

Wild, P.W. and J.A. Ames. 1974. A report on the sea otter, *Enhydra lutris L.* in California. Calif. Dept. Fish and Game, Mar. Res. Tech. Rep. 20. pp.93.

Table 2.1. Estimates of detectability and related parameters for 3 different altitudes (750 m circle search pattern without preceding strip count, circling continued until 5 minutes past last new otter sighting .

	Altitude		
	46m	92m	137m
Trials[a]	13	12	12
Groups[b]	58	43	44
Otters[c]	133	104	106
Detectability	.92	.91	.90
Detect=1[d]	.62	.50	.50
Disturbance[e]	.23	.08	.08

[a]Number of trials.

[b]Total number of otter groups observed by ground crews.

[c]Total number of otters observed by ground crews.

[d]Proportion of samples with detectability = 1.

[e]Proportion of samples in which otters appeared to be disturbed by the aircraft activity.

Table 2.2. Estimates of detectability and related parameters for 3 search patterns (strip count followed by circles or ovals until 5 minutes past last new otter sighting, 300 ft altitude).

	Pattern		
	400 m circle	750 m circle	800 m oval
Trials[a]	20	19	22
Groups[b]	58	40	86
Otters[c]	113	72	213
Detectability	.96	.93	.90
Detect=1[d]	.80	.79	.68
Disturbance[e]	.15	.26	.19[f]

[a]Number of trials.

[b]Total number of otter groups observed by ground crews.

[c]Total number of otters observed by ground crews.

[d]Proportion of samples with detectability = 1.

[e]Proportion of samples in which otters appeared to be disturbed by the aircraft activity.

[f]Based on 21 samples for which the presence or absence of disturbed behavior was recorded.

Table 2.3. Number of sample units (N) and numbers and ratios of dependent and independent sea otters by habitat type (S=shallow open coast; SB=shallow bay; Is= shallow island; D=deep open coast; DB=deep bay; Isd= deep island).

Habitat	N	Independent	Dependent	Ratio
S	27	226	105	68:32
SB	33	226	108	68:32
Is	10	40	16	72:28
D	31	42	16	72:28
DB	9	7	0	100:0
IsD	8	6	4	33:67
Total	119	547	249	69:31

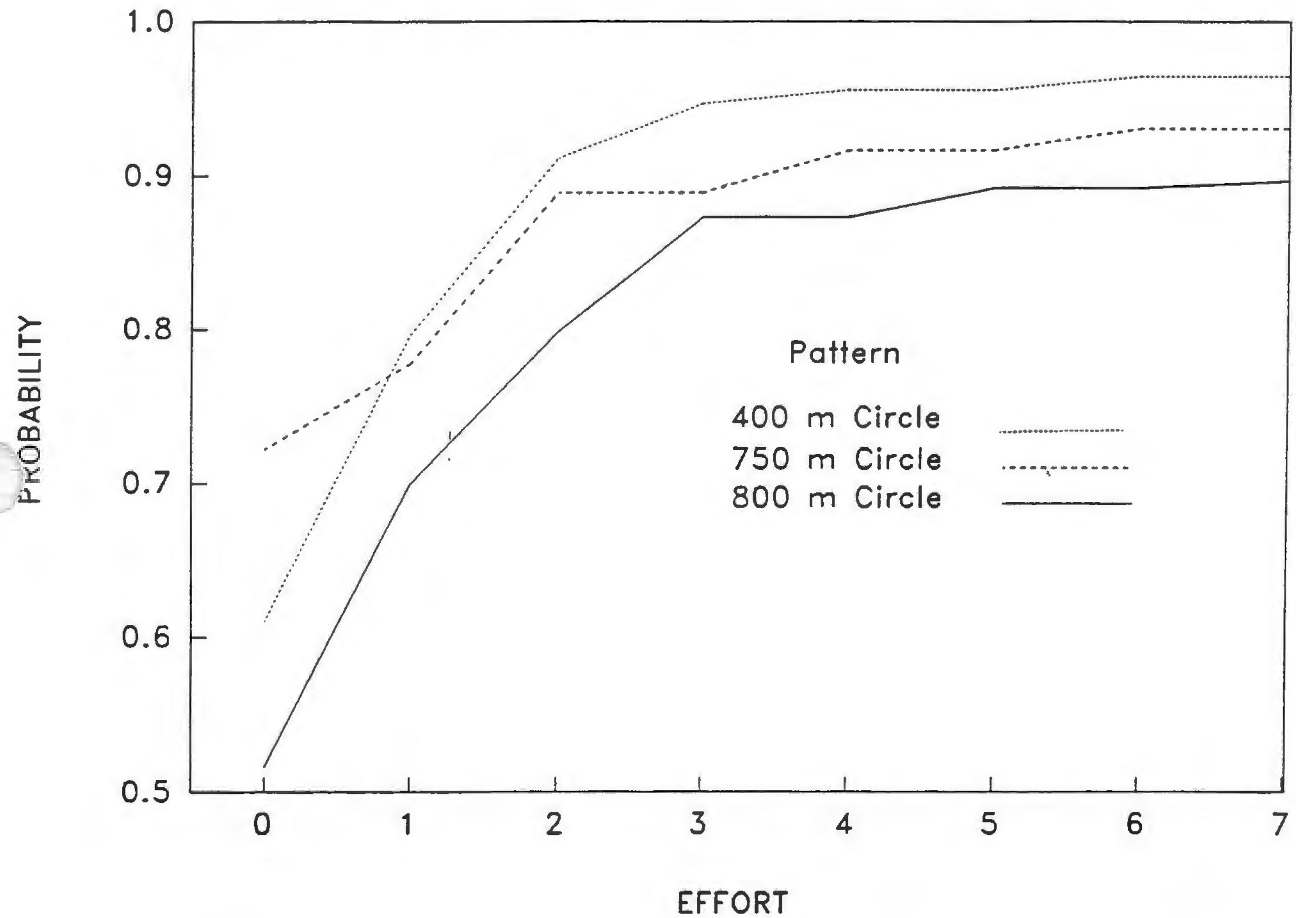


Figure 1. Detection probability as a function of search effort (number of additional circles or ovals after initial strip counts) for 3 search patterns.

Section 3

INTERSECT MODEL OF SEA OTTER MORTALITY

James L. Bodkin and Mark S. Udevitz

SUMMARY

Conceptual development of the intersect model to estimate potential exposure of sea otters to oil along the Kenai Peninsula is complete. Exposure was measured in terms of the amount and duration of oil in an otter's vicinity (gallon*days). Preliminary simulations indicate potential exposure of approximately 1,211 sea otters to some degree of oiling. Potential exposure within this group averged 32,655 gallon*days (SE = 3,902 gallon*days) ranging from 1,100 to 155,100 gallon*days of oil. Refinement of model components is continuing. We anticipate that this model will provide an estimate of sea otter mortality along the Kenai Peninsula resulting from the T/V Exxon Valdez oil spill. The model may may be extended to allow application throughout the spill zone. Extensions will depend on obtaining suitable representations of sea otter abundance and distribution in the additional areas.

OBJECTIVES

Develop a model capable of estimating rates of exposure to oil, degree of oiling and mortality of sea otters associated with oil released from the Exxon Valdez along the Kenai Peninsula, Alaska, 1989.

INTRODUCTION

Following the release and subsequent movement of oil from the T/V Exxon Valdez, live and dead oiled sea otters were observed within Prince William Sound and along the Kenai Peninsula. Oiled sea otter carcasses were retrieved and live oiled otters were captured for transport to rehabilitation centers in Valdez, Seward and Homer. The sum of dead oiled otters plus live oiled otters minus pre-spill dead otters provides a minimum estimate of the number of sea otters coming into contact with spilled oil. It is probable that some additional number of animals became oiled and died and their carcasses remained unrecovered while others may have become oiled and survived.

The purpose of this study is to develop an analytical model, relating exposure of sea otters to oil with subsequent mortality along the Kenai Peninsula. The approach involves estimating the abundance and distribution of sea otters in near-shore and off-shore habitat along the Kenai Peninsula at the time of the spill, estimating the level of exposure of each otter, estimating the degree of oiling received by otters at each exposure level, and estimating the mortality rate associated with each degree of oiling. This information will be integrated by the model to provide an estimate of the total spill induced mortality for this area.

STUDY METHODOLOGY

A computer model developed by NOAA (OSSM) was used to simulate the distribution of oil particles as they traveled through Prince William Sound and along the Kenai Peninsula. The OSSM model traces the movement of 10,000 particles of oil (each representing about 1,100 gallons, and covering about .3 to 1 mi^2 of sea surface) from their origin at Bligh reef. Under this model, about 1,250 (12%) of the oil particles moved out of Prince William Sound and along the Kenai Peninsula. We used the location of each particle at 3 hour intervals to represent the distribution of oil over time, along the Kenai Peninsula.

The abundance and distribution of sea otters in near-shore and off-shore habitat along the Kenai Peninsula at the time the oil passed through was estimated based on the spring 1989 helicopter survey (Douglas et al. 1990). The location of each observed otter was recorded during the survey on large scale maps. These locations were used as an estimate of the distribution of otters at the time of the spill. The total number of otters present was estimated as described by Douglas et al. (1990).

In order to measure exposure, an exposure region was defined for each otter as a circle with radius 1.4 km centered at the otter's location during the survey. This radius represents the average distance sea otters were observed to move between successive radio relocations recorded between 18 and 36 hours apart in California (Ralls et al. 1988). The Ralls et al. (1988) data includes movements of adult and sub-adult male and female sea otters (n=38).

The number of gallons per day times the number of days (gallon*days) that oil was within an exposure region was used as a measure of the exposure of that location to oil. This exposure was estimated for each otter location by counting the number of OSSM oil particles that were within its exposure region during each 24 hour interval, multiplying by 1100, and summing over the time period of the spill. The proportion of the observed otters at each location was used to estimate the proportion of the population with that location's level of exposure.

Data for relating exposure levels to oiling and mortality of otters were collected within two areas of Prince William Sound. The first of these areas was Herring Bay (60^0 28'N 147^0 45'W), on the north end of Knight Island where heavy oiling was observed to persist over time, most otters were oiled, the degree of oiling was heavy and mortality rates were high. The second site comprised the northeast third of Prince of Wales Passage, including Iktua Bay (60^0 06'N 148^0 00'W), between Evans and Bainbridge Island. This area was lightly oiled along most of the shoreline and oil appeared to pass through in a short time. Most sea otters were either non-oiled or lightly oiled and mortality was relatively low. Similar data are not available for the Kenai Peninsula. We consider these exposure levels and subsequent mortality estimates to possibly be biased low for the following reason. We were not at the capture sites at the time of initial oiling. Animals that suffered immediate mortality were removed from the pool of potential captures prior to our arrival. At the time of initial oiling, many sea otters in Prince of Wales Passage were observed in oil (B. Garrot, pers. comm.) and may have died and drifted out of the area prior to our arrival approximately two days later.

Comparisons of mortality rates between Prince William Sound and the Kenai Peninsula would initially indicate substantial differences between areas. However, sea otter capture efforts did not begin along the Kenai until 29 April, 1989. Bodkin and Weltz (1990) describe a pattern of declining degree of oiling and resultant mortality as the time interval between exposure and capture increased. This pattern led to diminishing sea otter capture efforts in the Sound about 21 April and a shift in the effort to the Kenai Peninsula where initial oiling occurred on or about 1 April. A comparison of the proportions of animals in each oiling category suggests more similar oiling rates within samples captured after more than about 2 weeks of potential exposure (Table 3.1). We suggest the delayed capture response along the Kenai Peninsula contributed to the observed differences in mortality rates between areas.

During the first 3 weeks of April, attempts were made to capture all otters in these areas with dip-nets and tangle-nets (Bodkin and Weltz 1990). Each otter was classified into 1 of 4 categories based on the quantity of oil observed on its pelage at the time of capture. The degree of oiling categories were defined as follows; heavy = complete or nearly complete coverage of the pelage with visible oil, moderate = partial oiling of about 25-50% of the pelage with visible oil, light = oil not easily visible or detectable, or a small proportion (<10%) of the pelage containing visible oil, and none = oil not visually or tactically evident on the pelage. The proportion of animals in these areas exhibiting each of the above degrees of oiling was estimated by the proportion of the of the animals captured or handled in each area that were classified into each category.

A total of 43 sea otters were captured or handled in the Prince William Sound areas, with 11 from Herring Bay and 32 from Prince of

Wales Passage. 31 otters were captured with dip-nets and 12 were captured with tangle nets. Tangle nets are usually assumed to obtain an unbiased sample of otters with respect to age and sex (Bodkin and Weltz 1990). Although sample sizes are small, the proportion of oiled otters obtained by each capture method was similar (92% oiled/ 8% non-oiled, dip-nets; 91% oiled/ 9% non-oiled, tangle nets), suggesting that if tangle nets obtained an unbiased sample with respect to oiling, then the dipnet samples were also unbiased.

With the exception of five non-oiled animals that were released after capture, all other captured otters were transported to rehabilitation centers, where they were cleaned and held. Mortality rates were estimated for each of the oiling categories as the proportion of animals that died. We assumed the five non-oiled animals survived. Sixty-five percent of the observed mortality occurred within 5 (65%) days of arrival (mean = 7.1 days; range 0 to 34 days) at a rehabilitation center. Pups born at the rehabilitation facilities, otters with an undetermined oiling status and otters exhibiting obvious non-oil related pathology (eg., paralysis or blindness) were excluded from oiling and mortality rate calculations (Table 3.1). Mortality rates of non-oiled sea otters were not used in the model because selective capture of debilitated animals would have resulted in relatively high mortality among these animals.

The range of exposure levels encountered in the 2 Prince William Sound areas will be estimated by calculating the exposure in gallon*days as described above for 10 randomly distributed points within each area. High exposure will be defined as greater than or equal to the minimum exposure value obtained for Herring Bay. Low exposure will be defined as less than or equal to the maximum exposure value obtained for Prince of Whales Passage. Moderate exposure will be defined as values between these 2 extremes.

The proportion of the estimated total near-shore and off-shore Kenai Peninsula sea otter population in high, moderate and low exposure categories will be determined based on the their estimated exposure values and the scale developed for the Prince William Sound areas. For the portion that have high exposure values, the proportion with each degree of oiling will be estimated using the proportions from Herring Bay. For the portion that have low exposure values, the degree of oiling proportions will be obtained from Prince of Whales Passage. For each of these segments of the population, the total mortality will be estimated by taking each of the products of the total population estimate, the exposure level proportion, a corresponding degree of oiling proportion and its associated mortality rate and then summing over the degree of oiling categories. Overall mortality rates for the high and low exposure categories will be estimated as the total mortality for that portion of the population divided by the size of that portion of the population. The overall mortality rate for the moderate exposure category will be estimated as the mean of the mortality rates for the high and low categories. Total mortality for the moderate exposure category will be estimated as the product of the total population estimate, the moderate exposure level proportion and its associated mortality rate. The total mortality for the Kenai Peninsula otters will be estimated as the sum of the totals for the three exposure categories for the near-shore and offshore habitats.

STUDY RESULTS

Helicopter surveys of the abundance and distribution of sea otters along the Kenai Peninsula during April 1989 counted 1,114 sea otters on transects. 1,083 and 31 sea otters were counted on near-shore and off-shore transects, respectively. These counts provided estimates of 1275 sea otters (SE = 26) in 778 km^2 of near-shore habitat and 1053 sea otters (SE = 215) in 3,353 km^2 offshore habitat.

Rates of oiling, degree of oiling and associated mortality rates for Herring and Prince of Wales Passage, with comparisons from sea otters captured throughout Western Prince William Sound and the Kenai Peninsula are presented in Table 3.1.

Results of preliminary intersect simulations indicate 122 of the near-shore sea otter exposure regions (buffers) were intersected with OSSM oil point vectors on one or more days between 24 March and 23 May 1989. These 122 buffers represent about 393 sea otters that encountered potential exposure to oil for one or more days. Potential exposure levels for this group in nearshore habitat averaged 33,583 gallon*days (range 1,100 to 155,100 gallon*days; SE = 4,037 gallon*days). Nine sea otter buffers occurring in off-shore habitat were intersected with OSSM oil point vectors. These nine buffers represent about 818 sea otters that encountered potential exposure to oil. Potential exposure for this group averaged 20,044 gallon*days (range 1,100 to 144,100 gallon days; SE = 15,554).

STATUS OF INJURY ASSESSMENT

Progress to date in this study has been the conceptual development of an intersect model to estimate sea otter mortality as a result of exposure to oil along the Kenai Peninsula. Preliminary simulations of the model indicate exposure to about 1211 (52%) of the Kenai Peninsula sea otter population. We are currently developing estimates of exposure levels for the Prince William Sound capture sites.

The near-shore habitats of the Kenai Peninsula represent areas for which have some of the best data on otter populations during the spill. This approach could be extended with a coarser resolution to other areas of the spill zone for which our information on otter abundance and distribution is not as precise.

We are unable to provide an estimate of our confidence in the value of this model, our its products, at this time. We anticipate this model will produce a reasonable estimate of sea otter exposure to oil and subsequent mortality, given an accurate representation of sea otter abundance and distribution, and relationships of exposure levels to mortality rates.

LITERATURE CITED

Bodkin, J.L. and F. Weltz. 1990. A summary and evaluation of sea otter capture operations in response to the Exxon Valdez oil spill, Prince William Sound Alaska. Abstract. Sea Otter Symposium, Anchorage, Alaska. April 17-19, 1990.

Douglas, D.C., D.H. Monson, C. Robbins, and L.F. Pank. Helicopter Surveys. In: Assessment of the magnitude, extent and duration of oil spill impacts on sea otter populations in Alaska. unpubl. rept., U.S. Fish and Wildlife Service, Alaska Fish and Wildlife Research Center, Anchorage Alaska.

Ralls, K., T. Eagle, and D.B. Siniff. 1988. Movement patterns and spatial use of California sea otters. In: Population status of California sea otters. (eds. D.B. Siniff and K. Ralls). U.S. Fish and Wildlife Service, Minerals Management Service, Contract No. 14-12-001-30033. 368pp.

Table 3.1 Sea otter mortality rates as related to degree of oiling for Herring Bay, Prince of Wales Pass, all of Western Prince William Sound, for animals captured in Western Prince William Sound after 13 April, and for all animals captured along the Kenai Peninsula (H=heavy, M=moderate) L=light, N=none).

Degree of Oiling		H	M	L	N
Herring Bay	N	5	4	2	0
(N=11)	%	.45	.36	.18	0
Mortality		.80	.50	.50	0
Prince of Wales	N	0	3	19	10
Pass (N=32)	%	0	.09	.59	.31
Mortality		0	.33	.37	.30
Combined Mortality (both sites)		.80	.43	.38	.30
All Western Prince	N	50	14	44	10
William Sound (N=118)	%	.42	.12	.37	.09
Mortality		.76	.50	.31	.70
Western Prince	N	3	5	16	3
William Sound [1] (N=27)	%	.11	.19	.62	.08
Mortality		.33	.20	.06	.67
Kenai Peninsula	N	3	19	70	32
(N=124)	%	.02	.15	.56	.26
Mortality		.00	.11	.11	.12

[1]sea otters captured after 13 April, 1989 (13 or more days after initial oil exposure).

Section 4

SEA OTTER PREY SELECTION AND FORAGING SUCCESS IN WESTERN PRINCE WILLIAM SOUND, ALASKA, 1991

Angela Doroff and James Bodkin

SUMMARY

Sea otter prey were determined by visual observation and scat analysis in western Prince William Sound in areas of heavy, moderate and no shoreline oiling. Patterns of prey use did not differ from historic data at Green and Montague Islands. Principle prey species were clam, mussel and crab for all study areas; clams were the most frequently retrieved prey item. There were no significant differences in forage success rates or mean number of prey retrieved per dive among areas. Mussel and clam were the most frequently observed prey in sea otter scat at Green Island. Prey species were collected at each site to assess variability in contamination of individual prey items. Samples currently wait hydrocarbon analysis. Sea otters were not observed to reject prey after retrieval in areas of heavy shoreline oiling. Continued exposure of sea otters to hydrocarbons through their prey remains likely in the spill area.

OBJECTIVES

1. To describe prey species and the relative frequency with each which prey species is consumed by sea otters in 3 areas affected by the Exxon Valdez oil spill.

2. To determine foraging success rates in each of three study areas

3. To compare prey species and foraging success rates from the Green Island area to historic data from the same region.

4. Estimate mean size and determine approximate caloric value per prey item.

5. To collect tissue samples of sea otter prey to assess hydrocarbon contamination in individual prey items.

INTRODUCTION

Sea otters have occupied southwestern Prince William Sound since at least the early 1950's and had expanded their range north to include western Knight Island by approximately 1970 (Lensink 1962; Garshelis 1986). In a study of sea otter forage behavior conducted during 1980-81 at Green Island (Fig. 1) sea otters spent approximately 50% of a 24 hr period foraging, and during the winter months (November-April) foraging activity increased (Garshelis 1986). Garshelis (1986) and Johnson (1987) concluded the sea otter population in western Prince William Sound at Green Island was food resource limited.

Sea otters commonly prey on a variety of benthic marine invertebrates that inhabit coastal waters ranging in depth from the intertidal to approximately 20 fathoms (Kenyon 1969). Principal prey species identified in Prince William Sound in the past include clam, mussel and crab (Calkins 1978; Garshelis 1986; Johnson 1987). Relative to other marine mammals, sea otters have a high metabolic demands to maintain their body temperature in cold North Pacific waters (Costa and Kooyman 1984). Juvenile and adult sea otters consume between 20-30% of their body weight per day (Kenyon 1969).

Damages to the nearshore benthic community resulting from the Exxon Valdez oil spill (EVOS) may influence the recovery of sea otters in affected habitats. Probable mechanisms of influence include 1) decreased food availability, and 2) consumption of prey contaminated by hydrocarbons. To evaluate hydrocarbon contamination in Prince William Sound, shellfish and coastal sediments have been sampled in portions of the sea otter range by the coastal habitat and fish/shellfish damage assessment studies. Preliminary results have shown elevated levels of hydrocarbons in sediments and bivalve mollusks (A. Weiner, unpub rpt 1991). However, information is lacking on the variation in contamination of individual prey items in areas where sea otters are known to forage.

Our objectives were 1) to describe prey species and the relative frequency with which each prey species is consumed by sea otters in 3 areas affected by the Exxon Valdez oil spill, 2) to determine foraging success rates in each of three study areas and compare prey species and foraging success rates from Green and Montague Islands area to historic data from the same region, and 3) to collect tissue samples of sea otter prey in areas where foraging occurs to determine hydrocarbon content of prey.

METHODS

Study Areas

Sea otter prey species were determined at three areas within western Prince William Sound, Alaska. Study areas included portions of Montague, Green and Squirrel Islands (Fig. 1) and were selected by the following criteria: 1) relative degree of shoreline oiling (based on DEC shoreline oiling maps) with Squirrel, Green and Montague Islands representing heavy, heavy to moderate and no shoreline oiling, respectively 2) capture location of sea otters from which blood and subcutaneous fat samples were available from living sea otters and 3) sample sites of other NRDA studies collecting sea otter prey species and sediments for hydrocarbon analysis. All areas contained primarily soft bottom sediments with broad expanses of shallow (< 10m) subtidal areas. Each study area was delineated by the viewing distance which observers could identify sea otter prey species from shore-based vantage points (maximum viewing distance approximately 1km). The approximate area monitored for foraging animals was 4, 5 and 6 km^2 for Squirrel, Green and Montague Islands, respectively. During the course of the study, survey flights were conducted to estimate the number of sea otters within and adjacent to the study areas. A survey flight was conducted 21 May, 1991 for Green Island in a 185 Cessna aircraft at airspeed of 60 kph and altitude of approximately 153m. The aircraft maintained a distance of 100m from shore. When large groups of sea otters were encountered, the aircraft circled until the observer felt the count was accurate. A second survey was conducted 22 July, 1991 for the Squirrel and Montague Island study areas. Methods were the same as the previous survey with the exception that the aircraft used was a Piper PA-18 Supercub.

Prey Identification

Observations were made by trained individuals with the aid of high resolution telescopes (Questar Corporation, New Hope, PA) and 10X binoculars. Data recorded included sex, age class of focal animal (adult or juvenile), number of prey and relative prey size (A: < 5 cm, B: $\geq$ 5 to < 7 cm , C: $\geq$ 7 cm to < 9 cm, D: $\geq$ 9 to < 12 cm and E: $\geq$ 12 cm), dive interval, surface interval, and prey item to lowest identifiable taxon. Repeated dives were recorded for a focal animal until a maximum of 50 identifiable prey items were observed per individual or until the animal was lost or discontinued foraging. Radio-implanted sea otters from damage assessment studies were used as focal animals when feasible. Focal animal selection was random when more than one otter was feeding at an observation site. Adult animals were categorized as male, independent female or female with a pup. Juveniles were identified as small dark-headed otters estimated to be less than 24 months of age. A minimum sample of 500 identified prey items were recorded for each study area. Data was collected only during daylight hours, during all tidal cycles. Tidal state and estimated water depth from navigational charts were recorded for all observations.

Study areas were sampled consecutively: 17 April - 11 May Green Island, 14 June - 3 July Squirrel Island, and 13 July - 24 July Montague Island. Each study area had several vantage points and observers rotated through them at irregular time intervals (weather and viewing conditions influenced our ability to have fixed schedules).

Data analysis

Kruskal-Wallis tests were used to test differences among the proportion of clam, crab and mussel in the diet of adult sea otters of varying sex classes (independent female, female with pup, male, and adult of unknown sex) and areas for all bouts having a records of $\geq$ 10 dives.

A successful dive was defined as any dive which obtained a prey item. Success rates were determined for all bouts of adult and juvenile sea otters having $\geq$ 10 dives. Unsuccessful dives were included in the data analysis; dives of unknown result were not included. An arcsin transformation was used to normalize distributions and a 2-way analysis of variance was used to test for differences among sex classes and areas. Differences in success rate by age (adult and juvenile) were tested by t-test for samples of equal variance. Data were normalized by an arcsin transformation.

Number of prey per dive was averaged per bout for all adult animals by sex class (independent female, female with pup, male, and adult of unknown sex) and area. Dives containing mussel were excluded for this analysis due to their clumped growth pattern and the difficultly in obtaining accurate counts on a per dive basis. Dives of unknown result were disregarded in this analysis. A 2-way analysis of variance was used to test differences among sex class and area.

Scat Analysis

During the period 20 April-2 May 1991, 253 sea otter scat samples were examined in the field along 8.5 km of beach on western Green and Barrier Islands (Fig.1). For each scat sample encountered the following information was recorded: location, single or multiple defecation, and the species of prey represented (when determined) and relative percentage each species contributed to the entire scat. Notes were made on unidentified, noncalcareous material within the scat. Data were compiled as frequency of occurrence of each species (Fig.2).

Prey Collection

Within each study area all forage observations collected were plotted on a gridded map with Universal Transverse Mercator coordinates. A polygon was drawn around the outermost foraging observations with a 100 m^2 grid overlay. Ten 100 m^2 plots were chosen at random for each area. Sites for clam collection within each plot were selected by a random boat anchor drop in each plot and searching with the aid of SCUBA (Self Contained Underwater Breathing Apparatus) for desired species from the anchor point in concentric circles. Water depth averaged 8m (range 5 - 12m). Clams were excavated with a venturi dredge (Keene Engineering Northridge, CA) powered with a Briggs and Staton 8 hp motor on the rear deck of a 7.6 m Boston Whaler. Divers attempted to locate 3 butter clams (Saxidomus giganteus) at each plot. This could not be accomplished at all plots and the design was broadened to include all known prey species of clam. Clams were brought to the surface in mesh dive bags, wrapped in chemically cleaned aluminum foil (Acetone and Hexane washed) and frozen in a small propane freezer aboard the 7.6 m Boston Whaler. When more than 3 clams were retrieved from a single plot, clams were randomly selected for hydrocarbon analyses. When more than 1 species was collected, additional samples were randomly selected to compare hydrocarbon levels in species among plots and areas. For hydrocarbon analysis, bivalves were thawed and all tissue was placed in chemically clean jars. Seventy-nine bivalve tissue samples currently await analysis.

RESULTS

Prey Analysis

Portions of 38 forage bouts (29 adult and 9 juvenile) were recorded at Green Island. At Squirrel Island, portions of 69 forage bouts (68 adult and 1 juvenile) were recorded and, at Montague Island, portions of 72 forage bouts were observed (69 adult and 3 juvenile).

Clams were retrieved on 67% (n=405), 34% (n=858) and 46% (n=735) of all successful dives recorded for adults at Green, Squirrel and Montague Islands respectively and were consistently the most frequently retrieved prey item. Figure 3 summarizes adult sea otter prey as the number of dives retrieving clam, crab, mussel, other invertebrates, and unidentified prey for each study area. Juveniles (for all areas pooled) also retrieved clams most frequently (51% n=427). The ratio of dives retrieving mussel/dives retrieving clam for juveniles and adults was 0.61 and 0.25, respectively.

Table 1 summarizes variation of prey use by adults at each study area. No significant differences were detected in independent females, females with pups, males and adults of unknown sex in percentage of dives retrieving clam, crab, and mussel at Green (P=0.78, P=0.45, P=0.82) or Montague (P=0.21, P=0.88, P=0.74) Islands. Significant differences were detected in the percentage of dives retrieving clams (P=0.01) among sexes for Squirrel Island; no significant differences were detected for crab (P=0.24) or mussel (P=0.38). No significant differences were detected among areas for the percentage of dives retrieving clam (P=0.09), however, significant differences were detected for crab (P=0.001) and mussel (P=0.03).

Greater than 70% of clams identified to species in all areas were butter clams (Saxidomus giganteus). The most frequent prey items identified to species were blue mussel (Mytilis edulis) for Green and Squirrel Islands and Helmet crabs (Telmessus spp.) for Montague Island.

Mean success rates for adult and juvenile sea otters in all study areas were 90% (n=82) and 92% (n=10), respectively. Success rates did not differ significantly (P=0.49) between adult and juvenile sea otters. At Green Island, adult and juvenile success rates were 87% (n=16) and 98% (n=8), respectively. Forage success did not differ significantly among sex classes (P=0.12) or among areas (P=0.29). The interaction between site and sex class was not significant (P=0.09).

Mean number of prey retrieved per dive averaged 1.2, 1.0 and 1.3 for Squirrel, Green and Montague Islands, respectively. No significant differences were detected among areas (P=0.11) or sex classes (P=0.83). The interaction between site and sex class was not significant (P=0.30).

Blue mussel (M. edulis) was observed most frequently (60%) in 253 sea otter scat examined on northeastern Green Island (Table 2). Clam species, primarily Protothaca staminea and S. giganteus, were identified in 46% of all scat examined. Crab and other small invertebrates were found in 19% and 20%, respectively. Of scats containing a single prey type, 76 were mussel, 23 clam and 13 contained one of the following: scallop (Chlymys sp.), snail (Natica sp.), Cockle (Clinocardium sp.), limpet (Notoacmea scutum).

Prey Sampling

A total of 79 prey were sampled from 20 plots from Green (n=7), Squirrel (n=7) and Montague (n=6) Islands. The species composition of the sample is as follows: 23 Macoma spp., 20 S. giganteus, 24 P. staminea, 6 Humilaria kennerleyi, 5 Gari californica (species yet to be verified), and 1 Serripes groenlandicus. Mean shell length and wet meat weight for sampled species are as follows: Macoma 42 mm and 4.7g, S. giganteus 44 mm and 10.7g, P. staminea 40 mm and

8.9g, H. kennerleyi 46 mm and 8.9g, G. californica 46 mm and 8.6g, and S. groenlandicus 56 mm and 16.2g.

All samples have been submitted for hydrocarbon analysis; results are not yet available.

DISCUSSION

Sea otter diet has remained relatively constant over time at Green Island and Montague Strait. Calkins (1978) reported major prey in Montague Strait were clam (S. giganteus), crab (Telmessus spp.) and sea stars (Evasterias troschelii). Johnson (1987) reported clam and mussel as the most important prey for adult and subadult animals at Green Island. Clams were the most frequently identified prey retrieved and mussel the most frequent prey in scats in our study. Study results are also consistent with the findings of Garshelis (1986) with the exception that clams comprised only 67% of the diet in our study compared to > 75% at Green Island during 1980.

Differences in prey use were not detected among sexes with the exception of percentage of clam at Squirrel Island. Johnson (1987) found highly significant differences among age classes; our sample sizes were insufficient to test age related differences in prey consumption. Juveniles consumed a higher proportion of mussels than did adult animals in our study areas. Mean number of prey per dive at Green Island was 1.0 (n=35, sd=0.38). Johnson (1987) was unable to determine mean prey per dive because clam size was too small to accurately determine the number of prey being consumed. Mean prey per dive were calculated only for those dives which prey number could be determined.

Forage success did not differ among sex classes or among areas in our study. Johnson (1987) observed success to be relatively constant in areas of different demographic composition with slightly lower success for prey items requiring excavation.

Sea otters in Prince William Sound haul out regularly throughout the year but more frequently in the winter months (Johnson 1987). Scat deposits collect on snow berms above mean high tide making it feasible to estimate over-winter diets by scat analysis. Scat analysis provides useful information on prey items often too small to be identified visually. Late April and early May scats were examined at Green Island. Mussels were the most frequent prey item identified in scat samples, followed by clam (Fig. 2). For large clams, shells are removed prior to ingestion but small clams (< 5 cm) are often ingested with shell parts (Johnson 1987). Visual observation data suggest few large clams are retrieved by sea otters (79% < 5cm, 20% 5-7 cm, and 1% 7-9 cm, n=479). Overall mean shell length of clams encountered while collecting prey was 43 mm (range 31-61mm). These observations are consistent with Garshelis (1986) and Johnson (1987) views that western Prince William Sound may be food resource limited.

Visual observations and scat analysis yield different results when comparing prey species frequency in sea otter diet. By visual observation, clams were most frequently retrieved and by scat analysis mussel was most frequent. We believe these differences reflect differences in methodology rather than a seasonal shift in prey preference. Scat analysis is biased toward small prey items where nondigestable parts are ingested and against prey where no hard parts are ingested. Shells of mussel tend to be thinner and consistently < 5cm in length where as shells of clams 5cm and greater will less likely be ingested.

Resampling of unmarked foraging otters likely occurred in our study area. Comparing aerial survey counts of each study area to numbers of bouts sampled provides a general measure of potential resample intensity. Aerial count to sample size ratio for Green, Squirrel and Montague were: 27/38, 23/69 and 65/72, respectively. Within or adjacent to the Green, Squirrel and Montague Island study areas were 9, 20 and 30, respectively, tagged sea otters from capture efforts during 1989-90. Forage observations occurred on only 2 tagged animals (1 at Green Island and 1 at Squirrel Island) throughout the entire observation period and repeat observations did not occur for these tagged individuals.

Sea otters demonstrated the ability to detect and reject prey contaminated by paralytic shellfish poisoning (Kvitek et al in press). We postulated sea otters may also be able to detect prey contaminated by hydrocarbons, however, foraging otters were not observed to reject retrieved prey at the surface in any of the study areas.

The results of this study indicate that sea otters have not changed their food habits in western Prince William Sound over the past decade. Sea otters continue to rely principally on clams and mussels as prey. High levels of hydrocarbons have been observed in both clams and mussels in the spill area (NRDA damage assessment studies-ref?). While sea otters continue to rely on these two prey items, continued exposure to hydrocarbons is likely in areas affected the EVOS. Analysis of prey samples collected during this study will allow us to estimate hydrocarbon exposure rates and to determine variation among individual prey items at each study site.

LITERATURE CITED

Calkins, D. G. 1978. Feeding behavior and major prey species of the sea otter, Enhydra lutris, in Montague strait, Prince William Sound, Alaska. Fish. Bull. 76(1):125-131.

Costa, D. P. and G. L. Kooyman 1984. Contribution of specific dynamic action to heat balance and thermoregulation in the sea otter Enhydra lutris. Physiol. Zool. 57(2):199-203.

Garshelis, D. L., J. A. Garshelis and A. T. Kimker 1986. Sea otter time budgets and prey relationships in Alaska. J. Wildlife Manage. 50(4):637-647.

Johnson, A. M. 1987. Sea otters of Prince William Sound, Alaska Unpublished Report, U.S. Fish and Wildlife Service, Alaska Fish and Wildlife Research Center, Anchorage, AK.

Kenyon, K. W. 1969. The sea otter in the eastern Pacific Ocean. North Amer. Fauna 68. 352 pp.

Kvitek, R. G., A. R. DeGange, and M. K. Beitler. In press. Paralytic shellfish poisoning toxins mediate sea otter feeding behavior. Limnology and Oceanography.

Lensink, C. J. 1962. The history and status of sea otters in Alaska. Phd Dissertation, Purdue University.

Table 4.1 Median proportion of dives retrieving clam, crab, and mussel for adult sea otters (*Enhydra lutris*) in Prince William Sound, Alaska, 1991.

	Green Island				Squirrel Island				Montague Island			
Sex Class	Clam	Crab•	Mussel•	N[1]	Clam	Crab•	Mussel•	N[1]	Clam	Crab•	Mussel•	N[1]
Independent female	0.41	0.0	0.18	2	0.29@	0.0	0.72	10	0.36	0.03	0.0	6
Female with pup	0.42	0.0	0.0	7	0.15@	0.63	.053	18	0.53	0.88	0.0	15
Independent male	0.79	0.0	0.0	14	0.58@	0.16	0.16	6	0.5	0.05	0.0	9
Sex unknown	0.41	0.0	0.0	1	0.96@	0.0	0.0	2	0.76	0.10	0.0	3

[1] Number of forage bouts containing ≥10 dives for each sex class.
@ Significant differences among sex classes in the proportion of dives retrieving clam ($P = 0.01$).
• Significant differences among areas in the proportion of dives retrieving crab ($P < 0.01$) and Mussel ($P = 0.03$).

Figure 4.3. Composition of prey by visual observation in western Prince William Sound, AK.

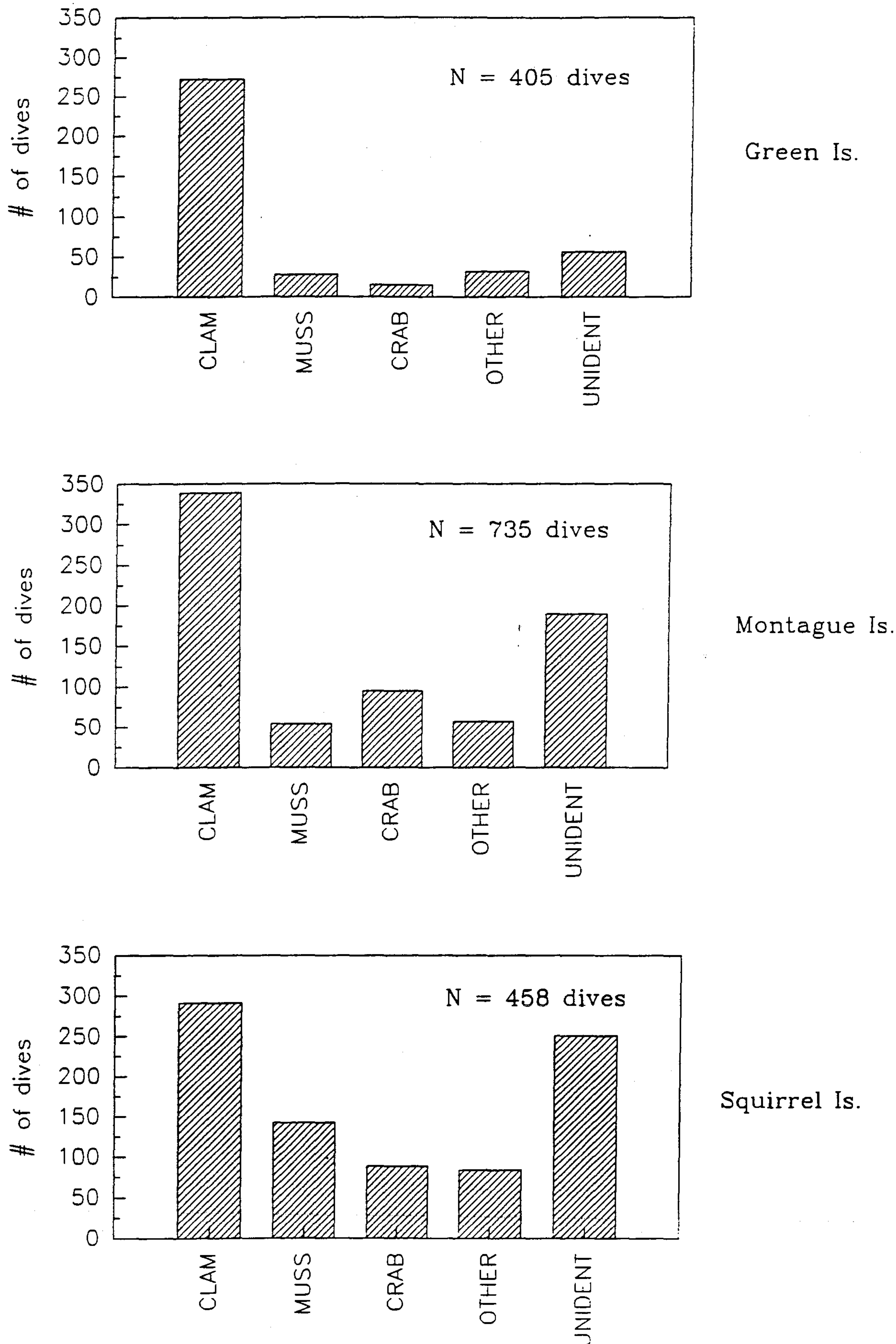


Figure 4.1. Sea otter forage study area locations in western Prince William Sound, Alaska, 1991.

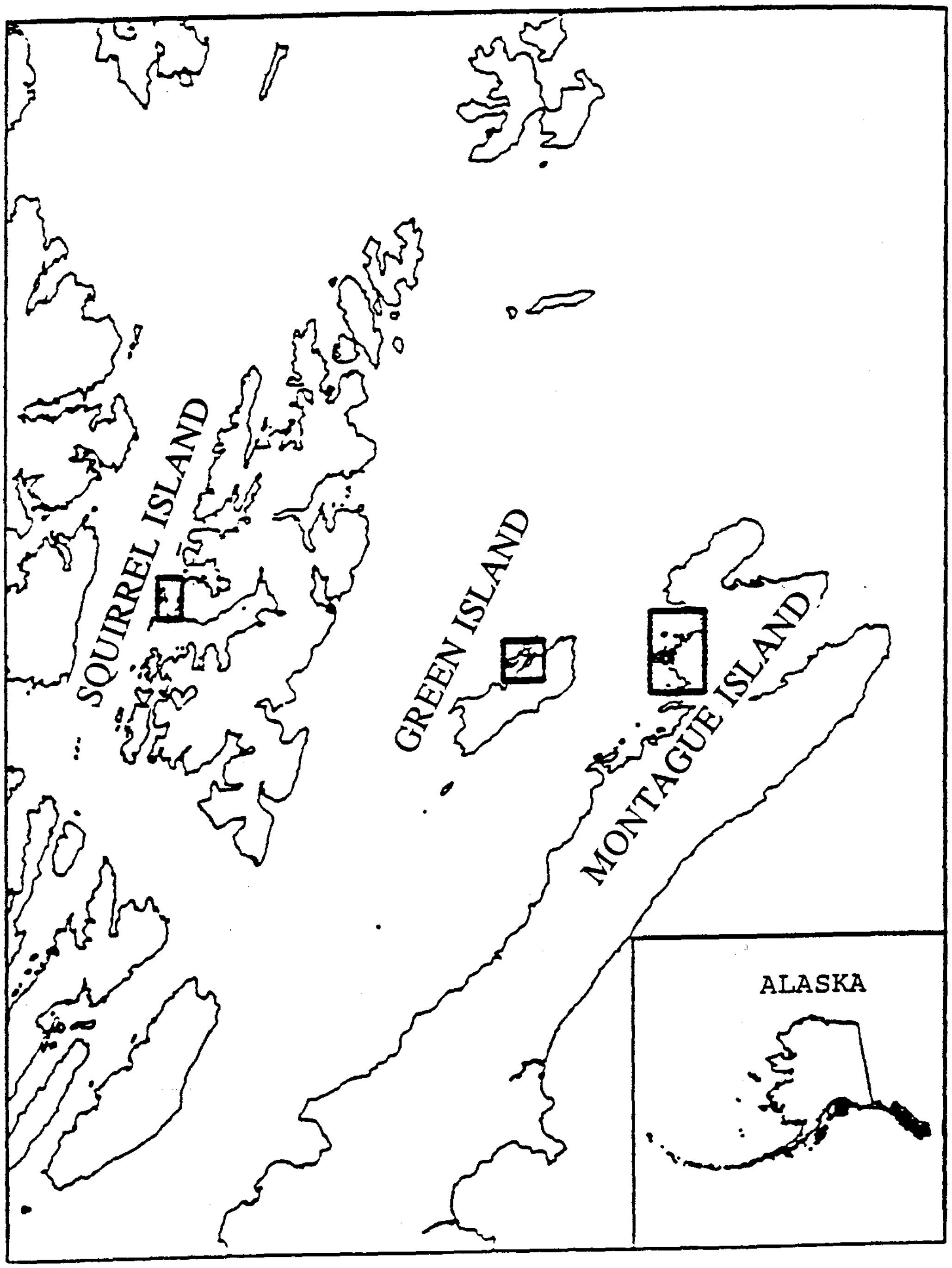
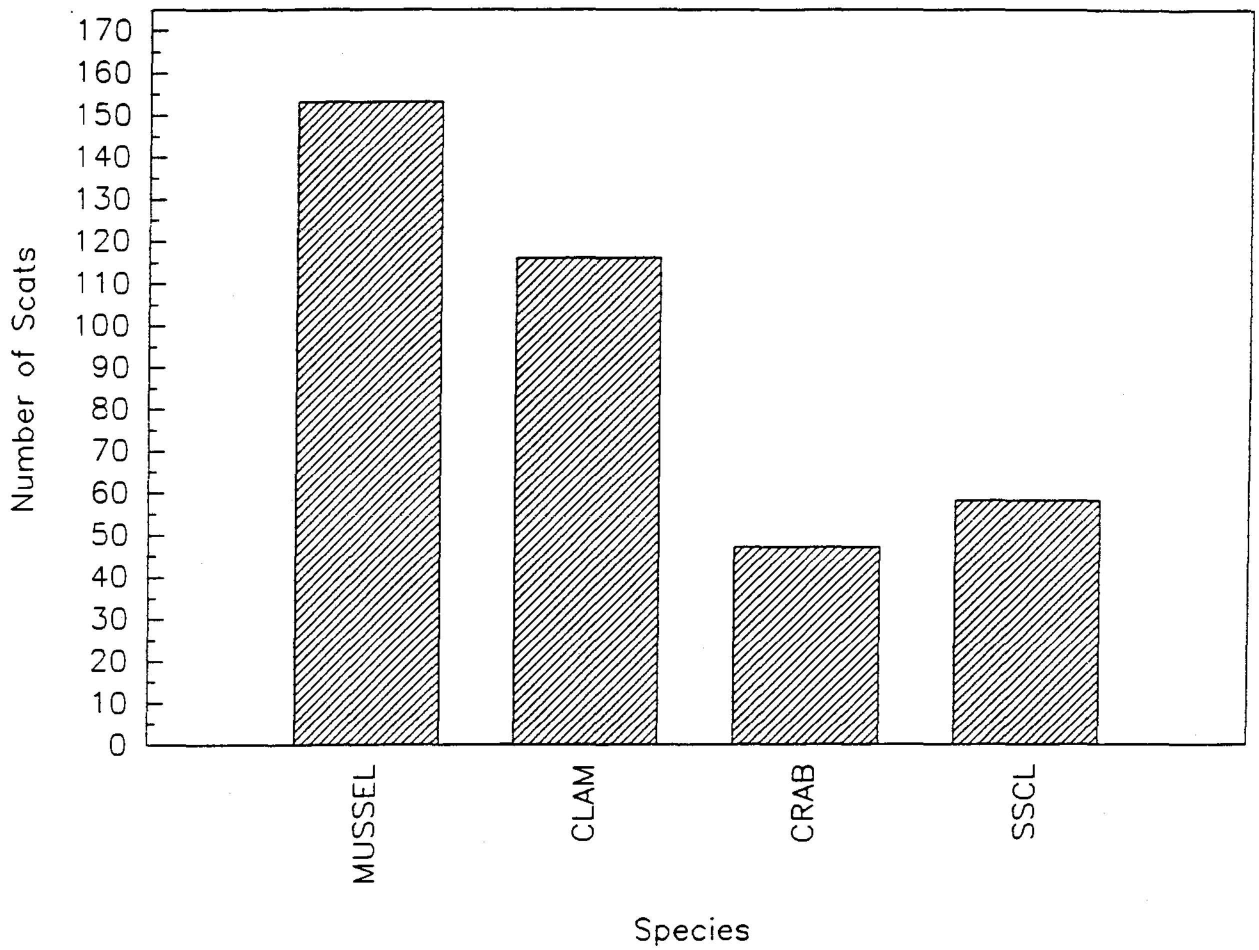


Figure 12. The composition of Mussel, Clam, Crab and other small invertebrates in 253 sea otter scats examined during 20 April to 2 May 1991, in Western Prince William Sound, Alaska.



1) *Mytilis edulis*
2) Frequency of *Saxidomas giganteus*, *Protothaca staminea*, *Humilaria kennerleyi*, and unknown shell fragments.
3) Species not identified.
4) SSCL equivalent to: Scallop (*Chlymys sp.*), Snail (*Natica sp.*), Cockle (*Clinocardium sp.*), Limpet (*Notoacmea scutum*), and other unidentified snail shell fragments.

Table 4.2 The composition of Mussel, Clam, Crab and other small invertebrates in 253 sea otter scats examined during 20 April to 2 May 1991 in Wester Prince William Sound, Alaska.

The number of scat containing the following percentages of Mussel, Clam, Crab and SSCL

Total	Percentage of 100%	90%	75%	50%	25%	10%	5%	in sample	total-No. of scat
Mussel[1]	76	24	10	13	14	6	10	153	(60%)
Clam[2]	23	22	8	15	21	10	17	116	(46%)
Crab[3]	0	2	2	5	21	10	7	47	(19%)
SSCL[4]	13	4	5	8	4	6	10	58	(20%)

---

1 <u>Mytilus</u> <u>edulis</u>

2 <u>Protothaca</u> <u>staminea</u>, <u>Saxidomas</u> <u>giganteus</u>, <u>Humilaria</u> <u>kennerleyi</u>: includes unidentified shell fragments.

3 Species not identified

4 SSCL equivalent to: Scallop (<u>Chlymys</u> <u>sp</u>.), Snail (<u>Natica</u> <u>sp</u>.), Cockle (<u>Clinocardium</u> <u>sp</u>.), limpet (<u>Notoacmea</u> <u>scutum</u>), and other unidentified snail shell fragments.

Section 5

POST-SPILL SEA OTTER MORTALITY IN PRINCE WILLIAM SOUND

Daniel H. Monson

SUMMARY

We compared the age class distributions of beach cast sea otter carcasses found in Prince William Sound from 1974 through 1986 (pre-spill), in 1989 as a direct result of the Exxon Valdez oil spill (spill year) and in 1990 and 1991 (post-spill). There were significant differences between pre-spill and spill year distributions and pre-spill and post-spill distributions. Spill year and post-spill distributions were not significantly different. The proportion of prime age animals dying in western Prince William Sound increased in both the spill year (1989) and post spill years (1990 and 1991). The observed differences represent a shift from a pre-spill composition of principally young and aged animals to an increased proportion of prime-age animals during and following the spill. The observed changes in the age distributions of dying sea otters suggest a prolonged, spill related affect on at least the western Prince William Sound sea otter population. Carcass recovery rates and the sex ratio of dying animals did not differ pre- to post-spill.

OBJECTIVES

1. To test the hypothesis that pre-spill levels of mortality (number of carcasses per linear kilometer of beach surveyed) are not significantly different from post-spill levels of mortality in Prince William Sound.

2. To test the hypothesis that the proportion of female carcasses found on beaches in pre-spill surveys is not significantly different from proportions found in post-spill beach surveys in Prince William Sound.

3. To test the hypothesis that the proportion of prime-age carcasses found on beaches in pre-spill surveys is not significantly different from proportions found in post-spill beach surveys in Prince William Sound.

INTRODUCTION

Following the EXXON VALDEZ oil spill (EVOS) sea otter populations in the path of the spill experienced severe mortality resulting in the collection of hundreds of carcasses (DeGange and Lensink, 1990). Acute and chronic exposure to hydrocarbons persisting in the environment may result in additional losses. Characteristics of mortality for these populations (i.e. mortality rates, age-class and sex composition of mortality) can be monitored using information gained from beach cast carcasses.

Kenyon (1969), Johnson (1987) and Bodkin and Jameson (1991) document and describe patterns of mortality for sea otter populations. Kenyon (1969) describes the age structure of dying sea otters at Amchitka Island in the western Aleutian chain as consisting primarily of juveniles (70%). Among adults found dead or dying, most showed signs of aging. Data from California suggest a similar mortality pattern with the majority of annual mortality comprised of sub-adult sea otters (Bodkin and Jameson, 1991). Johnson (1987) collected beach cast carcasses in Prince William Sound from 1974 through 1984. At Green Island, 163 carcasses were collected during this period. Aged carcasses were comprised of 45% juveniles (0 to 1 year) and 40% adults greater than 8 years of age (figure 5.1). This area has supported sea otters since at least the 1950's (Lensink, 1962) and has a well established population. In an area at the front of an expanding sea otter population in eastern Prince William Sound, Johnson collected only 25 carcasses during the same period. Juveniles comprised 17% of aged animals and 78% were greater than 8 years of age (Fig. 5.2). Thus, under normal conditions, age composition of beach cast carcasses would likely show similar bimodal patterns with prime-age mortality remaining relatively low and rates for juveniles and old sea otters higher depending upon habitat conditions such as the availability of resources.

The most sensitive indicator of change in mortality patterns may be the proportion of prime-age carcasses recovered. An increase in this proportion indicates altered mortality rates for the reproducing population which has the greatest impact on the stability of the population.

This study examines patterns of sea otter mortality as indicated by beach-cast carcasses in 1989, 1990 and 1991, following the EVOS and compares those data with pre-spill data collected by Johnson (1987).

STUDY METHODOLOGY

A beach survey, following methodology described by Johnson (1987), was conducted in portions of Prince William Sound between May 10 and May 19, 1990, and 12 April and 2 May, 1991. Study sites were the same as Johnson's (1987) and included Green Island, within the spill zone, and the Port Gravina area of northeastern Prince William Sound, outside the spill zone. Agencies and individuals known to be working in these areas were contacted to assure that carcasses would not be removed before our systematic search.

Rates of carcass deposition (number/kilometer of beach surveyed) were determined for systematic beach surveys in the Green Island area. Proportions of female and prime age carcasses were determined for Green Island and the Port Gravina area. Prime-age was defined as between 2 and 8 years of age, based on pre-spill beach-cast carcass collections (Johnson 1987).

The date of collection, carcass location, relative position on the beach, and condition, along with the sex and estimated age were recorded for each carcass. Only carcasses determined to have been deposited over the previous winter/spring were used in the analysis. This determination was based upon the presence of hide and cartilage on skeletal remains and the location of remains with respect to the previous years layer of dead vegetation (above or below). Skulls and baculum (when present) were collected. A pre-molar was removed for age analysis (Garshelis 1984).

The U. S. Fish and Wildlife Service requested the reporting and collection, when possible, of all sea otter carcasses found during the second and third year's spill monitoring and clean-up efforts. Carcasses were reported or collected throughout the spill area by various federal and state agencies as well as private groups and individuals during spring and summer, 1990 and 1991. When possible, each carcass was examined and a tooth collected by Service biologists. Only data from carcasses actually recovered from beaches are included in this analysis.

All teeth were sectioned and read (aged) by Gary Matson (Matson's lab, Milltown, MT) and many were read independently by James Bodkin (AFWRC, Anchorage, AK). Each assigned a quality to the reading as a measure of confidence in the age. Matson's age was used for all analyses with the second reading serving as verification.

Differences between age distributions and sex ratios were tested using Fisher's Exact Test (2-tailed) or a standard Chi-Square test. Where significant differences were not seen between post-spill years, data were pooled. In addition, if differences were not observed between Green Island data and incidental data collected in other areas of western Prince William Sound, data were pooled as all post-spill mortality data. Pooled data were then tested against pre-spill data and data collected at the time of the spill. Differences were considered significant at $p < 0.05$.

STUDY RESULTS

Systematic Beach Survey

Eighteen carcasses were recovered from 54 kilometers of coast at Green Island (oiled area) in 1990 for a recovery rate of 0.33/km. Sex was determined for 14 carcasses and 6 (43%) were female. Fifteen carcasses provided teeth for aging. Five (33%) were juveniles, 3 (20%) prime-age and 7 (47%) older than 8 years of age. In 1991, 9 carcasses were recovered on Green Island beaches for a recovery rate of 0.17/km. Sex was determined for 4 carcasses and 3 (75%) were female. Eight provided a tooth and 4 (50%) were juvenile and 4 (50%) were prime-age. There were no significant differences between carcass recovery rates and sex composition between years or between pre and post-spill data at Green Island. The difference between 1990 vs 1991 age distributions approached significance ($p = 0.08$) and the pooled post-spill age distribution (Fig. 5.3) was not significantly different from pre-spill data. Six recently deposited carcasses were recovered from 53 kilometers of coast in the Port Gravina (non-oiled) area in 1990 for a recovery rate of 0.11/km. Of these 4 (67%) were female. All 6 were aged and 2 (33%) were juvenile, 3 (50%) were prime-age and 1 (17%) was older than 8 years of age. No carcasses were recovered on these beaches in 1991. Carcass recovery rates could not be determined for pre-spill years. The proportion of females in the post-spill sample was significantly higher than the pre-spill sample ($p < 0.001$). Sample sizes were insufficient to test for differences in age structure between pre and post-spill.

Incidental Carcass Collection

Multi-agency beach assessment crews examined approximately 1105 km of beach in the spill zone of western Prince William Sound during the spring of 1990 (Dan Edging, pers. com.). In addition, approximately 500 km of beach were walked by the Prince William Sound Conservation Alliance (PWSCA) looking for oil and clean-up debris (David Janka, pers. com.). The over-lap between beaches walked by the PWSCA and the survey crews is not known but assumed to be great. These groups collected 52 carcasses from western Prince William Sound beaches of which 46 came from oil impacted areas (Table 5.2) for a recovery rate of between 0.03 - 0.04/km. The PWSCA collected 21 (40%) with the rest collected by EXXON crews, the U.S. Fish & Wildlife Service (USFWS), the US Forest Service (USFS), Alaska Dept. of Fish & Game (ADF&G), the Alaska Dept. of Environmental Conservation (ADEC) and various private individuals and groups. Of the 52 carcasses collected incidental to other work in the Sound 37 provided teeth for aging. Twelve (32%) were juvenile, 18 (49%) were prime-age and 7 (19%) were greater than 8 years of age. Sex was determined on 15 individuals and 3 (20%) were female.

Multi-agency beach survey crews examined 385 km of beach in the spring of 1991 (1991 Work Program Status, Continuing Programs Aug. 15, 1991). The PWSCA participated in these surveys but did no additional surveys. Eight carcasses were reported in 1991 and 7 were collected for a recovery rate of 0.02/km. Six carcasses have been aged and 1 (17%) was a juvenile, 3 (50%) were prime age and 2 (33%) were greater than 8 years old.

No significant differences were observed in sex ratios or age distributions between years for incidental samples. Combined post-spill age distribution (Fig. 5.4) was significantly different from pre-spill data at Green Island ($p < 0.0001$). There were no significant differences between age distributions or sex ratios for combined post-spill systematic and incidental data. We pooled incidental and systematic sex ratio and age for western Prince William Sound for 1990 and 1991. Age (Fig. 5.5) and the sex ratios for carcasses collected post-spill for all of western Prince William Sound were significantly different than pre-spill data from Green Island ($p = 0.0005$ and $p = 0.05$ respectively). Combined sex ratio data for western Prince William Sound are summarized in Table 5.2.

DISCUSSION

Sea otter mortality patterns vary between areas and over time as a result of factors such as seasonal weather patterns, yearly changes in otter distribution and abundance, sexual segregation of the population within an area and condition of the supporting habitat (ie. resource availability). Kenyon (1969), Johnson (1987), and Bodkin and Jameson (1991) using beach cast carcass data describe a general pattern of mortality for sea otter populations. A major proportion of dying sea otters are sub-adults (45%-70%). Mortality rates of prime age animals are generally low (5%-15%). Mortality rates for young of the year and aged animals increases with length of time otters have occupied an area. The majority of losses are observed in late winter/early spring when old and young animals in food-limited areas appear stressed. A peak in mortality has also been observed during late summer and early fall corresponding to the peak pup weaning periods of populations in California (Bodkin and Jameson, 1991). These studies conclude that data from beach cast carcasses can be a valuable indicator of trends in mortality for sea otter populations.

Systematic Beach Survey

Sea otter densities were considered to be relatively stable at Green Island at the time of Johnson's (1987) study. Rates of carcass deposition on Green Island beaches ranged from 0.13/km to 0.63/km (X^2 = 0.31/km, sd = 0.20). The spring 1990 rate of carcass deposition 0.33/km and mean post-spill rate (1990 and 1991 combined) of 0.26/km fall near the pre-spill mean. However, 1989-1991 winter densities of sea otters in the Green Island area may have been significantly lower than pre-spill densities due to loses observed during the EVOS, thus this rate may be high relative compared to sea otter abundance. Burn (Section 1, this document) found consistently lower densities of sea otters in coastal portions of Prince William Sound affected by oil. At this time we do not have information on winter densities of sea otters in this area. An accurate determination of winter densities will be important in interpreting pre and post-spill carcass deposition rates.

The overall 1976-1986 sex ratio of 99 sea otter carcasses identified to sex and collected at Green Island was 59 females (60%). This proportion did not change when pups were excluded from the analysis (47 female of 78 = 60%). This may reflect the areas status as a female area (Johnson, 1987). The post-spill sex ratio of carcasses identified to sex was not significantly different between years. The combined post-spill proportion of female carcasses (10 of 19 = 53%) does not significantly differ from the pre-spill proportion of females (60%).

The number of carcasses recovered in the non-oiled area of Port Gravina totaled only 25 over 10 years (2.5/year) prior to the EVOS (Johnson, 1987). The 6 carcasses recovered in the 1990 spring survey may reflect an increase in mortality expected as the length of time sea otters have occupied the area increases. Pre-spill data were collected during the first years of re-occupation as an advancing front of male sea otters moved through this area (Johnson, 1987). Mortality rates can be expected to have been low at this time as resources were abundant (Garshelis et. al., 1986). However, no carcasses were collected in the Spring of 1991, thus several more years of data collection may be needed before inferences can be made about mortality rates in the area.

One (6%) of 18 carcasses identified to sex in the Port Gravina area by Johnson (1987), was identified as female. This reflects the dominance of males in the area which was, at the time, the expanding front of the Prince William Sound sea otter population (Johnson, 1987). This contrasts with the Green Island pre-spill data of 60% (n = 99) female sea otters (significantly different at $p < 0.001$) which had a long established population at the time and contained female areas (Johnson, 1987). The spring 1990 beach survey recovered 67% (n = 6) female carcasses in the Port Gravina and is not significantly different from that observed at Green Island prior to the EVOS. This indicates the move of females into the area as the expanding population front of males moved east.

A summary of Johnson's pre-spill mortality data for the Green Island area indicates the proportion of prime-age carcasses found on beaches ranged from 0 to 29% with a 9 year mean of 14% (n=142 carcasses, sd=0.097) (Fig. 5.1) The spring 1990 and 1991 age distributions were not significantly different (but approached significance, p = 0.08). The basic age structure found in the spring 1990 survey (33% juvenile, 20% prime, 47% old, n = 15) was similar to the over-all average pre-spill structure at Green Island (Fig. 5.1). However, the 1991 distribution of 50% juvenile and 50% prime age (n = 8), had higher a proportion of prime age than any single year of pre-spill data. However, sample size was inadequate for a valid statistical comparison. The 1990 and 1991 age data were pooled (Fig. 5.3) and the combined age distribution of carcasses recovered at Green Island was not significantly different from pre-spill data. Several years of data may be needed before trends can be determined.

The pre-spill proportion of prime-age carcasses was low in the Gravina area of eastern Prince William Sound. Only 5% (n = 18) of aged carcass collected from 1974 to 1984 were prime-age (Fig. 5.2). The post-spill recovery of 50% (n = 6) prime-age carcass in spring 1990 may indicate an unusual year of sea otter mortality in this area, however the small sample size precluded valid statistical testing. No carcasses were collected in this area in 1991 and a number of years data will be needed before trends can be determined.

Age distribution of carcasses collected prior to the EVOS at Green Island and the Port Gravina area were significantly different ($p = 0.01$) due to an even lower rate of prime-age mortality in the Port Gravina pre-spill data. This finding along with what seem to be lower carcass deposition rates (none could be determined for pre-spill data at Port Gravina) are consistent with the conclusions drawn above for differences in mortality between long occupied vs newly established sea otter habitat.

Incidental Carcass Collection

Ages have been determined for 351 carcasses collected in Prince William Sound at the time of the EVOS. Of these, 152 (43%) were prime-age animals (Fig. 5.6). Mortality during the spill was expected to have been equal for all age classes and thus provide an estimate of the sea otter age distribution of the population at that time. If oil spill effects did not persist in the Sound during the winter of 1989/1990, we would expect the age distribution of mortality to return to the "normal" bimodal pattern (i.e., mortality dominated by old and very young animals), observed by Johnson prior to the spill in Prince William Sound.

The age distribution of carcasses collected by beach crews since the spill is not significantly different between years. And, the combined incidental post-spill data is not significantly different from the age distribution of carcasses collected at the time of the spill (Figs. 5.4 and 5.6). In addition, age data from incidental and systematic carcass collections were not significantly different. In fact, the combined age distribution of carcasses collected post-spill in western Prince William Sound (incidental and systematic) is very similar to the distribution observed at the time of the spill (Figs. 5.5 and 5.6) and both distributions are significantly different from pre-spill data ($p = 0.0005$ for post-spill data and $p < 0.0001$ for data collected at the time of the spill). This may be an indication of continuing damages to the sea otter population in oiled areas of Prince William Sound.

These data indicate all age groups may be experiencing equal mortality rates (ie. the probability of death is equal for juvenile, prime age and old sea otters) in portions of western Prince William Sound. This conclusion has serious implications for recovery of sea otter populations within the spill area. If this trend continues, the reproductive portion of the population may suffer increasingly significant losses and impede or prevent sea otter populations from recovering in the near future (next 10 years) or possibly precipitate a further decline in populations within the spill area.

Combined post-spill sex ratios for all of western Prince William Sound (Table 5.2) were significantly different from pre-spill data collected at Green Island and data collected at the time of the spill (38% female for post-spill data vs 60% female for both pre-spill data and data collected during the spill, $p = 0.05$ and $p = 0.02$ respectively). If the sex ratio from carcasses collected at the time of the spill is representative of actual sex ratio of the population of western Prince William Sound, these data indicate unequal levels of mortality for male and female otters post-spill. Sea otters do segregate by sex and this finding may reflect some factor influencing mortality in male areas more than female areas. However, male carcasses are more likely to be identified due to the presence of a baculum even when heavily scavenged. Sex has not been determined for the majority of incidentally collected carcasses and only 34 (41%) of 83 post-spill carcasses have been identified to sex. Thus, the post-spill data may be biased towards identification of male carcasses.

The number of carcasses collected in 1991 declined from 1990. However, this is most likely a reflection of the intensity of effort between the two years. Survey crews and the PWSCA searched more beach in 1990 than 1991 (1600 km vs 385 km). In addition reporting of carcasses (particularly heavily scavenged carcasses) was not as consistent in 1991 as the previous year. Thus the change in number of carcasses recovered may reflect reduced effort rather than a change in mortality between 1990 and 1991.

Changes in post-spill sea otter mortality may be reflected by changes in the age and sex ratios or beach cast sea otter carcasses and, to a lesser extent, the rate of carcass deposition on Prince William Sound beaches. The results of this study demonstrate that the age structure of the dying western Prince William Sound sea otter population after the oil spill is comprised of a significantly higher proportion of prime age animals than prior to the spill. The extent of the effects of this pattern of mortality on the recovery of the sea otter population remain unknown.

Reliability of Age Estimates

For a sample of 339 teeth read by two independent readers, the readings were highly correlated ($r = 0.94$, $p < 0.0001$). If only the teeth for which both biologists were highly confident of the reading are considered ($n = 137$), the correlation improves to $r = 0.97$ ($p < 0.0001$). In addition, these two biologists along with one other have performed blind readings of ten known-age teen from California and there was a high degree of accuracy and precision among readers. Questions on aging of sea otters using tooth cementum annuli should be addressed to Jim Bodkin at the Alaska Fish and Wildlife Research Center (tel. 907 786-3450).

STATUS OF INJURY ASSESSMENT

The prime-age sea otter mortalities observed through spill year 3 are evidence of an abnormal pattern of mortality continuing in parts of Prince William Sound. A high proportion of the prime-age carcasses were recovered in areas that received heavy oiling in both 1990 and 1991. The abnormal mortality pattern may be associated with oil contamination in these areas and indicate continuing damage to the population. Further monitoring of carcass deposition, with systematic searches of areas heavily impacted by oil, will provide data on the persistence and specific causes of this abnormal mortality pattern.

LITERATURE CITED

Bodkin J. L. and R. J. Jameson, 1991. Patterns of seabird and marine mammal mortality as indicated by beach cast carcasses along the coast of Central California, 1980 to 1986. Can. J. of Zoo.

DeGange, A. R., C. J. Lensink. in press. Distribution, age and sex composition of sea otter carcasses recovered during the response to the EXXON VALDEZ oil spill. in K. Bayha and J. Kormendy (eds.), Proceedings of the Sea Otter Symposium: effects of the T/V EXXON VALDEZ oil spill. U.S. Dept. Interior, Biological Reports 90(12).

Garshelis, D. L. 1983. Age estimation of living otters. J. Wildlife Manage. 48(2):456-463.

Garshelis, D. L., J. A. Garshelis, and A. T. Kimker. 1986. Sea otter time budgets and prey relationships in Alaska. J. Wildl. Manage. 50(4):637-647.

Johnson, A. M. 1987. Sea otters of Prince William Sound, Alaska Unpublished Report, U.S. Fish and Wildlife Service, Alaska Fish and Wildlife Research Center, Anchorage, AK.

Kenyon, K. W. 1969. The sea otter in the eastern Pacific Ocean. North Amer. Fauna 68. 352 pp.

Lensink, C. J. 1962. The history and status of sea otters in Alaska. Ph.D. Thesis, Purdue Univ. 188 pp.

Table 5.1 1990 and 1991 locations of sea otter carcasses found incidental to beach monitoring and clean-up activities in Prince William Sound.

Area	Spill Zone	Number
Knight Island	Yes	15
Eleanor Island	Yes	5
Naked Island	Yes	11
Perry Island	Yes	7
Long Island	Yes	1
Craft Island area	Yes	4
Evans Island	Yes	5
Latouch Island (SW Prince William Sound)	Yes	2
Green Island[1]	Yes	28
Stockdale Harbor (Montague Island)	No	1
Whittier area (NW Prince William Sound)	No	5
Valdez area	No	1
Unknown location within the Sound	Unk	1
Total collected		86

[1]Includes 27 carcasses collected during systematic beach walks.

Table 5.2 Sex ratios of beach cast sea otter carcasses collected in western Prince William Sound before, during, and after the EXXON Valdez oil spill.

	Female		Male		Total
Time Period	number	percent	number	percent	collected
Pre-Spill[1]	59	60%	40	40%	99
1989[2]	312	60%	208	40%	520
Post-Spill[2]	13	38%	21	62%	34

[1]Includes onln carcasses collected at Green Island.
[2]Includes carcasses collected all over western Prince William Sound.

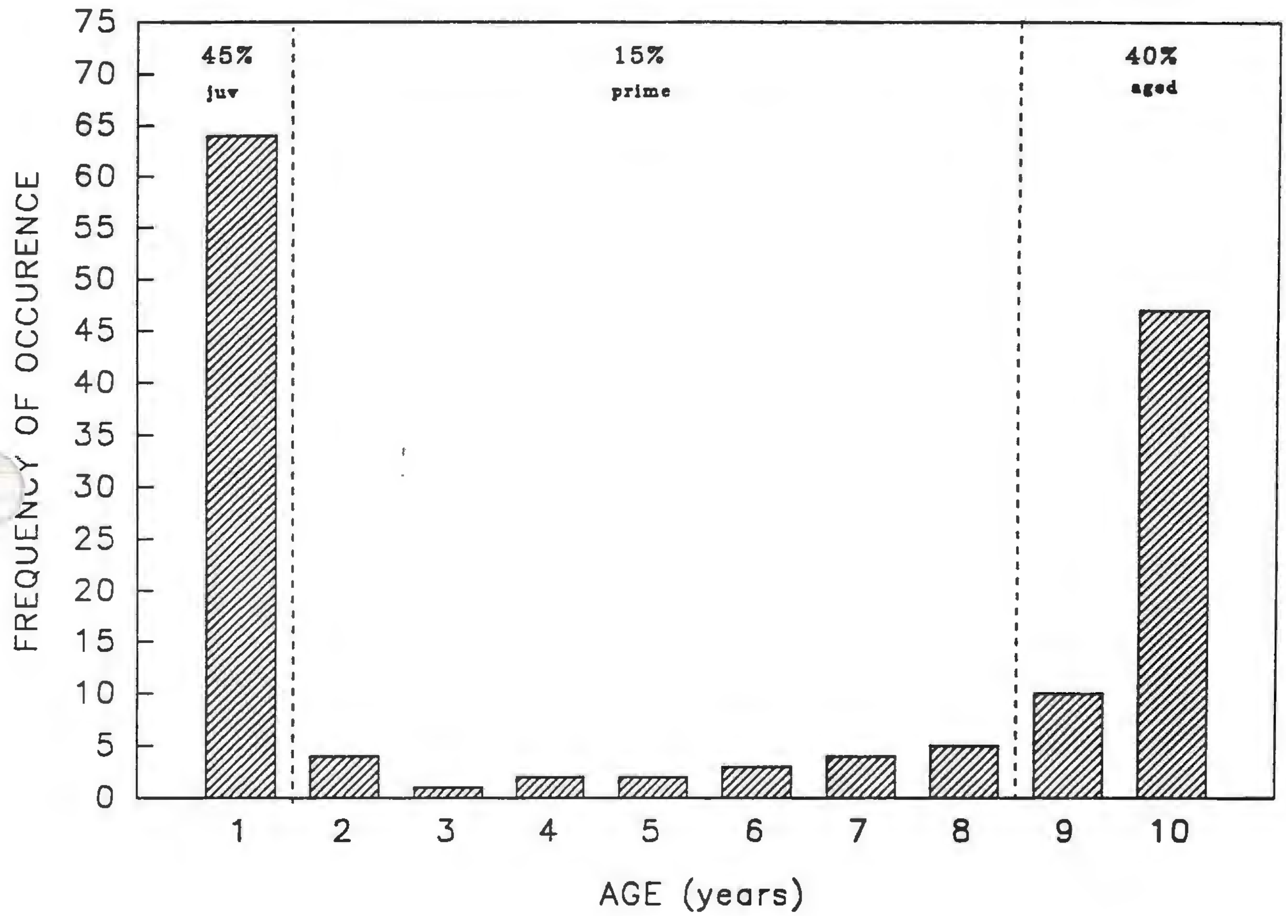


Figure 5.1. Age distribution of 142 sea otter carcasses collected on Green Island, Prince William Sound, Alaska, 1974–1984. (note: Ages > 10 combined at 10)

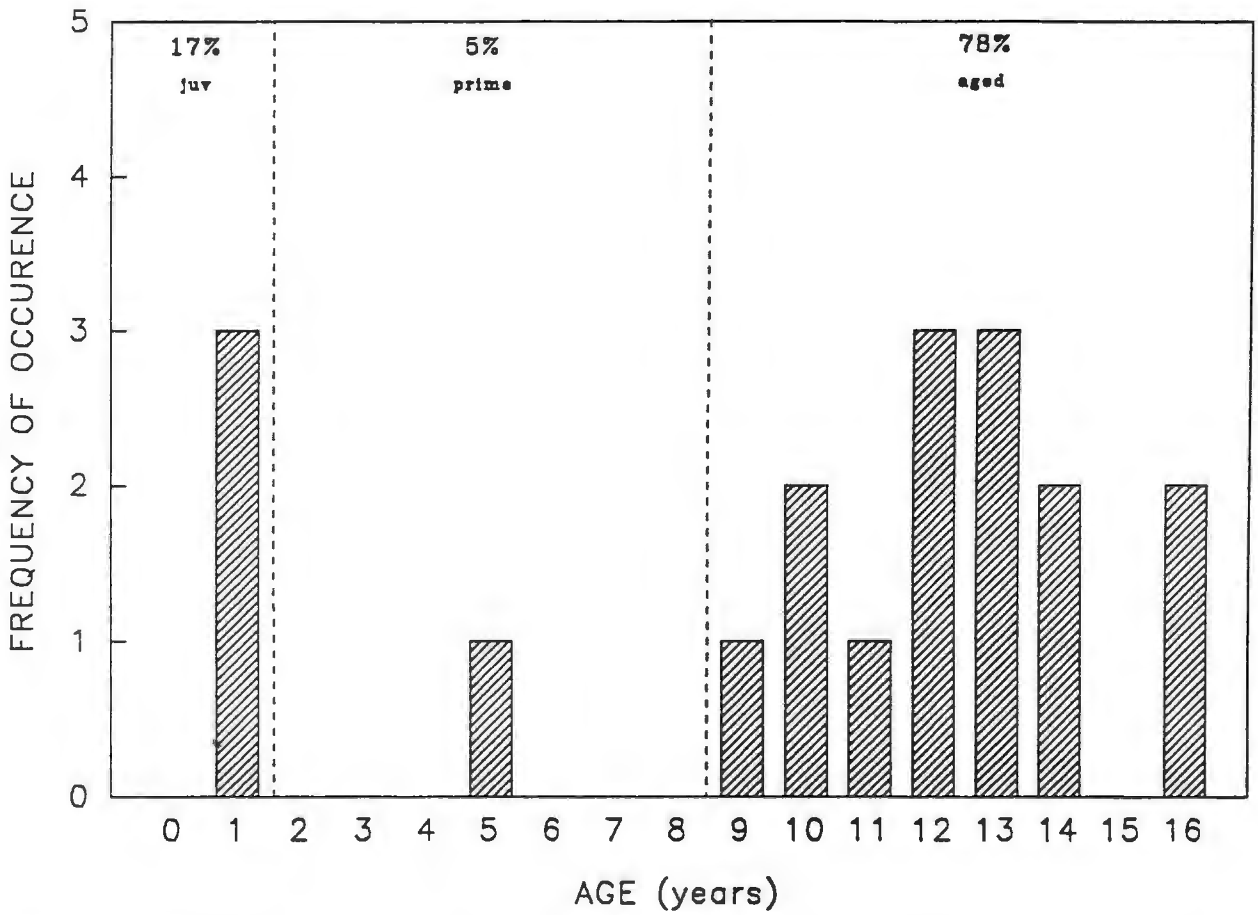


Figure 5.2. Age distribution of 18 sea otter carcasses collected in eastern Prince William Sound, Alaska, 1974–1984.

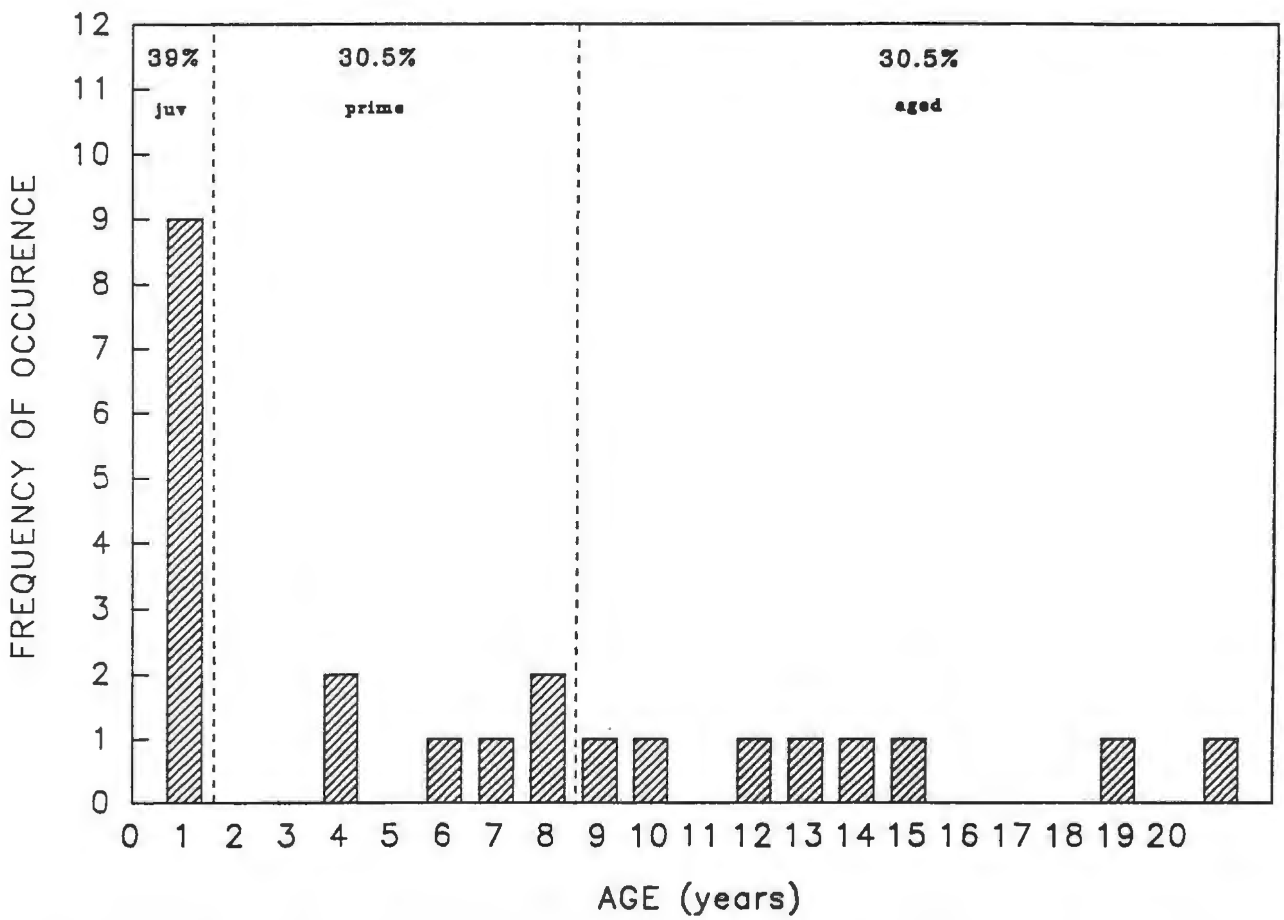


Figure 5.3. Age distribution of 23 sea otter carcasses collected on Green Island, Prince William Sound, Alaska, 1990-1991.

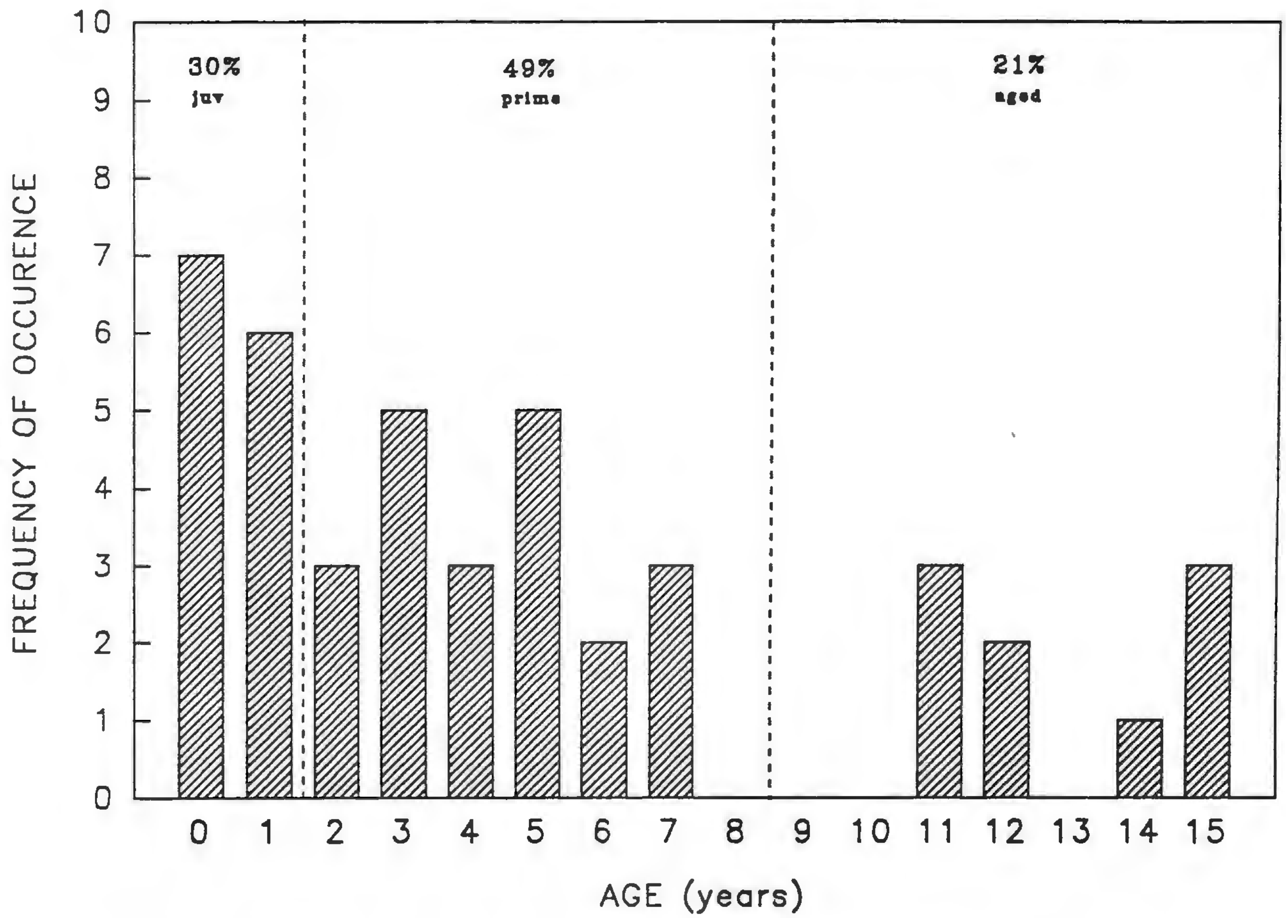


Figure 5.4. Age distribution of 43 sea otter carcasses collected in western Prince William Sound, Alaska, 1990–1991 (excluding Green Island).

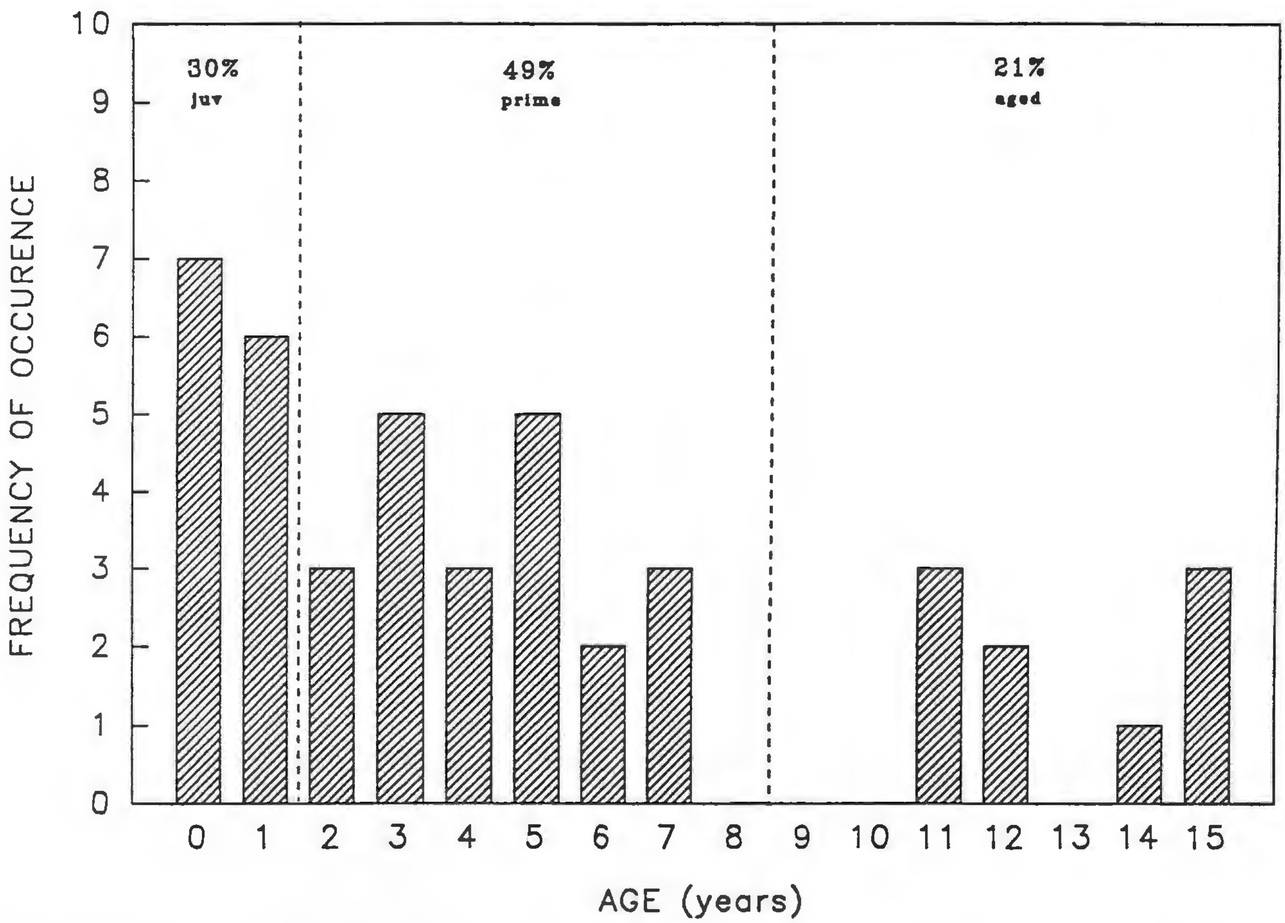


Figure 5.4. Age distribution of 43 sea otter carcasses collected in westerm Prince William Sound, Alaska, 1990-1991 (excluding Green Island).

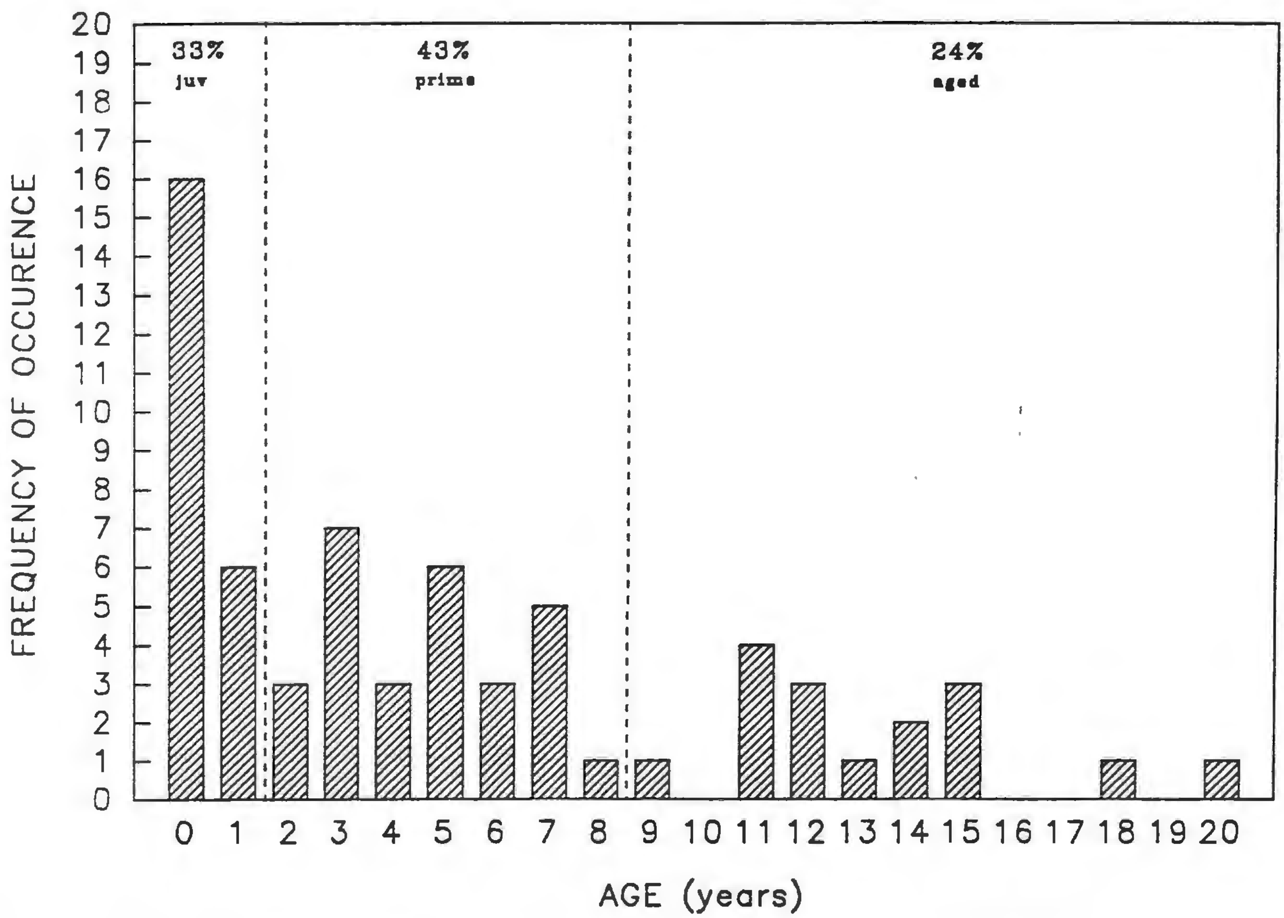


Figure 5.5. Age distribution of 66 sea otter carcasses collected in western Prince William Sound, Alaska, 1990–1991 (including Green Island)..

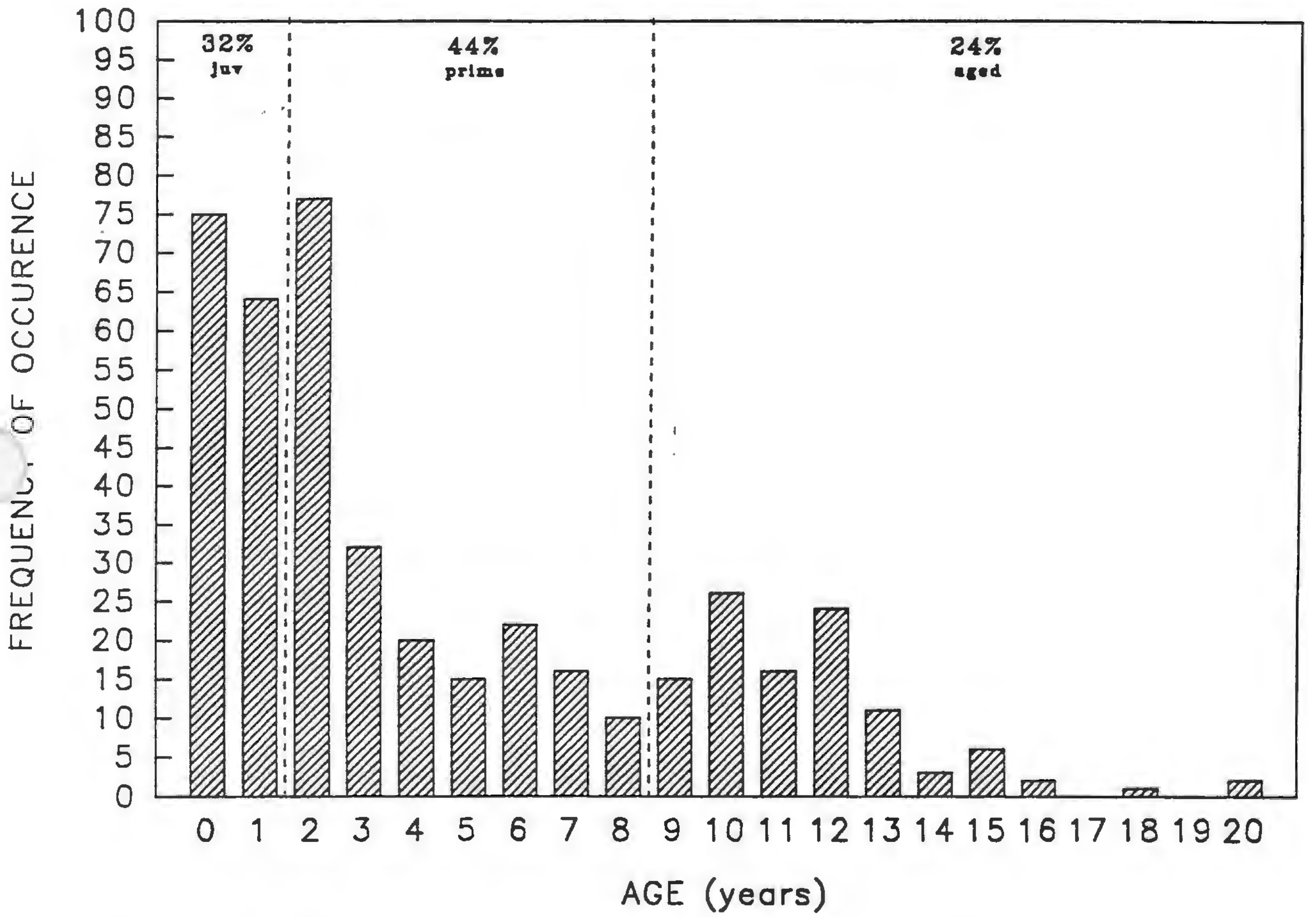


Figure 5.6. Age distribution of 437 sea otter carcasses collected in Prince William Sound, Alaska, 1989.

Section 6

HYDROCARBON CONTAMINATION OF SEA OTTER TISSUE SAMPLES

D. Mulcahy & B.E. Ballachey

SUMMARY

Sea otter tissue samples have been collected to measure hydrocarbon contamination following exposure of the otters to oil from the Exxon Valdez, and to evaluate associations between hydrocarbon levels and other information gathered on the sea otters, including clinical and histopathologies, and life histories. Samples are from sea otters that entered the rehabilitation centers, carcasses collected in the oil zone post-spill (1989, 1990 and 1991), and otters captured in Prince William Sound post-spill (1989, 1990 and 1991). Sea otters in southeast Alaska were sampled to provide a non-exposed control group. To date, over 400 samples have been analyzed. The hydrocarbon data, which consist of 93 primary analytes, calculated ratios and summations, have been entered into the sea otter data base, and an exploratory analysis of the data initiated. Results on approximately 200 more samples, including the control group, are pending. Full analyses of the data are expected to identify potential linkages between hydrocarbon contamination and deleterious effects associated with oil exposure noted in concurrent NRDA studies on sea otters. In addition, published literature on hydrocarbon levels in mammalian tissues is scant and this study will provide unique and valuable reference data on hydrocarbons in the event of future exposures of marine mammals to petroleum.

OBJECTIVES

The objective of this study is to evaluate levels of petroleum hydrocarbons and hydrocarbon metabolites in sea otter tissue samples as indicators of exposure to oil from the Exxon Valdez, and to relate contaminant levels to other data gathered on the sea otters, including clinical records, gross, clinical and histological pathologies, and rates of reproduction and survival. To address this objective, samples from the following groups are being examined:

A. Sea otters from the rehabilitation centers: 1) otters which died at the centers, with tissue samples collected at necropsy (see Appendix A), and 2) fat from sea otters captured in oiled areas, treated at the rehabilitation centers, and released into the wild in 1989 (see Appendix C).

B. Carcasses of sea otters recovered following the spill (1989, 1990 and 1991). For many of these, necropsy and histopathological information is also available (see Appendix A).

C. Blood and fat from sea otters captured in eastern and western Prince William Sound for radiotelemetry and bioindicator studies in 1989, 1990 and 1991 (see Appendices B and D).

D. Sea otters from south-east Alaska, representing a non-oiled control. In 1991, blood samples were collected from live caught otters, and tissue samples were collected from carcasses taken by a subsistence hunter.

The nine hypotheses listed below were initially formulated regarding hydrocarbon levels in tissue samples collected from sea otters at the rehabilitation centers, and from carcasses recovered following the spill.

Hypothesis 1. A. Levels of hydrocarbon contamination do not vary within tissue types between animals.
B. Levels of hydrocarbon contamination do not vary across tissues from a single animal.

Hypothesis 2. Hydrocarbon levels in sea otter tissues are independent of the degree of oiling.

Hypothesis 3. Hydrocarbon levels in sea otter tissues do not vary as a result of duration of potential exposure to oil.

Hypothesis 4. Hydrocarbon levels in sea otter tissue are independent of time between spill and exposure.

Hypothesis 5. Among lightly oiled sea otters exposed to oil for more than 20 days, hydrocarbon levels in tissues do not vary as a result of age of oil.

Hypothesis 6. A. Hydrocarbon levels in sea otter carcasses recovered in 1990 from western Prince William Sound do not differ from controls.
B. Hydrocarbon levels in sea otter carcasses recovered in 1990 from western Prince William Sound do not differ from those in carcasses of lightly oiled sea otters from western Prince William Sound in 1989.

Hypothesis 7. Hydrocarbon levels in tissue samples from sea otters exhibiting no external sign of oiling do not differ from control animals.

Hypothesis 8. Fetuses and pups of oiled female sea otters do not exhibit elevated hydrocarbon levels in tissues.

Hypothesis 9. Hydrocarbon levels in tissues of lightly oiled sea otters that died shortly after arrival at rehabilitation centers (within 3-4 days) do not differ from those of lightly oiled animals that survived 3-4 weeks.

INTRODUCTION

Alkane and aromatic hydrocarbons in tissues of sea otters which died during and after the EXXON VALDEZ oil spill, and sea otters captured in the course of concurrent NRDA studies are being analyzed. These data are expected to identify which sea otters collected alive or dead were exposed to oil from the spill and which sea otters have levels of petroleum hydrocarbons in their tissues that exceed normal background levels. Such information is critical in interpreting mortality and morbidity data being collected in several studies. Hydrocarbon data on individual sea otters and on similar groupings of sea otters will eventually be collated with gross and histopathological data obtained through necropsy of dead sea otters, and with demographic, life history and movement patterns of living sea otters.

Extensive laboratory analysis has been done of alkane and aromatic hydrocarbon levels in sea otter tissues submitted during these investigations. Scant information exists in the published literature for the levels of hydrocarbons to be considered normal in marine mammal tissues, the metabolic alteration of ingested and absorbed petroleum hydrocarbons which produced altered hydrocarbon products in tissues, and the level of non-petroleum, biogenically produced hydrocarbons. Interpretation of the detailed data obtained for the many analytes obtained in our studies is complicated by the lack of guidance provided by the published literature. Much of the analysis done during our studies will undoubtedly provide pathways for future investigation of similar events.

STUDY METHODOLOGY

Hydrocarbon Analyses

Samples were submitted through NRDA Technical Services Study Number 1 for hydrocarbon analyses. Two major classes of petroleum hydrocarbons, 1) alkanes or aliphatic compounds, and 2) aromatic compounds, are the focus of the analyses done on the samples. Alkane hydrocarbons contain only single bonds between carbon atoms and may be normal, branched or cyclic. Aromatic hydrocarbons consist of various combinations of the six-carbon benzene ring.

Hydrocarbon analysis of submitted tissue and fluid samples yield concentrations of 28 alkane and 39 aromatic primary analytes. In addition, seven alkane and 19 aromatic ratios or summations of the primary analytes are then calculated, for a total of 93 data points from each sample (Tables 6.1 and 6.2). While the primary analytes carry important information about each sample, the ratios and summations may offer a simpler first approximation of the data.

Alkane and aromatic hydrocarbons are widespread in nature. Some are produced by marine and terrestrial organisms, some are introduced into the environment from oil seeps and weathering of petrogenous rock and some come from sources of human pollution other than the EXXON VALDEZ oil spill. Determination of the source of hydrocarbons present within an animal is complicated, and made more difficult by the animal's metabolism of the hydrocarbons for storage and elimination. As general guidelines, tissues from non-exposed animals contain moderate levels of biogenic hydrocarbons such as C17, pristane, and odd carbon chain normal alkanes (C25 through C33). Oil is indicated in the alkanes by high levels of phytane and an constant level series of odd and even carbon chain normal alkanes. Oil is indicated in the aromatics by alkylated naphthalenes, phenanthrenes and dibenzothiophenes. The presence of the unresolved complex mixture (UCM) and the calculated carbon preference index (CPI) is an excellent indicator of the presence of degraded oil. Table 6.3 provides a brief explanation of some of the hydrocarbon measures considered to be of value in detecting exposure to petroleum.

Data Analyses

The hydrocarbon data is generally not normally distributed, but is characterized by a preponderance of low values with points extending through a 3-4 $\log_{10}$ range. A $\log_{10}$ transformation is being evaluated to change the distribution of the data from one dominated by measurements in the lowest intervals to one which is more normally distributed (Snedecor and Cochran, 1967; Humphrey et al. 1987).

Samples

Tissue samples were collected according to protocols established in Technical Services Study Number 1. For the hypotheses listed above, results of analyses on the following animals and tissues are being examined:

Hypothesis 1. Ten sea otter carcasses were selected that had been obtained in Western Prince William Sound, assessed as having the same degree of oiling (heavy) and all of which had died before 11 April 1989. The following tissues were collected and submitted for hydrocarbon analysis: liver, kidney, brain, muscle, intestine, fat (from six animals only) and testes (from two animals only). Levels of the alkane and aromatic hydrocarbons are being compared between tissue types of each animal (Hypothesis 1B) and the same organ compared among sea otters (Hypothesis 1A).

Hypothesis 2. Animals in this group fit the following criteria: all were collected between 2 April 1989 and 9 April 1989, all were obtained in Western Prince William Sound, and all spent between 0 and 7 days at rehabilitation centers before dying. Four sea otters were heavily oiled and seven otters were lightly oiled. Liver tissue was submitted for analysis.

Hypothesis 3. Animals selected for this test were controlled for degree of oiling (heavy or moderate), collected during the same period (for each group), and were brought to rehabilitation centers before dying. Six animals were considered to have been exposed to oil for less than 2 days and five animals for 8 to 11 days. Liver tissue was submitted for analysis.

Hypothesis 4. Moderately and heavily oiled sea otters were selected for this test. The animals were collected over a time gradient following the spill. The time gradient was established by collecting animals from three different geographic locations at different distances from the origin of the spill. Ten animals were collected from western Prince William Sound (these were the same animals used in Hypothesis 1), eight animals from the Kenai Peninsula, and eight from Kodiak Island. Liver tissue was submitted for analysis.

Hypothesis 5. Lightly oiled sea otters were collected from three different geographic locations (western Prince William Sound, Kenai Peninsula and Kodiak Island). These otters had been exposed to oil for less than 20 days. The oil at the three locations is presumed to have a differing hydrocarbon composition and different physical properties due to aging. Liver, hair and intestinal tissues were submitted for analysis.

Hypothesis 6. Hydrocarbon levels in tissues of sea otters found dead in the second year of the oil spill will be compared to the levels obtained from analysis of tissues from 11 sea otters collected by a subsistence hunter in southeast Alaska (Hypothesis 6A). Five sea otter carcasses recovered in Prince William Sound in 1990 will be used. The hydrocarbon levels in the 1990 sea otter carcasses will also be compared to the levels in tissues of lightly oiled sea otters that died in rehabilitation centers in 1989, the first year of the spill (Hypothesis 6B). Seven sea otters have been selected from 1989 to be compared with the five sea otters from 1990. Liver tissue was submitted for analysis.

Hypothesis 7. Ten otters were selected from those collected in 1989 that showed no external signs of oiling. The hydrocarbon levels found in their liver tissues will be compared to the levels in the liver tissues of the 11 subsistence-collected sea otters from southeast Alaska.

Hypothesis 8. Hydrocarbon levels in liver samples of nine sea otter neonates or fetuses born to oiled females in rehabilitation centers are to be compared with levels in livers from fetuses and neonates from unoiled female sea otters.

Hypothesis 9. Liver tissue was collected from 7 sea otters that died within 3 to 4 days following their arrival in rehabilitation centers. Hydrocarbon levels will be compared to levels in liver tissue from animals that survived in rehabilitation centers for 3 to 4 weeks before dying.

The control group consists of 11 sea otters killed by a subsistence hunter in southeast Alaska in the spring of 1991. Liver, kidney, muscle, and fat were collected. These tissues await submission for hydrocarbon analysis.

Female sea otters and sea otter pups were captured in 1989 and 1990 for instrumentation as part of the NRDA radiotelemetry studies, and fat and blood samples were collected at the time of surgery. Details of the capture and sampling methods are presented in Appendices B and D. Blood was also collected from adult male sea otters caught in 1990 for a NRDA study on bioindicators of oil exposure. The sea otters were captured in eastern Prince William Sound (considered the non-oiled control area), and within or immediately adjacent to the oil spill zone (treatment area) in western Prince William Sound. Areas peripheral to or on the edge of the spill zone in western Prince William Sound where sea otters were captured included Port Chalmers and Stockdale Harbor on Montague Island, and Channel and Little Green Islands near Green Island. Hydrocarbon analyses are complete on samples from 55 adult female otters, but are not yet complete on the pups or adult males.

Forty-five sea otters captured and treated at the rehabilitation centers were radio-instrumented prior to release in the summer of 1989. Fat tissues were collected from these animals at the time of surgery, and hydrocarbon analyses are complete. A summary of the survival, reproduction and movements of these otters is presented in Appendix C.

Necropsies have been done on all sea otter carcasses that were in suitable condition. Pathologists certified by Board of the American College of Veterinary Pathology performed the necropsies and completed the histopathology for carcasses recovered in 1989. Tissues from 51 oiled sea otters and six unoiled sea otters that died in the rehabilitation centers were taken for histopathological examination (Appendix A). An additional 214 necropsies were done on frozen sea otter carcasses to determine gross pathological changes. A suite of tissues was sampled from the carcasses at the time of necropsy, but only a subset (predominately liver samples) has currently been analyzed. Remaining samples are maintained in frozen storage pending the need for additional analyses.

STUDY RESULTS

Most of the hydrocarbon analyses completed to date have been on liver, fat and blood tissues. Some hypotheses required the use of other specific tissue types, and the submission and completion of hydrocarbon analyses on these samples have been given priority. Although many additional samples have been collected, it is not anticipated that analysis of them all will be required. A subset of the samples in storage will be submitted in 1992 to complete the data set and strengthen the value of the statistical analysis.

Data on over 400 samples has been entered into the sea otter data base, and an exploratory data analysis is underway to provide guidance in determining the variables of greatest value for identifying hydrocarbon exposure. Due, however, to the complex nature of the data (93 variables; Tables 6.1 & 6.2), the lack of previous studies providing guidelines, and the incomplete hydrocarbon analyses on certain samples, including the control group, preliminary results are not presented in this document.

Blood and fat samples collected from sea otter pups have been submitted for hydrocarbon analyses but results have not yet been returned. Data analyses will be conducted when these data are complete.

Fat samples were obtained from sea otters that were captured in oiled areas, treated at the rehabilitation centers, and instrumented with a radio for telemetry prior to release in 1989. These samples have been analyzed, and data analysis is pending.

For sea otter carcasses on which gross, clinical and histological pathology is available, tissues from several organs have been analyzed, and additional samples are being submitted to coordinate the sample analysis with the histopathological study on these carcasses. Data analyses will be completed at a later date.

The components and concentrations of hydrocarbons present in sea otters in and around the spill area must be evaluated against a control group of sea otters from well outside the spill area. Tissues from a group of 11 sea otters from southeast Alaska were obtained in the spring of 1991 from a subsistence hunter. The use of sea otters from southeast Alaska as controls is predicated on that geographic area being "pristine," at least on the basis of large, known oil spills. The control tissues have not yet been analyzed, but will be submitted in early 1992. Without the data describing the levels of hydrocarbons in these otters, the interpretation of hydrocarbon levels in the tissues from animals within the spill zone must be limited to comparisons of levels and the presence or absence of specific hydrocarbon components. Conclusive statements as to the contribution of the oil spill to total body loads of hydrocarbons and the presence of specific components of the hydrocarbon series must be made cautiously until control data is available.

Most studies of oil in the marine environment have dealt with the persistence of oil in sediment and in marine invertebrates (Cretney et al. 1987a; 1987b). A few studies have focused on fish (Al-Saad 1990; Luquet et al. 1983). Very little information is available on uptake and metabolism of petroleum hydrocarbons in mammalian systems, and almost nothing has been published on the "background" levels of alkane and aromatic hydrocarbons found in marine mammals living in non-oiled environments. Mammals do have advanced metabolic systems for handling toxic compounds, and if an animal survives an acute encounter with oil, it has the capacity to metabolize the hydrocarbons that are systemic. For example, the action of inducible mixed function oxidase (MFO) enzymes converts the hydrocarbons to water-soluble forms for excretion (Engelhardt 1982). This means that the form of the oil constituents are altered from the original to allow storage and elimination. Because of the paucity of data concerning the metabolism of petroleum hydrocarbons in mammalian systems, research into how the mammalian system handles oil contamination and how petrogenic hydrocarbon compounds are metabolically altered for storage and elimination would be beneficial.

STATUS OF INJURY ASSESSMENT

An exploratory analysis of hydrocarbon data is underway to test a number of hypotheses concerning the presence, detectability and composition of petroleum residues in organs of sea otters killed during or shortly after the oil spill. More than 400 samples, primarily liver, fat and blood, have been analyzed to date. Samples of other tissues have been collected and will be submitted to augment the results already obtained.

Preliminary results are not presented at this time in part due to the complex nature of the data and the risks inherent in drawing conclusions prior to complete analysis of all available data. To interpret the results, control samples against which samples from oiled areas can be compared are needed; these samples are slated for analysis in early 1992. Further examination of the data will focus on the biological significance of the differences noted by relating the findings to clinical, pathological and life history information on the otters, as available.

Hydrocarbon analyses of several categories of samples are pending:

1) Control samples (tissues) from south-east Alaska

2) Blood and fat from sea otter pups and adult males in Prince William Sound
3) Fat from sea otters which survived treatment at the rehabilitation center
4) Additional tissues from sea otter carcasses, to coordinate with the histopathological studies.

Although the threat of exposure to oil spills and other sources of petroleum continues for many marine mammals, published information on the metabolism of petroleum hydrocarbons in mammalian systems is minimal. Research should be encouraged into how the mammalian system handles oil contamination and how petrogenic hydrocarbon compounds are metabolically altered for storage and elimination. The lack of any prior data on hydrocarbon levels in mammalian tissues has increased the difficulty of analyzing the data gathered following the 1989 oil spill. Assuming the appropriate data analyses can be completed (dependent on continuing funding in 1992), the hydrocarbon contaminant data collected as part of the NRDA process on sea otters should prove to be of major importance for examining linkages between exposure and recovery of the sea otter populations in oiled areas. Furthermore, the data set will be of exceptional value in provision of reference baselines for sea otters and other marine mammals in the event of future oil spills or other events involving exposure to petroleum compounds.

LITERATURE CITED

Al-saad, H.T. 1990. Distribution and sources of aliphatic hydrocarbons in fish from the Arabian Gulf. Mar. Poll. Bull. 21(3):155-157.

Cretney, W.J., D.R. Green, B.R. Fowler, B. Humphrey, D.L. Fiest and P.D. Boehm. 1987a. Hydrocarbon Biogeochemical setting of the Baffin Island oil spill experimental sites. II. Sediments. Arctic 40(Suppl. 1):71-79.

Engelhardt, F. R. 1982. Hydrocarbon metabolism and cortisol balance in oil-exposed ringed seals, Phoca hispida. Comp. Biochem. Physiol. 72C(1):133-136.

Humphrey, B., P.D. Boehm, M.C. Hamilton and R.J. Norstrom. 1987. The fate of chemically dispersed and untreated crude oil in Arctic Benthic Biota. Artic 40 (Suppl. 1):149-161.

Luquet, P., J.P. Gravedi, G. Choubert, J. Tulliez and G. Bories. 1983. Long term ingestion by rainbow trout of saturated hydrocarbons: Effects of n-paraffins, pristane and dodecyclohexane on growth, feed intake, lipid digestibility and canthaxanthin deposition. Aquaculture 34:12-25.

Snedecor, G.W. and W.G. Cochran. Statistical Methods. 6th ed. pp. 329-330. Iowa State University Press, Ames Iowa.

Table 6.1. Interpretation of Hydrocarbon Data.

1. TOTAL ALKANES. The best comparison will be to the total alkanes found in organs from the unoiled, control animals. Until those analyses are available, use >1μg/g (>1000ng/g) as a threshold level for determining the presence of oil.

2. ODD:EVEN CARBON NUMBER. This ratio, which should apply to the high molecular weight n-alkanes (C25 through C34), should be 1 in petroleum and >1 if from natural sources. Use <1 as an indicator of oiling.

3. C17, PRISTANE AND ODD CARBON CHAIN NORMAL ALKANES (C25 THROUGH C34). Biogenic aliphatic hydrocarbons.

4. PHYTANE AND A SERIES OF ODD AND EVEN CARBON NUMBER ALKANES. Petrogenic aliphatic hydrocarbons. Their presence is an indicator of oil contamination but levels should be compared to unoiled controls.

5. PRISTANE:PHYTANE. This ratio should be very high (≈20?) for uncontaminated material. Levels of about 1 to 3 are indicative of oil contamination.

6. ALKYLATED NAPHTHALENES, PHENANTHRENES AND DIBENZOTHIOPHENES. Petrogenic aromatic hydrocarbons. Their presence is an indicator of oil contamination but levels should be compared to unoiled controls.

7. UNRESOLVED COMPLEX MIXTURE (UCM). Petrogenic hydrocarbons. Its presence is an indicator of oil contamination but levels should be compared to unoiled controls.

8. C18:PHYTANE. This ratio can be used as an indicator of biodegradation of oil. Use ≥1 as an indicator of recent oiling.

9. CARBON PREFERENCE INDEX (CPI). Equal to 1.0 for petroleum and <3.0 can be used to indicate oil contamination.

Table 6.2. Primary Alkane and Aromatic Analytes.

ALKANES:

1. C10	11. C20	21. C30	31. UNRESOLVED COMPLEX MIXTURE (UCM)
2. C11	12. C21	22. C31	32. ODD:EVEN
3. C12	13. C22	23. C32	33. PRIS:PHY
4. C13	14. C23	24. C33	34. C18:PHYTANE
5. C14	15. C24	25. C34	35. CARBON PREFERENCE INDEX (CPI)
6. C15	16. C25	26. PRISTANE	
7. C16	17. C26	27. PHYTANE	
8. C17	18. C27	28. TOTAL ALKANES	
9. C18	19. C28	29. TOTAL ODD ALKANES	
10. C19	20. C29	30. TOTAL EVEN ALKANES	

AROMATICS:

1. NAPHTHALENE
2. C1-NAPHTHALENE
3. C2-NAPHTHALENE
4. C3-NAPHTHALENE
5. C4-NAPHTHALENE
6. TOTAL METH. NAPHTHALENES
7. TOTAL NAPHTHALENES
8. BIPHENYL
9. ACENAPHTHYLENE
10. ACENAPHTHENE
11. FLUORENE
12. C1-FLUORENE
13. C2-FLUORENE
14. C3-FLUORENE
15. TOTAL METH. FLUORENES
16. PHENANTHRENE
17. ANTHRACENE
18. C1-PHENANTHRENE
19. C2-PHENANTHRENE
20. C3-PHENANTHRENE
21. C4-PHENANTHRENE
22. TOTAL METH. PHENANTHRENES
23. TOTAL PHENANTHRENES
24. DIBENZOTHIOPHENE
25. C1-DIBENZOTHIOPHENE
26. C2-DIBENZOTHIOPHENE
27. C3-DIBENZOTHIOPHENE
28. TOTAL METH. DIBENZOTHIOPHENES
29. FLUORANTHENE
30. PYRENE
31. C1-FLUORANTHENE-PYRENE
32. BENZ[a]ANTHRACENE
33. CHRYSENE
34. C1-CHRYSENE
35. C2-CHRYSENE
36. C3-CHRYSENE
37. C4-CHRYSENE
38. TOTAL METH. CHRYSENES
39. BENZO(b)FLUORANTHENE
40. BENZO(k)FLURANTHENE
41. BENZO(e)PYRENE
42. BENZO(a)PYRENE
43. PERYLENE
44. IDENO([1,2,3-cd)PYRENE
45. DIBENZO(a,h)ANTHRACENE
46. BENZO(g,h,i)PERYLENE
47. TOTAL PARENT AROMATICS
48. TOTAL METHYLATED AROMATICS
49. LOW MOL. WT. AROMATICS
50. BENZO(a)PYR.+ BENZO(e)PYR.
51. HIGH MOL. WT. AROMATICS
52. TOTAL AROMATICS
53. TOTAL PARENTS:TOTAL METH. ARO.
54. NAPHTHALENE:TOTAL METH. NAPS.
55. FLUORENE:METH. FLUORENES
56. PHENANTHRENE:METH. PHENS.
57. DIBENZOTHIOPHENE:METH. DIBS.
58. CHRYSENE:METH. CHRYSENE

Table 6.3. Calculated Ratios and Summations.

ALKANES:

28. TOTAL ALKANES=(C-EVEN+C-ODD+UCM+PRISTANE+PHYTANE)

29. TOTAL ODD=(C11+C13+C15+C17+C19+C21+C23+C25+C27 +C29+C31+C33)

30. TOTAL EVEN=(C10+C12+C14+C16+C18+C20+C22+C24+C26+C28 +C30+C32+C34)

32. ODD:EVEN=(TOTAL ODD/TOTAL EVEN)

33. PRIS:PHY=(PRISTANE/PHYTANE)

34. C18:PHYTANE=(C18/PHYTANE)

35. CARBON PREFERENCE INDEX (CPI)=(2[C27+C29]/[C26+C28+C30])

AROMATICS:

6. TOTAL METH. NAPHTHALENES=(C1-NAPHTHA+C2-NAPHTHA +C3-NAPHTHA+C4-NAPHTHA)

7. TOTAL NAPHTHALENES=(NAPHTHA+TOTAL METH. NAPHTHALENES)

15. TOTAL METH. FLUORENES=(C1-FLUORENE+C2-FLUORENE +C3-FLUORENE)

22. TOTAL METH. PHENANTHRENES=(C1-PHENANTHRENE +C2-PHENANTHRENE+C3-PHENANTHRENE+C4-PHENANTHRENE)

23. TOTAL PHENANTHRENES=(PHENANTHRENE +TOTAL METH. PHENANTHRENE)

28. TOTAL METH. DIBENZOTHIOPHENES=(C1-DIBENZOTHIOPHENE +C2-BIBENZOTHIOPHENE+C3-DIBENZOTHIOPHENE)

38. TOTAL METH. CHRYSENES=(C1-CHRYSENE+C2-CHRYSENE +C3-CHRYSENE+C4-CHRYSENE)

47. TOTAL PARENT AROMATICS (SELECTED)=(NAPHTHA+FLUORENE +PHENANTHRENE+DIBENZOTHIOPHENE+CHRYSENE)

48. TOTAL METH. AROMATICS (SELECTED)=(TOTAL METH. NAPHTHALENES+TOTAL METH.FLUORENES+TOTAL METH. PHENANTHRENES+TOTAL METH. DIBENZOTHIOPHENE)

49. LOW MOL. WT. AROMATICS=(NAPHTHA+TOTAL METH. NAPHTHALENES+BIPHENYL+ACENAPHTHALENE+ACENAPTHENE +FLUORENE+TOTAL METH.FLUORENE+PHENANTHRENE +ANTHRACENE+TOTAL METH. PHENANTHRENE)=TOTAL AROMATICS FROM NAPHTHA TO C4-PHENANTHRENE)

Table 6.3 continued. Calculated Ratios and Summations.

50. BENAPYR + BENEPYR=(BEN[A]PYR+BEN[E]PYR)

51. HIGH MOL. WT. AROMATICS=(CHRYSENE+TOTAL METH. CHRYSENES +DIBENZOTHIOPHENE+TOTAL METH. DIBENZOTHIOPHENES +FLUORANTHRENE+PYRENE+C1-FLUORANTHENE-PYRENE +BEN[A]ANTHRACENE+BEN[B]FLUORANE+BEN[K]FLUORANE +PERYLENE+I123CDPYRENE+D.B.AHANTHRACENE +B.GHI PERYLENE+{BENAPYR+BENEPYR})

=TOTAL AROMATICS FROM DIBENZOTHIOPHENE TO B.GHI PERYLENE)

52. TOTAL AROMATICS=(LOW MOL. WT. AROMATICS+HIGH MOL. WT. AROMATICS)

53. TOTAL PARENTS:TOTAL METH. AROMATICS=(TOTAL PARENT AROMATICS/TOTAL METH. AROMATICS)

54. NAPHTHALENE:TOTAL METH. NAPS.=(NAPHTHALENES/HIGH MOL. WT. AROMATICS)

55. FLUORENE:METH. FLUORENES=FLUORENE/TOTAL METH. FLUORENE)

56. PHENANTHRENE:METH. PHENANTHRENES=(PHENANTHRENES/TOTAL METH. PHENANTHRENES)

57. DIBENZOTHIOPHENE:METH. DIBENZOTHIOPHENES= DIBENZOTHIOPHENES+TOTAL METH. DIBENZOTHIOPHENES)

58. CHRYSENE:METH. CHRYSENE=(CHRYSENE+TOTAL METH. CHRYSENES)

Section 7A

Clinical and Clinical Laboratory Correlates in Sea Otters Dying Acutely in Rehabilitation Centers

A. H. Rebar

INTRODUCTION

Following the oil spill caused by the grounding of the Exxon Valdez oil tanker in Alaska's Prince William Sound, a major effort was made to treat oiled sea otters in rehabilitation centers in an attempt to return them to the wild. Sea otters presented to the centers were classified as heavily oiled, moderately oiled, lightly oiled, or unoiled on the basis of visual examination. This report details the clinical findings and principal laboratory changes in otters which died shortly (within the first 10 days) after entering the rehabilitation centers regardless of degree of oiling or approach to therapy. Another report (Appendix A) describes the gross pathologic and histopathologic alterations in the same as well as other otters dying acutely in the centers. Later reports will address the clinical pathology of otters surviving in the centers for longer period.

METHODS

Twenty three otters have been selected for inclusion in this report. Otters were selected based upon completeness of clinical records and availability of detailed gross and histopathologic necropsy reports. Otters were divided into three groups on the basis of degree of oiling. Otters with greater than 60% of their bodies covered by oil were classified as heavily oiled, otters with 30-60% coverage were considered moderately oiled, and those with evidence of oiling but less than 30% coverage were classified as lightly oiled.

Clinical laboratory data for these twenty three otters are more varied in terms of completeness and reliability than either clinical records or pathology reports. Laboratory data were collected primarily to aid the clinician in clinical assessment and treatment; consequently, there is considerable variation in the amount and type of laboratory data available for each otter. Logistical problems in sample management also impact upon the consistency of the laboratory data. The centers were established under emergency conditions without proper laboratory equipment. Consequently, laboratory samples were sent to four different reference laboratories for evaluation, and comparing data from these laboratories must be approached with extreme caution. Additionally, inclement weather hindered the transport of some samples to laboratories. In some cases, laboratory data were totally lost as a result of these delays. In other instances, results were reported but have not been included in this summary because the problems in sample management were considered so great that laboratory data were regarded as invalid. Every effort has been made to include only that data which resulted from acceptably collected, transported, and processed samples.

The majority of the samples were processed through the PML laboratories in Seattle, Washington. Sea otter hematology and clinical chemistry reference ranges have been established for this laboratory through the analysis of hematology samples collected from 8 and serum samples collected from 26 clinically normal adult sea otters from southeastern Alaska. These reference ranges are listed in Table 7.1. The reference range was considered to be the mean +/-2 standard deviations with one exception. The reference range for lymphocytes was too large to be clinically useful. Consequently, lymphocyte counts of less than 1000 were regarded as lymphopenia and greater than 6000/μl as lymphocytosis (standard for most mammals). All PML generated laboratory data in this report have been compared to these reference ranges. No specific sea otter reference ranges have been developed for any of the other laboratories and the few results generated in those laboratories must be interpreted empirically. Extreme caution has been used in interpreting these results.

RESULTS

Tables 7.2-4 summarize the individual laboratory findings and clinical observations for the 23 heavily, moderately, and lightly oiled otters included in this report. Table 7.5 summarizes the principal syndromes which the laboratory data and clinical comments delineate.

The most common clinical syndrome seen regardless of degree of oiling was shock. Shock was usually characterized by hypothermia and lethargy and often by hemorrhagic diarrhea. Shock was rarely observed at the time of presentation but in heavily and moderately oiled otters generally developed within 48 hours of initial examination at the centers. In the lightly oiled otters included in this report, shock generally occurred during the second week of captivity.

A high proportion of otters in all three groups died with convulsions. Four of seven heavily oiled, four of five moderately oiled, and three of nine lightly oiled otters were seizuring at or near the time of death.

Anorexia was also a common clinical problem for otters in the rehabilitation centers. Anorexia was reported in three of seven heavily oiled otters, two of five moderately oiled otters, and one of nine lightly oiled otters.

From a laboratory data perspective, the most common hematologic abnormalities included lymphopenia and leukopenia, usually accompanied by increased numbers of immature neutrophils. Among heavily oiled animals, six of six had lymphopenia and four of six had leukopenia with increased immature neutrophils. Of the moderately oiled otters, four of five had lymphopenia and two of five had leukopenia with increased immature neutrophils. Of the lightly oiled otters, four of seven had lymphopenia and two of seven had leukopenia with increased immature neutrophils.

Anemia was also a relatively common hematologic abnormality. Altogether, nine of eighteen otters had anemia. This included three of six among the heavily oiled otters, one of five of those which were moderately oiled, and five of seven of the lightly oiled otters. Reticulocyte counts were not done and blood films were not available for retrospective study; as a result, the anemias could not be further classified.

The most prevalent syndromes identified by clinical chemistry included azotemia, hyperkalemia, hypoglycemia, hepatocellular leakage, and hypoproteinemia/hypoalbuminemia.

Azotemia, indicated by elevated serum urea. was the most common finding followed closely by hepatocellular leakage as indicated by elevated serum transaminases. Six of six heavily oiled otters, three of four moderately oiled otters, and six of nine lightly oiled otters were azotemic. Urine specific gravities were not available to help differentiate prerenal from renal azotemia. However, using the conservative assumption that serum urea levels about 200 mg/dl indicated renal azotemia, one of four moderately oiled otters, and three of nine lightly oiled otters were in renal failure when sampled near death. Evidence of hepatocellular leakage was present in five of five heavily oiled otters, three of four moderately oiled otters, and five of nine lightly oiled otters.

Hypoglycemia, hypoproteinemia/hypoalbuminemia, and hyperkalemia were somewhat less frequent alterations. They were found in nearly equal proportions in all of the three groups.

DISCUSSION

The vast majority of the sea otters that died acutely (within the first ten days of confinement) in the Valdez and Seward rehabilitation centers appear to have succumbed to shock. Terminal signs included lethargy, anorexia, and convulsions, often accompanied by hemorrhagic diarrhea.

Whether or not shock was a direct effect of oiling or primarily an indirect effect secondary to confinement and handling in the rehabilitation centers is difficult to assess. Lightly oiled otters were as likely to die from shock as heavily oiled ones, suggesting that confinement was more important than direct exposure to oil. However, more heavily oiled otters developed signs of shock more rapidly than lightly oiled otters. In addition, heavily oiled otters generally had a higher proportion of laboratory abnormalities than lightly oiled otters. These findings suggest that at the least, exposure to oil was an important predisposing factor.

Laboratory findings correlated for the most part with clinical observations. The most frequent hematologic findings was lymphopenia. The most common cause of lymphopenia in animals is systemic stress which results in increased endogenous production of glucocorticoids and resultant sequestration and possible destruction of circulating lymphocytes. Certainly the otters treated in rehabilitation centers were stressed.

Leukopenia characterized by neutropenia with increased numbers of immature neutrophils (a degenerative left shift) was also extremely common. A degenerative left shift suggests severe inflammation. It is frequently observed in animals suffering from diarrhea with bowel stasis, proliferation of intestinal bacteria, and subsequent systemic endotoxemia. Such a scenario is likely in those otters suffering from diarrhea and hemorrhagic bowel syndrome.

Hyperkalemia and hypoproteinemia/hypoalbuminemia were probably also related to diarrhea and hemorrhagic bowel syndrome. Hyperkalemia was at least partially the result of release of potassium from dying cells in the hemorrhagic bowel. Acidosis, a common accompaniment of diarrhea, can also be a cause of hyperkalemia. Hypoproteinemia and hypoalbuminemia were probably the result of protein loss in the diarrhea fluid.

Azotemia was the most common syndrome identified from the laboratory data. As stated before, since urine specific gravities were not available for these animals, prerenal azotemia could not be absolutely differentiated from renal azotemia. However, necropsies did not reveal significant renal lesions (see Pathology report). It is therefore most likely that shock led to prerenal azotemia as a result of decreased renal perfusion. In the few animals that probably had true renal azotemia (those with serum urea nitrogen values greater than 200 mg/dl), it is likely that long-standing reduced renal perfusion eventually led to primary renal injury near the time of death.

Hypoglycemia probably resulted from anorexia. Sea otters have high metabolic rates and devour large quantities of food. Anorexia would be expected to quickly deplete hepatic glycogen stores, resulting in hypoglycemia. Hypoglycemia was probably the cause of many of the terminal convulsions.

Hepatocellular leakage may have been a reflection of primary hepatotoxicity but was more likely a nonspecific change associated with anorexia. In anorexia, decreased availability of carbohydrates as an energy source leads to mobilization of fat from tissues stores to the liver. Increases in fat within hepatocytes result in increased cell membrane permeability with leakage of transaminases into the blood. In these otters, elevated transaminases correlated most frequently with hepatic lipidosis histopathologically (Appendix A).

The cause(s) of anemia in these otters is difficult to determine, especially since the anemias were not well characterized. Certainly in those animals with hemorrhagic bowel syndrome, blood loss must be considered a contributing factor. Oil exposure has been reported to cause Heinz body hemolysis in birds; the possibility of Heinz body hemolysis in the otters can neither be substantiated nor refuted, but laboratory reports give no indication that Heinz bodies were ever observed.

Section 7B

SUMMARY REPORT: HEMATOLOGY AND CHEMISTRY

A.H. Rebar

Male Adult Sea Otters - 1989 and 1990

Hematologic and serum chemical analyses were performed on samples collected from 43 male adult Prince William Sound sea otters in 1989 and 1990. Twelve of these were from the east (unoiled) side while 31 were from the west. Data from the eastern otters were used to establish reference ranges (mean+/-2 standard deviations) for each of the analytes measured. Population data as well as individual animal data were compared to these reference ranges.

Hematologic differences between eastern and western adult males were minimal. Both hematocrits and hemoglobins were significantly higher in western otters than in eastern otters but the biologic significance of this is equivocal. From a biological perspective, the difference in oxygen carrying capacity of the blood at the values recorded is minimal. Western males had significantly higher absolute eosinophil counts, suggesting the possibility of systemic hypersensitivity reactions in western otters.

The important serum chemical differences between eastern and western males were found in protein and electrolyte levels. Western males had higher serum protein and serum globulin levels than eastern males. These findings suggest greater antigenic stimulation (more inflammatory and/or infectious conditions) in western than in eastern otters. This finding was supported by the trend (although not statistically significant) toward higher circulating neutrophil numbers in western males.

Serum sodium and serum chloride were significantly higher and serum potassium was significantly lower in western males than in their eastern counterparts. This pattern of electrolyte change was unusual; the possibility of stress-induced hyperadrenalism should be ruled out by measurement of serum cortisol levels.

Other differences between western and eastern males included lower lactate dehydrogenase (LDH), phosphorus, and glucose, and higher cholesterol, and carbon dioxide in western otters. LDH differences were disregarded because of the nonspecific nature of the enzyme. Glucose differences were not of biological importance because the relationship of sample collection to eating could not be ascertained and was undoubtedly not constant. Phosphorus differences were not important when considered in light of the large reference range. Cholesterol differences, like LDH, were not specific, difficult to interpret, and probably biologically insignificant. Differences in carbon dioxide levels were biologically insignificant.

Female Adult Sea Otters - 1989 and 1990

Hematologic and serum chemical analyses were performed on samples collected from a total of 103 female Prince William Sound sea otters in the fall of 1989 and the spring of 1990. Forty of these were from the east (unoiled) side while 63 were from the west (oiled) side. Data from the eastern otters were used to establish reference ranges (mean +/-2 standard deviations) for each of the analytes measured. Population data as well as individual animal data were compared to this reference range. There were no differences in hematologic parameters between eastern and western female otters. Some chemistry changes were present, but the degree of difference was small so that data must be interpreted cautiously.

Mean serum protein, albumin, and globulin levels for western female otters were within the eastern reference range. However, total protein and serum globulin levels were slightly higher in western females, a noteworthy finding since it mirrors the same trend seen in western adult males in 1989 and 1990. As mentioned previously, a trend to higher globulin levels suggests possible antigenic stimulation.

Liver enzyme levels (SGPT, alkaline phosphatase) for western females also fell within the eastern reference range but again mean values were somewhat higher for the western females than for the eastern otters. This suggests the possibility of subclinical liver disease and merits careful monitoring in the coming months and years. This is particularly important in light of elevated liver enzymes seen in otters brought to rehabilitation centers shortly after the oil spill. SGOT and LDH levels followed the same patterns as SGPT and alkaline phosphatase; however, these enzymes are nonspecific and are influenced by factors such as hemolysis. Consequently, less interpretive significance was given to these values.

Electrolyte levels in western females also generally fell within eastern reference ranges. Once again, however, a similar pattern to that seen in adult males was present; that is sodium and chloride mean values were somewhat higher and potassium mean values were somewhat lower in western females than in those from the east. Whether this subtle difference was biologically significant is still uncertain. However, as with males, a possible stress-induced hyperadrenalism should be ruled out by measurement of serum cortisol levels.

Sea Otter Pups - 1990

Hematologic and serum chemical analyses were performed on samples collected from a total of 57 Prince William Sound sea otter pups in the fall of 1990. Fifteen of these otters were from the east (unoiled) side of the Sound while 42 were from the western (oiled) side. Data from the eastern side were used to establish reference ranges for each of the analytes measured. Population data as well as individual animal data were compared to this reference range.

As a group, western pup hematocrits, hemoglobins, and red cell counts were significantly lower than those of eastern pups. From a biological perspective, these reductions were minimal but supported by individual animal data. MCHC was also significantly lower in western pups, but the degree of this decrease was not regarded as biologically significant.

When considered collectively, red cell data suggest a mild anemia in western pups. Although reticulocyte counts were not available, the normal red cell indices suggested that this anemia was most likely nonregenerative. The degree of anemia was minimal so that biological significance was equivocal.

Leukocyte group data for easter versus western pups showed minimal differences. The only real difference was a higher mean lymphocyte count in western pups. When the individual animal data was examined, this difference truly reflected a higher absolute lymphocyte count in a number of western pups. Lymphocytosis may be seen in animals with chronic antigenic stimulation; however, this change is usually accompanied by hypergammaglobulinemia and therefore elevated serum globulin levels. Globulin levels in western pups were normal, so it was difficult to suggest chronic antigenic stimulation in the present case. In some animals, most notably cats, lymphocytosis is seen when the animal is excited at the time of sample collection. While this may also be the case in sea otters, it is difficult to rationalize a relatively greater effect in western than in eastern pups. It is noteworthy that the eosinophilia seen in western adult males was not a prominent finding in the pups.

The only other interesting hematologic observation was the presence of a significantly elevated mean platelet count in western pups. On an individual animal basis, this elevation was seen in a relatively high proportion of individuals (10 of 24 measured). While the elevation appeared to be real, the degree of elevation from a biological perspective was not extreme and no particular interpretation could be attached to this finding.

Chemistry data were relatively unremarkable. Statistically significant differences in BUN, LDH, glucose, and triglycerides were not regarded as biologically significant. Both sodium and chloride levels were statistically lower in western pups than in those from the east. The degree of reduction was so slight as to be of no biologic consequence; however, the observation is noteworthy in that it is in direct contrast to findings described earlier for adults where sodium and chloride were increased while potassium was reduced.

In summary, hematologic and clinical chemical differences between eastern pups were not striking and at best were of equivocal biologic significance. Perhaps the most significant observation was that trends seen in adults were not present in the pups observed to date.

Table 7.1 Reference Ranges for Sea Otters in Southeast Alaska (Samples analyzed at PML Laboratory)

	Mean	2SD	Reference Range
WBC	9175.00	4507.00	4668.00-13682.00
HGB	18.88	1.94	16.94-20.82
RBC	5.08	0.67	4.41-5.75
HCT	62.00	9.43	52.57-71.43
MCV	122.25	11.99	110.26-134.24
MCH	37.25	2.78	34.47-40.03
MCHC	30.63	2.63	28.00-33.26
PLATELETS (1000)	295.00	128.75	166.25-423.75
SEGS	4136.00	2918.94	1217.06-7054.94
LYMPHS	3837.50	3750.26	87.24-7587.76
MONOS	208.50	99.57	108.93-308.07
EOS	942.00	719.27	222.73-1661.27
BASOS	51.00	102.40	0.00-153.40
GLUCOSE	156.04	92.48	63.56-248.52
TOTPROTEIN	6.30	1.26	5.04-7.56
CREATANINE	0.60	0.25	0.35-0.85
URIC ACID	2.41	1.20	1.21-3.61
CHOLERSTEROL	130.46	42.03	88.43-172.49
TRIGLYCERIDES	72.08	59.91	12.17-131.99
ALK PHOS	96.15	54.81	41.34-150.96
SGOT	202.81	280.50	0.00-483.31
SGPT	181.04	147.33	33.71-328.37
LDH	373.73	319.81	53.92-693.54
TOTBILI	0.49	0.37	0.12-0-0.86
SODIUM	148.12	21.11	127.01-169.23
POTASSIUM	3.93	0.72	3.21-4.65
CHLORIDE	111.35	15.29	96.06-126.64
CALCIUM	8.62	1.39	7.23-10.01
PHOSPHORUS	4.46	1.75	2.71-6.21
ALBUMIN	2.66	0.49	2.17-3.15
GLOBULIN	3.65	0.98	2.67-4.63
BUN	50.08	22.50	27.58-72.58
CPK	1642.89	4554.90	0.00-6197.79

Reference Range equal to mean +/-2 standard deviations
Sample size for CBC is 8
Sample size for Chem values is 26 (19 females and 9 males)
Samples size for CPK is 18
All otters at least one year of age

Table 7.2 Principal laboratory and clinical findings in heavily oiled sea otters dying acutely (within 10 days of presentation) at rehabilitation centers.

OTTER#	HEMO CRIT	TOT WBC	NEUT PHIL	Bands	LYMP CYTE	GLUC	TOT PROT	ALBU	GLOB	UREA NITR	ALAN ATRA	ALK PHOS	NA	K	CL	P
VZ111[1]	±↓	↓	↓	↑	↓	N	↓	±↓	N	↑	↑	N	-	-	-	-
VZ070[2]	-	-	-	-	-	N	N	N	N	↑	↑	N	±↓	↑	N	↑
VZ006[3]	N	↓	↓	↑	↓	↓↓	N	↓	N	↑	↑	N	N	N	±↑	↑
VZ135[4]	↓	↓	N	↑	↓	N	±↓	±↓	N	↑	↑↑	↑	N	N	N	↑
VZ035[5]	↑	N	N	N	↓	-	-	-	-	-	-	-	-	-	-	-
VZ023[3]	↓	↓	↓	↑	↓	±↓	±↓	±↓	N	↑	↑	N	N	N	N	±↑
VZ013[6]	N	N	N	↑	↓	↓↓	↓	↓	↓	↑	-	N	N	↑	N	↑
Total:	3/6↓ 1/6↑ 2/6N	4/6↓ 6/6N	3/6↓ 3/6N	5/6↑ 1/6N	6/6↓	3/6↓ 3/6N	4/6↓ 2/6N	5/6↓ 1/6N	1/6↓ 5/6N	6/6↑	5/5↑	5/5N	1/5↓ 4/5N	2/5↑ 3/5N	1/5↑ 4/5N	5/5↑

Key:
- N = Normal
- ↓ = Moderate decrease
- ↓↓ = Marked decrease
- ±↓ = Marginal decrease
- ↑↑ = Marked increase
- ↑ = Moderate increase
- ±↑ = Marginal increase

---

[1] Normal at presentation but mild hyperthermia, died in seizures within 12 hours.
[2] Within 2-3 days - became anorectic, lethargic and developed dark tarry stools. Developed seizures.
[3] Not available.
[4] Lethargic and anorectic, hypothermic, seizured. Died within 4 days.
[5] Dark diarrhea, lethargic.
[6] Anorectic, dark tarry stools, seizured, died.

Table 7.3: Principal laboratory and clinical findings in heavily oiled sea otters dying acutely (within 10 days of presentation) at rehabilitation centers.

OTTER#	HEMO CRIT	TOT WBC	NEUT PHIL	Bands	LYMP CYTE	GLUC	TOT PROT	ALBU	GLOB	UREA NITR	ALAN ATRA	ALK PHOS	NA	K	CL	P
VZ113[1]	N	↓	↓	↑	↓	↑	N	↓	N	↑↑	-	N	N	↑	N	↑
VZ100[2]	N	↓	±↓	N	↓	-	↓	±↓	↓	-	↑	↑	N	↑	N	↑
VZ085[3]	N	N	N	N	↓	↓	±↓	N	±↓	N	↑	N	N	N	N	↑
VZ080[4]	N	↓	N	N	↓	N	N	↑	N	↑	N	N	N	↑	N	↑
VZ043[5]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VZ109[6]	↓	↓	↓	↑	N	↓	N	N	N	↑	↑↑	N	N	↑	N	↑
VZ045[5]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total:	1/5↓	4/5↓	3/5↓		4/5↓	2/4↓	2/5↓	2/5↓	2/5↓							
				2/5↑		1/4↑		1/5↑		3/4↑	3/4↑	1/5↑		4/5↑	5/5↑	
	4/5N	1/5N	2/5N	3/5N	1/5N	1/4N	3/5N	2/5N	3/5N	1/4N	1/4N	4/5N	5/5N	1/5N	5N	

Key:
- N = Normal
- ↓ = Moderate decrease
- ↓↓ = Marked decrease
- ±↓ = Marginal decrease
- ↑↑ = Marked increase
- ↑ = Moderate increase
- ±↑ = Marginal increase

---

[1] Emaciated, pregnant at presentation, started to abort, became lethargic and hypothermic, seizured, died 36 hours after admission.

[2] Fair condition at presentation, died within 24 hours after seizures and anorexia.

[3] Died within 24 hours, lethargic and hypothermic.

[4] Within 24 hours of presentation; lethargic, hypothermic, vomiting. Died at 36 hours in seizures.

[5] Omit

[6] Thin on presentation. Within 24 hours - diarrhea, anorexia, decreased appetite. Died within 4 days with tarry diarrhea, lethargy, terminal seizures.

Table 7.4: Principal laboratory and clinical findings in lightly oiled sea otters dying acutely (within 10 days of presentation) at rehabilitation centers.

OTTER#	HEMO CRIT	TOT WBC	NEUT PHIL	Bands	LYMP CYTE	GLUC	TOT PROT	ALBU	GLOB	UREA NITR	ALAN ATRA	ALK PHOS	NA	K	CL	P
VZ141[1]	↓↓	N	N	↑	±↓	↑	↓	N	N	↑↑	↑↑	↑↑	N	↑	N	↑
SW127[2]	N	N	N	N	↓	N	N	N	N	N	N	N	N	N	N	N
SW125[2]	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
SW135[2]	-	-	-	-	-	N	N	N	N	N	N	N	N	N	N	N
VZ106[3]	↓	↓	↓	↑	±↓	N	↓	±↓	±↓	↑↑	↑↑	↑	N	↑	N	↑
VZ011[1]	↓	↓	↓	↑	↓	↓	↓	±↓	±↓	↑	N	N	N	↑	N	↑
VZ081[4]	↓	N	N	↑↑	N	↓	N	N	N	↑↑	↑	N	N	↑	N	↑
VZ136[5]	↓	N	N	↑	N	↓	N	↓	N	↑	↑	N	N	↑	N	↑
SW120[6]	-	-	-	-	-	↓	↓	↓	±↓	↑	↑	N	N	↑	N	↑
Total:	5/7↓	2/7↓	2/7↓		4/7↓	4/9↓	4/9↓	4/9↓	3/9↓							
				5/7↑		1/9↑				6/9↑	5/9↑	2/9↑		6/9↑		6/9↑
	2/7N	5/7N	5/7N	2/7N	3/7N	4/9N	5/9N	5/9N	6/9N	3/9N	4/9N	7/9N	9N	3/9N	9/9N	3/9N

Key:
- N = Normal
- ↓ = Moderate decrease
- ↓↓ = Marked decrease
- ±↓ = Marginal decrease
- ↑↑ = Marked increase
- ↑ = Moderate increase
- ±↑ = Marginal increase

[1] Not available.
[2] Inadvertently killed at rehabilitation center through hyperthermia.
[3] Black "oily" stool, seizures within 24 hours, then died.
[4] Normal at presentation.
[5] Geriatric poor doer at presentation. From presentation diarrhea and dyspnea. Anorexia developed at one week and animal died.
[6] Nursing pup that nursed well for 8 days. Found on eighth day in shock with seizures.

TABLE 7.5

Summary by Group
(Heavily, Moderately or Lightly Oiled)
of
Principal Clinical and Laboratory Findings

	Shock	Convulsions	Anorexia	Lymphopenia	Leukopenia/ Increased Bands	Anemia	Azptemia	Hperkalemia	Hypoglycemia	Hepatocellular Leakage	Hypoproteinemia/ Hypoalbuminemia
Heavily Oiled	5/7	4/7	3/7	6/6	4/6	3/6	6/6	2/5	3/6	5/5	4/6
Moderately	4/5	4/5	2/5	4/5	2/5	1/5	3/4	4/5	2/5	3/4	2/5
Lightly Oiled	7/9	3/9	1/9	4/7	3/7*	5/7	6/9	6/9	3/9	5/9	4/9
TOTAL	16/21	11/21	6/21	14/18	9/18	9/18	15/19	12/19	8/20	13/18	10/20

Table 7.5

Summary by Group
(Heavily, Moderately or Lightly Oiled)
of
Principal Clinical and Laboratory Findings

	Shock	Convulsions	Anorexia	Lymphopenia	Leukopenia/ incr bands	Anemia	Azotemia	Hyperkalemia	Hypoglycemia	Hepatocellular leakage	Hypoproteinemia/ Hypoalbuminemia
Heavily Oiled	5/7	4/7	3/7	6/6	4/6	3/6	6/6	2/5	3/6	5/5	4/6
Moderately Oiled	4/5	4/5	2/5	4/5	2/5	1/5	3/4	4/5	2/5	3/4	2/5
Lightly Oiled	7/9	3/9	1/9	4/7	3/7*	5/7	6/9	6/9	3/9	5/9	4/9
Total	16/21	11/21	6/21	14/18	9/18	9/18	15/19	12/19	8/20	13/18	10/20

Histopathologic Lesions Associated with Crude Oil Exposure in Sea Otters

T. P. Lipscomb, R. K. Harris, R. B. Moeller, J. M. Pletcher,
R. J. Haebler, B. E. Ballachey

Department of Veterinary Pathology, Armed Forces Institute of Pathology,
Washington, DC; Ecosystems Branch, Environmental Protection Agency,
Narragansett, RI; Alaska Fish and Wildlife Research Center,
U. S. Fish and Wildlife Service, Anchorage, AK

Lesions in Oil Exposed Otters

Abstract. Following the Exxon Valdez oil spill in Prince William Sound, Alaska, sea otters (Enhydra lutris) that appeared oiled, were in danger of becoming oiled, or were behaving abnormally were captured and taken to rehabilitation centers. Oil exposure was assessed by visual examination on arrival at the centers. Tissues from 51 oiled sea otters and from 6 unoiled sea otters that died in rehabilitation centers were examined histologically. Pulmonary interstitial emphysema, gastric erosion and hemorrhage, centrilobular hepatic necrosis, and hepatic and renal lipidosis were common in oil exposed otters and were absent or uncommon in unoiled otters. Histologic examinations were performed on tissues from 5 sea otters found dead with external oil present shortly after the spill. Hepatic and renal lipidosis was common, and pulmonary interstitial emphysema was found. Necropsies were performed on 214 sea otters that had been collected and frozen in the period following the oil spill. Histologic examination was not performed. Pulmonary interstitial emphysema and gastric erosion and hemorrhage were common in animals with external oil present; these lesions were found much less frequently in animals without detectable external oil. Tissues from 6 apparently normal sea otters collected from an area not affected by the oil spill were examined histologically, and none of these lesions were found. We conclude that pulmonary interstitial emphysema, gastric erosion and hemorrhage, centrilobular hepatic necrosis, and hepatic and renal lipidosis were associated with exposure to crude oil in sea otters.

On March 23, 1989, the oil tanker Exxon Valdez ran aground on Bligh Reef in Prince William Sound, Alaska. The resulting spill of approximately 11 million gallons of North Slope crude oil was the largest in the history of the United States. In the months following the spill, over 1,000 sea otters from oil spill-affected areas are known to have died. The actual number dead was probably much greater. As part of an effort to determine the effects of the oil spill on sea otters, we examined tissues from otters that died in rehabilitation centers and that were found dead with and without external oil present. We also examined tissues from apparently normal sea otters from an area not contaminated by crude oil.

Materials And Methods

Following the oil spill, sea otters that appeared oiled, were in danger of becoming oiled, or were behaving abnormally were captured and taken to one of several rehabilitation centers. Oil exposure was assessed by visual examination on arrival at the centers. Degree of oiling was graded according to the following criteria: greater than 60% body coverage - heavily oiled; 30-60% body coverage - moderately oiled; less than 30% body coverage or light sheen on fur - lightly oiled. If there was no oil visible, otters were considered unoiled. Oiled otters that died in rehabilitation centers (Group 1), unoiled otters that died in rehabilitation centers (Group 2), and otters that were found dead with external oil present (Group 3) were necropsied by various veterinarians. This fact and the lack of a standard necropsy protocol during the first few weeks after the spill resulted in great variation in the tissues collected. Documentation of necropsy findings ranged from minimal to thorough. In some cases, no necropsy report was available. Only otters with documented oil-exposure assessment were included in this study. Otters that died in rehabilitation centers were collected from oil-contaminated areas of Prince William Sound from 30 March to 17 July 1989 and died between 3 April and 4 August 1989. Animals that were found dead and necropsied were collected from contaminated areas in early April 1989. During the summer of 1989, biologists collected tissues from 6 apparently healthy sea otters (Group 4) that had been killed by gunshot in the waters surrounding the Kuril Islands, Union of Soviet Socialist Republics, as part of unrelated research. Pups were not included in the study because of the small number available.

Tissues were placed in 10% neutral buffered formalin and processed in paraffin. Tissues collected included adrenal gland, aorta, bone marrow, brain, esophagus, eye, heart, intestine, kidney, liver, lung, lymph node, mammary gland, ovary, pancreas, parathyroid, pituitary gland, skeletal muscle, skin, spinal cord, spleen, stomach, testis, thymus, thyroid, tongue, tonsil, trachea, urinary bladder, and uterus. Tissues collected from individual animals varied. Sections were cut at 5um and stained with hematoxylin and eosin for light-microscopic examination. Selected sections were stained with oil red O.

In July and August 1990, complete necropsies were performed on 214 sea otters that had been collected from oil spill affected areas, placed in plastic bags, and frozen in the period following the spill (Group 5). Presence of external and internal oil was noted in the necropsy reports. Histologic examination was not performed because the tissue had been frozen.

Results

Data on individual Group 1, 2, and 3 otters are presented in Table 1. Numbers of Group 1, 2, and 3 otters of each gender with each of the common lesions are presented in Table 2.

In Group 1 sea otters, pulmonary interstitial emphysema was the most prevalent lesion, being present in 11 of 15 (73%) heavily oiled, 5 of 11 (45%) moderately oiled, and 3 of 20 (15%) lightly oiled animals. Overall, the lesion was present in 19 of 46 (41%) Group 1 otters. It was common in heavily and moderately oiled otters that died within 8 days of arrival at the rehabilitation centers, being present in 16 of 22 (73%) animals. Histologically, the lesion appeared as expanded areas of clear space with rounded contours within the interlobular septa (Fig. 1). Occasionally, adjacent parenchyma was compressed.

Gastric erosions were seen in 2 of 14 (14%) heavily oiled, 7 of 9 (78%) moderately oiled, and 4 of 17 (24%) lightly oiled Group 1 sea otters. Among total Group 1 otters, 13 of 40 (32%) had the lesion. Histologically, there were focal areas of coagulative necrosis, measuring 1 to 3 mm, affecting superficial to mid-level gastric mucosa (Fig. 2). Variable amounts of hemorrhage and blood pigments were present in the necrotic areas. Small numbers of neutrophils were sometimes scattered along the margins of the erosions.

Hepatic lipidosis was present in 8 of 16 (50%) heavily oiled, 5 of 12 (42%) moderately oiled, and 1 of 19 (5%) lightly oiled Group 1 otters. Among total Group 1 otters, 14 of 47 (30%) had the lesion. The prevalence of renal lipidosis was somewhat less than that of hepatic lipidosis. Overall, 10 of 42 (24%) Group 1 otters had renal lipidosis. All Group 1 animals with hepatic or renal lipidosis were female. All animals with renal lipidosis also had hepatic lipidosis. Several of the affected animals were pregnant or lactating, but several others were not. Both lesions were common in heavily and moderately oiled animals that died within 8 days of arrival at the centers (13 of 22 (59%) animals with hepatic lipidosis and 10 of 22 (45%) animals with renal lipidosis) and did not occur in animals that died later. The liver lesion was characterized by the presence of usually multiple but occasionally single, round, unstained intracytoplasmic vacuoles in periportal to midzonal hepatocytes (Fig.

3). Affected proximal convoluted tubular epithelium of the kidney contained similar intracytoplasmic vacuoles that were usually single (Fig. 4). In oil red O-stained sections of liver and kidney, the intracytoplasmic vacuoles stained red, indicating the presence of lipid.

Centrilobular hepatic necrosis occurred in 4 of 16 (25%) heavily oiled, 3 of 12 (25%) moderately oiled, and 4 of 19 (21%) lightly oiled Group 1 otters. Among all Group 1 otters, 11 of 47 (23%) were affected. In affected livers, centrilobular hepatocytes had undergone coagulative necrosis (Fig. 5). Among all Group 1 otters, multifocal hepatic necrosis was present in 6 of 47 (13%) and focally extensive hepatic necrosis suggestive of infarction was present in 4 of 47 (8%). Multifocal hepatic necrosis occurred in an animal that died on the first day in captivity and in animals that died after 3, 4, 5, 26, and 27 days. Focally extensive hepatic necrosis was found in animals that died after 4, 6, 8, and 27 days.

Of the 6 unoiled otters that died in rehabilitation centers (Group 2), one (17%) had gastric erosions, 1 (17%) had hepatic lipidosis and multifocal hepatic necrosis, and 1 (17%) had focally extensive hepatic necrosis.

Of the 5 sea otters found dead with external oil present (Group 3), 1 had pulmonary interstitial emphysema and hepatic and renal lipidosis, and 2 others had hepatic and renal lipidosis. One of the otters with hepatic and renal lipidosis was male and the other 2 were female.

Of the 6 apparently previously healthy sea otters collected from an area that had not been affected by an oil spill (Group 4), none had pulmonary interstitial emphysema, gastric erosions, hepatic or renal lipidosis, or hepatic necrosis. Four were male and 2 were nonpregnant, nonlactating females.

Two hundred fourteen sea otter carcasses that were collected, placed in plastic bags, and frozen in the period following the spill (Group 5) were thawed and necropsied. One hundred fifty-two (71%) had detectable external oil present, and 62 (21%) had no detectable oil present. Pulmonary interstitial emphysema was present in 100 of 152 (66%) otters with external oil present and in 13 of 62 (21%) otters with no detectable external oil. Interlobular septa of affected lungs were expanded by bubbles of trapped air that ranged from 1 mm to 3 cm in diameter. The emphysema was frequently diffuse and severe. In such cases, large amounts of adjacent pulmonary parenchyma were compressed. Extension of the air into the mediastinum was common, and involvement of the pericardium and the subcutis of the neck and thorax were occasionally found. Gastric erosions were present in 83 of 152 (55%) otters with external oil present and in 4 of 62 (6%) otters with no detectable external oil. The erosions generally were 1 to 3 mm punctate mucosal defects with dark red bases. Occasionally, erosions were linear and up to 1 cm in length. In some cases only a few erosions were present in the pylorus, but often erosions were numerous and were scattered throughout the gastric mucosa. Occasionally, similar erosions were present in the proximal duodenum. Accompanying hemorrhage was always present and varied from scant in animals with few erosions to abundant in animals with numerous erosions. Internal oil was found in 32 of 152 (21%) otters with external oil present and in 1 of 62 (2%) otters with no detectable external oil. The oil appeared as multiple, small, usually less than 3 mm diameter, black or brown flecks and was found on the tracheal, bronchial, esophageal, and gastric mucosae. Exposure of the oil to ultraviolet light in a darkened room caused the oil to glow and appear yellow to green. Blood did not glow or change color under these conditions. Specific liver and kidney lesions could not be confidently identified by gross examination.

Various incidental lesions were found infrequently in Groups 1, 2,3, and 5. Thyroid follicular ectasia was common in all groups examined histologically.

Discussion

Pulmonary interstitial emphysema was prevalent in oiled sea otters that died in rehabilitation centers and in sea otters with external oil present that were found dead, frozen, and later thawed and necropsied (Group 5). The incidence of the lesion correlated with degree of oiling in Group 1 otters. It was also present in 1 of 5 otters found dead with external oil present. Emphysema was not seen in unoiled otters that died in rehabilitation centers nor in apparently normal otters; however, it was present in several Group 5 otters that did not have detected external oil. Interstitial emphysema was diagnosed by others in many oiled sea otters presented to rehabilitation centers.[18] Although not recognized prior to the Exxon Valdez oil spill, it is clear that exposure to crude oil causes sea otters to develop emphysema. The pathogenesis of the lesion in this setting is unclear. Alveolar tears are the usual route by which air enters the pulmonary interstitium. Alveolar tears can occur when there is a combination of forced expiration or coughing and bronchiolar obstruction that produces sharply increased pressures within alveoli.[6,7] In anatomically predisposed species such as cattle the lesion may occur agonally, presumably due to forced expiration combined with bronchiolar collapse.[7] Pulmonary interstitial emphysema has been reported in sea otters with pneumonia [2,14] and has been seen rarely as a mild focal lesion in sea otters that died without evidence of respiratory disease or oil exposure (personal observation, TPL). Sea otters may have an anatomical predisposition to development of interstitial emphysema, but exposure to crude oil resulted in a remarkably high incidence of the lesion. During the early days of the spill, inhalation of volatile components of crude oil such as benzene might have damaged alveolar septa and caused the lesion, but neither interstitial pneumonia nor other lesions that might result from inhalation of an irritant vapor were found in affected sea otters. Aspiration of oil may have caused powerful forced expirations that could result in interstitial emphysema. Oiled sea otters attempt to remove oil by grooming,[15] which involves use of the mouth; this process provides ample opportunity for aspiration. However, aspiration pneumonia was not found. We speculate that sea otters may have a highly developed cough reflex that effectively prevents aspiration of oil into the lungs but promotes the development of interstitial emphysema. The Group 5 otters with emphysema and no detectable oil present may have successfully removed detectable oil prior to death, or the emphysema may have been caused by a different mechanism. Postmortem examination failed to indicate the cause of the emphysema in these otters.

Gastric erosions were common in oil-exposed sea otters that died in rehabilitation centers and in oil-exposed sea otters found dead and examined grossly but not histologically. They were also found in an unoiled otter that died in a center and in a few Group 5 otters with no detectable oil. An explanation for the relatively low frequency in heavily oiled Group 1 otters (Table 1) is not readily apparent. Only rarely was oil found in stomachs of otters with gastric erosions. Rapidly developing gastric erosions that appear following severe stress occur in humans and animals.[1,5] Gastrointestinal erosion/ulceration and hemorrhage have been reported in sea otters that died in captivity and in the wild and have been attributed to stress.[14,16] All of the gastric erosions seen in this study were acute; none showed signs of healing. Those present in otters that died shortly after arrival at the rehabilitation centers might have developed prior to capture because of stress associated with oil exposure, as a direct effect of oil on the gastric mucosa, or because of stress associated with capture and captivity. Erosions caused by ingestion of corrosive liquids are extensive[8], but the erosions we encountered were small and relatively uniform. Those seen in otters that died several days or more after arrival at the centers clearly developed in captivity.

Hepatic lipidosis was common in oiled otters that died in rehabilitation centers and in oiled otters that were found dead. The incidence of the lesion correlated with the degree of oiling. It was also seen in an unoiled otter that died in a rehabilitation center. Renal lipidosis was somewhat less common and occurred only in otters that also had hepatic lipidosis. All animals with hepatorenal lipidosis were female except for 1 oiled male that was found dead. When the oil spill occurred, many females were in late gestation or had recently pupped and were lactating. Hepatic lipidosis is known to have various causes including toxins, mobilization of stored fats due to inadequate food intake, hepatocellular hypoxia, certain metabolic disorders such as diabetes mellitus, and obesity.[11] Causes of renal lipidosis include toxins, hypoxia, and decreased food intake.[9,10] Studies of experimentally oiled otters report marked increases in activity and metabolic rate with unchanged or decreased time devoted to feeding.[3,15] Animals with high energy demands like those that occur during peak lactation or late gestation are predisposed to hepatic lipidosis.[13] Thus, hepatic and renal lipidosis may have been caused by an oil exposure-associated increase in energy demand with constant or decreased food intake resulting in mobilization of stored fat. Many of the affected otters were further predisposed because of high energy demands due to lactation or pregnancy. Hepatic lipidosis in pregnant and lactating females may have been "physiologic," as occurs in ruminants, although this phenomenon has not been reported in sea otters. A direct toxic effect is possible, but accompanying hepatic and renal necrosis was not regularly present, and it is unusual for toxins to preferentially affect one gender. The fatty liver of hepatocellular hypoxia primarily affects centrilobular hepatocytes,[11] but lipid accumulation in these otters was periportal to midzonal. The high incidence of lipidosis in otters that died during the first few days of captivity, its absence in otters that died after captivity day 8, its presence in 3 of 5 oiled otters that were found dead in the wild, and the absence of reports of lipidosis in otters that died in captivity suggest that captivity was not the cause of the lesion in our otters.

Centrilobular hepatic necrosis was also relatively common in oiled otters that died in rehabilitation centers and was not found in unoiled otters that died in the centers. Causes of centrilobular hepatic necrosis include toxins and conditions that cause hepatic ischemia, such as anemia, shock, and heart failure.[11] Some oiled otters became anemic while at rehabilitation centers.[19] Crude oil ingestion[12] and gastric erosion with hemorrhage are possible causes of anemia. However, gastric erosions and centrilobular hepatic necrosis were found in the same otter infrequently, so anemia due to gastric hemorrhage was not a common cause of centrilobular hepatic necrosis. It is likely that many otters experienced shock.[19] Shock might result from oil exposure or captivity, but centrilobular hepatic necrosis has not been reported previously in otters that died in captivity. Multifocal hepatic necrosis and focally extensive hepatic necrosis suggestive of infarcts occurred at low frequency in both oiled and unoiled sea otters that died in rehabilitation centers. The causes of these lesions were not found.

Sea otters are largely dependent on the insulating properties of their pelage for protection from the cold waters they inhabit. It had been suspected that hypothermia would be a major problem in oiled sea otters because oil markedly increases the thermal conductance of their coats.[17] Hypothermia was a common problem in oiled sea otters presented to rehabilitation centers.[18] Death caused by hypothermia can occur without distinctive gross or microscopic lesions.[4] It is likely that stress and shock were significant medical problems.[19] Both oil exposure and captivity are stressful to sea otters.[15,16] We believe that hypothermia, stress, shock, respiratory compromise associated with interstitial emphysema, hemorrhage from gastric erosions, and hepatic necrosis contributed to the deaths of oiled sea otters.

In summary, pulmonary interstitial emphysema, gastric erosion and hemorrhage, hepatic and renal lipidosis, and centrilobular hepatic necrosis were common in oiled sea otters that died in rehabilitation centers and were absent or uncommon in the small group of unoiled sea otters that died in rehabilitation centers. Pulmonary interstitial emphysema and gastric erosion and hemorrhage were prevalent in oiled sea otters that were examined grossly but not histologically; these lesions were found much less commonly in sea otters without detectable oil that were examined grossly but not histologically. None of these lesions were seen in apparently normal, unoiled sea otters and, with the exception of gastric erosion and hemorrhage, have not been previously reported in association with death in captivity. Additionally, pulmonary interstitial emphysema and hepatic and renal lipidosis were present in a small group of oiled sea otters that were found dead in the wild. Pathologic examination of larger numbers of both oiled and unoiled sea otters not held in captivity would be useful in separating lesions resulting from exposure to crude oil and those resulting from effects of captivity.

Acknowledgements

The authors thank D. Bruden and R. A. V. Ferris for technical assistance.

The opinions and assertions contained herein are those of the authors and are not to be construed as official or representing those of the Department of the Army or the Department of Defense.

MAJ T. P. Lipscomb, LTC R. B. Moeller, and COL J. M. Pletcher are members of the U. S. Army. LtCol Harris is a member of the U. S. Air Force.

Request reprints from MAJ T. P. Lipscomb, Department of Veterinary Pathology, Armed Forces Institute of Pathology, Washington, DC 20306-6000 (USA).

REFERENCES

1 Barker IK, Van Dreumel AA: The Alimentary System. In: Pathology of Domestic Animals, ed. Jubb KVF, Kennedy PC, Palmer N, 3rd ed., pp. 44-45. Academic Press, Orlando, 1985

2 Cornell LH, Osborn KG, Antrim JE, Simpson JG: Coccidioidomycosis in a California sea otter (Enhydra lutris). J Wildl Dis 15: 373-378, 1979

3 Costa DP, Kooyman GL: Oxygen consumption, thermoregulation, and the effect of fur oiling and washing on the sea otter, Enhydra lutris. Can J Zool 60: 2761-2767, 1982

4 Cotran RS, Kumar V, Robbins SL: Environmental Pathology. In: Robbins Pathologic Basis of Disease, 4th ed., p. 501. WB Saunders, Philadelphia, 1989

5 Cotran RS, Kumar V, Robbins SL: The Gastrointestinal Tract. In: Robbins Pathologic Basis of Disease, 4th ed., pp. 847-848. WB Saunders, Philadelphia, 1989

6 Cotran RS, Kumar V, Robbins SL: The Respiratory System. In: Robbins Pathologic Basis of Disease, 4th ed., pp. 771-772. WB Saunders, Philadelphia, 1989

7 Dungworth DL: The Respiratory System. In: Pathology of Domestic Animals, ed. Jubb KVF, Kennedy PC, Palmer N, 3rd ed., pp. 443-447. Academic Press, Orlando, 1985

8 Fenoglio-Preiser CM, Lantz PE, Davis M, Listrom MB, Rilke FO: Acute Corrosive Gastritis. In: Gastrointestinal Pathology, An Atlas and Text, pp. 252-255. Raven Press, New York, 1989

9 Jones TC, Hunt RD: Cellular Infiltrations and Degenerations. In: Veterinary Pathology, 4th ed., pp. 36-37. Lea and Fibiger, Philadelphia, 1983

10 Jones TC, Hunt RD: The Urinary System. In: Veterinary Pathology, 4th ed., pp. 1474-1475. Lea and Fibiger, Philadelphia, 1983

11 Kelly WR: The Liver and Biliary System. In: Pathology of Domestic Animals, ed. Jubb KVF, Kennedy PC, Palmer N, 3rd ed., pp. 253-255. Academic Press, Orlando, 1985

12 Leighton FA: Clinical, gross, and histologic findings in herring gulls and Atlantic puffins that ingested Prudhoe Bay crude oil. Vet Pathol 23: 255-263, 1986

13 Mac Lachlan NJ, Cullen JM: Liver, Biliary System, and Exocrine Pancreas. In: Special Veterinary Pathology, ed. Thomson RG, pp. 237-238. B C Decker, Toronto, 1988

14 Mattison JA, Hubbard RC: Autopsy findings on thirteen sea otters (Enhydra lutris nereis) with correlations with captive animal feeding and behavior. Proc 6th Ann Conf Sonar and Diving Mammals, pp. 99-101. Stanford Research Institute, Menlo Park, 1969

15 Siniff DB, Williams TD, Johnson AM, Garshelis DL: Experiments on the response of sea otters Enhydra lutris to oil contamination. Biol Conserv 23: 261-272, 1982

16 Stullken DE, Kirkpatrick CM: Physiological investigation of captivity mortality in sea otters (Enhydra lutris).Transac Twentieth N Amer Wildlife Conf, pp. 476-494. Wildlife Management Institute, Washington, DC, 1955

17 Williams TM, Kastelein RA, Davis RW, Thomas JA: The effects of oil contamination and cleaning on sea otters (Enhydra lutris). I. Thermoregulatory implications based on pelt studies. Can J Zool 66: 2776-2781, 1988

18 Williams TM, Wilson R, Tuomi P, Hunter L: Critical care and toxicologic evaluation of sea otters exposed to crude oil. In: Sea Otter Rehabilitation Program: 1989 Exxon Valdez Oil Spill, ed.

Williams TM, Davis RW, pp. 92-96. International Wildlife Research, 1990
19 Wilson RK, Tuomi P, Schroeder JP, Williams T: Clinical treatment and rehabilitation of oiled sea otters. In: Sea Otter Rehabilitation Program: 1989 Exxon Valdez Oil Spill, ed. Williams TM, Davis RW, pp. 106-111. International Wildlife Research, 1990

TABLE 1

GROUP 1 (oiled, died in center)

Otter Number	Gender	Arrival Date	Death Date	Days In Center	EMP	GE	HL	RL	CLHN
			Heavily Oiled						
1	F	7Apr	7Apr	<1	X	X	X		
2	F	4Apr	5Apr	1		X			
3	F	9Apr	10Apr	1	X		X	X	
4	F	6Apr	7Apr	1	X		X		
5	F	6Apr	7Apr	1					X
6	F	5Apr	8Apr	3	X		X	X	
7	F	31Mar	3Apr	3	X		X		
8	F	4Apr	7Apr	3	X				
9	F	19Apr	23Apr	4			X	X	
10	F	3Apr	7Apr	4	X				
11	F	5Apr	10Apr	5	X		X	X	
12	M	30Mar	5Apr	6	X				
13	M	2Apr	9Apr	7	X				X
14	F	1Apr	9Apr	8	X		X	X	X
15	M	1Apr	10Apr	9					
16	M	2Apr	28Jul	117					X
			Moderately Oiled						
17	F	9Apr	10Apr	1			X	X	
18	F	4Apr	5Apr	1	X		X	X	X
19	F	8Apr	9Apr	1	X	X	X	X	
20	F	7Apr	8Apr	1			X	X	
21	F	6Apr	8Apr	2	X		X	X	X
22	F	3Apr	6Apr	3	X	X			
23	M	9Apr	13Apr	4		X			
24	F	4Apr	9Apr	5		X			X
25	M	18Apr	29Apr	11					
26	F	5Apr	18Apr	13	X				
27	F	11May	24May	13		X			
28	M	5Apr	5May	30		X			
29	F	11May	24Jul	74		X			

EMP = emphysema
GE = gastric erosion
HL = hepatic lipidosis
RL = renal lipidosis
CLHN = centrilobular hepatic necrosis
F = female
M = male

TABLE 1 (cont.)

Otter Number	Gender	Arrival Date	Death Date	Days In Center	EMP	GE	HL	RL	CLHN
			Lightly Oiled						
30	F	20Apr	20Apr	<1					X
31	F	5Jun	5Jun	<1					
32	F	6Apr	7Apr	1					
33	F	5Jun	6Jun	1					
34	M	13Jun	14Jun	1		X			
35	F	9Apr	11Apr	2			X		
36	F	1Apr	4Apr	3					
37	F	4Apr	7Apr	3	X	X			
38	M	6Apr	12Apr	6	X				
39	F	10May	17MAy	7					
40	M	19Apr	27May	8					X
41	F	25May	4Jun	10		X			
42	M	20May	31May	11					
43	F	13Jun	27Jun	14					
44	F	8Apr	28Apr	20		X			X
45	M	8Apr	29Apr	21					
46	M	8Apr	1May	23					
47	M	6Apr	29Apr	23					
48	F	6Apr	30Apr	24	X				
49	F	10Apr	6May	26					X
50	F	11May	7Jun	27					
51	F	20May	19Jun	30					
		GROUP 2 (unoiled, died in center)							
52	F	29May	29May	<1					
53	M	13Apr	14Apr	1					
54	F	5Jul	6Jul	1			X		
55	M	25Jun	27Jun	2					
56	F	19Jun	3Jul	14					
57	M	17Jul	4Aug	18		X			
			Group 3 (found dead oiled)						
58	M								
59	M						X	X	
60	M								
61	F						X	X	
62	F				X		X	X	

TABLE 2

GROUP 1 (oiled, died in center)

Degree of Oiling	Gender	Emphysema	Gastric Erosion	Hepatic Lipidosis	Renal Lipidosis	Centrilobular Necrosis
HO	F 12	9(11)82%	2(10)20%	8(12) 67%	5(11) 45%	2(12)17%
HO	M 4	2 (4)50%	0 (4) 0%	0 (4) 0%	0 (2) 0%	2 (4)50%
HO	F&M 16	11(15)73%	2(14)14%	8(16) 50%	5(13) 38%	4(16)25%
MO	F 10	5 (8)62%	5 (6)83%	5 (9) 56%	5 (9) 56%	3 (9)33%
MO	M 3	0 (3) 0%	2 (3)67%	0 (3) 0%	0 (3) 0%	0 (3) 0%
MO	F&M 13	5(11)45%	7 (9)78%	5(12) 42%	5(12) 42%	3(12)25%
LO	F 15	2(14)14%	3(13)23%	1(12) 8%	0(12) 0%	3(12)25%
LO	M 7	1 (6)17%	1 (4)25%	0 (7) 0%	0 (5) 0%	1 (7)14%
LO	F&M 22	3(20)15%	4(17)24%	1(19) 5%	0(17) 0%	4(19)21%
			Group 1 Totals			
	F 37	16(33)48%	10(29)34%	14(33) 42%	10(32) 31%	8(33)24%
	M 14	3(13)23%	3(11)27%	0(14) 0%	0(10) 0%	3(14)21%
	F&M 51	19(46)41%	13(40)32%	14(47) 30%	10(42) 24%	11(47)23%
			GROUP 2 (unoiled, died in center)			
U	F 3	0 (3) 0%	0 (3) 0%	1(3) 33%	0(3) 0%	0 (3) 0%
U	M 3	0 (3) 0%	1 (3)33%	0(3) 0%	0(3) 0%	0 (3) 0%
U	F&M 6	0 (6) 0%	1 (6)17%	1(6) 17%	0(6) 0%	0 (6) 0%
			GROUP 3 (found dead oiled) Totals			
	F 2	1 (2)50%	0 (2) 0%	2(2)100%	2(2)100%	0 (2) 0%
	M 3	0 (3) 0%	0 (3) 0%	1(3) 33%	1(3) 33%	0 (3) 0%
	F&M 5	1 (5)20%	0 (5) 0%	3(5) 60%	3(5) 60%	0 (5) 0%

HO = heavily oiled
MO = moderately oiled
LO = lightly oiled
U = unoiled
F = female
M = male
F&M = female and male totaled
() = number available for comparison; all of the relevant tissues were not available from all otters.

Otter Number Key

Heavily Oiled

# in Paper	AFIP #	Rehab #
1	2270227	VZ094
2	2270216	VZ054
3	2269894	VZ111
4	2269849	VZ077
5	2269852	VZ078
6	2269884	VZ070
7	2269871	VZ006
8	2270212	VZ053
9	2269937	VZ135
10	2269882	VZ042
11	2269919	VZ059
12	2269867	VZ001
13	2270231	VZ035
14	2269868	VZ023
15	2269951	VZ013
16	2275590	VZ029

Moderately Oiled

# in Paper	AFIP #	Rehab #
17	2269892	VZ113
18	2269862	VZ049
19	2269895	VZ100
20	2270229	VZ085
21	2270233	VZ080
22	2269847	VZ043
23	2269949	VZ109
24	2269893	VZ045
25	2269920	VZ134
26	2269946	VZ060
27	2244498	SW076
28	2269927	VZ065
29	2244493	SW077

Lightly Oiled

# in Paper	AFIP #	Rehab #
30	2269933	VZ141
31	2244226	SW127
32	2270214	VZ075
33	2244228	SW125
34	2244233	SW135
35	2269888	VZ106
36	2269864	VZ011
37	2270209	VZ047
38	2269956	VZ081
39	2269914	SW050
40	2269913	VZ136
41	2244241	SW120

42	2244217	SW104
43	2244507	SW132
44	2269875	VZ102
45	2272018	VZ103
46	2269955	VZ099
47	2269923	VZ074
48	2269930	VZ079
49	2244497	SW115
50	2244224	SW067
51	2244227	SW103

Group 2

52	2272017	VZ156
53	2269924	VZ121
54	2243617	SW163
55	2244223	SW160
56	2242106	SW149
57	2244490	SW170

Group 3

58	2269855	VD123
59	2269877	VD093
60	2269857	VD110
61	2269859	VD112
62	2269874	VD097

DRAFT

Technical Report: Marine Mammals Study Number 6

Mortality of Sea Otter Weanlings in Eastern and Western Prince William Sound, Alaska, During the Winter of 1990-91

Lisa Mignon Rotterman and Charles Monnett

P. O. Box 1846
Cordova, Alaska 99574

In Cooperation With:

Prince William Sound Science Center
P.O.Box 705
Cordova, AK 99574

and

Alaska Fish and Wildlife Research Center
U. S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, AK 99503

August 1, 1991

DRAFT

SUMMARY

A total of sixty-four dependent sea otters (control n = 24; oil-spill treatment n = 40) were captured, examined, instrumented with radio-transmitters, and monitored in Prince William Sound between September 1990 and present as part of a group of interrelated studies aimed at assessing the impact of the *T/V Exxon Valdez* oil spill on sea otters in Prince William Sound, Alaska.

The peak of life history milestones such as birth, weaning, and mortality of young of the year may occur a month or more later in the southwestern (the oil spill area) than in the northeastern (the control area) portion of Prince William Sound. While the timing of instrumentation was similar for pups in the control and treatment areas, pups in the southwestern sound weighed significantly less at the time of capture than their counterparts in the northeastern sound. Subsequently, most pups in the northeastern sound became independent of their mothers in October, whereas mother-pup separation typically occurred in November and December in the oil spill area. Most mortality in the northeastern sound occurred during November and December of 1990, whereas most mortality in the southwestern sound occurred during January 1991.

Contingency chi-square analyses indicated that survival rates of weanlings over their first winter (analyses consider data until May 1, 1991) were significantly higher in the northeastern sound (the control) than in the southwestern Prince

William Sound (the oil spill region). This result was the same regardless of whether missing animals were assumed to be dead ($\chi^2 = 4.64$, 1 D.F., $p < 0.05$) or were eliminated from the analyses ($\chi^2 = 4.70$, 1 D.F., $p < 0.05$).

DRAFT

DRAFT

INTRODUCTION

On March 24, 1989, over 11 million gallons of crude oil were spilled in Prince William Sound, Alaska, due to the wreck of the *T/V Exxon Valdez*. The research discussed in this report was undertaken as part of Natural Resource Damage Assessment (NRDA) studies aimed at determining if the spill caused damage to the sea otter population(s) in the region, and, if so, the type, magnitude, and significance of the damage(s). The specific goal of this study was to test whether overwinter mortality rates were equivalent among weanling sea otters in southwestern and eastern areas of Prince William Sound. While this report is narrow in its focus on this question, this information is crucial to understanding the overall extent of damage to the sea otter population(s); to understanding whether the affected sea otter population(s) are in a recovery phase; to estimating the rate and pattern of recovery; and to formulating restoration and response policies for sea otters throughout their range.

OBJECTIVE

The specific objective of this study was originally defined in the corresponding statement of work as follows:

> To test ~~the hypothesis~~ that weanling survival at various age intervals is not different between oiled and unoiled areas at alpha = 0.20.

DRAFT

STUDY METHODOLOGY

Definitions

For consistency, the use of terms in this report follows that in previous Natural Resource Damage Assessment reports and study plans. Thus, "dependents" or "pups" are individuals accompanied by their mothers. For the purposes of this report, individuals were classified as "weanlings" when they were no longer accompanied by their mothers. This term is used only to make it comparable to previous NRDA sea otter literature. We have no information about the date at which individuals actually stopped nursing.

Status classifications are made based on consideration of data to May 1, 1991 (see below). Individuals classified as dead are known to be dead because their carcass or other remains were observed and, in some cases, recovered. "Missing" individuals are those whose radio signal cannot be detected by boat or aircraft radio searches within Prince William Sound or adjacent areas (see Monitoring section below). The classification of "alive" is based on visual observations of the individual.

The estimated weaning date is that date midway between the dates when the individual was last observed with its mother and when it was first observed to be independent. Estimated date of death is that date midway between the dates when the individual was last confirmed to be alive and when it was found dead.

DRAFT

Study Groups

Data from two groups of sea otters are compared: those captured as dependents in the fall of 1990 in the southwestern portion of Prince William Sound (sometimes referred to as the oil-spill area) and those captured as dependents in the fall of 1990 in eastern Prince William Sound during 1990 (i.e. the control area).

Capture and Examination

Sea otters were captured at night in tangle nets and during the daytime with dip nets using methods previously described (Monnett et al. 1991). In most cases when dependent pups were being instrumented, mother-pup pairs were captured together and the mother was held in a floating net-pen while the pup was instrumented. However, some pups were captured with hand-held dip nets and brought aboard a 25 foot Boston Whaler for instrumentation. In those cases, the mother remained free-swimming while instrumentation was completed. However, for the purposes of calculating "take" (as defined under the 1972 Marine Mammal Protection Act of the United States) both the mother and the pup are counted in all pairs in which at least one of the pair was harassed or captured.

Anesthetized sea otters were placed in a nylon mesh bag and weighed on a hanging scale to the nearest 0.5 pound. Total body length was measured to the nearest 0.5 inch with a nylon tape. The tape was placed upon a flat surface. The otter was placed on

DRAFT

its back and measured as it was stretched along the tape by two researchers.

Marking and Instrumentation

Following capture, otters were brought aboard various vessels for anesthesia, examination, tagging of the hind flippers, insertion of a transponder and instrumentation with implanted radio-transmitters following established protocols. Details of these protocols are found in Monnett (1988) and Monnett et al. (1991). Following completion of instrumentation, collection of biological samples, and other data collection procedures, otters were released near the site at which they were captured.

For this study, an individual was not considered to be suitable for instrumentation if: a) its weight was less than 18 lbs; b) it was in very poor physical condition; c) its mother was inattentive prior to injection of the anesthetic; d) its initial temperature was greater than 102°F and could not be stabilized; or e) it did not respond to the anesthetic.

Monitoring

Radio-instrumented sea otters were monitored by observers in aircraft and Boston Whaler skiffs. Aircraft and skiffs were equipped with right- and left-mounted Yagi antennas and programmable, scanning FM receivers. Aircraft were flown at variable height depending upon whether observers were attempting to locate radio signals or make visual observation on individual sea otters. An attempt was made to find and visually examine each otter at least biweekly. All areas of Prince William Sound have been searched thoroughly by aircraft for missing animals. Additionally, a radio search of the nearcoastal areas between Prince William Sound and Homer, Alaska (to the west) and to Controller Bay (to the southeast) was made by aircraft, specifically to search for the missing individuals in this study. Data were recorded directly on xeroxed topographical maps and in "Rite-in-the-Rain books" for later entry into Lotus 123 on personal computers.

DRAFT

Comparison of Overwinter Mortality of Weanlings

Contingency chi-square analyses were used to compare the frequencies of weanling sea otters known to be alive, those known to be dead, and those that were missing as of May 1, 1991 in the control and oil-spill areas (see definitions above). Thus, a categorical statistical model was employed (rather than Kaplan-Meier survival estimation procedure as described in the corresponding study plan) because, given the nature of the study subjects and the short duration of the study, the biologically meaningful comparisons were the survival frequencies of weanlings to a specific life-history milestone: through the end of their first winter. The cutoff date of May 1, 1991 was used based on previous (Monnett 1988) information indicating that human causes of mortality, especially death associated with gillnet fisheries, become important in the eastern sound, but probably not in the southwestern sound, shortly thereafter due to the initiation of fishing activity.

DRAFT

STUDY RESULTS AND DISCUSSION

Study Population and Monitoring

A total of 252 sea otters were captured or taken by harassment in Prince William Sound between 3 September 1990 and 15 October 1990 (Table 1). The locations of capture of instrumented sea otter pups are shown in Figure 1. Distribution of the date of instrumentation in the two general areas is shown in Figure 2. Twenty-four dependent pups in the eastern sound [16 males (67%) and 8 females (33%)]} and 40 pups in the oil spill area [25 males (60%) and 15 females (40%)] were instrumented with intraperitoneal radiotransmitters. Two individuals (one male and one female both from the eastern sound), whose deaths may have been related to capture/instrumentation activities, were excluded from all summaries and statistical comparisons (one was found dead with an infected incision, whereas the other individual died 2 weeks after instrumentation). A female pup in the southwestern sound that was still with its mother on May 1, 1991 (and hence, was not a weanling) was included in the comparison of body weight at the time of capture, and in summaries of the date of instrumentation, but eliminated from other comparisons. Her dependency length is much greater than those previously observed in Prince William Sound. Most importantly, since previous work (Monnett 1988) has shown that the probability of dying greatly increases after mother-pup separation, it would not be appropriate to include her in comparisons of outcome. Some pups that were last seen alive with their mothers were either dead at

DRAFT

the next observation or became missing. These pups were eliminated from the figure summarizing weaning date.

The sample size for this study differs markedly from that outlined in the study plan for this portion of the damage assessment research which called for the instrumentation of 100 pups split evenly between control and treatment areas. Too few radios were ordered to permit implantation of 100 pups.

Size at Capture, Timing of Weaning and Peak Mortality

There is some indication that in 1990-1991, the peaks of pupping, weaning, and weanling mortality may have occurred at least a month or two later in the oil-spill area than in the control region of Prince William Sound. However, at this time it cannot be ascertained whether these apparent differences in timing reflect normal differences, or whether the timing differences could be related to the spill.

The timing of instrumentation was similar for pups in the control and treatment areas (Figure 2). However, the mean body weight at capture of male and female dependent pups in the oil-spill treatment group was significantly less than that of pups in the control group [(MALES: west: X = 25.28, S.E. = 0.72, N = 25; east: X = 32.27, S.E. = 0.83, n = 15, t = 5.57, 38 D.F.., p < 0.001); FEMALES: west: X = 24.17, S.E. = 0.97, N = 15; east: X = 30.36, S.E. = 1.03, n = 7, t = 3.53, 20 D.F.., p < 0.003)]. These differences and unpublished data on the actual timing of pupping of instrumented adult females (Monnett and Rotterman, unpublished. data) indicate that the peak in pupping in 1990 was

DRAFT

later in southwestern Prince William Sound than in northeastern Prince William Sound, and thus, it is likely that the southwestern sound pups were younger at the time of capture. Dates of weaning tended to be a month to two months later in the oil-spill area than in the control region. At present it is not clear whether this later date of weaning is explained sufficiently by the temporal shift in pupping or whether dependency periods tended to be longer in the oil spill area. However, most pups in the northeastern sound became independent of their mothers in October, whereas mother-pup separation typically occurred in November and December in the oil spill area (Figure 2).

Since available data (Monnett and Rotterman, unpublished. data) suggest that mortality of large pups is very low (ie., while they are large but still with their mother), it is not surprising that with a shift in the peaks of weaning, the period of highest weanling mortality is also later. Most mortality in the northeastern sound occurred during November and December of 1990, whereas most mortality in the southwestern sound occurred during January 1991 (Figure 2).

Further effort needs to be focused on determining whether these apparent timing differences are persistent, whether the shifts in weaning and mortality dates are explained by a shift in the peak of pupping of the same magnitude, or whether they reflect longer dependency periods and/or differences in the length of survival after weaning. Integration of these data with

DRAFT

data from the reproductive behavior of instrumented adult females will be especially insightful in this regard.

Mortality Rate Comparisons

Contingency chi-square analyses indicated that survival rates of weanlings over their first winter (analyses consider data until May 1, 1991) were significantly higher in the northeastern sound (the control) than in the southwestern Prince William Sound (the oil spill region) (Table 2). This result was the same regardless of whether missing animals were assumed to be dead (X^2 = 4.64, 1 D.F., $p < 0.05$) or were eliminated from the analyses (X^2 = 4.70, 1 D.F., $p < 0.05$).

Figures 3 and 4 indicate the locations where the carcasses of instrumented weanlings were discovered.

As noted previously, the status of weanlings as of May 1, 1991 was compared because previous data (Monnett 1988) suggests that, after that time, fishing-related deaths are an important source of mortality to male weaning sea otters in eastern Prince William Sound. However, consideration of the current (as of July 15, 1991 status of the surviving weanlings does not alter the conclusions of this study. Between May 1 and July 15th, one individual in the eastern sound dropped out of the study due to radio failure and one additional weanling in the western sound became missing.

It is not the purpose nor the intent of this report to attempt to fully develop the significance of this difference in overwinter weanling survival to the larger question of damage to

DRAFT

sea otters from the *T/V Exxon Valdez* oil spill. Rather, the data presented here address a focussed and narrow objective: to test the hypothesis that overwintering mortality is similar between the defined control and oil-spill areas over the winter of 1990-1991. We reject that null hypothesis. Weanlings in the oil spill area died at higher frequency than did their control counterparts. A more complete interpretation of the significance of this finding to potential damage to the sea otter population(s) from the oil spill would be possible if integrated with existing data on: a) reproductive patterns of instrumented adult females (in order to determine the relationship between pupping peaks and weaning peaks); growth rates of pups in the eastern and western sound; movement patterns (to determine whether the putative mothers of the control group actually were less likely to have been exposed to crude oil from the spill than the mothers of pups caught in that region); data from the clinical exams of pups included in this study; data on the blood chemistry and hematology of pups and adult females; data on the kinds and levels of petroleum-derived hydrocarbon burdens of both adult females and pups caught in the control and oil-spill areas; and data from gross necropsies and histopathological examination of tissues of sea otters caught in Prince William Sound from September 1989 through present. However, data from future studies will be most useful with regards to understanding the effects of the oil spill if collected in conjunction with information on the outcomes of individuals rather than as

DRAFT

independent statistical analysis of data collected at unrelated locations and different times from the data on outcome.

DRAFT

LITERATURE CITED

Monnett, C. W. 1988. Patterns of movement, postnatal development and mortality of sea otters in Alaska. Ph. D. dissertation, University of Minnesota, Minneapolis, Minnesota.

Monnett, C., L. M. Rotterman and D. B. Siniff. 1991. Sex-related patterns of postnatal development of sea otters in Prince William Sound, Alaska. J. Mamm. 72:37-41.

ACKNOWLEDGEMENTS

For assistance with data collection we thank K. Balog, S. Bottoms, L. Larson, K. Modla, K. St. Jean, S. Schmidt, and C. Stack. K. Balog, J. Lietzau, S. Schmidt, and C. Stack assisted with data tabulation, entry, and editing. We thank R. Paulus and R. Norton for their contributions during capture activities. For veterinary assistance, we thank K. Hill. We are deeply grateful to the Alaska Department of Fish and Game in Cordova for generously providing office space and support. The Prince William Sound Science Center provided contract administration and office space. We thank the damage assessment reviewers and attorneys, especially B. Friedman, R. Garrott, D. Malins, R. Spies, and D. Siniff for their careful review, advice and support at various stages of this project. This project was funded through cooperative agreements between the U.S. Fish and Wildlife Service and the Prince William Sound Science Center and by the author's personal funds.

Table 1. Summary of Sea Otters Taken by Capture or Harrassment As Part of Capture Activities Between September 1, 1990 and October 15, 1990.

AREA	AGE/SEX CATEGORY	NUMBER TAKEN	NUMBER IMPLANTED
E PWS	Adult Male	8	0
	Adult Female (indep)	37	4
	Mother-Pup Pairs	106 (53 prs.)	24 pups
	Unknown	2	0
	Area Total	153	28
W PWS	Adult Male	2	0
	Adult Female (indep)	1	0
	Mother-Pup Pairs	96 (46 prs.)	40 pups
	Unknown	0	0
	Area Total	99	40
	Total Number of Pups	99	64
	Grand Total	252	68

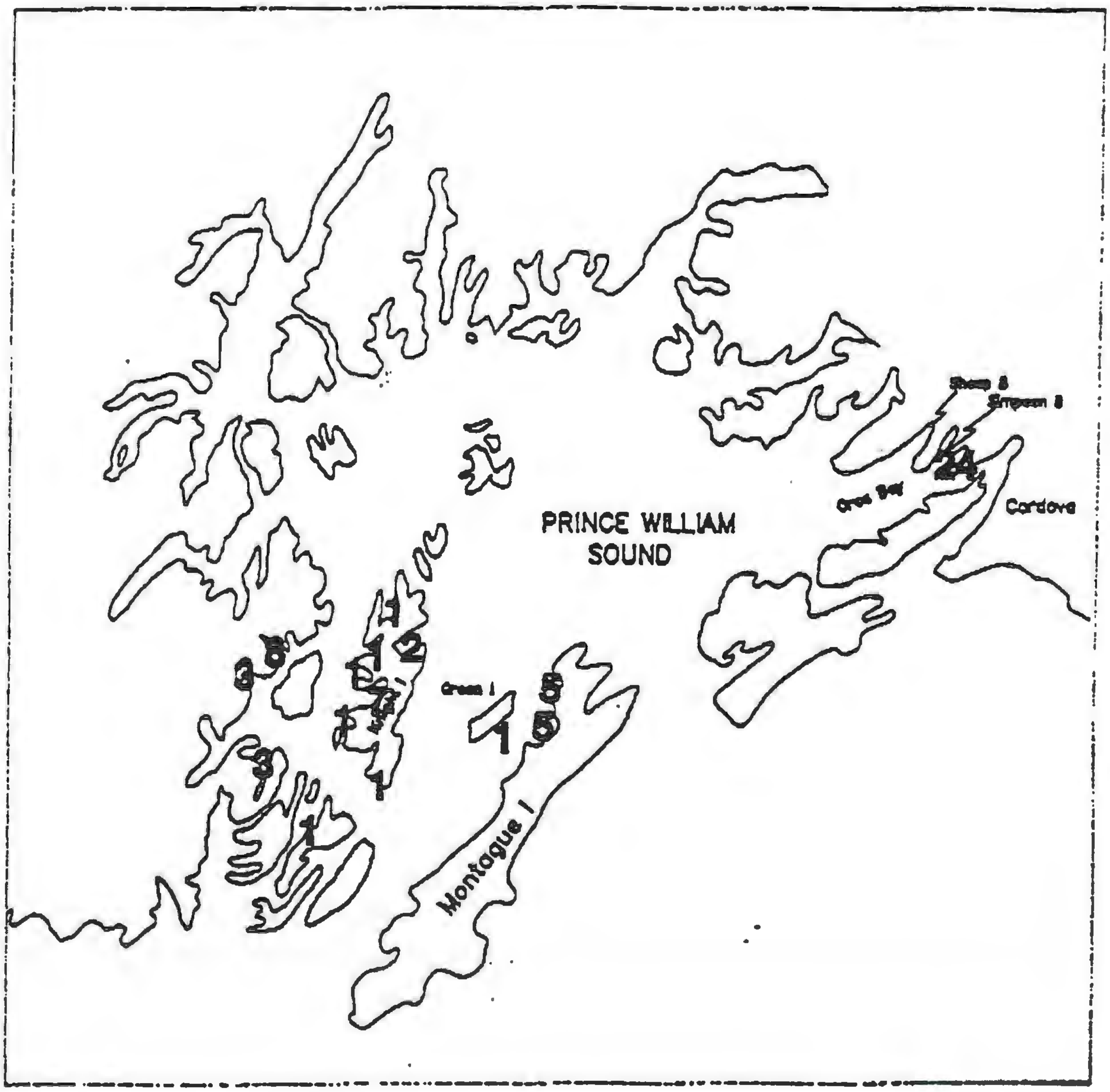
DRAFT

Table 2. Status of Radio-Instrumented Weanlings in Prince William Sound, Alaska, As of May 1, 1991. Two individuals whose death may have been related to capture/intrumentation activities were excluded from analyses, as was one pup that was still with its mother on May 1, 1991.

SEX	AREA	TOTAL	ALIVE	DEAD	MISSING
MALES	E PWS	15	5(.33)	8(.53)	2(.13)
	W PWS	25	2(.08)	17(.68)	6(.24)
FEMALES	E PWS	7	3(.43)	2(.29)	2(.29)
	W PWS	14	3(.21)	9(.64)	2(.14)
SEXES COMBINED	E PWS	22	8(.36)	10(.45)	4(.18)
	W PWS	39	5(.13)	26(.67)	8(.21)

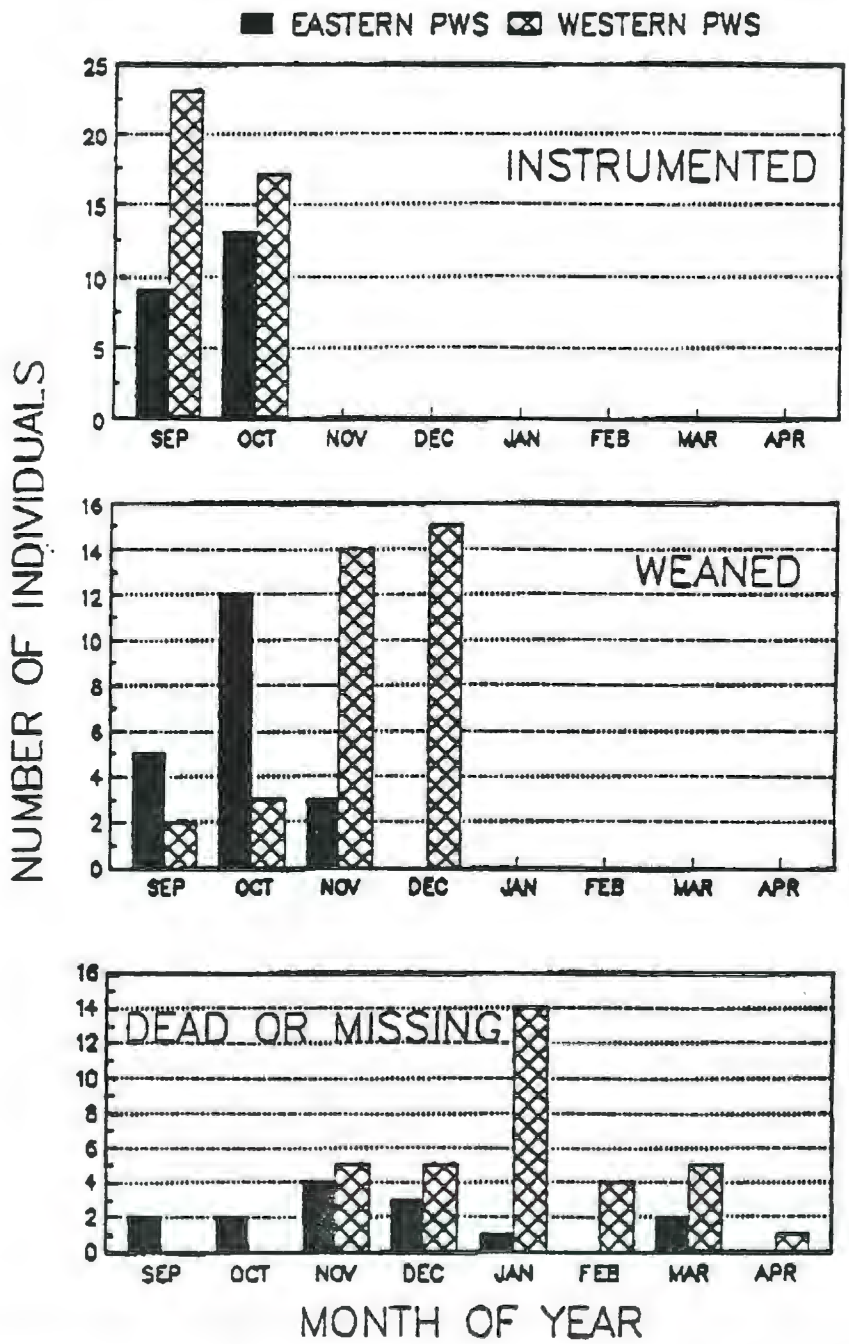
DRAFT

Figure 1. Capture locations of sea otter pups instrumented with implanted radio-transmitters during the fall, 1990, in Prince William Sound, Alaska. The numbers represent the number of individuals instrumented at each location.



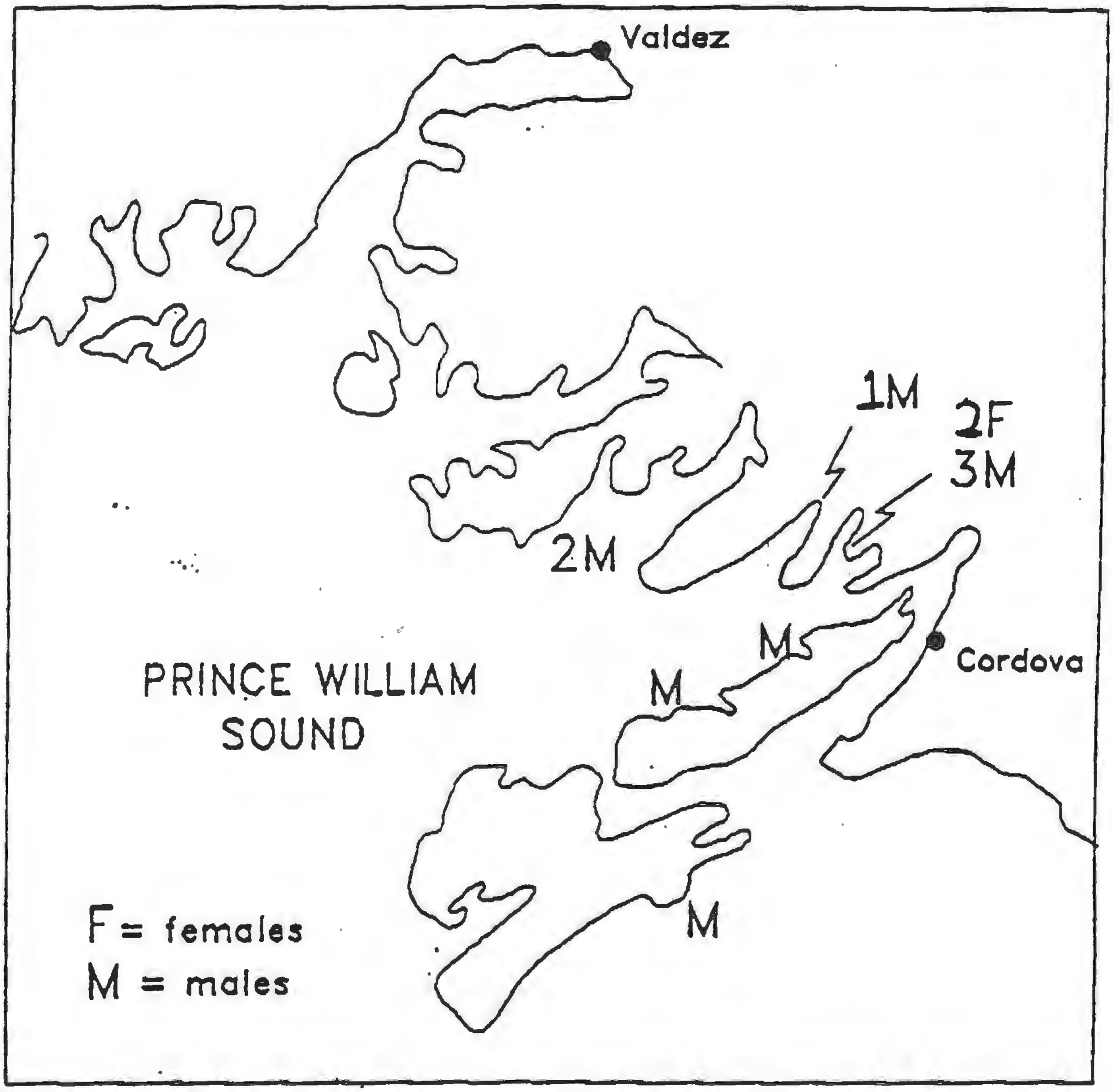
DRAFT

Figure 2. Summary of timing of instrumentation, weaning and mortality of sea otters in Prince William Sound, 1990-91.



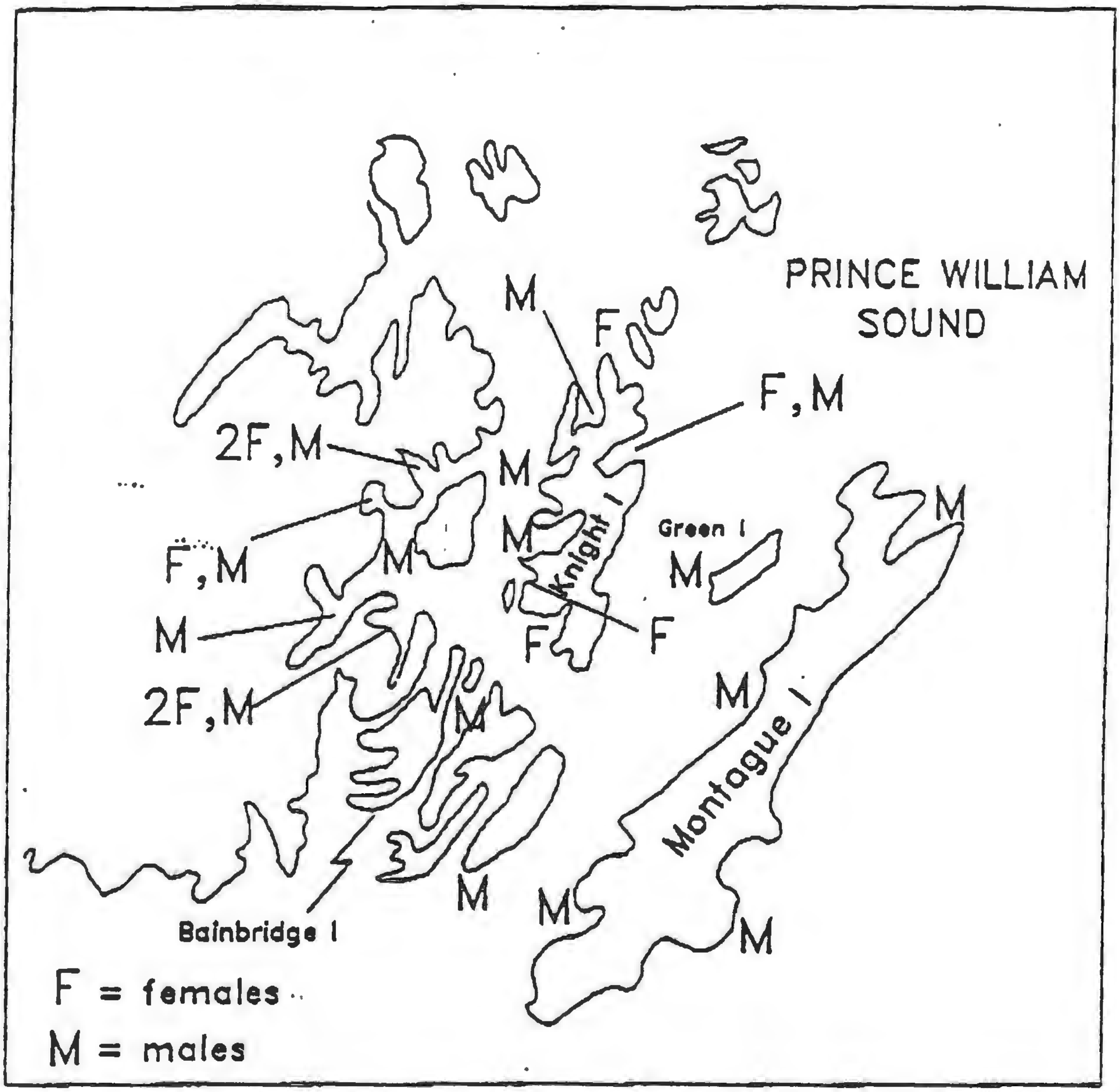
DRAFT

Figure 3. Locations at which remains of radio-instrumented weanling sea otters were recovered in Eastern Prince William Sound, Alaska, September 1990 - March 1991.



DRAFT

Figure 4. Locations at which remains of radio-instrumented weanling sea otters were recovered in Western Prince William Sound, Alaska, November 1990 - April 1991.



DRAFT

Technical Report: Marine Mammal Study Number 7

Mortality and Reproduction of Sea Otters Oiled and Treated as a Result of the Exxon Valdez Oil Spill

DRAFT

Charles Monnett and Lisa Mignon Rotterman

P. O. Box 1846

Cordova, Alaska 99574

In Cooperation with:

Prince William Sound Science Center

P.O.Box 705

Cordova, Alaska 99574

and

Alaska Fish and Wildlife Research Center

U. S. Fish and Wildlife Service

1011 E. Tudor Road

Anchorage, AK 99503

August 15, 1991

LITIGATION SENSITIVE
ATTORNEY/CLIENT WORK PRODUCT

DRAFT

SUMMARY

Radio-instrumented sea otters (N = 45) that were released into eastern Prince William Sound during summer, 1989, following efforts to rehabilitate them at otter treatment centers, have been monitored regularly for approximately 2 years. During this time, survivorship and pupping rates were generally lower than that of sea otters in other study populations.

INTRODUCTION

In response to the massive oil spill caused by the wreck of the *T/V Exxon Valdez*, a large number of sea otters (Enhydra lutris) were captured and brought into centers that were established in order to wash them, and to provide them with medical and other supportive treatment (e.g., see Williams et al. 1990). Many of the sea otters that survived such treatment were eventually released into wild populations in Prince William Sound and along the Kenai Peninsula. Of these survivors, forty-five were equipped with radio-transmitters and monitored during subsequent months. The goal of the study reported herein, was to provide data on the survival and reproduction of the radio-instrumented sea otters, and by doing so, to gain insights into both the damage done to the Prince William Sound sea otter population by that spill and into the efficacy of the "rehabilitation" strategy.

LITIGATION SENSITIVE
ATTORNEY/CLIENT WORK PRODUCT

DRAFT

OBJECTIVES

The specific objectives of this study were originally defined in the corresponding statement of work as follows:

1. To test the hypothesis that survival of sea otters that underwent oiling, cleaning, treatment and release is not different from that of sea otters that were not affected by the oil spill.

2. To test the hypothesis that reproductive rates of female sea otters that underwent oiling, cleaning and treatment does not differ significantly from that of female sea otters that were not affected by the oil spill.

METHODS

Definitions

Status classifications are made based on consideration of data through July 31, 1991. Individuals classified as "dead" are known to be dead because their carcass or other remains were observed and, in some cases, recovered. "Missing" individuals are those whose radio signal cannot be detected by boat or aircraft radio searches within Prince William Sound or adjacent areas along the Kenai Peninsula and Copper River Delta. The classification of "alive" is based upon visual observations of the individual.

Females were classified as having pupped based upon visual observations that they were accompanied by a pup.

Study Groups

Data from the treatment center otters were compared with concurrent data from otters that were captured in Prince William Sound.

Forty-five adult sea otters (28 females (TC FEMALES) and 17 males (TC MALES)) were selected as candidates for radio-instrumentation from individuals being held at the three treatment centers (see Haebler et al. 1990). Of these, 9 were captured in Prince William Sound, 34 along the Kenai Peninsula and 2 in the Kodiak Archipelago (Table 1). Capture/admission dates for this group were distributed: April = 17 otters; May = 21 otters; June = 5 otters; July = 2 otters.

The eastern Prince William Sound grouping (EPWS FEMALES) consisted of 44 females that were instrumented during 1987, 22 females that were instrumented during 1989 and 23 females that were instrumented during 1990. The western Prince William Sound grouping (WPWS FEMALES) consisted of 9 females instrumented during 1989 and 42 females instrumented during 1990. The EPWS FEMALES and WPWS FEMALES groupings were combined into the ALL FEMALES grouping.

Data on survival were separated temporally into two groupings relative to the release of the otters from the treatment centers: year one (August 1989 - July 1990) and year two (August 1990 - July 1991). Survival analysis was completed on both temporal groupings. Analysis of pupping rates was completed on only the 1990 data set because the 1991 pupping season is still underway.

Instrumentation and Monitoring

Individuals in this study were anesthetized and radio-transmitters were surgically implanted in their peritoneal cavities (Garshelis and Siniff 1983; DeGange and Williams 1990). After a recovery period, individuals from the treatment centers were released in eastern Prince William Sound during July and August, 1989. Sea otters in the EPWS FEMALE and WPWS FEMALE study groupings were released at the location of capture immediately after recovering from their anesthesia. An attempt was made to locate each individual at least once each week, using aircraft or boats equipped with Yagi antennas. Additional methodological details are provided in Monnett et al. (1990).

Analyses

Probabilities of survival and 95% confidence intervals (CI's) are calculated using Pollock et al.'s (1989) staggered entry modification to the Kaplan and Meier (1958) product limit procedure. Differences in the probability of survival between study groups are tested using the procedure described by Cox and Oakes (1984; see also Pollock et al. (1989) and White and Garrott (1990)). Contingency Chi-squared analyses were used to test for differences in pupping rates between study groupings. Differences were judged to be significant if the probability of type II error was < 0.05.

LITIGATION SENSITIVE
ATTORNEY/CLIENT WORK PRODUCT

DRAFT

RESULTS AND DISCUSSION

Results of this study through spring 1990 have been previously reported (see Appendix II).

Survival rates

Of the 45 sea otters from the treatment centers that were instrumented and released, as of 31 July 1991, 14 were known dead, 16 were missing and presumed to have died, 1 radio-transmitter had malfunctioned prematurely. Fourteen individuals were alive and being monitored. Locations of the last radio-locations of dead and missing sea otters from the treatment centers are shown in Figure 1. Last locations of live sea otters from the treatment centers are shown in igure 2. Data on the fates of sea otters by groupings used in the llowing analyses are summarized in Table 2 and Table 3.

No differences were found between the survival rates of male and ale sea otters from the treatment centers for either year of the ly; Year 1 probability survival: males = 0.401, females = 0.445, X^2 02, 1 DF, N.S.; Year 2 probability survival: males = 0.714, les = 0.692, X^2 = 0.003, 1 DF, N.S. (Table 4).

Male treatment center otters were not included in further ral analysis due to lack of sufficient sample sizes and lack of ically appropriate groups for comparison.

r year-one, female sea otters from the treatment centers ed lower survival rates than female sea otters from groupings ALES (missing individuals were assumed to be dead: X^2 = 13.82, < 0.001; missing individuals were excluded: X^2 = 8.36, 1 DF, p

< 0.01) and ALL FEMALES (missing individuals were assumed to be dead: $X^2 = 12.97$, 1 DF, $p < 0.001$; missing individuals were excluded: $X^2 = 6.88$, 1 DF, $p < 0.02$) (Table 4). Insufficient females were available in the WPWS FEMALES grouping to warrant inclusion in analysis for year-one.

For year-two, probability of survival was not significantly different between female sea otters from the treatment centers and female sea otters in the EPWS FEMALES and ALL FEMALES groupings. However, the females in the WPWS FEMALES did exhibit a higher survival rate than females released from the treatment center during year-two when missing individuals were assumed to have died (missing individuals were assumed to be dead: $X^2 = 5.93$, 1 DF, $p < 0.02$; missing individuals were excluded: $X^2 = 1.03$, 1 DF, N.S.) (Table 4).

We suggest that the lack of difference in survival rates between the TC FEMALES grouping and the EPWS FEMALES grouping (probability survival, missing individuals assumed to be dead: TC FEMALES = 0.692 cf. EPWS FEMALES = 0.648) should not be construed to indicate that treatment center females are exhibiting a "normal" rate of survival. Either value is abnormally low for prime-aged sea otter females (cf. probability survival year-two, WPWS FEMALES = 0.934, missing individuals assumed to be dead; and year-one values Table 4). The question of the unusually low survival rates for females in eastern Prince William Sound will be treated in a future technical report on the survival of non-treatment center sea otters.

Summaries of survival data, rates and confidence intervals for various groupings are given in tabular form in Appendix 3.

DRAFT

Pupping

Three females that were resident near the western end of the Kenai Peninsula were not included in the analysis of pupping rates because monitoring was infrequent and unreliable during the summer of 1990 (see Appendix I).

None of the 28 females released from the treatment centers pupped following release during the summer or fall, 1989. Fourteen of the 28 females survived through the summer of 1990; 11 were monitored adequately for data to be included in analysis (Kenai otters excluded as explained above). Based upon body size, all 11 were mature individuals and should have been capable of pupping during 1990. However, only 2 of the females pupped. The proportion of females released from the treatment centers that pupped was lower than the proportions of females pupping during 1990 in both the EPWS FEMALES grouping ($X^2 = 3.29$ 1 DF, $P < 0.08$) and the WPWS FEMALES grouping ($X^2 = 6.19$ 1 DF, $P < 0.02$). However, the former comparison was not significant by the criteria established in the methods section (ie. $p < 0.05$). Reproduction by instrumented females released from the treatment centers is summarized in Table 6.

DRAFT

REFERENCES CITED

Cox, D. R. and D. Oakes. 1984. Analysis of Survival Data. Chapman & Hall, New York. 201pp.

DeGange, A. R. and T. D. Williams. 1990. Procedures and rationale for marking sea otters captured and treated during the response to the Exxon Valdez oil spill. Pp. 394-399 in Bayha, K. and J. Kormendy, Technical Coordinators. Sea Otter Symposium. U. S. Fish and Wildlife Service, Biological Report 90(12) 485 pp.

Garshelis, D. L. and D. B. Siniff. 1983. Evaluation of radio-transmitter attachments for sea otters. Wildlife Society Bulletin 11:378-383.

Kaplan, E. L. and P. Meier. 1958. Nonparametric estimation from incomplete observations. J. Am. Stat. Assoc. 53:457-481.

Haebler, R. J.; R. K. Wilson and C. R. McCormick. 1990. Determining the health of rehabilitated sea otters before release. Pp. 375-384 in Bayha, K. and J. Kormendy, Technical Coordinators. Sea Otter Symposium. U. S. Fish and Wildlife Service, Biological Report 90(12) 485 pp.

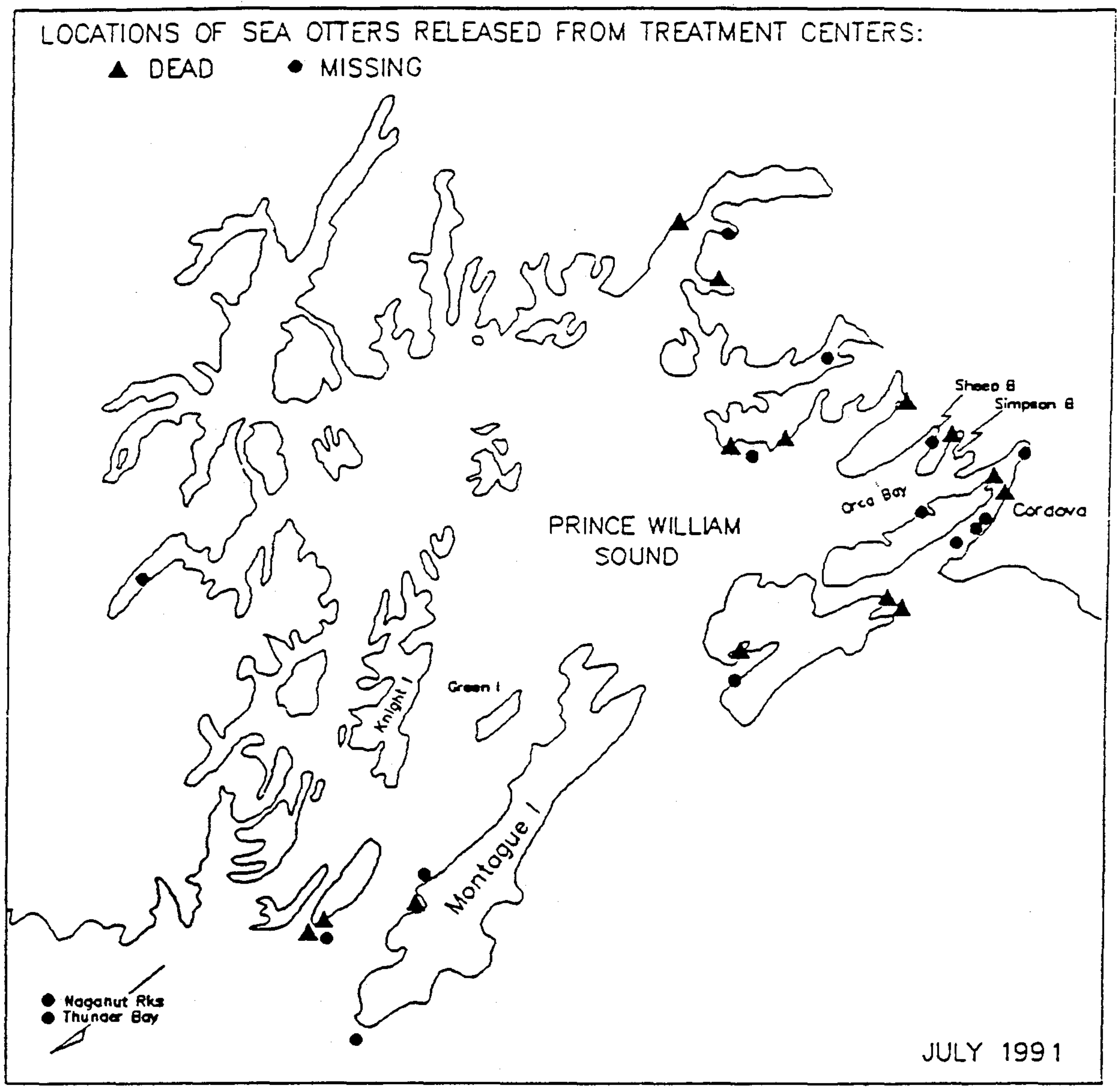
Monnett, C., L. M. Rotterman, C. Stack and D. Monson. 1990. Post-release monitoring of radio-instrumented sea otters in Prince William Sound. Pp. 400-420 in Bayha, K. and J. Kormendy, Technical Coordinators. Sea Otter Symposium. U. S. Fish and Wildlife Service, Biological Report 90(12) 485 pp.

Pollock, K. H.; Winterstein, S. R. ; Bunck, C. M. and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. J. Wildlife Management 53: 7-15.

White, G. C. and R. A. Garrott. 1990. Analysis of Wildlife Radio-Tracking Data. Academic Press. New York. 383 pp.

Williams, T. M., J. McBain, R. Wilson, and R. Davis. 1990. Clinical evaluation and cleaning of sea otters impacted by the oil spill. Pp. 236-257 in Bayha, K. and J. Kormendy, Technical Coordinators. Sea Otter Symposium. U. S. Fish and Wildlife Service, Biological Report 90(12) 485 pp.

Figure 1. Locations of last radio-telemetry fixes of dead and missing instrumented sea otters released from otter treatment centers during summer, 1989.



DRAFT

Figure 2. Summary of recent locations of sea otters released from otter treatment centers during 1989.

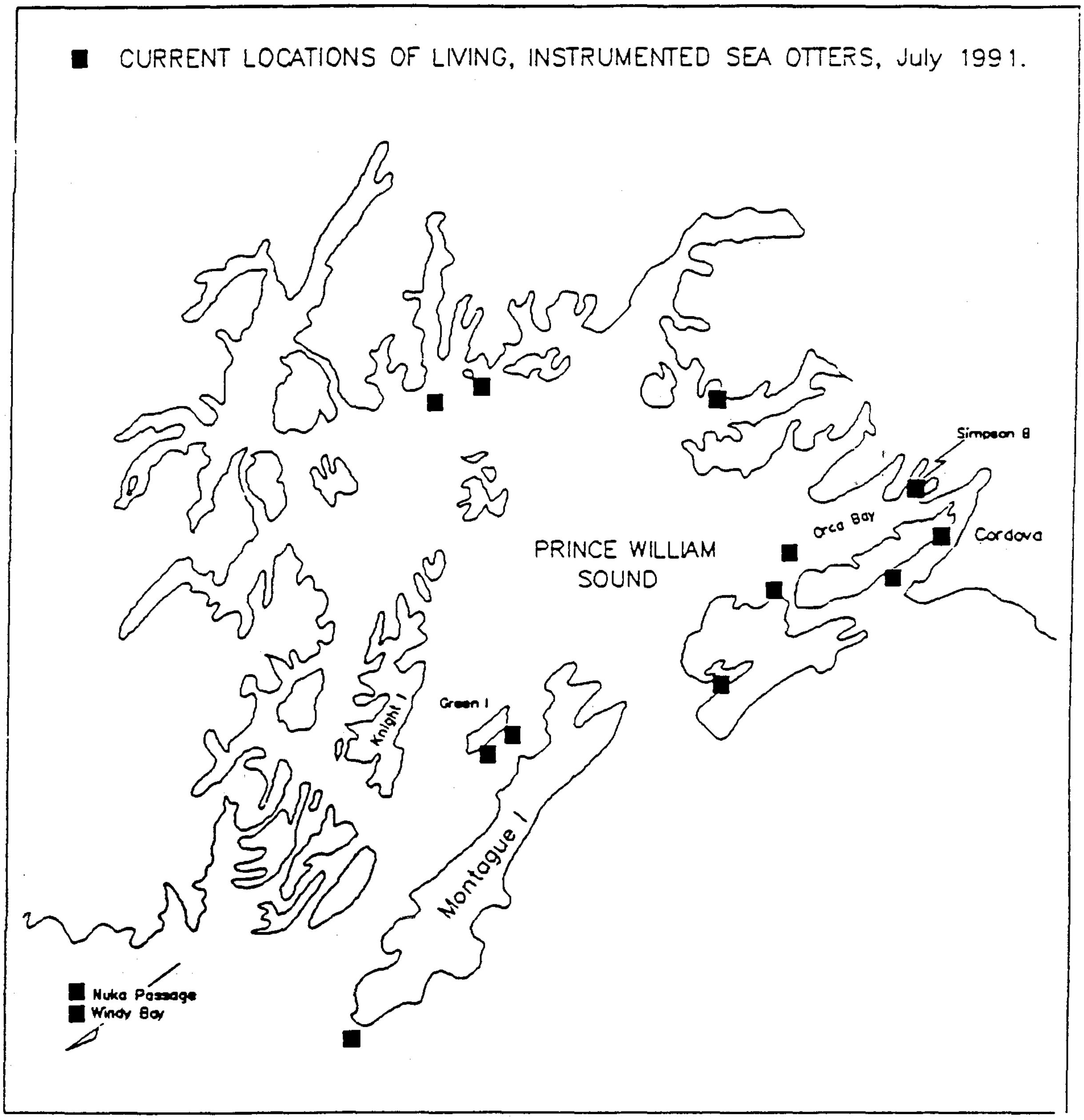


TABLE 1. INDENTIFICATION AND STATUS INFORMATION OF SEA OTTERS FROM TREATMENT CENTER.

TREATMENT CENTER ID	SEX	CAPTURE LOCATION	TREATMENT CENTER	DATE IMPLANTED	DATE RELEASED	CURRENT STATUS	DATE LAST SEEN	LOCATION LAST SEEN	TOTAL DAYS OBSERVED
S-002	f	Tonsina B	Valdez(Sew)	17-Jul-89	26-Jul-89	alive	05-Apr-91	Nuka Passage	618
S-124	f	Rocky B, KP	Seward	04-Aug-89	15-Aug-89	missing	26-May-90	Cape Cleare	284
S-069	f	Rocky B, KP	Jakolof	11-Aug-89	22-Aug-89	alive	27-Jul-91	Fairmont I	704
S-162	f	Long I,Tonsina	Seward	04-Aug-89	15-Aug-89	missing	22-Sep-89	Windy B.,Hawk.I	38
V-123	m	Natoa I	Valdez	17-Jul-89	26-Jul-89	dead	31-Mar-90	s.Latouche I	248
S-015	f	Bootleg B	Valdez(Sew)	17-Jul-89	26-Jul-89	missing	17-Oct-89	Port Fidalgo	83
S-157	f	Rocky B, KP	Seward	04-Aug-89	15-Aug-89	missing	04-Oct-89	Orca Inlet	50
S-068	f	Rocky B, KP	Valdez(Sew)	17-Jul-89	26-Jul-89	TXfailure	01-Sep-89	Deep B	37
V-048	m	Flemming I	Valdez(Sew)	17-Jul-89	26-Jul-89	dead	12-May-90	Strawberry Hill	290
V-139	m	Crab B, Evans	Valdez	17-Jul-89	26-Jul-89	alive	26-Jul-91	Makarka Pt	730
V-104	m	Ikuta B	Valdez	17-Jul-89	26-Jul-89	dead	17-Apr-90	s.Valdez	265
S-045	f	Picnic Hbr.	Valdez(Sew)	17-Jul-89	26-Jul-89	alive	05-Apr-91	Windy B	618
S-060	f	Windy B	Seward	11-Aug-89	22-Aug-89	dead	04-Mar-90	s.Latouche I	194
S-152	m	Rocky R, entr.	Seward	11-Aug-89	22-Aug-89	missing	18-Sep-89	Kings B	27
S-161	f	Long I,Tonsina	Seward	04-Aug-89	15-Aug-89	alive	27-Jul-91	Olsen Is	711
S-038	m	Windy B	Jakolof	11-Aug-89	22-Aug-89	dead	26-Jan-90	Cordova Channel	157
V-130	m	Natoa I	Valdez	17-Jul-89	26-Jul-89	missing	02-Jun-90	Orca Inlet	311
S-003	f	Tonsina B	Jakolof	11-Aug-89	22-Aug-89	dead	22-Feb-90	n.Simpson B	184
V-138	m	Crab B, Evans	Valdez	17-Jul-89	26-Jul-89	missing	03-Feb-90	Danger I	192
S-080	f	Rocky B, KP	Jakolof	11-Aug-89	22-Aug-89	dead	10-Feb-90	Boswell Rock	172
S-054	f	Windy B	Jakolof	11-Aug-89	22-Aug-89	dead	20-Jan-90	Constantine Hbr	151
V-029	m	Green I	Valdez	17-Jul-89	26-Jul-89	alive	23-Jul-91	Channel I	727
S-006	f	Tonsina B	Jakolof	11-Aug-89	22-Aug-89	missing	30-Jul-90	sw.Montague I	342
S-122	m	Kupreanof St.	Jakolof	11-Aug-89	22-Aug-89	missing	22-Aug-89	Nelson B	0
V-145	f	Tonsina B	Valdez	13-Jul-89	26-Jul-89	missing	13-Oct-90	Port Etches	444
S-114	f	Uyak B,Kodiak	Jakolof	11-Aug-89	22-Aug-89	missing	04-Jan-90	Jack B	135
S-044	m	Taylor B	Jakolof	11-Aug-89	22-Aug-89	dead	22-Feb-90	Beartrap B	184
S-057	f	so.B.Natoa I	Jakolof	11-Aug-89	22-Aug-89	missing	16-Dec-89	Sheep B	116
S-043	f	Taylor B	Seward	15-Jul-89	22-Aug-89	dead	17-Apr-90	Galena B	238
V-152	m	Berger B, KP	Valdez	17-Jul-89	26-Jul-89	dead	20-Aug-90	Deep B	390
S-007	f	Tonsina B	Jakolof	11-Aug-89	22-Aug-89	missing	28-Feb-91	Nagahut, Kenai	555
S-053	f	Windy B	Jakolof	11-Aug-89	22-Aug-89	missing	03-Feb-90	Thunder B	165
S-155	f	Rocky B, KP	Seward	04-Aug-89	15-Aug-89	missing	18-Jul-91	Red Head	702
S-017	f	Bootleg B	Valdez(Sew)	14-Jul-89	26-Jul-89	alive/pup	07-Aug-91	Constantine	742
S-146	f	Windy B	Seward	04-Aug-89	15-Aug-89	alive/pup	26-Jul-91	Yelper C	710
S-059	f	Windy B	Valdez(Sew)	14-Jul-89	26-Jul-89	alive	05-Aug-91	Green I	740
V-062	m	Hogan B,Knight I	Valdez(Sew)	17-Jul-89	26-Jul-89	alive	04-Aug-91	Mummy I	739
S-035	f	Windy B	Valdez(Sew)	17-Jul-89	26-Jul-89	dead	12-May-91	Hanning B	655
V-137	m	Crab B, Evans	Valdez	13-Jul-89	26-Jul-89	dead	31-Jan-90	Knowles Head	189
S-128	f	Rocky B, KP	Seward	04-Aug-89	15-Aug-89	dead	26-Aug-89	Hells Hole	11
V-150	f	Tonsina B	Valdez	13-Jul-89	15-Aug-89	alive	08-Aug-91	e.Simpson B	723
V-146	m	Hardover P,NukaB	Valdez	13-Jul-89	26-Jul-89	alive	02-Aug-91	Cape Cleare	737
V-068	f	Herring B	Valdez	13-Jul-89	26-Jul-89	alive	27-Jul-91	Boulder B	731
V-140	m	Crab B, Evans	Valdez	13-Jul-89	26-Jul-89	alive	09-Aug-91	Mud B	744
V-148	m	Bainbridge	Valdez	14-Jul-89	15-Aug-89	missing	26-Nov-90	Orca Inlet	468

Table 2a. Summary of the fates of female sea otters radio instrumented and released from the sea otter treatment centers.

Month	# at Risk	# Dead	# Missing	Tx Expired	# Added
Jul 89	0	0	0	0	9
Aug 89	9	1	0	0	19
Sep 89	27	0	1	1	0
Oct 89	25	0	2	0	0
Nov 89	23	0	0	0	0
Dec 89	23	0	1	0	0
Jan 90	22	1	1	0	0
Feb 90	20	2	1	0	0
Mar 90	17	1	0	0	0
Apr 90	16	1	0	0	0
May 90	15	0	1	0	0
Jun 90	14	0	0	0	0
Jul 90	14	0	1	0	0
Aug 90	13	0	0	0	0
Sep 90	13	0	0	0	0
Oct 90	13	0	0	0	0
Nov 90	13	0	1	0	0
Dec 90	12	0	0	0	0
Jan 91	12	0	0	0	0
Feb 91	12	0	1	0	0
Mar 91	11	0	0	0	0
Apr 91	11	0	0	0	0
May 91	11	1	0	0	0
Jun 91	10	0	0	0	0
Jul 91	10	0	1	0	0
Aug 91	9				

LITIGATION SENSITIVE
ATTORNEY/CLIENT WORK PRODUCT

Table 2b. Summary of the fates of male sea otters radio instrumented and released from the sea otter treatment centers.

Month	# at Risk	# Dead	# Missing	Tx Expired	# Added
Jul 89	0	0	0	0	12
Aug 89	12	0	1	0	5
Sep 89	16	0	1	0	0
Oct 89	15	0	0	0	0
Nov 89	15	0	0	0	0
Dec 89	15	0	0	0	0
Jan 90	15	2	0	0	0
Feb 90	13	1	1	0	0
Mar 90	11	1	0	0	0
Apr 90	10	1	0	0	0
May 90	9	1	0	0	0
Jun 90	8	0	1	0	0
Jul 90	7	0	0	0	0
Aug 90	7	1	0	0	0
Sep 90	6	0	0	0	0
Oct 90	6	0	0	0	0
Nov 90	6	0	0	0	0
Dec 90	6	0	1	0	0
Jan 91	5	0	0	0	0
Feb 91	5	0	0	0	0
Mar 91	5	0	0	0	0
Apr 91	5	0	0	0	0
May 91	5	0	0	0	0
Jun 91	5	0	0	0	0
Jul 91	5	0	0	0	0
Aug 91	5				

DRAFT

Table 3. Summary of the fates of radio-instrumented sea otters in study groupings used in survival analysis for comparison with sea otters released from sea otter treatment centers.

	1987 Study EPWS Females					1987 Study EPWS Males					1989-90 EPWS Females					1989-90 WPWS Females					1989-90 WPWS Males				
Month	R[1]	D	M	E	A	R	D	M	E	A	R	D	M	E	A	R	D	M	E	A	R	D	M	E	A
Jul 89	39	1	0	0	0	12	0	0	0	0															
Aug 89	38	1	1	0	0	12	3	0	0	0															
Sep 89	36	0	0	0	0	9	0	1	0	0															
Oct 89	36	0	0	0	0	8	0	0	0	0					22										
Nov 89	36	1	0	1	0	8	0	0	0	0	22	0	0	0	0					8					2
Dec 89	34	0	1	1	0	8	0	1	0	0	22	0	2	0	0	8	0	0	0	0	2	0	0	0	0
Jan 90	32	0	1	0	0	7	1	0	0	0	20	0	0	0	0	8	0	0	0	0	2	0	0	0	0
Feb 90	31	0	0	2	0	6	1	1	0	0	20	0	0	0	0	8	0	0	0	0	2	0	0	0	0
Mar 90	29	0	0	1	0	4	1	0	0	0	20	1	0	0	14	8	0	0	0	0	2	0	0	0	0
Apr 90	28	0	0	0	0	3	0	0	0	0	33	0	0	0	4	8	0	0	0	39	2	0	0	0	1
May 90	28	0	0	1	0	3	0	0	0	0	37	1	0	0	0	47	0	0	0	0	3	0	0	0	0
Jun 90	27	0	0	4	0	3	0	0	1	0	36	0	0	0	0	47	0	0	0	0	3	0	0	0	0
Jul 90	23	0	0	2	0	2	0	0	0	0	36	0	0	0	0	47	0	0	0	0	3	0	0	0	0
Aug 90	21	0	0	3	0	2	0	0	0	0	36	0	0	0	0	47	0	0	0	0	3	0	0	0	0
Sep 90	18	0	0	5	0	2	0	0	0	0	36	0	1	0	2	47	1	0	0	0	3	0	0	0	0
Oct 90	13	0	0	0	0	2	0	0	2	0	37	1	1	0	2	46	0	0	0	0	3	0	0	0	0
Nov 90	13	0	0	5	0	0					37	0	1	0	0	46	0	0	0	0	3	0	0	0	0
Dec 90	8	0	0	8	0						36	1	1	0	0	46	0	0	0	0	3	0	0	0	0
Jan 91	0										34	0	0	0	0	46	0	0	0	0	3	0	1	0	0
Feb 91											34	0	0	0	0	44	0	0	0	0	2	0	0	0	0
Mar 91											34	1	0	0	0	44	0	0	0	0	2	0	0	0	0
Apr 91											33	0	1	0	0	44	0	0	0	0	2	0	0	0	0
May 91											32	0	0	0	0	44	0	0	0	0	2	0	0	0	0
Jun 91											32	0	4	0	0	44	0	2	0	0	2	0	0	0	0
Jul 91											28	0	3	0	0	42	0	0	0	0	2	0	0	0	0
Aug 91											25					42					2				

[1]KEY:

R: Number of sea otters at risk during month
D: Number of sea otters that died during month
M: Number of sea otters classified missing during month
E: Number of sea otters having transmitters expire during month
A: Number of sea otters added to study during month

DRAFT

Table 4. Summary of statistics on survival of sea otters radio-instrumented and released in Prince William Sound. Study groupings include individuals released from otter treatment centers (T.C.), individuals from eastern Prince William Sound (EPWS) and individuals from western Prince William Sound (WPWS).

MISSING ASSUMED DEAD	p Survival	C.I.	x^2	D.F.	p
1989-90					
T.C. Females	0.445	(0.223-0.667)	0.02	1	N.S.
T.C. Males	0.401	(0.133-0.670)			
1990-91					
T.C. Females	0.692	(0.421-0.964)	0.003	1	N.S.
T.C. Males	0.714	(0.314-1.115)			

1989-90

MISSING ASSUMED DEAD	p Survival	C.I.	x^2	D.F.	p
All Females	0.85	(0.757-0.943)	13.82	1	0.001
T.C. Females	0.445	(0.223-0.667)			
EPWS Females	0.834	(0.733-0.934)	12.97	1	0.001
T.C. Females	0.445	(0.223-0.667)			

MISSING ELIMINATED	p Survival	C.I.	x^2	D.F.	p
All Females	0.932	(0.862-1.001)	8.36	1	0.01
T.C. Females	0.674	(0.412-0.935)			
EPWS Females	0.923	(0.847-0.999)	6.88	1	0.02
T.C. Females	0.674	(0.412-0.935)			

1990-91

MISSING ASSUMED DEAD	p Survival	C.I.	x^2	D.F.	p
All Females	0.798	(0.716-0.880)	0.79	1	N.S.
T.C.Females	0.692	(0.421-0.964)			
EPWS Females	0.648	(0.506-0.790)	0.19	1	N.S.
T.C.Females	0.692	(0.421-0.964)			
WPWS Females	0.934	(0.862-1.006)	5.93	1	0.02
T.C.Females	0.692	(0.421-0.964)			

MISSING ELIMINATED	p Survival	C.I.	x^2	D.F.	p
All Females	0.956	(0.915-0.998)	0.3	1	N.S.
T.C.Females	0.909	(0.713-1.105)			
EPWS Females	0.930	(0.848-1.011)	0.19	1	N.S.
T.C.Females	0.909	(0.713-1.105)			
WPWS Females	0.979	(0.936-1.021)	1.03	1	N.S.
T.C. Females	0.909	(0.713-1.105)			

LITIGATION SENSITIVE
ATTORNEY/CLIENT WORK PRODUCT

DRAFT

TABLE 5. SUMMARY OF REPRODUCTION BY FEMALES FROM TREATMENT CENTERS VS. WILD CAPTURED FEMALES IN PRINCE WILLIAM SOUND 1990.

	Females Pupping	Females Not Pupping	
Treatment Center Females	2	9	$X^2 = 3.29$ 1 D.F. $p < 0.08$
1989-90 East PWS Females	14	14	

	Females Pupping	Females Not Pupping	
Treatment Center Females	2	9	$X^2 = 6.19$ 1 D.F. $p < 0.02$
1989-90 West PWS Females	22	14	

	Females Pupping	Females Not Pupping	
Treatment Center Females	2	9	$X^2 = 5.52$ 1 D.F. $p < 0.02$
1989-90 All PWS Females	36	28	

Table 6. Summary of reproduction by individual instrumented female sea otters following release from sea otter treatment centers.

TX	Otter ID	July 1990 Status	Date Last Seen	Est. Date Pupped	Fate of Pup	July 1991 Status	Date Last Seen	Est. Date Pupped	Fate of Pup
4098	S-002	alive		didn't pup		alive	05-Apr-91	didn't pup	
4135	S-124	missing	26-May-90	didn't pup					
4148	S-069	alive		19-Oct-90	weaned	alive	27-Jul-91	didn't pup	
4176	S-162	missing	22-Sep-89	didn't pup					
4225	S-015	missing	17-Oct-89	didn't pup					
4238	S-157	missing	04-Oct-89	didn't pup					
4257	S-068	TX failure	01-Sep-89	didn't pup					
4340	S-045	alive		06-Apr-90	unknown	alive	05-Apr-91	didn't pup	
4355	S-060	dead	04-Mar-90	didn't pup					
4398	S-161	alive		didn't pup		alive	27-Jul-91	didn't pup	
4447	S-003	dead	22-Feb-90	didn't pup					
4478	S-080	dead	10-Feb-90	didn't pup					
4498	S-054	dead	20-Jan-90	didn't pup					
4547	S-006	alive		didn't pup		missing	30-Jul-90	didn't pup	
4593	V-145	alive		didn't pup		missing	13-Oct-90	didn't pup	
4608	S-114	missing	04-Jan-90	didn't pup					
4649	S-057	missing	16-Dec-89	didn't pup					
4696	S-043	dead	17-Apr-90	didn't pup					
4728	S-007	alive		didn't pup		missing	28-Feb-91	didn't pup	
4755	S-053	missing	03-Feb-90	didn't pup					
4789	S-155	alive		didn't pup		missing	18-Jul-91	didn't pup	
4796	S-017	alive		31-Dec-89	weaned	alive/pup	07-Aug-91	07-Feb-91	w/mother
4815	S-146	alive		didn't pup		alive/pup	26-Jul-91	16-May-91	w/mother
4825	S-059	alive		didn't pup		alive	05-Aug-91	didn't pup	
4857	S-035	alive		didn't pup		dead	12-May-91	didn't pup	
4928	S-128	dead	26-Aug-89	didn't pup					
4935	V-150	alive		didn't pup		alive	08-Aug-91	didn't pup	
4966	V-068	alive		didn't pup		alive	27-Jul-91	didn't pup	

Technical Report: Marine Mammal Study Number 6

Mortality and Reproduction of Female Sea Otters in Prince William Sound, Alaska

Charles Monnett and Lisa Mignon Rotterman

P. O Box 1846

Cordova, Alaska 99574

In Cooperation with:

Prince William Sound Science Center

P.O.Box 705

Cordova, Alaska 99574

and

Alaska Fish and Wildlife Research Center

U. S. Fish and Wildlife Service

1011 E. Tudor Road

Anchorage, AK 99503

November 1, 1991

SUMMARY

Ninety-six female sea otters were instrumented with implanted radio-transmitters in Prince William Sound, Alaska, during 1989-1990. Females in eastern Prince William Sound exhibited a lower survival rate than those in western Prince William Sound. No differences were observed between rates of pupping or between rates of survival of dependent pups for sea otters in the two areas.

INTRODUCTION

On March 24, 1989, over 11 million gallons of crude oil were spilled in Prince William Sound, Alaska, due to the wreck of the *T/V Exxon Valdez*. The research discussed in this report was undertaken as part of Natural Resource Damage Assessment studies aimed at determining if the spill caused damage to the sea otter population(s) in the region, and, if so, the type, magnitude,and significance of the damage(s). The goals of this study were to determine whether the mortality and reproductive rates of adult females were different in areas within or near the areas through which large amounts of crude oil were spilled than in areas in which no crude oil was known to have passed. This information is crucial to understanding the overall extent of damage to the sea otter population(s); to estimating the rate and pattern of recovery; and to formulating restoration and response policies for sea otters throughout their range.

OBJECTIVES

The specific objectives of this study were defined in the corresponding statement of work as follows:

1. To test the hypothesis that survival of adult female sea otters is not different in oiled and unoiled areas.

2. To test the hypothesis that pupping rates of adult female sea otters are not different between oiled and unoiled areas.

3. To test the hypothesis that pup survival pre-weaning is not different between oiled and unoiled areas.

METHODS

Definitions

Status classifications are made based on consideration of data through July 31, 1991. Individuals classified as "dead" are known to be dead because their carcass or other remains were observed and, in some cases, recovered. "Missing" individuals are those whose radio signal cannot be detected by boat or aircraft radio searches within Prince William Sound or adjacent areas along the Kenai Peninsula and Copper River Delta. The classification of "alive" is based upon visual observations of the individual.

Females were classified as having pupped based upon visual observations that they were accompanied by a pup.

Study Groups

The eastern Prince William Sound grouping (EPWS) consists of 22 females that were instrumented during 1989 and 23 females that were instrumented during 1990. The western Prince William Sound grouping (WPWS) consisted of 9 females instrumented during 1989 and 42 females instrumented during 1990 (Table 1). Capture locations are summarized in Figure 1.

Instrumentation and Monitoring

Individuals in this study were anesthetized and radio-transmitters were surgically implanted in their peritoneal cavities (Garshelis and Siniff 1983; Monnett 1988). Sea otters were released at the location of capture immediately after recovering from their anesthesia. An attempt was made to locate each individual at least once biweekly, using aircraft or boats equipped with Yagi antennas.

Analyses

Probabilities of survival and 95% confidence intervals (CI's) are calculated using Pollock et al.'s (1989) staggered entry modification to the Kaplan and Meier (1958) product limit procedure. Differences in the probability of survival between study groups are tested using the procedure described by Cox and Oakes (1984; see also Pollock et al. (1989) and White and Garrott (1990)). Contingency Chi-squared analyses were used to test for differences in pupping rates between study groupings. Differences were judged to be significant if the probability of type II error was < 0.05.

Analysis of survival of dependent pups was confined to pups during the first 60 days following birth. It has been shown that sea otter pups in Prince William Sound may become independent and survive at less than 90 days of age (Monnett 1988). Thus, it was not possible to ascertain whether separation of older pups from mothers was due to weaning or mortality.

RESULTS AND DISCUSSION

Monitoring

Intervals between radio-locations were on average: EPWS (1990) = 5.8 days (SD = 1.0), (1991) = 5.9 days (SD = 3.2); WPWS (1990) = 8.7 days (SD = 1.4), (1991) = 11.1 days (SD = 4.7). Intervals between visual observations were on [illegible] (1990) = 8.8 days (SD = 1.8), (1991) = 7.3

days (SD = 5.3); WPWS (1990) = 10.7 days (SD = 2.6), (1991) = 12.7 days (SD = 5.3).

Survival rates of adult females

If females that were classified as missing are assumed to have died, the survival rate of females in WPWS was higher than that of females in EPWS (Table 2). If females classified as missing are excluded from the analysis, no differences exist (Table 2).

Pupping rates

No differences were found in pupping rates of adult females between EPWS and WPWS in either 1990 or 1991: (1990) EPWS = 13/28 (46%) females pupped versus WPWS = 21/36 (58%) females pupped ($X^2 = 0.92$, 1 DF, $p > 0.50$); (1991) EPWS = 21/30 (70%) females pupped versus WPWS = 29/37 (78%) females pupped ($X^2 = 0.61$, 1 DF, $p > 0.50$).

Pup survival

The survival rates of dependent pups for the first 60 days following birth were compared between EPWS and WPWS. No differences were found between the survival rates of dependent pups in either 1990 or 1991: (1990) EPWS = 9/13 (69%) pups survived versus WPWS = 15/21 (76%) pups survived ($X^2 = 0.19$, 1 DF, $p > 0.70$); (1991) EPWS = 17/21 (81%) pups survived versus WPWS = 28/29 (97%) pups survived ($X^2 = 3.29$, 1 DF, $p < 0.08$).

REFERENCES CITED

Cox, D. R. and D. Oakes. 1984. Analysis of Survival Data. Chapman & Hall, New York. 201pp.

Garshelis, D. L. and D. B. Siniff. 1983. Evaluation of radio-transmitter attachments for sea otters. Wildlife Society Bulletin 11:378-383.

Kaplan, E. L. and P. Meier. 1958. Nonparametric estimation from incomplete observations. J. Am. Stat. Assoc. 53:457-481.

Monnett, C. W. 1988. Patterns of movement, postnatal development and mortality of sea otters in Alaska. Unpublished Ph.D. dissertation, University of Minnesota, 134 pp.

Pollock, K. H.; Winterstein, S. R. ; Bunck, C. M. and P. D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. J. Wildlife Management 53: 7-15.

White, G. C. and R. A. Garrott. 1990. Analysis of Wildlife Radio-Tracking Data. Academic Press. New York. 383 pp.

Figure 1. Capture locations of female sea otters in Prince William Sound.

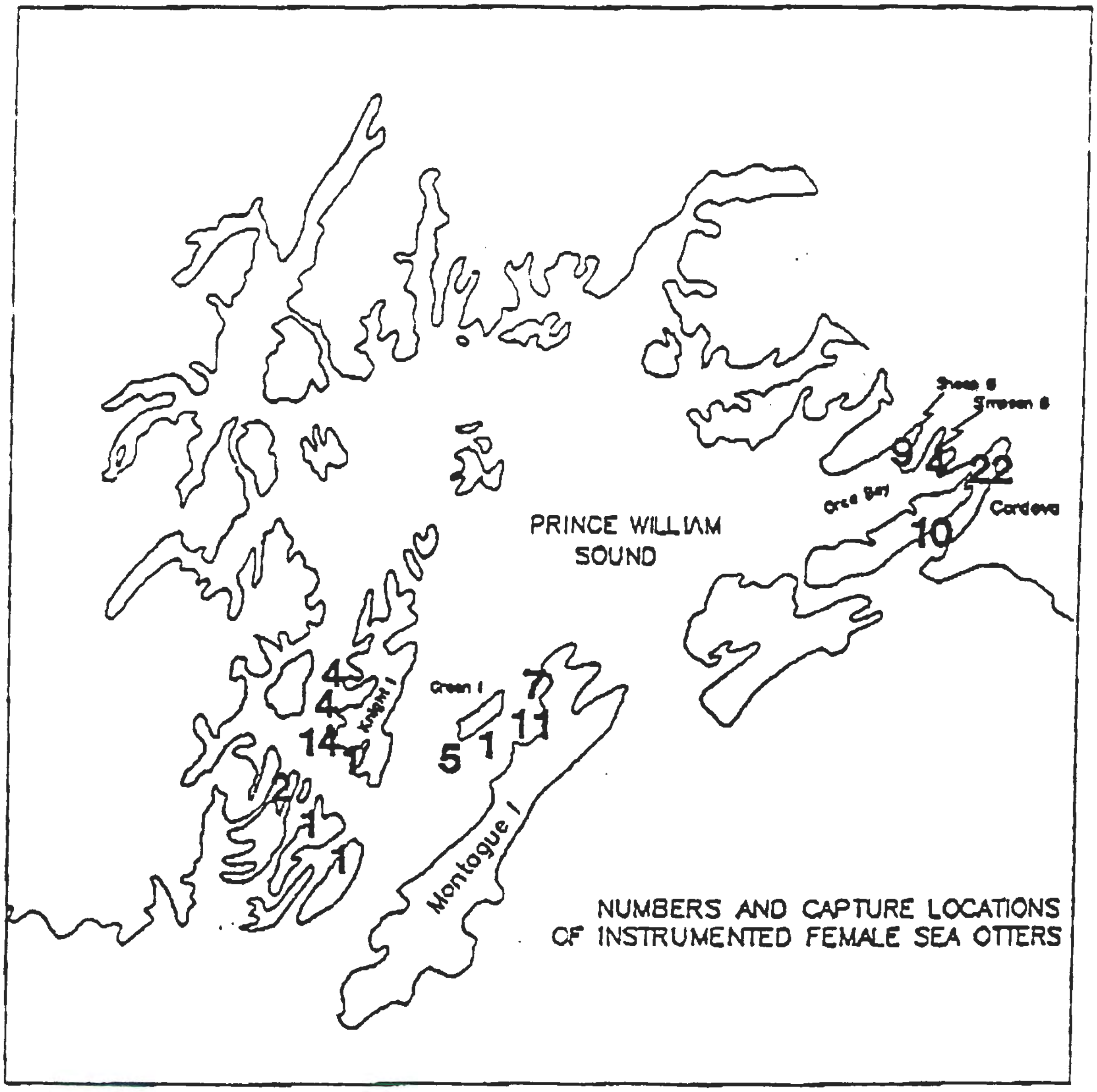


Table 1. Data on instrumentation of female sea otters in Prince William Sound (PWS). Study groupings: E.P.W.S. = Eastern Prince William Sound; W.P.W.S. = Western Prince William Sound.

Otter ID	Study Grouping	Date Instrumented	Location Instrumented
89101	E.P.W.S.	08-Oct-89	Sheep Bay
89102	E.P.W.S.	08-Oct-89	Sheep Bay
89103	E.P.W.S.	08-Oct-89	Sheep Bay
89104	E.P.W.S.	08-Oct-89	Sheep Bay
89105	E.P.W.S.	09-Oct-89	Sheep Bay
89106	E.P.W.S.	12-Oct-89	North Island
89107	E.P.W.S.	12-Oct-89	North Island
89108	E.P.W.S.	12-Oct-89	North Island
89109	E.P.W.S.	12-Oct-89	North Island
89110	E.P.W.S.	12-Oct-89	North Island
89111	E.P.W.S.	12-Oct-89	North Island
89112	E.P.W.S.	13-Oct-89	North Island
89113	E.P.W.S.	13-Oct-89	North Island
89114	E.P.W.S.	13-Oct-89	North Island
89115	E.P.W.S.	20-Oct-89	North Island
89116	E.P.W.S.	20-Oct-89	North Island
89117	E.P.W.S.	20-Oct-89	North Island
89118	E.P.W.S.	20-Oct-89	North Island
89121	E.P.W.S.	22-Oct-89	North Island
89122	E.P.W.S.	22-Oct-89	North Island
89124	E.P.W.S.	22-Oct-89	North Island
89125	E.P.W.S.	22-Oct-89	North Island
89126	E.P.W.S.	22-Oct-89	North Island
89127	W.P.W.S.	04-Nov-89	Chicken Island, Latouche P.
89128	W.P.W.S.	06-Nov-89	Bainbridge Passage
89131	W.P.W.S.	07-Nov-89	Bainbridge Passage
89140	W.P.W.S.	12-Nov-89	Port Chalmers
89141	W.P.W.S.	13-Nov-89	Port Chalmers
89142	W.P.W.S.	13-Nov-89	Channel Island, Green Is.
89150	W.P.W.S.	15-Nov-89	Port Chalmers
89153	W.P.W.S.	15-Nov-89	Port Chalmers
89155	W.P.W.S.	16-Nov-89	Port Chalmers
90001	E.P.W.S.	16-Mar-90	North Island
90004	E.P.W.S.	16-Mar-90	North Island
90005	E.P.W.S.	16-Mar-90	North Island
90006	E.P.W.S.	16-Mar-90	North Island
90008	E.P.W.S.	18-Mar-90	Quarry, Orca Inlet
90013	E.P.W.S.	22-Mar-90	Quarry, Orca Inlet
90014	E.P.W.S.	22-Mar-90	Quarry, Orca Inlet
90016	E.P.W.S.	24-Mar-90	Quarry, Orca Inlet
90017	E.P.W.S.	24-Mar-90	Quarry, Orca Inlet
90018	E.P.W.S.	26-Mar-90	Quarry, Orca Inlet
90019	E.P.W.S.	26-Mar-90	Quarry, Orca Inlet
90020	E.P.W.S.	26-Mar-90	Quarry, Orca Inlet
90022	E.P.W.S.	26-Mar-90	Quarry, Orca Inlet
90023	E.P.W.S.	27-Mar-90	Quarry, Orca Inlet

Table 1 (cont.). Data on instrumentation of female sea otters in Prince William Sound (PWS). Study groupings: E.P.W.S. = Eastern Prince William Sound; W.P.W.S. = Western Prince William Sound.

Otter ID	Study Grouping	Date Instrumented	Location Instrumented
90024	E.P.W.S.	04-Apr-90	Sheep Bay
90027	E.P.W.S.	05-Apr-90	Sheep Bay
90028	E.P.W.S.	05-Apr-90	Sheep Bay
90029	E.P.W.S.	05-Apr-90	Sheep Bay
90031	W.P.W.S.	09-Apr-90	Little Green Island
90033	W.P.W.S.	11-Apr-90	Port Chalmers
90034	W.P.W.S.	11-Apr-90	Port Chalmers
90035	W.P.W.S.	11-Apr-90	Port Chalmers
90036	W.P.W.S.	11-Apr-90	Port Chalmers
89010	W.P.W.S.	11-Apr-90	Port Chalmers
90037	W.P.W.S.	11-Apr-90	Little Green Island
90038	W.P.W.S.	11-Apr-90	Port Chalmers
90039	W.P.W.S.	13-Apr-90	Squire Island, Knight Is.
90040	W.P.W.S.	13-Apr-90	Squire Island, Knight Is.
90041	W.P.W.S.	13-Apr-90	Squire Island, Knight Is.
90042	W.P.W.S.	13-Apr-90	Squire Island, Knight Is.
90043	W.P.W.S.	13-Apr-90	Squire Island, Knight Is.
90044	W.P.W.S.	13-Apr-90	Squire Island, Knight Is.
90045	W.P.W.S.	13-Apr-90	Squire Island, Knight Is.
90046	W.P.W.S.	13-Apr-90	Squire Island, Knight Is.
90047	W.P.W.S.	13-Apr-90	Squire Island, Knight Is.
90048	W.P.W.S.	13-Apr-90	Squire Island, Knight Is.
90049	W.P.W.S.	13-Apr-90	Squire Island, Knight Is.
90052	W.P.W.S.	22-Apr-90	Mummy Island, Knight Is.
90053	W.P.W.S.	22-Apr-90	Mummy Island, Knight Is.
90054	W.P.W.S.	22-Apr-90	Mummy Island, Knight Is.
90055	W.P.W.S.	22-Apr-90	Mummy Island, Knight Is.
90056	W.P.W.S.	23-Apr-90	Iktua Bay, Evans Island
90057	W.P.W.S.	24-Apr-90	Squire Island, Knight Is.
90058	W.P.W.S.	24-Apr-90	Squire Island, Knight Is.
90059	W.P.W.S.	24-Apr-90	Squire Island, Knight Is.
90061	W.P.W.S.	26-Apr-90	Squirrel Island, Knight Is.
90062	W.P.W.S.	26-Apr-90	Squirrel Island, Knight Is.
90063	W.P.W.S.	26-Apr-90	Squirrel Island, Knight Is.
90064	W.P.W.S.	26-Apr-90	Squirrel Island, Knight Is.
90065	W.P.W.S.	27-Apr-90	Mummy Bay Reef
90066	W.P.W.S.	28-Apr-90	Stockdale Harbor
90067	W.P.W.S.	28-Apr-90	Stockdale Harbor
90068	W.P.W.S.	28-Apr-90	Stockdale Harbor
90070	W.P.W.S.	29-Apr-90	Stockdale Harbor
90071	W.P.W.S.	29-Apr-90	Stockdale Harbor
90072	W.P.W.S.	29-Apr-90	Stockdale Harbor
90073	W.P.W.S.	29-Apr-90	Stockdale Harbor
90074	W.P.W.S.	30-Apr-90	Little Green Island
90075	W.P.W.S.	30-Apr-90	Little Green Island

4. Identification of Upland Habitats Used by Marbled Murrelets in Prince William Sound

1991
#4

INTERIM SUMMARY OF THE 1991 MARBLED MURRELET RESTORATION PROJECT

Kathy Kuletz, USFWS, 20 November, 1991

Introduction

To enhance the natural recovery of the marbled murrelet from losses suffered from the Exxon Valdez oil spill (EVOS), the Restoration Planning Work Group (RPWG) initiated a study to identify marbled murrelet nesting habitat. This project will identify upland habitat used by murrelets and ultimately guide acquisition or protection of habitat that would benefit murrelet reproduction. In 1990 a pilot study was begun by U.S. Fish and Wildlife Service (USFWS) personnel stationed on Naked Island, Prince William Sound. Forty-seven dawn watches were carried out at 22 sites to test methodologies developed at lower latitudes. Results of the pilot study are summarized in 'Restoration Feasibility Study Number 4 - Identification of Upland Habitats Used by Wildlife Affected by the EVOS: Marbled Murrelets', which is available at the USFWS and RPWG Oil Spill Offices. In 1991, a full-scale restoration project was initiated in cooperation with the U.S. Forest Service (USFS). A full report on the results of the 1991 season, including integration with 1990 data, will be available in early 1992. This summary provides an outline of methods, accomplishments and recommendations for further study.

Objectives

The objectives of the 1991 study were:

A. Refine the censusing protocol for marbled murrelets at upland sites in Prince William Sound.

B. Document tree nesting of marbled murrelets in Prince William Sound.

C. Determine marbled murrelet activity in selected upland habitat sites in Prince William Sound.

D. Describe habitat associations in documented use areas in Prince William Sound.

Methods and Results

Objective A: Refining censusing at upland sites

The dawn watch is the basic method used to census for upland activity of marbled murrelets. An observer, using a microcassette recorder, notes murrelet vocalizations and visual observations (detections). The watch is usually 45min before and 75min after official sunrise. In 1991 various applications of the dawn watch were used to improve upland surveys for murrelets. To monitor seasonal patterns in murrelet activity, three sites were censused at approximately two-week intervals from 27 May to 15 August. Twenty-one dawn watches were conducted at these sites, with a total of 1,568 detections. Because these three sites were also observed in 1990, it will also be possible to compare yearly variation. Although data have not been analyzed, murrelet activity appeared to follow patterns observed in 1990 at Naked Island, and at other latitudes. That is, detections were moderately high in May and early June, declined and remained stable through late June and early July, and then increased to a peak of activity in late July. Detections declined dramatically after 9 August. There is some indication of differences in daily timing of activity compared to lower latitudes. On clear mornings, especially early in the season, murrelet activity often began earlier and was sometimes heard throughout the twilight period, perhaps due to continuous light.

A pilot study was conducted to test the efficacy of tape recordings in detecting murrelet activity during dawn watch hours. On 20 occasions, a Sony tape recorder was set to record approximately 20m from an observer doing a dawn watch. The tape was later transcribed independent of the observer's transcription. The number and types of murrelet detections will be compared between observer and tape.

A Marantz stereo recorder was used to record murrelet vocalizations during dawn activity. These were done near camp on Naked Island, in a known high-use area where only marbled murrelets have been observed. Three 90min tapes were made and sent to Steve Singer (Santa Cruz Natural History Museum, California) for sonogram analysis. The vocalizations will be compared to recordings made in California, Oregon and Washington to identify specific calls and determine if there are geographic differences.

Objective B: Document tree nesting

Using dawn watches and 'ground search' techniques, four marbled murrelet nests were found on Naked Island in 1991. This brought to 23 the total number of murrelet tree nests found throughout their range, and was the first documentation of tree nesting north of southeast Alaska. All four nests were in high-volume stands of mixed conifer old-growth. The nests were similar to those found at lower latitudes, although the trees were smaller. Two nests were in mountain hemlocks and two in western hemlocks. Each nest cup was located on a large moss platform. All nests were found during the egg stage. At least one egg hatched but all nests failed, most likely from avian predation.

A total of 211 hours were spent in dawn stake-out efforts, whereby one to four observers focused on specific areas or trees to catch incubation exchanges or chick feeding in attempts to locate nests. Two of the nests were found using this method. In both cases, an incubating bird was heard landing in a tree and was eventually located with the naked eye. One nest was found during a dawn watch at a remote site after hearing an incubation exchange. The last nest was spotted by a tree climber during a check of a failed nest. This last nest, being only four meters from Nest #2, in an adjacent tree, may have been a renesting attempt. Murrelets were occasionally observed to land on a branch or fly into a section of a tree where no nest was found. Murrelets may land on branches other than their nest site, or these were sites of failed nesting attempts.

Opportunistically, observations were done at the nests to record incubation, incubation exchange behavior and chick feedings. Ravens, crows and Steller's jays were observed in the vicinity of nests, and at least one of the eggshells found below a failed nest had holes caused by a corvid beak. Bald Eagles made attempts on murrelets on the water and Peregrin falcons, which prey heavily on murrelets (Hughes, pers. comm.), may take murrelets as they fly inland. The sharp-shinned hawk was added to the list of predators taking adult murrelets. This was documented when an observer retrieved an adult male murrelet with a brood patch, following an apparent attack while the murrelet was in a tree (the nest was not found). Predation pressures on murrelets appear to be high and for some species, such as Peregrin falcons, murrelets may be an important food source. A dead immature Peregrin falcon was found on Naked Island in 1991, and one Peregrin nest has been located on Naked Island.

Objective C: Determine murrelet activity among habitat types

For the habitat study, 80 sites were randomly chosen among four habitat types on Naked, Storey and Peak islands. The features were chosen from the 1974 USFS timber typing maps, and from features that have been suggested as potentially important to murrelets. These features were tree volume class and stand class (tree size). Twenty sites were randomly chosen within each habitat type. Seventy-three of these sites were censused. An effort was made to rotate among habitats throughout the summer, to insure that results were not biased by seasonal murrelet activity patterns. Other features were taken from maps, aerial photos or on site by the observer, including slope angle and aspect, elevation, distance from shore, nearest freshwater, drainage system, tree measurements within a 50m radius and weather conditions during the watch. Over 2,500 murrelet detections were recorded at these sites. In most cases, the site was also visually searched for nests. Data for Objective C has not been analyzed yet. The four habitats will first be compared (ANOVA) for total number of murrelet detections and second, for the number of nearby, below-canopy detections at each site. The latter is believed to be indicative of a nest in the immediate vicinity.

Objective D: Describe habitat associations in documented use areas

A 'documented use area' is any site with evidence of upland murrelet nesting. The best documentation is locating an actual nest. At each Naked Island nest site, measurements of the nest and surrounding trees were taken following Pacific Seabird Group protocol. The USFS personnel also recorded habitat data according to their plant association protocol. After nest failure, samples of the nest's moss and lichen platform were taken, as well as eggshell fragments and feathers in the nest cup. Plant samples are currently being identified by USFS plant ecologists. A full compilation and analysis of the nest trees and stand characteristics will be provided in the 1992 report.

Using the 73 sites censused for Objective C, analysis will also be done on murrelet detections at the sites using all recorded habitat features, including the USFS plant association classification. When the USFS completes digitization of the study area for their ecological mapping units system, it will be possible to analyze murrelet activity relative to this new habitat data base.

Perry Island and Unakwik Inlet

Naked, Storey and Peak islands do not have alpine habitat, so five days were allotted for a pilot effort on Perry Island. The objective was to compare observers paired in adjoining patches of forested and alpine habitats. With the support of the vessel 'Auklet', under contract with the USFS and in cooperation with USFS plant ecologists on board, we conducted six dawn watches on Perry Island. Adverse weather obstructed work on Perry Island, so on two mornings we tested the use of nearshore dawn watches from the boat's deck at two sites (four dawn watches) in Unakwik Inlet. Additionally, we censused at-sea numbers of both marbled and Kittlitz's murrelets along the entire shoreline of Unakwik Inlet.

The Unakwik diversion proved valuable for several reasons. First, we found the boat deck dawn watches to be convenient and applicable to much of the habitat found throughout the spill zone. While an observer could not always tell exactly which habitat the murrelets were using for nesting, the general activity pattern and flight paths indicated the potential for documented use areas. Second, we identified Mueller Cove as a site of very high murrelet upland activity. Several other specific sites were also identified as potential future study sites, based on concentrations on the water and flight patterns of murrelets with fish. Finally, we were able to determine distribution of the two closely related murrelet species in the Inlet, as well as provide a density estimate in the nearshore waters.

Distribution of murrelets at-sea

The foraging requirements of murrelets during the breeding season may be as critical to successful nesting as availability of nesting habitat. A pilot effort was conducted in 1991 to test the applicability of stratified random sampling in a relatively small area of marine habitat. The estimated population of marbled murrelets around Naked Island was estimated at 3,000 birds in 1978, but this was not based on a systematic sampling method. The only existing at-sea counts for the study area are five transects and a shoreline census, which can only provide indexes of changes in murrelet numbers. In 1991, we tried a 1km grid system overlaid on a nautical chart. Three strata were use: 1) Shoreline to 200m from shore, which was done using a complete shoreline census; 2) From 200m to 2km from shore, creating a buffer zone surrounding Naked, Storey and Peak Islands. Thirty blocks were randomly chosen in this strata; 3) From 2km to 5km from shoreline. Thirty blocks were randomly chosen in this strata. For the second and third strata, the actual transect line was randomly chosen among five possibilities, based on latitude or longitude increments of two degrees. The lines ran north-south or east-west, whichever was perpendicular to the prevailing shoreline.

In this way, sixty 200m wide, 1km long transects were censused on 7-9 June and 8-9 August. Each census was completed in two or three mornings and was repeatable using latitude and longitude taken from the Global Positioning System and Loran. These censuses randomly sampled the desired area in a statistically sound manner. Analysis will provide an estimate of the local murrelet population and distribution relative to the distance from shoreline, local bathymetry and other insular features.

Conclusions and Recommendations

This phase of the marbled murrelet restoration project proved that it is possible to locate murrelet nests in forested habitat using a ground-based observer searching technique. It documented tree nesting by murrelets in southcentral Alaska. Following complete analysis of the habitat study, a broader picture of upland habitat used by murrelets will be available in the 1992 report. The project monitored seasonal changes in murrelet activity and increased our knowledge of dawn flight behavior and vocalizations. It also tested the use of tape recorders for dawn watches and conducting dawn watches from anchored vessels. A method of censusing murrelets at-sea in a relatively small area was developed which will provide an estimate of the local murrelet population to compare with upland activity and distribution.

Based on experience from the 1991 field season and a subjective summary of the data, the following recommendations are made for future study. This should not be considered a definitive list as final data analysis may alter conclusions or provide more suggestions.

1. More murrelet nests need to be located, since such nesting habitat data is undisputable. The probability of locating more nests at the same study site is now very high. Success can be increased by beginning earlier in the season (early May) and dedicating a team of people solely to that purpose. In 1991, nest searches accounted for a small percentage of our field time and did not begin until 27 May. Although late May is probably the peak laying period, success could be enhanced by observing murrelets selecting nest sites early in the season. Those nests which fail would be less likely to be missed.

2. By intensive searching for murrelet nests at known high-use areas on Naked Island, it should be possible to determine nesting density and patterns of nest dispersal. This important information is currently unknown, and unlikely to be obtained in areas where murrelet numbers are low.

3. By locating more nests, information can be obtained on reproductive chronology and success. Specifically, the species or mechanisms responsible for the apparent high predation can be ascertained. Additionally, these nests can be monitored for behavior in conjunction with dawn watches. This information will help refine our interpretation of dawn watch data throughout the spill zone. For example, what flight behaviors or vocalizations are most indicative of a nest nearby, and how far from the nest do these activities occur ? Is there a correlation between the level of murrelet activity in an area and how many pairs are actually nesting there ?

4. The murrelet nests were located by experienced people and adherence to a rigorous search technique. The success of all future work will depend on developing an Alaska protocol for upland murrelet surveys and a pool of trained personnel. This effort should be emphasized in 1992. Video tapes of flight behavior and cassette tapes of vocalizations and their categorization should be made. Eventually, training in all aspects of conducting a dawn watch should be developed and begun prior to the breeding season. This will insure standardization of methodology among observers and make comparisons between sites possible. This pool of experienced people would also be critical to the success of identifying specific habitats for acquisition.

5. There is currently no information on how to distinguish between the upland flight or vocalizations of marbled and Kittlitz's murrelets, yet they co-exist throughout most of

the spill zone and may overlap in nesting habitat. An Alaska protocol and training program needs to address both species to adequately serve the goals of the restoration effort. Requests for guidance on this issue have also been made by USFS personnel attempting to survey murrelets in their districts within the spill zone.

6. Once the data from the habitat study has been analyzed, any significant associations between habitat features and murrelet activity should be further tested in the field for verification. The applicability of the USFS ecological mapping units to murrelet activity should be examined and expanded to other habitats.

7. Upland murrelet activity should be surveyed in a broader array of habitats throughout the spill zone. A practical method of accomplishing this at many sites over a wide area would be by conducting dawn watches from shore or the deck of an anchored boat. Once hot spots of activity are located, more detailed upland surveys can be conducted.

8. Intensive nest search efforts may need to be done in an area with alpine and forest habitat, in an attempt to determine their relative use by murrelets and to separate the nesting habitats of Kittlitz's and marbled murrelets. The study site should be somewhat insular, relatively accessible and have a large population of both murrelet species. Perry Island is isolated and accessible but does not have a high density of murrelets. Unakwik Inlet has high densities of both species, but has extensive uplands and shoreline. Kachemak Bay has a large breeding murrelet population which is primarily confined to the bay's south side and is semi-isolated from other coastlines. It is accessible from Homer and has some roads and trails for upland access. It's accessibility early in the season may facilitate a training program. With preparation, it could also serve to educate the public on the restoration program through the Alaska Maritime National Wildlife Refuge visitor center.

9. It was advantageous to have on-site personnel trained in tree climbing. Tree climbing was used to check suspected nest sites, and was responsible for finding one of the nests opportunistically. Tree climbing was used to gather samples and measurements of the nest contents, nest and tree. The isolated nature of the study site and restrictions imposed by weather make importing tree climbers on a temporary basis impractical. While these trees are small by murrelet standards further south, climbing is still time consuming and requires expert training. The program provided through the USFS in 1991, (Chuck McDonald of Quinault Ranger District, Washington), should be continued.

10. Identification of upland nest habitat should eventually be integrated with knowledge of foraging requirements. This should take the form of identifying prey species and documenting nearshore foraging patterns during the breeding season. At Naked Island, or any site where intensive nest searches are conducted, the use of the local marine environment should also be investigated. Ideally, the relationships between nest sites and forage sites can be identified. Useful information can also be obtained by studying the murrelet's use of its foraging habitat, and the distribution of birds at sea relative to their nesting distribution.

5. Prince William Sound Harlequin Duck Breeding Habitat Analysis

1991
#5

Preliminary Status Report of the Harlequin Duck Restoration Project in Prince William Sound

Project ID Number:	
Written by:	David W. Crowley, B.S., Assistant Investigator
As directed by:	Dr. Samuel M. Patten, Principal Investigator
Field Technicians:	Charles Hastings, Michael Knehr, John Kristopeit, Jon Syder, Paul Twait, David Vandenbosch
Leading Agency:	Alaska Department of Fish and Game Division of Wildlife Conservation
Cooperating Agency:	U.S. Fish and Wildlife Service
Date initiated:	May 2, 1991
Date of Report:	November 20, 1991

TABLE OF CONTENTS, LIST OF TABLES, FIGURES

EXECUTIVE SUMMARY....3
OBJECTIVES....5
INTRODUCTION....6
- Project History....6
- Harlequin Life History....7

STUDY METHODOLOGY....9
- Study Area....9
- Harlequin Capture....9
- Radio Telemetry....10
- Reproduction....10
- Breeding Habitat....10
  - Hydrology....11
  - Vegetation....12
- Coastline Surveys....12
- Activity Budgets....13

STUDY RESULTS....14
- Habitat Analysis....15
- Reproduction....15
- Coastline Surveys....16
- Activity Budgets....17

STATUS OF HARLEQUIN RESTORATION....18

LITERATURE CITED....20

List of Tables
- Table 1. Characteristics of 9 known breeding streams selected by Harlequin hens for nesting and brood-rearing....23
- Table 2. Data collected from captured Harlequin....24
- Table 3. Aquatic data collected at Harlequin nests....25
- Table 4. Terrestrial data collected at Harlequin nest sites....26
- Table 5. Locations of 5 Harlequin duck nests on coastal mountain streams in Prince William Sound....27
- Table 6. Hierarchical description of Harlequin duck breeding streams and habitat from 5 nests located in 1991....28
- Table 7. Harlequin nesting streams investigated....29
- Table 8. Suspected non-nesting streams....30
- Table 9. Summary of Harlequin duck breeding productivity in northeastern Prince William Sound and comparison to other Harlequin populations....31
- Table 10. Results of radio telemetered hens....32
- Table 11. Broods observations recorded during 1991 in Prince William Sound, Alaska....33

List of Figures
- Figure 1. Diagram of hierarchical system levels for the description and classification of stream habitat in Prince William Sound....34

EXECUTIVE SUMMARY

Harlequin ducks continue to be effected by the Exxon Valdez oil spill (EVOS) in western Prince William Sound, experiencing the second consecutive year of an essentially complete reproductive failure in the oil spill area in 1991 (Patten 1991). Kuchel (1977) stated that several consecutive years of very low production or damage to winter habitat could completely eliminate a local Harlequin population. Harlequin ducks are highly philopatric to breeding and wintering areas; repopulation would occur slowly by random wanderings from other areas. Restoration of this Harlequin population requires knowledge of undisturbed breeding, feeding and molting habitat.

Information on Harlequin ducks, which are unique, stream-nesting specialists throughout their North American range, is limited, particularly for coastal breeding Harlequins. The Harlequin Duck Restoration Project was designed to collect habitat information necessary for an effective policy of restoration and management of Harlequin populations in coastal communties. The primary objectives of this project were to document undisturbed nesting habitat and determine potential impacts of timber harvest on Harlequin reproduction. This study in eastern PWS, where Harlequins are reproducing normally, also acts as a control case for the Natural Resources Damage Assessment (NRDA) Harlequin Study in the EVOS area, where reproduction is reduced or nonexistent.

The initial field season in 1990 documented breeding streams and developed a Harlequin breeding stream profile. The wariness of Harlequin ducks required development of innovative capture and radio-tracking techniques during the 1991 season. We captured 23 Harlequins in mist nets suspended over 14 suspected nesting streams and outfitted 14 hens with radio transmitters. By radio-tracking hens into coastal mountains, we located and recorded habitat for 5 Harlequin nests, representing the first successful attempt to locate nests of coastal-breeding Harlequins. We developed a hierarchical system to document vegetation, hydrology and topography of riparian, aquatic and forest habitat and implemented it during 1991. Our discovery of Harlequin hens' exclusive use of mature and old growth forest in Prince William Sound for nesting has important implications for management of habitat in Harlequin breeding areas scheduled for logging.

Extensive boat surveys were conducted along 350 miles of coastline from Valdez to Cordova. These were repeated 3 times to locate breeding Harlequins in the spring, molting flocks in mid-summer and broods in late summer. We documented habitat for 55 molting sites (occupied by approximately 1200 Harlequins), observed 14 broods and located 4 previously unknown breeding streams.

The NRDA Harlequin Project in the EVOS area has documented that Harlequins failed to reproduce in 1990 and 1991. Probable causes

are direct mortality of returning females, sublethal effects of hydrocarbon ingestion through the food chain, and massive disturbance to Harlequin breeding areas by clean-up and monitoring activities conducted in response to the EVOS (Patten 1991). The distressed status of the Harlequin population in the oil spill area necessitates protection and management of populations in eastern PWS for restoration purposes. As a result of these findings, Harlequins duck hunting was closed during the 1991 waterfowl season in PWS. Acquisition of undisturbed riparian corridors within timber sales may be essential for restoration and recolonization of Harlequin populations.

OBJECTIVES

These objectives are revised from Patten (1990b).

A. Locate, identify and describe Harlequin nesting streams in Prince William Sound.

B. Identify habitats used by nesting Harlequins by documenting topographic, hydrologic and vegetative characteristics at nest sites.

C. Identify other Harlequin breeding habitat parameters such as distance from nest to coast, distance from nest to stream and physical features of nest sites.

D. Construct a model that predicts potential Harlequin nesting streams and high quality habitat along those streams using the characteristics identified in objectives B. and C.

E. Measure Harlequin breeding productivity by identifying clutch size, hatching success and duckling mortality.

F. Document sightings of Harlequin duck breeding behavior including pair-bonding, nest prospecting, nesting, and brood-rearing in eastern PWS to provide a study control for the NRDA Harlequin Project in the EVOS area.

G. Determine width of forested buffer strips required to protect Harlequin breeding sites from the effects of timber harvest in Prince William Sound.

INTRODUCTION

The *Exxon Valdez* Oil Spill of March 24, 1989 (EVOS) heavily impacted the Harlequin duck (*Histrionicus histrionicus*) population in western Prince William Sound (PWS). The NRDA Harlequin Study in the EVOS area has observed nearly complete reproductive failure, patchy Harlequin distribution, and unusual plumage coloration on many individuals (Patten 1991, Jarvis pers. comm.). Harlequins forage in the intertidal, consuming a wide variety of invertebrates including blue mussels (*Mytilus edulis*). Established blue mussel beds may continue to discharge hydrocarbons for years, possibly causing ongoing sublethal contamination of Harlequin populations. Massive disturbance associated with oil spill cleanup response at breeding locations has also contributed to reproductive failure (Patten 1991).

The impaired status of Harlequin populations in the EVOS area of western PWS necessitates protection and management of populations in northern, eastern, and southern (all referred to as "eastern" unless specified) PWS. Patten (1990b) and this study have documented successful Harlequin reproduction in 1990 and '91 in unoiled, eastern PWS. Protection of breeding habitat could best be accomplished through the acquisition of undisturbed riparian corridors within timber sale areas. This acquisition may be essential for eventual recolonization of breeding Harlequins in the EVOS area.

Project History

Prior to the 1991 field season little was known about habitat requirements of Harlequin ducks breeding in PWS. Harlequins are among the least understood waterfowl species in North America. State and federal biologists attending the EVOS restoration planning meeting (April 1990) placed a priority rating on identification of breeding habitat requirements of Harlequin ducks. This subsequent project represents the first effort to study the specific nesting and brood-rearing habitat requirements of Harlequin ducks in Alaska. This knowledge is mandatory to develop an effective policy of restoration and management of Harlequins in PWS.

In 1990 a concentration of breeding Harlequins was located in northeastern Prince William Sound (Patten 1990b). This area was not impacted by the Exxon Valdez oil spill. However, mature and old growth forest habitat favored by Harlequin ducks and timber investors is currently scheduled for logging. Potential impacts of timber harvest on breeding Harlequins may be portrayed with a better understanding of breeding ecology.

Protection and management of riparian ecotones is now recognized as critically important in areas of disturbance (Petts 1990). By regulating the flow of nutrients and materials between upland forest and stream ecosystems, riparian ecotones maintain specific aquatic habitat required by fish and invertebrates (Petts 1990, Petterjohn and Correll 1984). Aquatic-terrestrial ecotones sustain biological diversity over a short period of time by providing habitat diversity (Risser 1990, Petts 1990). Should surrounding ecosystems undergo dramatic changes by timber harvest, protected riparian habitat may sustain bio-diversity over the long term by maintaining minimal populations of species once common in the undisturbed habitat, by providing corridors for recolonization (Petts 1990, Koehler et. al. 1975), and by maintaining quality aquatic habitat for such obligate stream breeders as fish and Harlequin ducks.

Because the Harlequin is an riparian breeder in PWS, clear-cutting surrounding forest and riparian habitat could theoretically eliminate breeding from those streams. Buffer zones left adjacent to streams could satisfy breeding habitat requirements of Harlequin ducks. Maintaining the current level of Harlequin brood production on a stream once its watershed has been harvested would indicate that the ecotone within the buffer zone is continuing to function (ie. maintaining terrestrial and aquatic habitat). Conversely, a decrease in productivity could indicate that wider buffer zones are needed. Wallen (1987) suggested that the Harlequin be considered an indicator of pristine ecosystems both because of sensitivity to human disturbance and nutritional importance to Harlequins of invertebrates considered to be biological indicators of healthy streams.

A riparian ecotone is in large part determined by its adjacent forest and stream ecosystems. As an interfacing system between relatively stable ecosystems, a riparian ecotone is sensitive to change (Risser 1990, Petts 1990, Wiens et. al. 1985). Changes that occur despite preservation of buffer zones after the adjacent forest ecosystem has been harvested could potentially lower reproductive success on that stream. For example, increased movment of sediments through an ecotone could lower invertebrate and spawning salmon numbers (Frissell et. al. 1986) thus reducing the amount of forage available for Harlequin broods. The protection of critical breeding habitat within timber sales in northeastern PWS is an important component of the restoration of Harlequin ducks. Currently, 66 ft (28.8 m) buffer strips are required by the State Forestry Act to protect spawning habitat in anadromous salmon streams on private timber holdings in PWS (Martin Maricle, ADNR, pers. comm.). Determining width of buffer zones required to protect Harlequin breeding habitat from degradation and human activity disturbance is an objective of this project.

Other studies on breeding Harlequins indicate their sensitivity to human disturbance (Cassirer and Groves 1990, Wallen 1987, Kuchel 1977, Bengtson 1972). Reproductive failure resulting from human disturbance could potentially occur even with intact riparian buffer zones should logging activities take place during the nesting season. In addition to timber harvest, other impending development activities such as aquaculture, mariculture and hydroelectric projects along Harlequin breeding and molting areas in Prince William Sound could impede recovery from the EVOS (Patten 1990b).

Harlequin Life History

Throughout their range Harlequin ducks breed and feed along turbulent mountain streams, displaying considerable diving expertise as they forage for invertebrates in rushing water. Breeding and non-breeding Harlequins in Iceland migrate up interior rivers in the spring (Bengston 1966, 1972). Non breeding ducks congregate at "clubs" (community loafing sites), remaining on the rivers until the molt in July. Non-breeding and post-breeding males and some non-breeding hens then migrate back to sea, rejoining Harlequin males that had remained at coastal streams for breeding Bengtson 1966, Bellrose 1980).

Breeding hens conceal nests under dense brush, windfalls, tree roots and in rock crevices within the riparian ecotone (Bellrose 1980, Bengtson 1966, Inglis et al. 1990). Average clutch size in Iceland is 5.5 (Bengston 1966), with 1 egg laid every 2 days. Icelandic Harlequin hens are quite attentive to the nest during the 28 - 30 day incubation period (Bellrose 1980, Bengston 1966). Brooding and non-breeding hens remain on inland and coastal rivers until ducklings are nearly fledged. Bengtson (1966, 1972) and Bengtson and Ulfstrand (1971) concluded that Harlequin ducks in Iceland nested on any stream with enough food and nesting cover, but that invertebrate food resources were a more important limiting factor than cover on inland streams.

Invertebrate productivity on breeding streams may be less important to Harlequins ducks in eastern PWS. Unlike interior Harlequins of Iceland (Bengtson 1972), Wyoming (Wallen 1987), and Montana (Kuchel 1977), coastal-nesting Harlequins fly downstream from nests to intertidal estuaries to forage (Dzinbal and Jarvis 1982, Bengtson 1972). Harlequins consume small mussels, clams, snails, chitons and limpets in the intertidal before the arrival of spawning salmon. Brood-rearing on coastal streams corresponds with the anadromous salmon run. Drifting salmon roe provides an easily obtainable and nutritious food source for broods and non-breeding Harlequins in lower stream reaches and estuaries during July and August (Dzinbal and Jarvis 1982).

Harlequin breeding pairs and non-breeding females are conspicuous on or near estuaries and lower reaches of nesting streams from mid-May to mid-June in PWS. Non-breeding males also feed on estuaries but are more likely observed on offshore rocks, small islands and headlands in PWS. Dzinbal and Jarvis (1982) reported much loafing but relatively low feeding activity around this exposed rocky habitat. Post-breeding males join non-breeders on offshore rocks for molting in mid-June. Harlequin hens and broods, often in groups of mixed age classes and non-breeding "aunts", remain on breeding streams until broods are nearly fledged in late August. Breeding streams, intertidal and marine areas used by Harlequins are all important during the breeding season and should therefore be regarded as critical habitat in restoring and managing Harlequin ducks in PWS.

Mean brood size in non-oiled areas of PWS during 1990 was 3.1 ducklings/brood (Patten 1990b). Boat surveys initiated in 1971 by the USFWS indicated a resident population in PWS of approximately 6000 Harlequin ducks, supplemented in the winter by an additional 4000 migrants (Patten 1990b, Isleib and Kessel 1973).

STUDY METHODOLOGY

Study Area

The restoration project crew (4 - 6 workers) was stationed in Olsen Bay, Port Gravina, approximately 30 km northwest of Cordova. The study area consisted of all streams, estuaries and coastline from Cordova to Valdez and limited areas of Hinchinbrook and Hawkins Islands. Our study area was positioned outside the limits of the oil spill. The NRDA Harlequin staff (2 - 4 workers) was based in Herring Bay, Knight Island, in the oil spill area.

Harlequin Capture

We began an intensive capture effort in late May on streams presumed to be used by breeding Harlequins. We selected streams for investigation based on previous brood sightings, presence of mated pairs on estuaries during Spring surveys, and on a breeding stream profile developed from previous brood sightings (Patten 1990b) listed in Table 1. We captured Harlequins during their nest prospecting, egg-laying and incubation periods by suspending mist nets (by Avinet, Inc., Dryden NY) over potential breeding streams (Dzinbal 1982, Wallen 1987) from 5 to 200 m upstream from estuaries. Harlequins fly within 0.5 - 1.5 meters of the stream surface at mid-channel and were usually captured during twilight hours as they flew to and from estuaries. Initially, fast-flying Harlequins burst through mist nets of lighter gauge mesh (2 ply 2-3/8" mesh, # 8N-110/2), but were adequately restrained in stronger nets. Large, long-handled landing nets were useful in scooping ensnared Harlequins from streams; ducks often struggled free of lighter mist nets as we approached within 1 or 2 meters.

We attempted to use a net-gun (Coda Enterprises, Mesa, AZ) to capture Harlequins roosting on rocky shores and islands. This method was not effective because of the limited range of the net-gun (<10 m) and wariness of Harlequins towards approaching boats.

All captured Harlequins were weighed, measured and banded with a USFWS leg band as indicated in Table 2. Blood was drawn from each Harlequin to determine physiological condition. Samples are being analyzed by Pheonix Laboratories (Pheonix, Arizona). All Harlequin hens regardless of breeding status were fitted with a small radio transmitter.

Radio Telemetry

A radio transmitter weighing 4.5 g (built by Advanced Telemetry Systems; Isanti, Minnesota) with a lithium battery pack was epoxy-glued to the base of the tail retrices of each hen captured on breeding streams. The transmitter was nearly covered by uppertail coverts with only the whip antennae exposed. Quinlan and Hughes (1990, cited in Patten 1990b) used a similar method to locate the nest of a marbled murrelet (a diving seabird) in old growth forest habitat. By using this attachment technique, we avoided changes in feeding and reproductive behavior (Perry 1981, Sorenson 1989 and Korschgen et al. 1984), and feather wear or loss (Gilmer et al. 1974, Greenwood and Sargeant 1973, Perry 1981) induced by back packs and neck collars. We considered implanting radio transmitters but the required invasive surgery and reduced effective range (Korschgen et al. 1984) added complexity and unacceptable risk.

We radio-tracked incubating hens initially via Supercub airplane with twin 4 element Yagi antennae to determine general location of incubating hens. We then followed up on foot using Telonics receivers (model # TR-4) and 4 element portable Yagi antennae. Our ability to readily locate nesting hens was hampered by distances of nests from the coast, difficult terrain and radio signal reflection off surrounding mountains. Most incubating hens required 10 - 15 hours (round-trip) of tracking on foot to locate. These expeditions were often repeated when trackers pinpointed a nesting hen on the opposite bank of an unfordable torrent. Once found, nest locations and habitat data were recorded on data forms (see Breeding Habitat below).

Reproduction

Harlequin eggs were counted, weighed, measured and candled to determine approximate stage of incubation (Weller 1956). This was often done in cool, rainy weather. We minimized egg handling time and covered nest bowls with down and a hat while doing habitat work to reduce cooling and to keep the eggs dry. We will return to these nests during the 1992 field season to count membranes or addled eggs to determine hatching success. The Mayfield method (Klett and Johnson 1982) will be used to determine nesting success.

Productivity data and breeding behavior observations from the Harlequin Duck Restoration Project are also being used as a study control for the NRDA Harlequin Study. The NRDA team compared characteristics of Harlequin nesting streams in the restoration study area to streams in the EVOS area and consulted a breeding stream profile (Patten 1990b, listed in Table 1) to identify potential (or historical) breeding streams in western PWS. We initially proposed capturing and placing radios on 60 breeding Harlequins hens in the EVOS area and on 60 breeding hens in unoiled eastern PWS for comparison of productivity and habitat utilization. Harlequins in the EVOS area did not use estuary or stream habitat during the breeding season (see Study Results, Reproduction below). As a result Harlequins were not captured and objectives for the NRDA project were revised to examine causes of reproductive failure in wetsern PWS.

Breeding Habitat

Because the structure and dynamics of stream habitat are determined by the surrounding watershed (Osborne and Wiley 1988), Frissell et. al. (1986) and Lotspeich and Platts (1982) recommended integrating both aquatic and terrestrial habitat characteristics of streams into a hierarchical system of classification. We have developed a model similar to that of Frissell et. al. (1986), but one specifically designed to provide both a general classification of breeding streams and to delineate specific Harlequin nesting habitat within a stream reach. Figure 1 indicates system levels, boundaries of each level, and variables that characterize habitat features within system levels. Variables in the LANDFORM, STREAM and SEGMENT systems are determined from topographic (1:63,360), geological, and vegetation maps. The lower hierarchical levels (of higher resolution) REACH, POOL/RIFFLE and MICROHABITAT are documented in the field by completing data forms shown in Tables 3 and 4.

The advantages of using a hierarchical system of classification reported by Frissell et. al. (1986) are that: 1) the number of variables to be recorded at lower levels in the hierarchy is reduced since many are already recorded in the upper levels; 2) it maintains organization of data while allowing the integration of data from a variety of sources and levels of resolution; and 3) it permits selection of the level of resolution that is most appropriate in meeting project objectives and budgets. For example, it might be determined through a principal components analysis that only the variables Substrate (of POOL/RIFFLE system level) and mainland (LANDFORM level) are necessary in predicting potential nesting streams. The presence of boulder runs at the MICROHABITAT system level (determined in the field) may predict use by Harlequin broods, but so might the presence of steep sideslopes at the SEGMENT level (determined from topographic maps) since boulders most often reach the stream channel by landslides (Frissell et. al. 1986). By determining important characteristics and levels of resolution we can construct a model to aid in the inventory of Harlequin nesting streams required in pre- and post-impact studies.

Hydrology

Oswood and Barber (1982) developed a diagrammatic mapping technique to predict habitat quality and fish abundance on streams in southeastern Alaska. They selected habitat features important to spawning adult and resident juvenile salmonids, measured the features using a flowmeter, meter-stick and meter-tape, and mapped the features to scale. Areas (m^2) were determined using planimetry or a digitizing computer. Consistency of results among work crews, logistics and time constraints were considered in the development of their technique (Oswood and Barber 1982).

We are using a variation of Oswood and Barbers' (1982) technique to record stream features important to Harlequin ducks at the MICROHABITAT system level since Harlequin hens and anadromous salmon share many habitat requirements. We measured a 30 meter stream plot adjacent to each nest site, mapping the stream characteristics listed in Table 3. Classes of stream habitat at the MICROHABITAT level are being developed from the proportion of area of each feature in the plot and tested using a Chi-square analysis for frequency of selection (Zar 1984, Neu et. al. 1974).

Vegetation

We began a detailed analysis of riparian vegetation on Harlequin nesting streams in PWS during 1991. In addition to serving as a flow regulator between ecosystems, vegetation provides protection from unfavorable weather conditions and cover from predators, both important to nesting waterfowl (Bellrose 1980, Bengtson 1972). We collected data for each of 4 tiers of vegetative characteristics at nest sites located in 1991: 1) Dominant climax species of area at nest elevation (Area); 2) plant species composition within a 30 m^2 plot around nest site (Vicinity); 3) plant species composition within a 10 m^2 plot of the nest bowl (Nest Site); and 4) plant species composition over the nest bowl (Cryptic Nest Cover). Determining percent species composition for the most abundant 3 plant species at each of the 4 levels allows us to test frequency of selection of habitat classes using a Chi-square analysis. Randomly selected 30 m^2 plots along nesting streams will be used to analyze utilization vs. availability of riparian habitat (Neu et. al. 1974, Byers et. al. 1984).

We are comparing vegetative, aquatic and topographic characteristics (listed in Tables 3 and 4) of nesting streams and an equal number of non-nesting streams using a discriminant analysis (Patten 1990) and a principal components analysis followed by stepwise regression (M. Wilms, USFWS, pers. comm., Kleinbaum et. al. 1988). These procedures will determine which characteristic, or suite of characteristics are most important to breeding Harlequins.

Coastline Surveys

During the last 2 weeks of May, 1991, approximately 350 miles of unoiled coastline and estuaries from Cordova to Valdez were surveyed for Harlequin flocks and breeding pairs. Similarly, NRDA surveyed coastline and estuaries in the EVOS area. Surveys were repeated in late June through early July in both study areas to locate and document important molting habitat, and were repeated again in August for brood documentation. We also surveyed all coastline and estuaries in Port Gravina bi-weekly throughout the season to document changing Harlequin numbers, sex ratios, molt chronology, appearance of broods and preferred habitat.

Harlequin surveys were conducted from 2 skiffs; a 22 ft fiberglass boat powered by a 225 hp outboard, and an 18 ft fiberglass boat with a 90 hp outboard. One crew member piloted the boat near the coastline, islands and offshore rocks, and in intertidal estuaries. A second researcher using 8 - 10x binoculars recorded Harlequin numbers, sex when possible, location, habitat, tide and weather conditions. To save time on extensive surveys we quickly scanned shoreline habitat known to be avoided by Harlequins, concentrating our search on more classic habitat. This method was validated by more thorough, bi-weekly Port Gravina surveys, where the occurrence of Harlequins in apparent unfavorable habitat, such as near vertical cliffs, was extremely rare.

All coastal habitat in Port Gravina was recorded on 1:63360 U.S.G.S topographic maps so that a utilization-availability test can be conducted on Harlequin use of marine habitat (Neu et. al. 1974, Byers et. al. 1984). Marine habitat was placed into the following categories:

- 1e: Boulder or bedrock islands, unvegetated, that remain exposed at high tide.
- 1s: Boulder or bedrock islands, unvegetated, that are submerged at high tide.
- 2: Uniform gravel or cobble beaches on mainland or vegetated islands.
- 3: Intertidal estuaries of permanent streams.
- 4: Rocky points off mainland or vegetated islands.
- 5: Vertical or sharply sloping cliffs.

Activity Budgets

Behavioral activities of randomly selected Harlequins were recorded every minute for a minimum of 10 minutes (Dzinbal 1982). We collected morning, afternoon and evening activities for 3 habitats: estuaries (inhabited by hens only at the time), offshore rocks and gravel beaches. Activities (conventional to capitalize) documented included RESTING, FEEDING, PREENING LOCOMOTION, ALERT, and INTERACTIONS (Dzinbal 1982). When possible, behaviors were categorized further. For example HEADNOD, RUSH and NECK STRETCH are agonistic behaviors which fall under INTERACTIONS (Inglis and Torrence 1990).

STUDY RESULTS

Habitat Analysis

5 Harlequin nests were located during June and July, 1991, on high, steep banks of mountain streams in predominantly mature and old-growth spruce-hemlock forest in eastern PWS. Table 5 provides a detailed location of each nest site. Western hemlock (Tsuga heterophylla) was much more prevelant than was Sitka spruce (Picea

sitchensis) at nest sites. Nests were concealed under Vacccinium, Rosa, fern spp. and hemlock seedlings, on southern exposed, mossy banks. Streams used by nesting hens were fast-flowing, shallow and turbulent, ranging in width at the nest site from 1.5 m to 4 m. Table 6 lists all parameters of the hierarchical system with corresponding habitat data from the 5 nest sites located in 1991. Table 7 lists characteristics and Harlequin breeding status of nesting streams investigated in 1991. For comparison, Table 8 lists the characteristics of suspected non-nesting streams. The following is a further discussion and summarization of breeding stream characteristics.

LANDFORM: Four of the five nests and 7 of 9 breeding streams (defined by presence of nests and brood sightings) were located on the mainland. Two breeding streams were identified on Hinchinbrook Island. However, much more capture and survey effort was expended on mainland streams.

STREAM: Origin of all breeding streams was non-glacial, fed by melt water and precipitation runoff. We did not determine Harlequin use of clear, tributary streams flowing into large, predominantly glacial rivers (such as the Gravina and Rude rivers) because of difficult access through braided, shallow estuaries and unnavigable river channels. We surveyed the lower 1.5 km of the Gravina River once only during a very high tide. No Harlequins were observed on the river nor on the outer estuary which was surveyed regularly. Because of the proximity of coastal mountains to the sea, most non-glacial stream lengths were relatively short, from 2 - 8 km.

SEGMENT: Valley sideslopes were categorized into Enclosing (Encl), Moderate (Mod) and Distant (Dist). Enclosing sideslopes were steep, and rose directly off the stream over most or all of its length. Moderate slopes were generally steep, but did not rise directly from the stream over most of its length. Distant sideslopes were less steep, and were far enough away so that landslides did not affect stream channel or substrate. All sideslopes are heavily forested with exposed bedrock and boulders.

Streams often flowed through deep gorges. Some stream segments contained whitewater rapids and cataracts of such intensity that it was difficult to imagine young Harlequin ducklings surviving the trip from nest to estuary much less remaining together as broods. This could partially explain why we consistently saw clutch sizes of 6 - 7 in nests upstream and broods of 1 - 3 below on estuaries.

REACH: At each nest site we measured a 30 m stream channel plot and determined percent of vegetation species, dominant substrates and hydrological characteristics. Although dense, alder/willow (Alnus crispa/Salix spp.) riparian vegetation was available, often on the opposite stream bank, nests were located on high cut, relatively open banks of hemlock forest. Alder/willow banks were lower, much more subject to flooding and received less direct sunlight because of the dense canopy. Stream banks selected by Harlequin hens were south-facing, well-drained and noticeably dry compared to surrounding rain forest type habitat. Nests were positioned 2 - 5 meters above streams; hens could launch directly into flight from nests.

Although stream banks by Harlequin hens were fairly open, nests were well-concealed under small blueberry (Vaccinium ovalifolium) or rose (Rosa acicularis) shrubs and ferns. Nests were usually positioned on moss-covered rock ledges or crevices but one hen nested on an old, mossy stump 2.0 m off the forest floor. Incubating hens held tightly when approached, usually flushing when we were within 1 m or less of the nest.

POOL/RIFFLE: All nests were located above or very near shallow (<.5 m) fast water. Stream substrate was most often gravel/cobble or cobble/boulder mix resulting in riffles and boulder runs with limited pocketwater. No salmon were observed in streams at nest sites; steeper gradients and waterfalls block passage of spawning salmon generally within 1.5 km of estuaries. The three broods observed while still on streams were in riffles with gravel/ cobble substrate.

MICROHABITAT: This will be a further dissection of POOL/RIFFLE whereby each type of aquatic habitat was measured and mapped to scale. This data will be used to determine proportion of each type within the plot. Analysis will be completed after a larger sample of plots has been obtained.

Reproduction

Harlequins ducks successfully reproduced within the Restoration Project study area in eastern PWS during 1991. We observed a minimum of 49 breeding pairs (many more were mixed in with large flocks) during Spring surveys. One copulation was observed in Olsen Bay on May 11. Average clutch size for 5 nests was 6.2 eggs/clutch. Hatching success was determined for 18 eggs in 3 clutches. All hatched except 2 eggs; 1 from a clutch of 4 and 1 from 7 (89% success). A larger sample will be required in 1992 to determine predation and abandonment. Radio transmitter loss or damage to antennae (hens were able to break off antennae near bases) did not allow relocation of radio-tagged hens with broods on estuaries during 1991 so that duckling mortality for these particular broods is unknown. Average size for 13 Harlequin broods observed in marine habitat was 3.4 ducklings/brood. See Table 9 for comparison of breeding results among this and other Harlequin studies.

A crude estimate of mortality can be calculated by 100 - (average brood/average clutch size)*100. This indicates a duckling mortality rate of 45.2% at 3 - 5 weeks of age. This is almost certainly an underestimate of mortality because loss of entire broods is not known nor included in the calculation. Improved transmitter mounting, stronger antennae and greater number of radio-tagged hens will allow us to determine loss of entire broods as well as survival of individual broods over time in 1992.

Table 10 lists data collected from radio-tagged hens. Of the 14 hens we radio-tagged in 1991, 7 nested or were suspected nesters, 5 did not or were suspected not to breed, 1 possible breeder was killed and devoured by an unidentified predator, and 1 hen was never relocated after capture, possibly because of radio failure or loss. This indicated a minimum hen breeding frequency of approximately 50%.

In contrast to our findings of successful Harlequin reproduction in eastern PWS, extensive boat surveys of estuaries and 121 hours of mist-netting of potential nesting streams revealed a failure of Harlequins to reproduce in the EVOS area. Mated pairs common in eastern lagoons and estuaries were not observed in the EVOS area, nor was nest-prospecting by hens. One brood was observed in the EVOS area in 1991 (Patten, pers. comm.) It was seen on marine habitat in the Bay of Isles in mid-September, 1 month later than when broods of similar age class began appearing in eastern PWS. Four broods were observed on the periphery of the oil spill area (Patten, pers. comm.). No broods were documented in the EVOS area in 1990.

Coastline Surveys

We counted 572 Harlequin ducks during Spring surveys, including 49 pairs, 103 females, and 124 males (our ability to discern between males and females at a distance improved with time). Pairs were observed more often on or near estuaries than were singles. Nearly all Harlequins observed in eastern PWS were on offshore rocks (types 1e and 1s), rocky points (4) or intertidal estuaries.

Preliminary results of mid-season surveys indicate a preference of 1200 Harlequins in 55 molting flocks for rocky points interspersed with gravel/cobble beach and offshore rocks near such beaches. Use of this habitat was much greater than would be predicted by random use of available habitat. Molting areas were along seaward exposed beaches with protection from storms offered only by the rocks themselves. These findings were similar to those of Dzinbal (1982). Loafing rocks generally were 50 - 100% covered with *Fucus* and 25% - 50% barnacle coverage. Molting areas in eastern PWS appeared rich in other fauna and flora and occurred in fairly shallow water (which is auto-correlated with emergent, offshore rocks), generally less than 15 m deep. Seemingly identical habitat in Port Fidalgo, except that seaward exposure was limited to 1.5 km or less of reach, was nearly devoid of Harlequins. We speculated that areas of exposed coastline had stronger currents or upwellings that carried in deep-water nutrients, than did ports and bays of limited seaward reach.

We located 14 broods of Class 2a - 3 during late August surveys on marine habitat in 1991 (Table 11), all of which were on or very near estuaries of breeding streams. Two broods were observed on stream habitat in July.

Activity Budgets

Preliminary results indicate that male molting flocks on outer rocks and gravel beaches spend much of the day resting or preening. Feeding occurs most often in the morning. Harlequin males fed together in small flocks in shallow (1 - 10 m) water. Dive times averaged 29.3 seconds, resting time 22 seconds, and feeding bouts approximately 35 minutes. Feeding areas of molting flocks were within a short swim (50 m) of favorite loafing rocks or gravel spits. The few agonistic displays between molting males that were recorded occurred over occupation of particularly favorable loafing spots; usually rounded, Fucus-covered rocks barely emerged above the tide.

Hen flocks (6 - 16 ducks) present in estuaries from mid-July through August, fed much more than did molting male flocks in their respective habitat. Harlequin hens fed vigorously in fresh water among spawning pink salmon, staying just ahead of the high tide line. A typical feeding bout lasted 15 - 30 minutes. Dives lasted .5 - 2 seconds in water less than .5 m deep. Hens fed by swimming about in riffles "PEERING" repeatedly (submerging bill and eyes beneath the surface) above spawning salmon. When food items were located after much peering, hens made repeated dives to the stream bed, diving to the same spot each time. These small feeding areas (<1 m^2) were temporarily defended against other feeding hens approaching within .5 - 1 m. Intruders were driven off with a RUSH, NECK STRETCH, PECK and a high pitched SQUEAK. Feeding was also accomplished at the surface by skimming and below the surface by tipping-up.

Dzinbal (1982) and Dzinbal and Jarvis (1982) determined that waste salmon roe is nutritionally important to coastal-nesting Harlequins. From our observations we believe that Harlequins were also feeding directly from salmon redds possibly as eggs were being laid. This would explain the hens' sudden interest in and temporary defense of small feeding spots on the stream bed among spawning salmon. Often a hen diving repeatedly at a site would suddenly rush to the surface and "run away" for 1 - 2 meters. Although we could not determine conclusively why these sudden escapes were performed because of limited visibility among spawning fish, hens were possibly being driven off redds by defensive male salmon.

Harlequin hens loafed on emergent rocks and on the stream bank. The grassy bank, well trampled by brown bears (Ursus arctos), offered good visibility to roosting hens. Hens sat close together, often in physical contact, along the bank without agonistic behavior as displayed by roosting males. ALERT behavior was telegraphed among hen flocks with HEAD UP and EXTREME HEAD UP. Disturbed harlequins were able to leap directly into flight with less than 1 meter of bank elevation.

STATUS OF HARLEQUIN RESTORATION

A. We located 9 harlequin nesting streams identified by actual capture of nesting Harlequin hens or by observations of broods on estuaries. Vegetative, hydrological and topographical characteristics of each stream were described using the hierarchical model. We require a larger sample size of nest sites, nesting streams, and non-nesting streams to statistically test selection of habitat in order to determine conclusively nesting habitat requirements. We have identified up to 26 suspected non-nesting streams, presented in Table 9. It is unknown, however, if marginally adequate streams may be used intermittently as Harlequin populations fluctuate. For example, Harlequin broods were reported on East and West Olsen Creeks (which share an estuary) in 1990, and we observed the early-Spring use of the estuary by 2 breeding pairs in 1991. After 65 net-hours of capture effort we observed only limited nest prospecting by breeding Harlequins, no nesting and no broods. It is possible that our presence caused breeding hens to nest elsewhere. Classification as non-nesting streams should be made tentatively after the second season of trapping and brood surveys.

B. We documented hydrological, vegetative and topographical characteristics at five nest sites. One nest was constructed during the previous breeding season, was located approximately 10 m from a current nest and was almost certainly used by that same hen since Harlequins are highly philopatric (Wallen 1987).

C. We recorded other breeding parameters of Harlequins including distance to the coast, distance from the stream and physical features of 5 nest sites.

D. We have developed a working hierarchical structure in which to describe breeding habitat. A larger sample size is required before statistical tests can be applied (see A. above).

E. We have obtained limited data on productivity including clutch size for 5 nests, observation of 14 broods on marine habitat (productivity indicator for Harlequins) and female breeding frequency of approximately 50%. An increase in overall sample size will improve accuracy of our current data. Our data thus far are similar to those reported in the literature (Table 9).

F. Documented sightings of Harlequin duck breeding behavior including courtship, copulation, nest prospecting, location of 5

Harlequin nests and 16 broods in eastern PWS during 1991 indicate that Harlequins successfully reproduced in the restoration study area in 1991. Harlequins essentially failed to reproduce in the EVOS area in 1990 - '91.

G. Petts (1990) stated that the most important parameter to be determined for effective management of land-water ecotones is the minimum size (i.e. width) required to sustain both riparian habitat and function of this habitat as a flow regulator between systems. Petterjohn and Correll (1984) reported that 50 m of riparian forest habitat removed most of the excess nutrients and pollutants from overland and throughflow water in an agricultural watershed. Cassirer and Groves (1990) observed Harlequin broods more often on undisturbed streams away from roads and human activity in National Forests of northern Idaho. They also coincidentally recommended a 50 m undisturbed riparian corridor, visual isolation, and limited human activity during the breeding season to minimize impacts of timber harvest.

We located Harlequin nests within 25 m of streams or small tributaries to streams. Current required buffer strips of 28.8 m may provide enough nesting habitat, but would not visually isolate nesting hens from human disturbances associated with logging. Buffer strips are only required on anadromous fish streams; 3 of the five nests located in 1991 were on very small tributaries (1 - 1.5 m wide, .25 m or less deep) where buffer strips would not be required. We tentatively conclude that 50 m buffer strips would adequately protect Harlequin nesting habitat but believe that human and machinery disturbances associated with logging would be a much more serious hindrance to reproducing Harlequins than would lack of nesting habitat. Harlequin ducks in Iceland, Greenland, North Slope of the Brooks Range, Siberia and Aleution Islands do not nest in old growth forest, but do require adequate streamside vegetation ranging from dwarf birch (Betula nana) to Salix spp (Bengtson 1972, Bellrose 1980).

Most streams within the Two Moon timber sale in Port Fidalgo were probably not used by breeding Harlequins, although 2 pairs were present in Two Moon Bay in late May. Irish Creek (Irish Cove, adjacent to Two Moon Bay) appeared of adequate size for breeding Harlequins but an ADF&G Commercial Fisheries crew monitoring a wier site was present all summer. This could potentially have caused enough disturbance to discourage breeding Harlequins from nesting on the stream.

The identification of Harlequin habitat requirements by this project is an important first step toward management of riparian ecotones within timber sales in PWS. The inventory of breeding streams and identification of nesting and brood rearing habitat on those streams will providing a model to aid in identification of potential nesting streams in western PWS and in other coastal Harlequin populations. The detail with which we document vegetation and hydrology at the Microhabitat, Pool/riffle, and Reach levels will be highly useful in determining specific areas of vulnerability to impacts of timber harvest (Desaigues 1990). This effort, combined with surveys for estimating population size and productivity, will also provide a record of pre-harvest conditions that will be valuable in post-impact assessment of habitat condition and population trends (Cassirer and Groves 1990, Oswood and Barber 1982). Subsequent management decisions based on this information can be applied to western PWS, Southeast Alaska in areas of extensive timber harvest, and the northeastern coast of North America where in 1990 the Harlequin duck was placed on the list of endangered species by the Canadian Wildlife Service.

LITERATURE CITED

Bellrose, F. C. 1980. Ducks, geese, and swans of North America. Stackpole Books. Harrisburg, PA.

Bengston, S. -A. and S. Ulfstrand. 1971. Food resources and breeding frequency of Harlequin ducks in Iceland. Oikos 22:2.

----- 1966. Field studies on the Harlequin duck in Iceland. Wildfowl Trust 17th Annual Report: 79-84.

----- 1972. Breeding ecology of the Harlequin duck. Ornis Sand. 3:1 pp 1-9.

Byers, C. R, R. K. Steinhorst, and P. R. Krausman. 1984. Clarification of a technique for analysis of utilization-availability data. Wildl. Soc. Bull.

Desaigues, B. 1990. The socio-economic value of ecotones. IN: R.J. Naiman and H. Decamps eds. The ecology and management of aquatic-terrestrial ecotones. Parthenon Publishing, New Jersey. pp. 263-301.

Cassirer, E.F. and C. R. Groves. 1990. Distribution, habitat use and status of Harlequin ducks (*Histrionicus histrionicus*) in northern Idaho, 1990. Nat. Her. Section, Nongame and Endg. Wildl. Prog., Bureau of Wildl. Idaho Dept. Fish and Game.

Cole, G. A. 1983. Textbook of limnology. Waveland Press, Inc. Prospect Heights, IL. 401 pp.

Dzinbal, K. A. and R. L. Jarvis. 1982. Coastal ecology of Harlequin ducks in Prince William Sound, Alaska, during summer. IN: Marine birds: their feeding ecology and commercial fisheries relationships. D. A. Nettleship, G. A. Sanger, and P. F. Springer, eds. Proc. Pacific Seabird Group Symp., Seattle WA., Can. Wildl. Serv. Spec. Publ.

Dzinbal, K. A. 1982. Ecology of Harlequin ducks in Prince William Sound, Alaska, during summer. M.S. Thesis, Oregon State University, Corvallis. 89 pp.

Frissell, C. A., W. J. Liss, C. E. Warren and M. D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environ. Manage. 10(2):199-214.

Gilmer, D. S., I. J. Ball, L. M. Cowardin and J. H. Riechmann. 1974. Effects of radio packages on wild ducks. J. Wildl. Manage. 38(2):243-252.

Greenwood, R. J. and A. B. Sargeant. 1973. Influence of radio packs on captive mallards and blue-wing teal. J. Wildl. Manage. 37(1):3-9.
Inglis, I., R. J. Lazarus, and R. Torrence. 1990. Pre-nesting behavior and time budget of the Harlequin duck. Wildfowl 40:55-71.
Isleib, M. E. and B. Kessel. 1973. Birds of the North Gulf Coast-Prince William Sound Region, Alaska. Univ. Alaska Biol. Papers No. 14. 149 pp.
Karlstrom, T. N. V. 1964. Surfacial geology of Alaska. U. S. Geological Survey, Dept. Interior, Washington, D. C.
Kleinbaum, D. G., L. L. Kupper, and K. E. Miller. 1988. Applied regression analysis and other multivariable methods. 2nd ed. Kent Publishing Co. Boston.
Klett, A. T. and D. H. Johnson. 1982. Variability in nest survival rates and implications to nesting studies. The Auk. 99:77-78.
Koehler, G. M., W. R. Moore, and A. R. Taylor. 1975. Preserving the marten: management guidelines for western forests. Western Wildlands. 2: 31-36.
Korschgen, C. E., S. J. Maxon, and V. B. Kuechle. 1984. Evaluation of implanted radio transmitters in ducks. J. Wildl. Manage. 48(3):982-987.
Kuchel, C. R. 1977. Some aspects of the behavior and ecology of Harlequin ducks breeding in Glacier National Park, Montana. M. S. Thesis. Univ. Montana. 130 pp.
Lotspeich, E. B. and W. S. Platts. 1982. An integrated land-aquatic classification system. N. Amer. J. Fisheries. Manage. 2:138-149.
Neu, C. W., C. R. Byers and J. M. Peek. 1974. A technique for analysis of utilization-availability data. J. Wildl. Manage. 38(3):541-545.
Osborne, L. L. and M. J. Wiley. 1988. Empirical relationships between land use/cover and stream water quality in an agricultural watershed. J. Environ. Manage. 26: 9-27.
Oswood, M. E. and W. E. Barber. 1982. Assessment of fish habitat in streams: goals, constraints and a new technique. Fisheries 7(3):8-11.
Patten, S. M. 1990a, unpublished. Injury assessment of hydrocarbon uptake by sea ducks in Prince William Sound and the Kodiak Archipelago, Alaska. Draft, Preliminary NRDA Status Report. Bird Study No. 11. Alaska Dept. Fish and Game. Anchorage, AK.
----- 1990b. Prince William Sound Harlequin duck breeding habitat analysis. Bird Study Number 11. Alaska Dept. Fish and Game. Anchorage, AK.
----- 1991. unpublished. Injury assessment of hydrocarbon uptake by sea ducks in Prince William Sound and the Kodiak Archipelago, Alaska. Draft, Preliminary NRDA Status Report. Bird Study No. 11. Alaska Dept. Fish and Game. Anchorage, AK. 75 pp.
Perry, M. C. 1981. Abnormal behavior of canvasbacks equipped with radio transmitters. J. Wildl. Manage. 45(3):786-789.
Petterjohn, W. T. and D. L. Correll. 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a

riparian forest. Ecology 65(5):1466-1475.

Petts, E. G. 1990. The role of ecotones in aquatic landscape management. IN: R.J. Naiman and H. Decamps eds. The ecology and management of aquatic-terrestrial ecotones. Parthenon Publishing, New Jersey. pp. 263-301.

Quinlan, S. E. and J. H. Hughes. 1990. Location and description of a marbled murrelet tree nest site in Alaska. Condor 92:1068-1073.

Risser, P. G. 1990. The ecological importance of land-water ecotones. IN: R.J. Naiman and H. Decamps eds. The ecology and management of aquatic-terrestrial ecotones. Parthenon Publishing, New Jersey. pp. 301-320.

Sorenson, M. D. 1984. Effects of neck collar radios on female redheads. J Field. Ornithol. 69(4):523-528.

Wallen, R. L. 1987. Habitat utilization by Harlequin ducks in Grand Teton National Park. M. S. Thesis, Montana State Univ. Bozeman, MT

Weller, M. W. 1956. A simple field candler for waterfowl eggs. J. Wildl. Manage. 20(2):11-13.

Wiens, J. A., C. S. Crawford and J. R. Gosz. 1985. Boundary dynamics: a conceptual framework for studying landscape ecosystems. Oikos 45: 421-427.

Zar, J. H. 1984. Biostatistical analysis. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Table 1. Characteristics of 9 known breeding streams selected by Harlequin hens for nesting and brood-rearing in Prince William Sound, Alaska.

Stream Characteristics[a]
10 - 30 m wide at mouth
Extensive intertidal areas in estuary
Moderate gradient
Discharge rate: 1.5 - 7.0 cu. m/sec
Depth .3 - .5 m
Elevation at onset: 750 ft
Clear, not turbid
Substrate: large stones, boulders
Stream length: 5 - 8 km
Forest: Mature Spruce-hemlock
Spawning salmon species: Pink, Chum

[a]From Patten (1990b)

Table 2. Data collected from captured Harlequin Ducks in Prince William Sound, Alaska, 1991.

CAPTURED HARLEQUIN DUCK DATA FORM

Harlequin Duck Restoration Project, Prince William Sound, Alaska

Bird #:______________

IDENTIFICATION

Sex: F M
Age: AHY FY AFY
Unknown
USFWS
Band#:______________
Species: ____________
(if not HARL)

LOCATION

Stream: ____________
Bay: ____________
Estuary: Y N
Roosting: Y N
Sbstrt: BE BO CO SA
SO LI VE
Comment:

PLUMAGE

Coverts: Trapezoid
Rounded
Tail tips: Pointed
Forked
Worn
Brood Patch: Y N
Appearance: G Poor
Oiled

CAPTURE CONDITIONS

Time:______________
Date:______________
Sky: CLD PTCL CLR
Precip: NONE FOG MIST
DRZL RN SNW
Tide: INCO OUTG HIGH LOW

CAPTURE METHOD

Mist Net
Net Gun
Decoy Trap
Comment:

MEASUREMENTS

Weight:__________g
Tarsus:__________mm
Left or rght
Culmen:__________mm
Wingcord:__________mm
Left or rght
10th Prm:__________mm

BIRD CONDITION

Cloaca distended: Y N
Keel Depth: None Slight
Comments:

RADIO TELEMETRY

Frequency:
Date/Time released:
Behavior after release:

BLOOD SAMPLES

Taken: Y N
I.D.#:

COMMENTS:

Table 3. Aquatic data collected at Harlequin nest sites in Prince William Sound, Alaska in 1991.

HARLEQUIN DUCK NESTING HABITAT: STREAM DATA FORM

Harlequin Restoration Project, Prince William Sound, Alaska

DATE:	BROOD SIZE:
TIME:	HEN I.D.#:
LOCATION:	FREQ:

Mark location on map

MAP TO SCALE 30 m STREAM PLOT[a]: 1 at nest site, 2 random w/in .5 km

STREAM CHARACTERISTICS		DESCRIPTIONS
TA	Total Area	Measure of stream size since length is constant
SS	Shallow Fast	Area of water <.5m deep, velocity <.3m/s.
SF	Shallow Fast	Area of water <.5m deep, velocity >.3m/s.
DS	Deep Fast	Area of water >.5m deep, velocity <.3m/s.
DF	Deep Fast	Area of water >.5m deep, velocity >.3m/s.
BR	Boulder Run	Area of DF water with boulder induced turbulence.
FD	Forest Debris	Area of logs, branches in and over streams.
RV	Ripariation Veg	Area of over-hanging vegetation.
UN	Undercut Bank	Area of undercut stream bank.
PW	Pocketwater	Area of SF or DF water creating small pools.
BW	Backwater	Area of slack water off main stream channel.
FA	Falls	Area of waterfalls > 1m high, include plungepools.
LO	Loafing Sites	Number emergent, slightly submergent boulders.

STREAM VARIABLES[b]

SUBSTRATE

BE Bedrock
BO Boulder (>30cm)
CO Cobble (8-30cm)
GR Gravel (.2-8cm)
SA Sand
SI Silt

CHANNEL TYPE

ME Meander
BR Braided
ST Straight
CU Curved

TURBIDITY

CL Clear
ST Slight turbid
TU Turbid

ORGANISMS

Salmon present: Y N
Species:
Spawning: Y N

HYDROLOGY

Stream length:
Dist. to estuary:
Width at nest site:
Discharge at mouth:

TOPOGRAPHY

Gradient:
Altitude at origin:
Aspect:
Stream order:

COMMENTS:

[a]Compiled, in part, from Oswood and Barber (1982).
[b]Compiled, in part, from Cassirer and Groves (1990).

Table 4. Terrestrial data collected at Harlequin nest sites in Prince William Sound, Alaska in 1991.

HARLEQUIN DUCK NESTING HABITAT: TERRESTRIAL DATA FORM*

Harlequin Restoration Project, Prince William Sound, Alaska

DATE: BROOD SIZE:
TIME: HEN I.D.#:
LOCATION: FREQ:
Mark location on map

NEST SITE HABITAT: Complete 1 for 30 m, 1 for 10 m plots.

NEST SUBSTRATE

BE Bedrock
BO Boulder (>30cm)
CO Cobble (8-30cm)
GR Gravel (.2-8cm)
SA Sand
SI Silt
LI Litter/vegetation

LANDFORM

MN Mainland
IS Island
PE Peninsula
SB Streambank
- UN Undercut
- VE Verticle
- SL Sloping

FL Floodplain

NEST BOWL MATERIAL

GS Grasses
DO Down
VE Vegetation

UNDERSTORY (ht<1m)

Sp1:________________%______
Sp2:________________%______
Sp3:________________%______
Veg Density: HE MOD SP

OVERSTORY (ht>1m)

Sp1:________________%______
Sp2:________________%______
Sp3:________________%______
HEV MOD SPARSE

CRYPTIC NEST COVER

RO Rock crevice
TR Tree cavity
DF Deadfall
VE Vegetation
% Species:

Measure Distance To:
STREAM:___________
FOREST:___________
HARVEST:___________

AREA HABITAT

SPRUCE-HEMLOCK FOREST

(specify if not S-H)

OG Old growth
MA Mature
IM Immature
PO Pole
SA Sapling
SE Seedling

HARVEST STATUS

UN Unharvested
RH Recent (<10 yr)
OH Old harvest (>10yr)
SG Second growth
BU Buffer width:
CL Clear-cut no buffer

BANK COMPOSITION

(list species and % on back)

TR Trees
SH Shrubs
TS Tree/shrub mosaic
GF Grass/forb
DE Debris
SA Sand
SI Silt
GR Gravl/cobbl/bould
BE Bedrock
RO Roots

TOPOGRAPHY: Altitude:______ Slope:______ Aspect:_______

*Compiled, in part, from Cassirer and Groves (1990).

Table 5. Locations of 5 Harlequin duck nests on coastal, mountain streams in Prince William Sound, Alaska in 1991.

Hen I.D.#	Stream Name	Location	Alaska Stream Catalog Number	Latitude[a] Longitude	Elevation
EPWS0891[b]	Beartrap	Beartrap Bay Port Gravina	221-30-10480	60°46'30" 146°28'00"	220 m
EPWS1991	East Cove	Jack Bay Valdez Arm	221-50-11230	61°00'30" 146°34'45"	100 m
EPWS2091	East Cove	Jack Bay Valdez Arm	221-50-11230	61°00'15" 146°34'15"	175 m
E[illegible]2191	Hinchinbrook (near Nuchek)	Port Etches Hinchinbrook Island	None	60°15'30" 146°28'00"	220 m

[a]Determined from 1:63369 USGS topographic maps.
[b]Two nests were found at this location, 1 current and 1 from a previous breeding season. Because Harlequins are highly philopatric, these were presumably constructed by the same hen.

Table 6. Hierarchical description of Harlequin duck breeding streams and habitat from 5 nests located in 1991 in Prince William Sound, Alaska.

System Level			# Nests	# Broods	# Streams
LANDFORM	Mainland		4	13	6
	Peninsula		0	1	1
	Island		1	1	2
STREAM	Origin	Glacial:	0	0	0
		Runoff:	5	15	9
	Topography	Slope:	4 - 13%, Mean 8%		
		Aspect:	5 SW, 2 E, 1 NW, 1 W		
		Length:	2.0 - 8.5 km, Mean 5.0 km		
	Geology		"Dominantly coarse, rubbly deposits associated with steep-sloped mountains with high percentage of exposed bedrock" (Karlstrom et. al. 1964).		
SEGMENT	Stream order[a]:		1 - 3, Mode 2		
	Valley sideslopes:		7 Enclosing, 2 Moderate		
	Stream discharge at mouth:		1.5 - 7.0 cu.m/sec[b]		
	Stream width at mouth:		1.5 - 10 m, Mean 6.4		
	Climax vegetation:		Mature to old growth coastal Spruce-Hemlock forest		
REACH	Channel slope:		5.3 - 30%, Mean 17.4%		
	Channel pattern:		Straight or curved, no meanders		
	Bank vegetation:		Tree shrub mosaic to trees only		
	Bank configuration:		Sloping (45 - 90°), 1 - 5 m high		
	Nest site vegetation:		Western hemlock, Vaccinium		
	Cryptic nest cover:		Vaccinium or hemlock seedlings		
	Distance to coast:		1.25 - 2.75 km, Mean 2.15 km		
	Nest to stream:		1.5 - 22 m. 2 m most common.		
POOL/RIFFLE	Fish species:		No fish near nest sites		
	Dominant hydrology:		Shallow fast		
	Stream width at nest:		1.5 - 5 m		
	Dominant substrate:		Gravel and cobble		
MICROHABITAT	Proportion of each substrate type listed in Table 4.				

[a] Rating of size based on number of tributaries contributing to segment (Cole 1983).
[b] From Table 1 (Patten 1990b).

Table 7. Harlequin duck breeding streams, identified by trapped hens or presence of broods, investigated in Prince William Sound, Alaska during 1991.

STREAM NAME	A.S.C.[a] #	LENGTH Km	% SLOPE	BASIN ASPECT	WIDTH(m) AT MOUTH	LAND FORM	SIDE SLOPES	# TIMES SURVEY[b]	# NET HOURS	# HENS TRAPPED	# NESTS FOUND	# BRDS
Beartrap	10480	7.0	8	SW	10	Main	Encl	25	47	5	2	3[c]
Constantine	18150	8.5	4	SW	unkw	Isl	Encl	1	0	0	0	1
Duck	11160	2.0	7	SW	7	Main	Encl	6	0	0	0	1
East Jack Cove	11230	3.5	6	NW	4	Penn	Encl	12	18	2	2	2
Fish Bay	10950	3.5	13	E	4	Main	Mod	3	0	0	0	2
Hinchinbrook	none	2.0	11	SW	1.5	Isl	Encl	2	0	0[d]	1	N/A
Rain	10450	6.0	7	W	4	Penn	Mod	14	9	0	0	2
Sheep	10360	7.0	6	SW	10	Main	Encl	10	22	3	0	3[c]
Stellar	11530	6.0	11	E	8	Main	Encl	14	53.5	3	0	2
	MEAN:	5.0	8		6.4			TOTAL:	149.5	13	5	16
	STDEV:	2.4	2.9		3.1							

[a]Alaska Stream Catalog number.
[b]Number of times each stream was surveyed, an index of effort. Visits range in duration from 3 minutes to 10 hours.
[c]One of these broods was sighted on the stream so is not included in productivity calculations.
[d]This hen was captured twice on Nuchek Creek though the streams do not meet except at low tide in the outer estuary. She apparently used the larger Nuchek to travel into the hills, then flew several hundred meters through or above the forest to the nest site on Hinchinbrook creek.

Table [illegible] Coastal streams determined not to be u[illegible] by breeding Harlequin ducks during 199[illegible] Prince William Sound, Alaska through surveying and trapping at stream mouth.

STREAM NAME	A.S.C. #	LENGTH Km	% SLOPE	BASIN ASPECT	WIDTH(m) AT MOUTH	LAND FORM	SIDE SLOPES	# TIMES SURVEYED	NET HOURS	HARLEQUIN SIGHTINGS
St. Matts	221-30-10560	3.5	13	SW	4	P	M	19	23	none
East Olsen	221-30-10516	7.5	12	S	4	M	M	25	32	1 pair, 1 hen,
West Olsen	221-30-10517	5.5	9	S	5	M	M	25	35	2 pr nearby, Spring
Control	221-30-10520	5	13	SE	4	P	M	22	24	Aug. hen flock; 13
West Cove	221-40-11212	5	13	N	4	P	E	5	4	6 pr nearby, Spring
2 Moon	221-40-10735	2	2	N	3	P	D	5	10	4 pr nearby, Spring
Irish	221-40-10760	4	7	N	5	P	D	5	0	none
Whalen	221-40-10800	7	13	W	8	P	D	5	0	1 pr in bay, Spring
Surf	221-20-10380	7	9	SE	3	P	D	8	0	2-6 near all summe
Close Sheep	221-20-10370	4	13	SE	2	P	E	3	0	molting flock nearb
GravinaRock	221-30-10410	4.5	4	NW	2	P	D	10	0	molting flock nearb
'Ganzer	221-30-10430	2	22	NW	1.5	P	E	10	0	molting flock nearb
RottenHumpy	221-30-10440	2.5	23	NW	2	P	E	10	0	molting flock nearb
StMattSeep	221-30-10540	5	13	S	2	P	M	9	0	none
SahlinFalls	none	4.5	20	SE	4	M	E	6	0	none
Comfort	221-30-10460	4	17	W	5	P	M	11	0	1 hen, mid-late Aug
Koppen	221-20-10350	5.5	20	SW	3	M	M	7	5	none
Gravina	221-20-10450	15	9	W	15	M	D	5	0	none
Nuchek	228-60-18120	8.5	5	SW	4	I	D	3	11.5	1 hen captured[a]
East Nuchek	228-60-18110	4.5	5	SW	2	I	D	1	3	none
Native	221-30-10470	3.5	9	W	4	M	M	10	0	3-4 near all summer
Indian	221-50-11170	6.5	18	S	7	P	M	4	5	none
LittleShark	221-30-10420	0.5	8	NW	1.5	P	M	9	0	molting flock neart
Little Ole	221-30-10513	1.5	29	S	2	P	M	9	0	molting flock neart
West Olsen	221-30-10530	1.5	38	E	1.5	P	E	9	0	none
Little Bear	221-30-10490	1.5	21	SW	1.5	M	E	9	0	none
	MEAN:	4.7	14		3.8			TOTAL:	150	
	STDEV:	2.9	8		2.8					

[a]This hen nested on Hinchinbrook Creek, Table 8.

Table 9. Summary of Harlequin duck breeding productivity in northeastern Prince William Sound, Alaska during 1991 and comparison to other Harlequin populations[a].

Investigator	Year	Location	%Male Sex Ratio	Mean Clutch Size	Hatch Success	Mean Fldged Brood Size	% Duckling Mort
This study	1991	PWS, AK	55	6.2	89%	3.4	>45
Dzinbal	1982	PWS, AK	60	---	---	2.5	---
Bengtson	1972	Iceland	56	5.7	87%	2.8	45
Kuchel	1974	Wyoming	62	---	---	3.9	---
Wallen	1987	Montana	50	---	---	---	---
Cassirer	1990	Idaho	---	---	---	3.0	---

[a]The estimates presented are intended only as a comparison of production amoung studies and were not necessarily derived using the same method or parameters.

Table 10. Harlequin hens captured and radio-tagged in northeastern Prince William Sound during 1991.

Hen I.D. #	Brood Patch	Disten Cloaca	Capture Date	Nest Located Date	Stream Name	Breeding Status[a]	Approx. Hatch Date	Clutch Size	Radio Locations: Date and habitat[b]
01	No	N/A	6/2	N/A	Beartrap	Unknwn	N/A	N/A	Mortality 6/6-S
05	No	Yes	6/5	No	Beartrap	Nonbrd	N/A	N/A	7/1, 7/2, 7/9, 7/11-M
08	Yes	N/A	6/5	7/6	Beartrap	Breeder	7/6	7	7/7-S; 7/9-M
09	Yes	Yes	6/6	No	Beartrap	Breeder	Unkwn	Unkwn	7/17-M
10	N/A	N/A	6/6	No	Beartrap	Nonbrd	N/A	N/A	7/1, 7/9-M
13	Yes	Yes	6/11	No	Sheep	Breeder	7/7	Unkwn	7/9, 7/10-S
14	No	No	6/11	No	Sheep	Nonbrd	N/A	N/A	7/9, 7/17-M
15	Yes	N/A	6/12	No	Sheep	Breeder	7/8	Unkwn	7/7, 7/10-S; 7/9-M
16	Yes	N/A	6/19	No	Stellars	Nonbrd	N/A	N/A	6/25, 8-8-M
17	No	No	6/20	No	Stellars	Nonbrd	N/A	N/A	6/22-S; 6/29-M
18	No	Yes	6/21	No	Stellars	Unkwn	N/A	N/A	None
19	No	Yes	6/20	6/25	East Cove	Breeder	7/4	7	8/6-S; 8/8-M
20	Yes	No	6/24	6/27	East Cove	Breeder	7/10	4	8/5-S
21	Yes	Yes	7/2	7/3	Hinchinbrook	Breeder	7/6	6	N/A

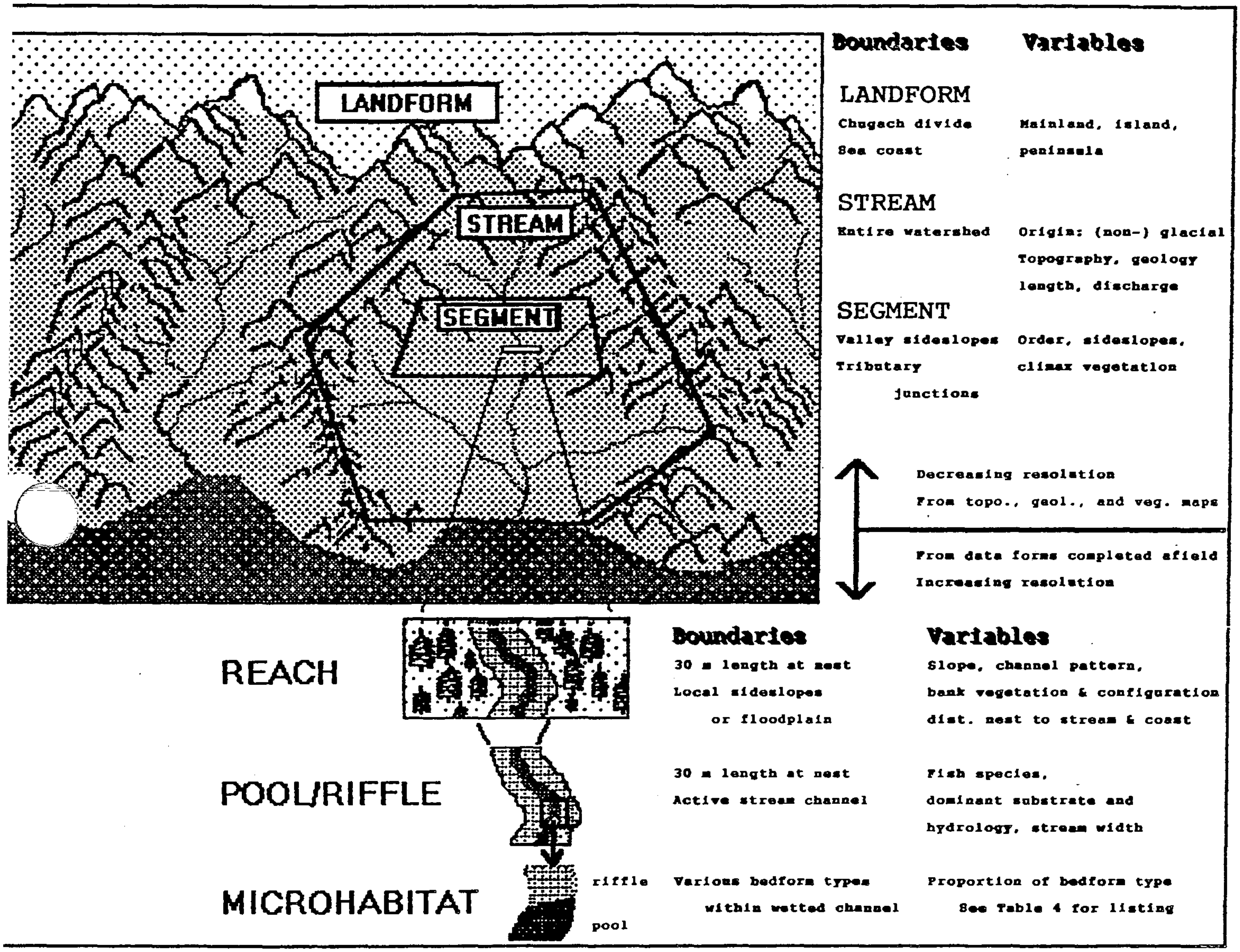
[a] Breeding status was determined when nests were not located by a combination of factors including presence of brood patch, distended cloaca, and subsequent relocations.

[b] Habitat: S = upstream, assumed to be at nest site; M = marine, including estuaries.

Table 11. Brood observations recorded during 1991 in Prince William Sound, Alaska.

Location	A.S.C	Date	# Young	Age Class	Habitat	Hen ID#
Beartrap	10480	7/7	7	Ia	Nest Bowl	EPWS0891
Beartrap	10480	8/14	2	IIa	Estuary	N/A
Beartrap	10480	8/18	1	IIc	Estuary	N/A
Constantine	18150	8/7	8	IIa	Estuary	N/A
Duck River	11160	8/4	1	Ic	Estuary	N/A
Fish Bay	10950	8/19	2	IIc	Estuary, Bay	N/A
Fish Bay	10950	8/19	4	IIIa	Estuary, Bay	N/A
Jack Bay	11230	8/20	4	IIc	Estuary	N/A
Jack Bay	11230	8/20	6	IIb	Estuary	N/A
Rain	10450	8/22	1	IIc	Estuary	N/A
Rain	10450	8/22	2	IIIa	Estuary	N/A
Sheep	10360	7/10	2	Ia	Stream riffle	EPWS1391
Sheep	10360	8/15	3	IIc	Estuary	N/A
Sheep	10360	8/15	4	IIIa	Estuary	N/A
Stellar	11530	8/20	2	IIc	Estuary	N/A
Stellar	11530	8/20	5	IIb	Estuary	N/A

gure 1. Diagram of hierarchical system levels for description and classification of stream habitat in Prince William Sound.



6. Feeding Ecology and Reproductive Success of Black Oystercatchers in Prince William Sound

1991
#6

1991 Restoration Project Report

<u>Title</u>: Feeding Ecology and Reproductive Success of Black Oystercatchers in Prince William Sound

<u>Lead Agency</u>: U.S. Fish and Wildlife Service, Marine and Coastal Bird Project, Anchorage, Alaska

<u>Principal Investigator</u>: Brad Andres, Ohio Cooperative Fish and Wildlife Research Unit 1735 Neil Avenue Columbus, OH 43210

co-investigator: Maureen DeZeeuw, U.S. Fish and Wildlife Service, Marine and Coastal Bird Project, Anchorage, Alaska

<u>Project Supervisor</u>: Kent Wohl, U.S. Fish and Wildlife Service, Marine and Coastal Bird Project, Anchorage Alaska

November 1991

Executive Summary

Studies of black oystercatchers (Haematopus bachmani) were conducted on Green and Montague Islands in 1989 and extended to Knight Island in 1991. The focus of this research has been 3-fold: 1) contrast measures of reproductive success between oil impacted and oil non-impacted sites, 2) determine habitat requirements of breeding oystercatchers and 3) explore how the feeding strategy of oystercatchers may effect populations of invertebrate prey species.

Effects of oiling on the reproductive success of oystercatchers were manifested in several ways. The relative egg volume of clutches on impacted sites was substantially lower than clutches on non-impacted sites. While hatching success, fledging success and productivity were essentially invariant among sites, weight gained by chicks on impacted nest-sites was significantly lower than chicks on non-impacted sites. However, the biomass delivered to chicks at impacted sites was significantly greater than the biomass presented at non-impacted sites. Thus, differences in food quality may be driving the differences in growth rates. Indeed, mussel mortality was significantly higher on Green than on Montague in 1989 and persistent contamination of mussel beds is possibly being transferred to oystercatchers . Direct disturbance by beach-cleaning procedures significantly reduced oystercatcher productivity on Green Island (1990).

Density of breeding oystercatchers on Green/Montague Island was 10x the density on Knight Island. The steep, rocky coast of Knight Island vastly differed from the gradual, gravelly shores of Green/Montague Island. Higher nest mortality was incurred on smooth, basaltic nest substrates than on coarse, gravelly substrates. Knight Island oystercatcher pairs that nested in proximity to arctic terns had a much greater chance of fledging young (63%) than pairs that nested alone (4%). Despite high human disturbance, Herring Bay pairs had unusually high fledging success. Preliminary counts indicate that numbers of oystercatcher predators in Herring Bay were similar to other sites.

Recovery of oystercatchers on Green Island is most likely occurring. The number of breeding oystercatcher pairs increased 50% between 1989 and 1991. On Montague, however, the number of breeding pairs stayed constant. Whether the low density and low productivity found on Knight Island in 1991 is characteristic or not of this population remains to be determined.

Preliminary analyses indicate that oystercatchers select large sizes of both mussel and limpet prey. Additionally, a clear preference for large limpets was demonstrated through platter experiments. Adult oystercatchers can remove as many as 2 mussels/minute during a feeding bout. Further work will clarify the impact oystercatchers have on invertebrate resources.

OBJECTIVES

1. Determine the habitat requirements of Prince William Sound (PWS) black oystercatchers. Identify the key features of shoreline habitats that lead to variation in oystercatcher distribution. Evaluate habitat features on a scale that can be detected remotely and can be applied to the entire PWS area.

2. Contrast the reproductive success of black oystercatchers nesting on oil impacted and oil non-impacted shorelines. Sharp (1990) suggested that chick survival is lower on territories impacted by oil. Test the generality of these conclusions by sampling replicate sites in PWS. By resampling sites visited in 1989, trends in reproductive success and population recovery of oystercatchers will be documented.

3. Determine if chick growth rates are depressed at impacted sites and are responsible for decreased survival. Compare the frequency of feeding trips made to chicks and the biomass of prey delivered to chicks between impacted and non-impacted sites.

4. Compare the foraging ecology of black oystercatchers on impacted and non-impacted shorelines. Determine how their feeding is being affected (i.e. handling time, encounter rate, prey profitability). Elucidate the role that oystercatchers play in structuring the intertidal invertebrate community — specifically, the effect that oystercatchers have on the size structure of the limpet and mussel assemblage.

METHODS

Study Subject

Oystercatchers provide an ideal subject for studying marine shoreline impacts as well as investigating basic biological questions of foraging ecology and reproductive success. Black oystercatchers are completely dependent upon the intertidal shoreline for their life's requirements. Throughout their annual cycle, oystercatchers are found only on rocky shorelines. The conspicuousness and size of the adults (and their prey) is quite advantageous for investigating feeding ecology. Establishment and maintenance of feeding and nesting territories, coupled with extensive parental care, enables observers to handily quantify differences in the outcome of reproductive events. The general uncommonness of the black oystercatcher renders the population sensitive to environmental perturbations.

Study Area

The 1991 study area included the majority of the Knight Island area, the entirety of the Green Island area and the Port Chalmers area of Montague Island (Figure 1,2). Corresponding areas on Green and Montague Islands were investigated during the breeding season of 1989 (Sharp 1990). Green Island was visited briefly by U.S. Fish and Wildlife Service personnel in 1990. Work on Knight Island was deliberately concentrated in Herring Bay to overlap with studies conducted by the University of Alaska's Coastal Habitat Project.

Shoreline types in the entire study area were categorized from maps generated by the Alaska Department of Environmental Conservation (ADEC, 1989, 1990). Classification of shorelines by oil impact was initially assigned from ADEC beach walk surveys and was "truthed" by the testimony of researchers who were present in PWS during post-spill 1989 (Table 1). Because of ambiguity in determining mutually exclusive cleaning treatments, shorelines were categorized into impacted and non-impacted groups (Highsmith et al. 1990b). Shoreline categories were summed over the entire study area and included: exposed rocky, sheltered rocky, and gravel/tidal flats. Merger of the last category resulted from the rarity of tidal flats in this portion of the sound. Maximum coastal elevation was measured 0.40 km (¼ mile) perpendicular to the shoreline at each point where a 1.609 km (1 mile) section line intersected the waters of the sound. Chi-square analysis was used to determine if nests were distributed proportionally to shoreline types. The study area was geographically sub-divided to produce estimates (means and variance) of oystercatcher density.

Regression models and standard t-tests are the most frequently used statistical procedures in this report. Satterthwaite's approximation for testing 2 population means was used to determine degrees of freedom for all t-tests (Snedecor and Cochran 1980). Linear model-checking procedures involved visual inspection of residuals plotted against predicted values, correlation of residuals and predicted values, and calculation of Cook's D and tolerances. Most analyses were carried out using the statistical package SYSTAT®.

Oystercatcher Reproduction

Fieldwork in 1991 began on 30 May and terminated 14 August. A 2-person crew initially surveyed all shorelines by a combination of zodiac-foot searches. It was immediately evident that boat surveys alone were not adequate to detect oystercatchers present on the small, rocky islets of Knight Island. Special effort was made to check all previous (1989) nest-sites on Green and Montague Islands. Upon finding a pair (or single bird) its location was mapped and its status (single, pair, pair with nest) noted. Behavioral cues of adults were used to determine if a pair was breeding. When nests were discovered, the following information was recorded: number of eggs or chicks, substrate of the nest (gravel, smooth rock, mixed gravel/rock), landform (point, beach, island <25 meters), number of adults, and reaction of the adults (sneak, call, distract). Extreme caution was used to avoid attracting predators to the nest-site. Unless noted, the ultimate outcome of the pair (resulting from either the 1st or 2nd attempt) was used for all considerations.

Most nest-sites were visually and aurally surveyed, by slowly motoring in an 1-kilometer diameter swath around the nest-site, once during the summer for the presence of oystercatcher predators (magpies, crows, ravens, eagles, canids and mustelids).

Nest-sites were revisited from every 7 to 10 days to determine if they were still active and to locate new breeders. When present, chicks ≥7 days of age, were banded with a USFWS aluminum band and an unique combination of color bands. Weights (g) and bills lengths (mm) were recorded along with time of day (later converted to position in the tidal cycle) and age of the chicks (Webster 1942). These extraneous factors were incorporated, along with oiling, into a covariate model of chick growth. After approximately 10 days, chicks were remeasured. Instantaneous change in bill length and weight was calculated according to the following equation (Ricklefs 1983):

$$r = \frac{\ln(wt_2) - \ln(wt_1)}{t_2 - t_1} \qquad (1)$$

where, wt = weight or bill length of 1st or 2nd measurement
t = time at 1st or 2nd measurement

Because sibling rivalry exists in oystercatcher broods (Groves 1984) and therefore, chicks within a brood are likely to vary in growth rate as much as chicks from other broods, individual chicks were the independent experimental unit. Hatching success was calculated as the proportion of all nests that hatched ≥1 chick. Similarly, fledging success was calculated as the proportion of all hatched nests that fledged ≥1 young. Average number of young hatched and fledged (successful nests only), average clutch size and average brood reduction were also estimated. All analyses were fitted into a context of site and oil impact. When comparing oiling categories, nests known to be washed out by storm tides were eliminated.

Feeding Ecology

Adult delivery of food items to dependent chicks was quantified. Each observation period began approximately 1 hour before low tide and ended 1 hour after low tide. Pairs were allowed to acclimate to a single observer prior to beginning observations. Data collection commenced when an adult delivered the first prey item. For this delivery, and for each subsequent delivery, the time, the type of prey item and the size of the prey item (scaled to 10^{ths} of the bill) were noted. Observers practiced identifying de-shelled prey items and estimating prey size prior to data collection. Any distractions of the adults by predators or intraspecific competitors during observational bouts were noted.

Incidental observations of foraging adults were also made during the low tide period. The number of prey items, taken from the start of the foraging bout to the end of the bout or until a maximum of 50 items, was recorded. Observations of foraging adults were restricted to gravel or mixed sand/gravel beaches. Prey type and size were recorded for each successfully pursued item. Handling times, the time from attack to ingestion, were also opportunistically collected.

Samples of the most important oystercatcher prey items were collected to construct length-weight conversions. Varying numbers of limpets, mussels, clams and chitons were segregated into 5 or 10 mm size classes. Shell lengths were individually measured and combined to produce an average shell length for each size class. Tissue lengths of a subsample (5 from each size class) were measured and used to calculate a shell-length:tissue-length ratio. Shells of invertebrates were removed and the remaining tissue was desiccated in a Coleman® oven in the field. The resulting average weights were then regressed against average tissue length using natural log models (Table 2). For limpets, separate regressions for Lottia pelta and Techtura persona and for T. scutum were calculated. An overall estimate for each size class was produced by weighting the estimates for each group by their representation in the size class (determined by shell collections and the Coastal Habitat data, see below).

Prey Abundance

Mussels were measured by using three 20x30 cm quadrats randomly placed on gravel or mixed sand/gravel feeding territories. All quadrats were selected within the rockweed (Fucus) zone of the intertidal. Individuals were measured to the nearest millimeter and placed into 5-mm size-classes. Percent algal and barnacle cover was estimated for each quadrat. Quadrats were combined to produce 1 estimate for each foraging site. These procedures follow the Standard Operating Procedures of the Coastal Habitat Project (Highsmith et al. 1990b). Information on limpet composition, abundance and size structure was graciously provided by Anthony Hooten of the UAF Coastal Habitat Study.

Platter Studies

To determine if oystercatchers had a true "preference" for larger prey items, adult oystercatchers were presented with a choice of an approximately 25mm and 15mm limpet (Techtura scutum). Two limpets were secured to a flat rock and placed near nesting adults. Observing the nest-site from a remote position, the platter was quickly retrieved when a bird was seen to strike the rock. Only 1 trial was conducted with each pair.

Adult oystercatchers were also presented with a platter of 2 similar-sized T. scutums ranging from 20mm to 25mm. After securing the limpets to a flat rock, one of the individuals was coated with weathered Prudhoe Bay crude oil and the other was presented naturally. In all cases coated scutums were always the slightly larger of the two. As in the other platter experiment, birds were presented the platter and only 1 trial was conducted on each pair.

Past Studies

This report additionally summarizes 1989 data presented by Sharp (1990) and 1990 Green Island reproductive data reported by Mary Cody (unpublished). Whereas Sharp considered Channel Island an impacted site, this report treats it as non-impacted (Cody, pers. comm.). Two-dimensional egg measurements taken in 1989 were combined to yield an estimate of volume (based on thirds of the volume of a sphere, cylinder and cone) by the following algorithm:

$$Volume = \frac{1}{2}\left(\frac{4}{3}\pi\left(\frac{1}{2}(h+r)\right)^3\right) + \pi r^2 h + \frac{1}{3}\pi r^2 h \tag{2}$$

where,

$$h = \frac{1}{3}length$$

$$r = \frac{1}{3}width$$

Values generated by this algorithm were tested using water displacement measurements of chicken eggs. Estimates of 5 eggs were all within 1% of the estimate produced by the algorithm. To account for the correlation of adult body size and egg size, a average relative difference for each clutch was calculated for 3-egg clutches and averaged for impacted and non-impacted sites as follows:

$$\overline{y} = \frac{\sum_{i=1}^{n}\left[\frac{\frac{ev_1-ev_2}{ev_1}+\frac{ev_1-ev_3}{ev_1}}{2}\right]}{n} \tag{3}$$

where,

ev_j = egg volume

Variance estimates were obtained using the standard formula for simple random sampling.

RESULTS

Habitat Features

Ninety breeding pairs were located along 448 km of shoreline (Figure 3). Of these ninety pairs, 15.5% (14) renested after their 1^{st} attempt failed. The Knight Island area was dominated by steep, rocky shorelines and greatly differed from the gradual, gravelly shores of Green and Montague Islands (Table 3). Consequently, the density of breeding pairs on Green/Montague Islands was a magnitude higher than the density on Knight Island (Table 3). Clearly, black oystercatchers disproportionately used gravel shorelines for initial nest-sites over other shoreline types (χ^2=30.1, p≤0.001, Table 4). Similarly, disproportionate numbers of renests occurred on gravel shorelines (χ^2=6.87, p≤0.05, Table 4).

Even among Knight Island sites, the proportion of gravel shoreline in an area was a good predictor of breeding oystercatcher density (Figure 4). Although highly correlated with the amount of gravel shoreline in an area, elevation of the shoreline would explain additional variation among the sites.

Gradual, gravel shorelines most likely expose a greater surface area for foraging during a falling tide than do steep, rocky shorelines and hence, render more prey available to oystercatchers at any given time. Because of their obligatory strategy of stabbing gaping bivalves that occur in shallow water, mussel-feeding birds may particularly benefit from foraging on gravel shorelines. Further work needs to be conducted to corroborate this thesis.

Oystercatchers also differed between the Knight Island area and the Green/Montague Island area in the placement of their nests . While 80.6% (n=36) of all nests placed along a beach or point of land occurred on Green or Montague Islands, 98.1% (n=52) of nests placed on islets (<25 m in diameter) occurred on Knight Island.

Despite its small size (1.97 km of shoreline), Channel Island was occupied by 10 breeding oystercatcher pairs. The island also hosted >100 pairs of arctic terns, 10 pairs of mew gulls, 15 pairs of pigeon guillemots and 30 pairs of tufted puffins.

Assuming a 27-day incubation period (Webster 1941), nests were back-dated from hatching to produce the 1991 season's nesting phenology (Figure 5). Clutch initiation in mid-May is typical of Prince William Sound oystercatchers (K. Kuletz pers. comm.). Thus, any further study of oystercatcher reproductive biology should commence by mid-May.

Hatching success was significantly higher ($t=3.10$, $df=67$, $p \le 0.005$) at Green/Montague Island sites than at Knight Island sites. Significantly more pairs ($t=2.75$, $df=18$, $p \le 0.025$) fledged young on Green/Montague Island than did pairs on Knight Island. These combined factors resulted in higher brood reduction (from eggs to fledglings) of nests on Knight Island than nests on Green/Montague Island (Table 3). Clutch size and average number of young hatched or fledged did not differ between island groups (Table 3). Herring Bay was a Knight Island enigma. Despite heavy oiling in 1989 and high human disturbance in 1991, all 4 nests (and 1 additional nest with 14 day-old young when the study was terminated) fledged young. Conceivably, high human disturbance apparently tolerated by oystercatchers may result in a local dispersing of oystercatcher predators. However, preliminary predator counts in Herring Bay do not differ from sites with low productivity.

Although other measures of reproductive success did not differ between shoreline types, a disproportionate number of young were produced from nests on gravel shorelines ($\chi^2=27$, $p \le 0.005$, Table 4).

Nysewander (1977) suggested that nest substrate was responsible for variability in nest predation. Nests placed in substrates where gravel size was similar to egg size were most likely to hatch. Indeed, fewer nests placed on smooth substrates (which dominated the Knight Island area) hatched young than did nests placed on gravelly substrates. The best assurance to produce young on Knight Island was to nest in proximity to arctic terns. Sixty-three percent of oystercatcher nests associated with terns or mew gulls fledged young whereas only 4% of solitary nests produced any young ($t=3.94$, $df=11$, $p \le 0.01$). Cursory counts indicated no differences between the number of predators in the vicinity of nests on Knight Island and those on Green/Montague Islands. Further work needs to be directed toward understanding the role of predators in regulating oystercatcher numbers.

Oiling Effects

Clutch size was rather invariant among years and sites (Table 5). However, relative egg volume of 3-egg clutches on Green Island sites was substantially lower ($t=-2.08$, $p \le 0.07$, $df=9$) than clutches on Montague Island (1989) indicating that breeding females in oiled sights may have been stressed. Ranging from 10% to 88%, hatching success was quite variable among sites in 1991 (Table 5). Hatching success was very similar between years on Green Island but varied between years on Montague Island (Table 5). On Knight Island (1991), a greater proportion of nests hatched young in impacted sites than did nests in non-impacted sites ($t=3.57$, $p \le 0.005$, $df=29$). Fledging success varied little among sites (Table 5). Productivity per nest site, however, was significantly higher ($t=3.05$, $p \le 0.01$, $df=21$) on Green Island than it was on Montague Island. Surprisingly, impacted sites on Knight Island had intermediate levels of productivity (Table 5). Disparities in overall productivity were reduced when all nests (including failed nests) were considered (Table 5). Under this consideration, Knight Island had the lowest production.

Trends in the relationship of brood reduction to degree of oiling were not consistent between years (Table 6). Losses of eggs in heavily oiled sites were reduced from 47% in 1989 to 8% in 1991. It is unclear whether the increase in egg survival was due to oiling effects or predator effects.

Despite high productivity on Green Island in 1991, direct oil-related impacts did influence productivity. In 1990, beaches on Green Island received several bioremediation and manual pickup treatments. This intense cleaning activity resulted in dramatic differences in productivity between disturbed and undisturbed nest-sites (Figure 6). Many pairs that had disturbance-induced reproductive failures in 1990 did successfully rear young in 1991. Thus, the suite of disturbance to oystercatchers extends beyond the direct effects of oiled beaches.

Chicks on oiled sites gained weight at a significantly slower rate than did chicks on unoiled sites (Figure 7, $R^2_{adj}=0.73$, $t_{oil}=-2.61$, $p\leq0.012$). Because growth rates decline with increasing age, an age covariate was included in the model. Neither brood size nor height of the tide during measurements explained additional variation in growth rates. Similar results were obtained when instantaneous growth rates were averaged for each brood. Although a difference occurred in weight gain, bill growth did not vary between groups. Because the bill is such an important structure for an oystercatcher, chicks may first supply energy for bill growth and secondarily direct it toward weight gain. Decreased weight gain could be caused by either the amount of food delivered to the chicks or the quality of the food delivered. Sharp (1990) found that the intake rate of adults (ingestions/min.) was lower on Green Island than on Montague Island. Although delivery rates (# of items/hour/chick) were comparable between oiled and unoiled sites in 1991, biomass delivered to chicks was significantly lower on impacted sites than on non-impacted sites. Prey biomass was standardized in several ways: mass/time/ck, mass/time/Σ chick weight, and mass/delivery/ chick. In all cases, significantly less prey biomass was being provided to chicks on impacted nest sites than to chicks on non-impacted nest sites ($t\geq2.76$, $p\leq0.025$, df=8). Thus, it appears that depressed growth rates are being driven by the quality of the prey provided to the chicks. Counts done in 1989 indicate that significantly higher mortality ($t=3.00$, $p\leq0.01$, df=18) occurred in mussel populations on Green Island than occurred on Montague Island. Too few adult birds were observed to infer about any foraging differences. Further work, planned for 1992, will examine the link between the persistent contamination of mussels, and possibly limpets, to the transmission to oystercatchers.

Although only a few, late season trials were conducted, an interesting result regarding selection/avoidance of oiled limpets has emerged. When platters were retrieved within 4 hours of placement, only unoiled limpets were removed. If platters were left for 36 hours, both limpets were removed. This experiment needs further replication to determine whether oystercatchers can or can not discern oiled prey and thus, if they can avoid the deleterious effects of consuming oiled prey.

Recovery of the PWS Oystercatcher Population

Although many reproductive variables appear to be rather invariant between sites and years, there is evidence that black oystercatchers are rebounding from the perturbation caused by the 1989 spill. Green Island, occupied by 14 breeding pairs of oystercatchers in 1989, hosted 21 breeding pairs in 1991 - a population increase of 50%. From 1989 to 1991, Montague Island remained constant at 18 breeding pairs. Greater numbers of non-breeders were present around Green Island in 1989 (29%) than in 1991 (9%). Despite an apparent recovery on Green Island, further work is needed to determine of low productivity is characteristic of birds inhabiting Knight Island. The high productivity enigma of Herring Bay needs to be explored within a context of predation pressure on oystercatchers and how this may interact with oiling effects. Additionally, persistent mussel contamination could provide a continued threat to the PWS-wide recovery of oystercatchers.

Foraging Ecology

Only preliminary analysis has been completed on the foraging ecology of black oystercatchers. From these preliminary analyses, it is clearly evident that oystercatchers are selecting a larger size of mussels (Figure 8) and limpets (Figure 9) than are represented in the environment. A clear preference of larger-sized limpets was demonstrated by the platter experiment. Five out of 5 birds chose the larger-sized scutum over a smaller alternative. To further address the impact of oystercatchers on their intertidal prey, several planned studies include: determining the rate that adult oystercatchers remove various prey species, determining if oystercatchers can deplete benthic prey over the course of the breeding season, comparing the size structure of prey population within foraging territories to the size structure outside territories, and examining the variation in daily and seasonal feeding ecology.

LITERATURE CITED

Alaska Department of Environmental Conservation. 1990. Impact maps and summary reports of shoreline surveys of the Exxon Valdez spill site, Prince William Sound.

Alaska Department of Environmental Conservation. 1989. Impact maps and summary reports of shoreline surveys of the Exxon Valdez spill site, Prince William Sound.

Groves, S. 1984. Chick growth, sibling rivalry, and chick production in American black oystercatchers. Auk 101:525-531.

Highsmith, R., J. Schimel, W. Barber and S. Jewett. 1990a. Comprehensive assessment of injury to coastal habitats phase II: Standard operating procedures. 87pp.

Highsmith, R. C., M. Stekoll and W. E. Barber. 1990b. 5.2 Experiments in Herring Bay. In: Coastal habitat study number 1: Phase 1 and phase II, pp. 64-97. Draft preliminary status report.

Nysewander, D. R. 1977. Reproductive success of the black oystercatcher Washington state. M. S. Thesis. Univ. of Washington. Seattle WA

Ricklefs, R. E. 1983. Avian post-natal development. In: Avian Biology VII, D. S. Farner, J. R. King and K. C. Parkes (eds.), pp. 2-83. Academic Press. New York, New York. 542pp.

Sharp, B. 1990. Black Oystercatchers in Prince William Sound: Oil Effects on Reproduction and Behavior in 1989. Unpubl. Rept. U.S. Fish and Wildl. Serv. Anchorage, AK.

Snedecor, G. W. and W. G. Cochran. 1980. Statistical methods, 7th ed. Iowa State University Press. Ames, Iowa. 507pp.

Webster, J. D. 1942. Notes on the growth and plumages of the black oyster-catcher. Condor 44:205-213.

Webster, J. D. 1941. The breeding of the black oyster-catcher. Wilson Bull. 53:141-156.

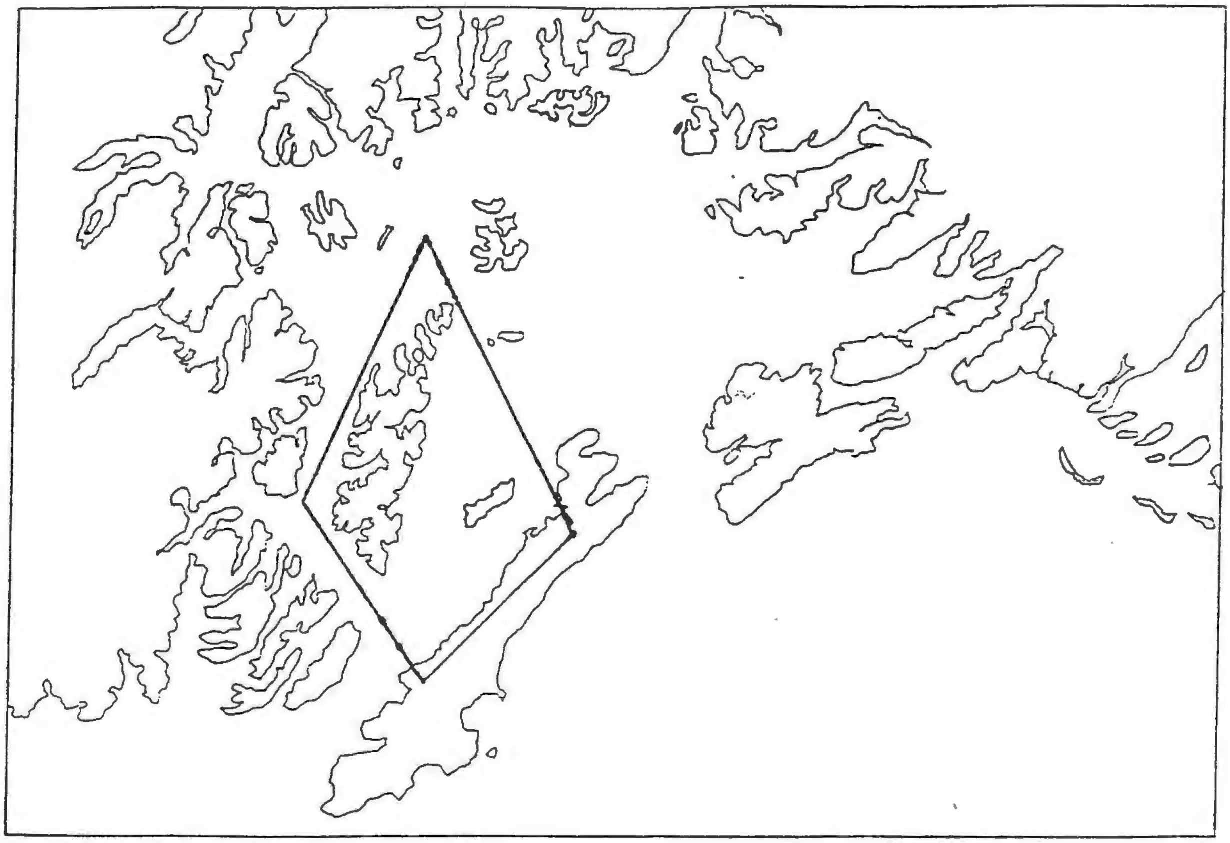


Figure 1. Location of black oystercatcher study area in Prince William Sound - 1991.

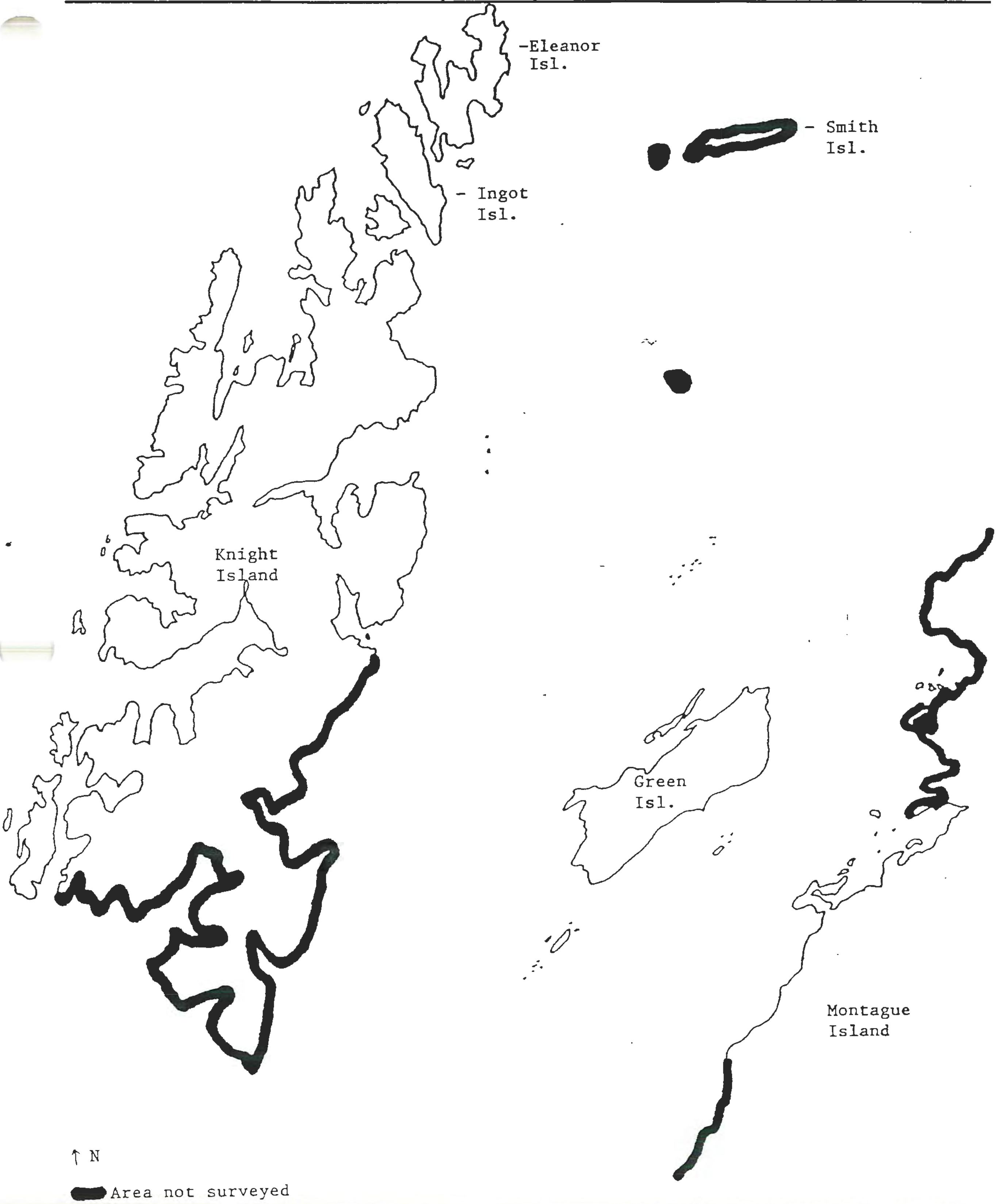


Figure 2. Area survyed on Knight, Green, Montague Islands - 1991.

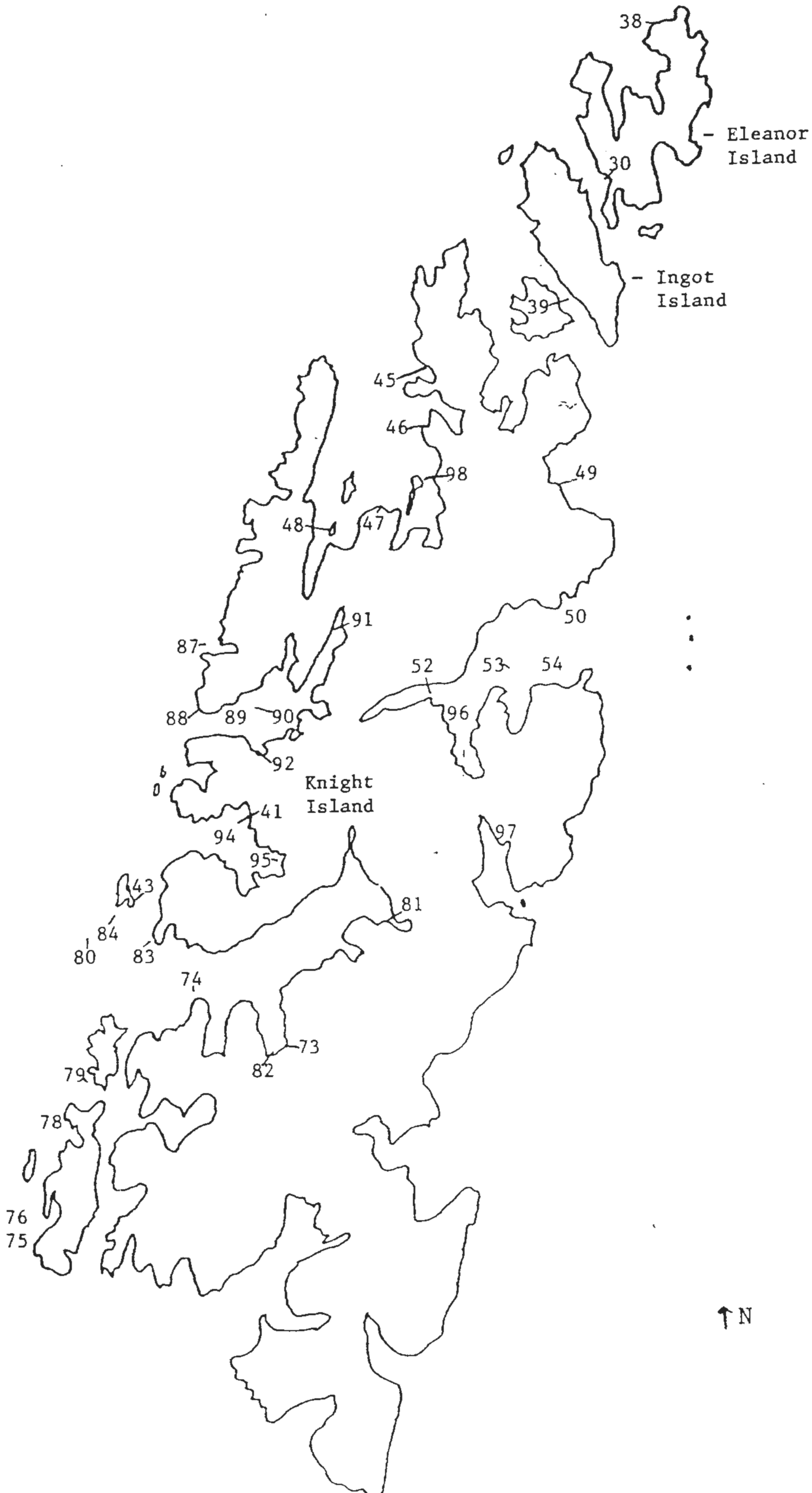


Figure 3. Location of breeding oystercatcher pairs on Knight, Green and Montague Islands - 1991.

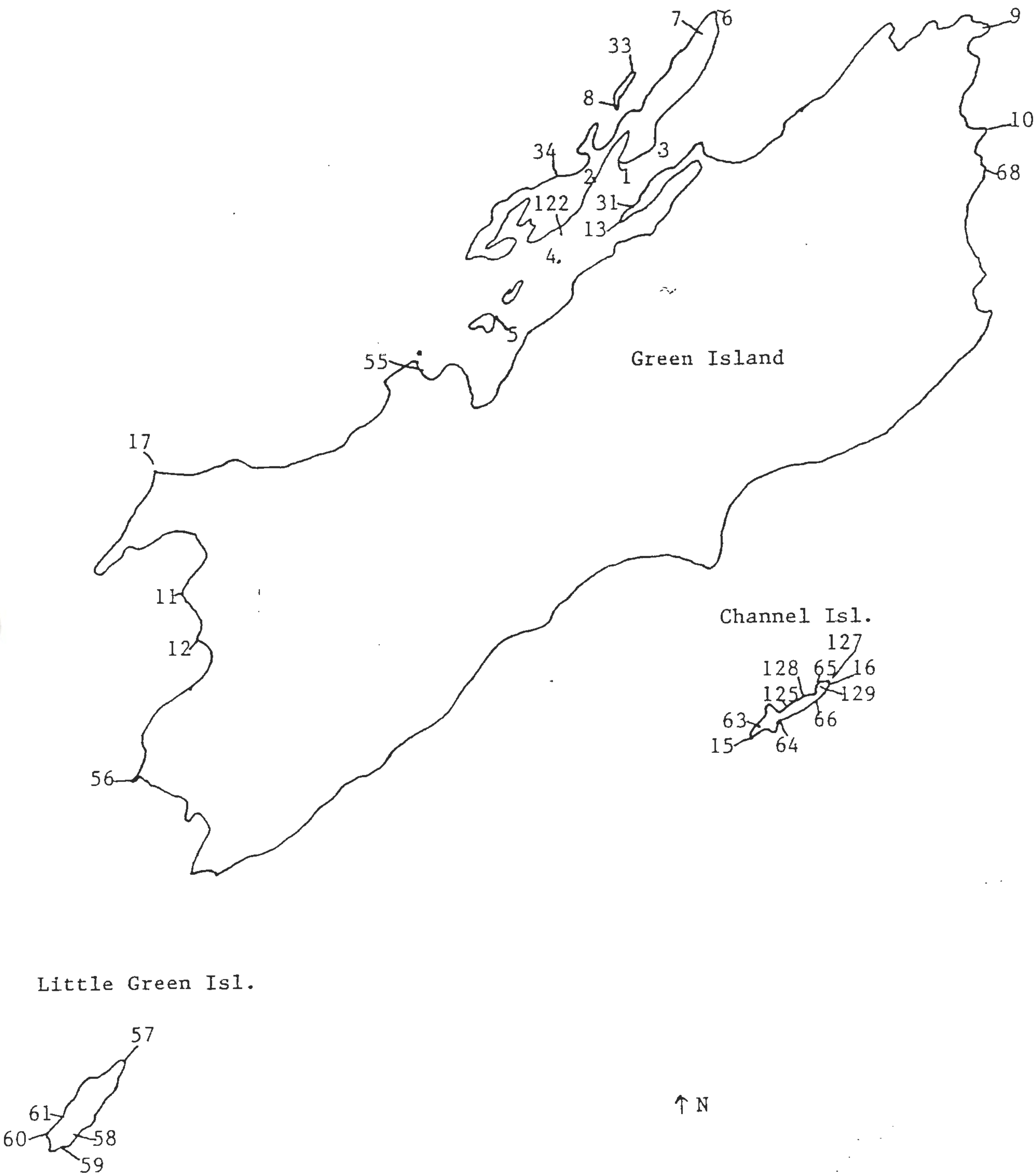


Figure 3. (cont.)

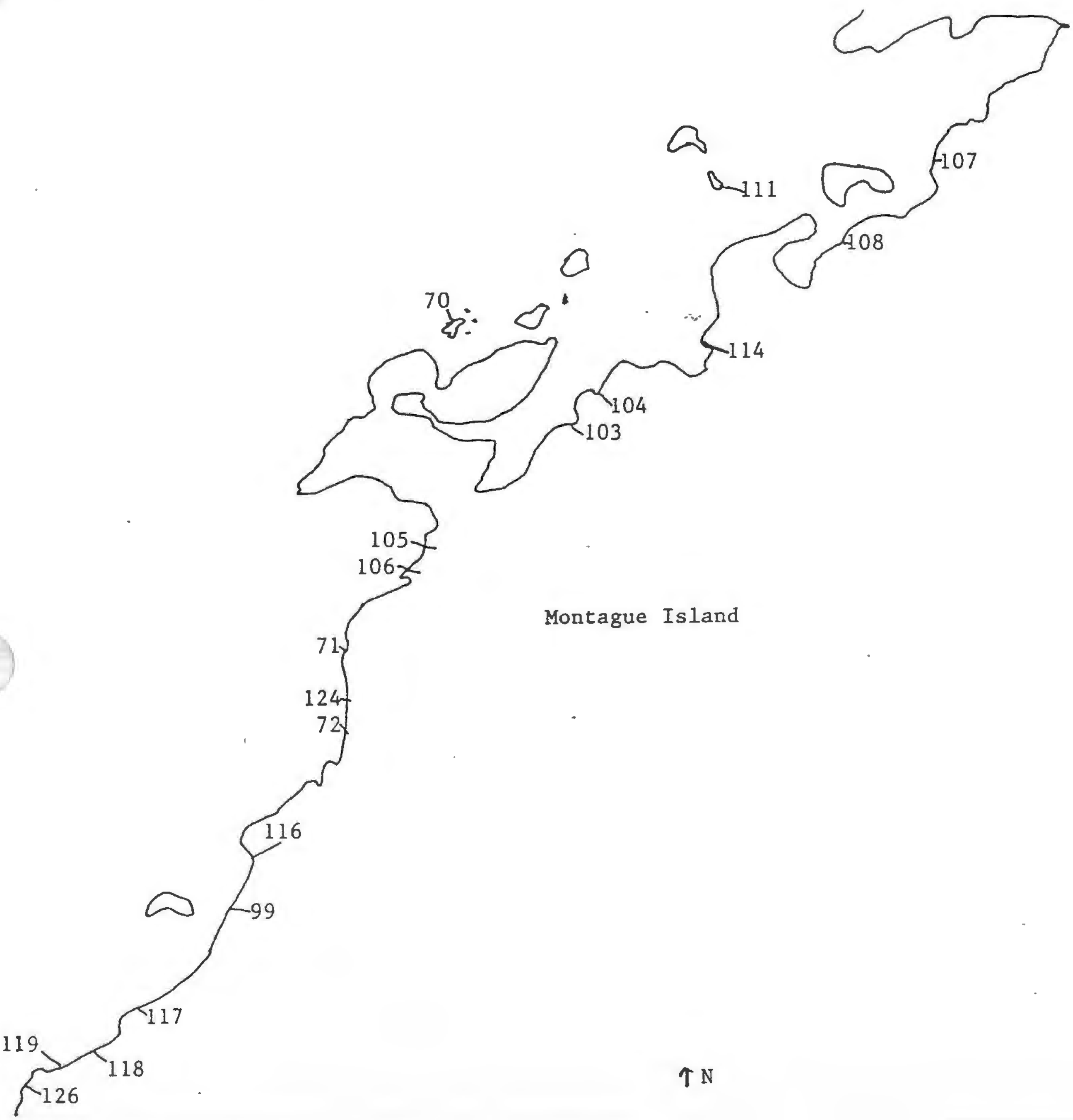


Figure 3. (cont.)

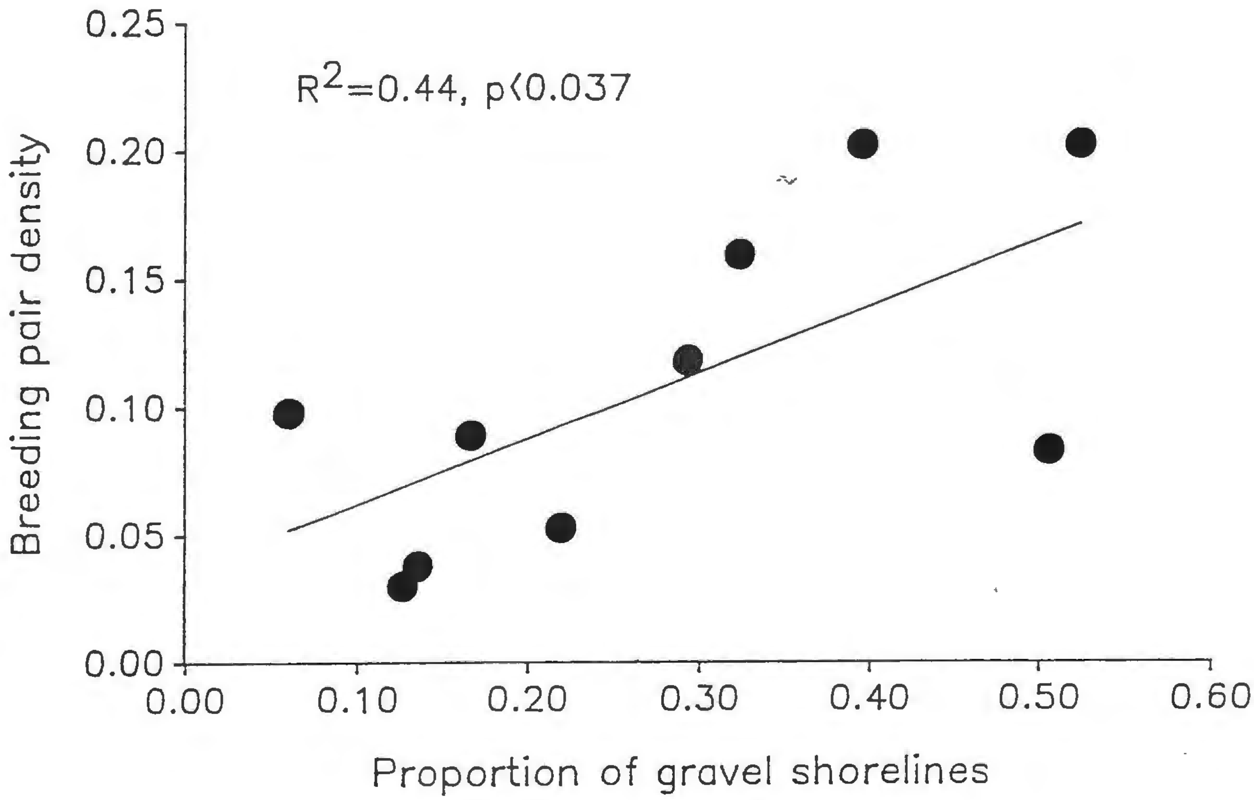


Figure 4. Relationship of the proportion of gravel shoreline and the density of breeding oystercatcher pairs on Knight Island - 1991.

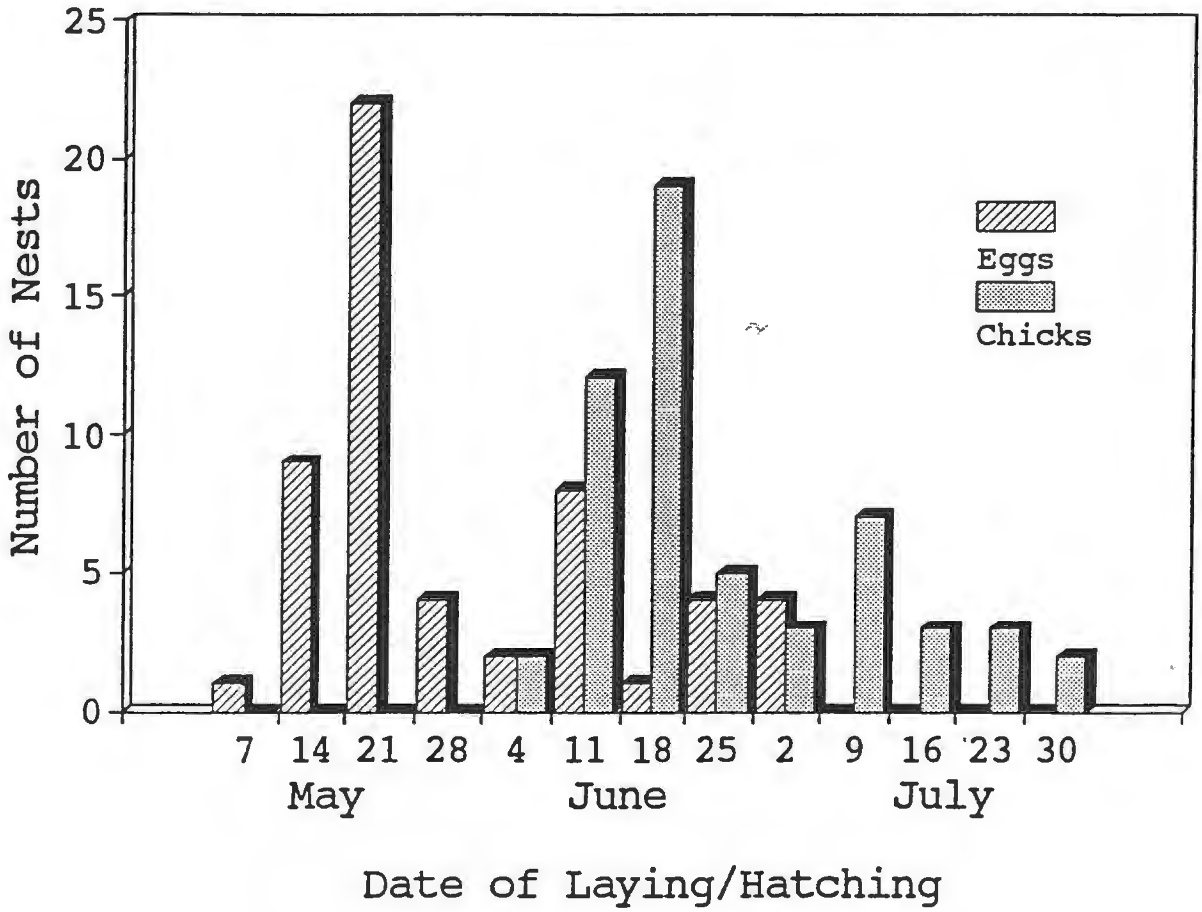


Figure 5. Nesting phenology of PWS oystercatchers -1991.

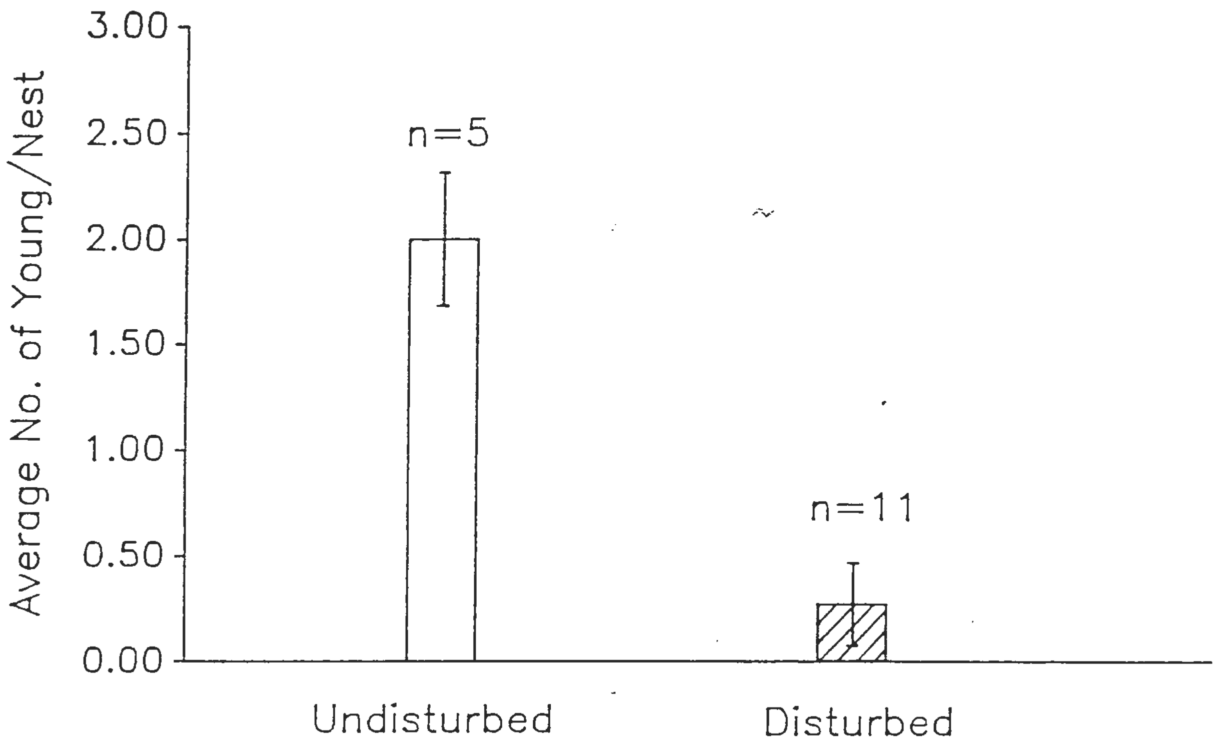


Figure 6. Effect of disturbance on the productivity of oystercatchers on Green Island - 1991.

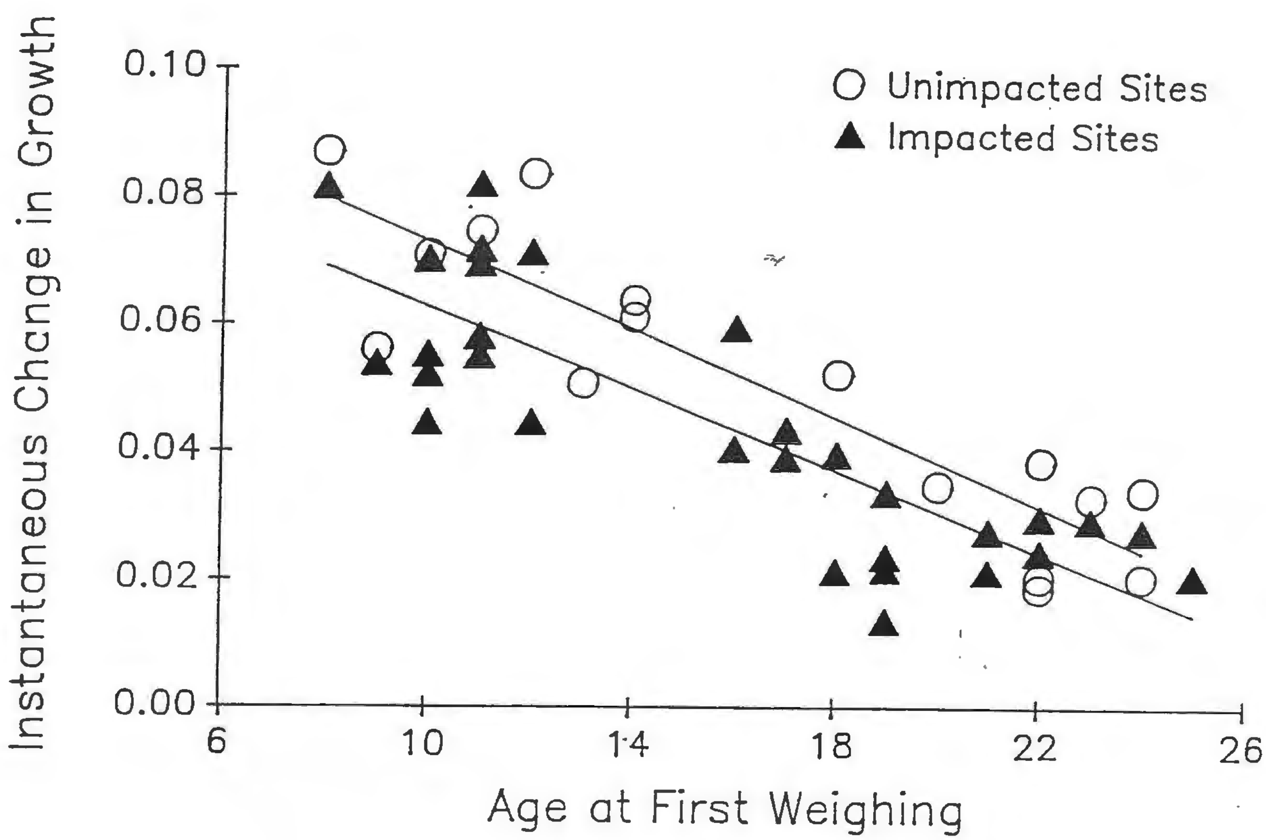


Figure 7. Effect of oiling and age on hatchling oystercatcher weight gain.

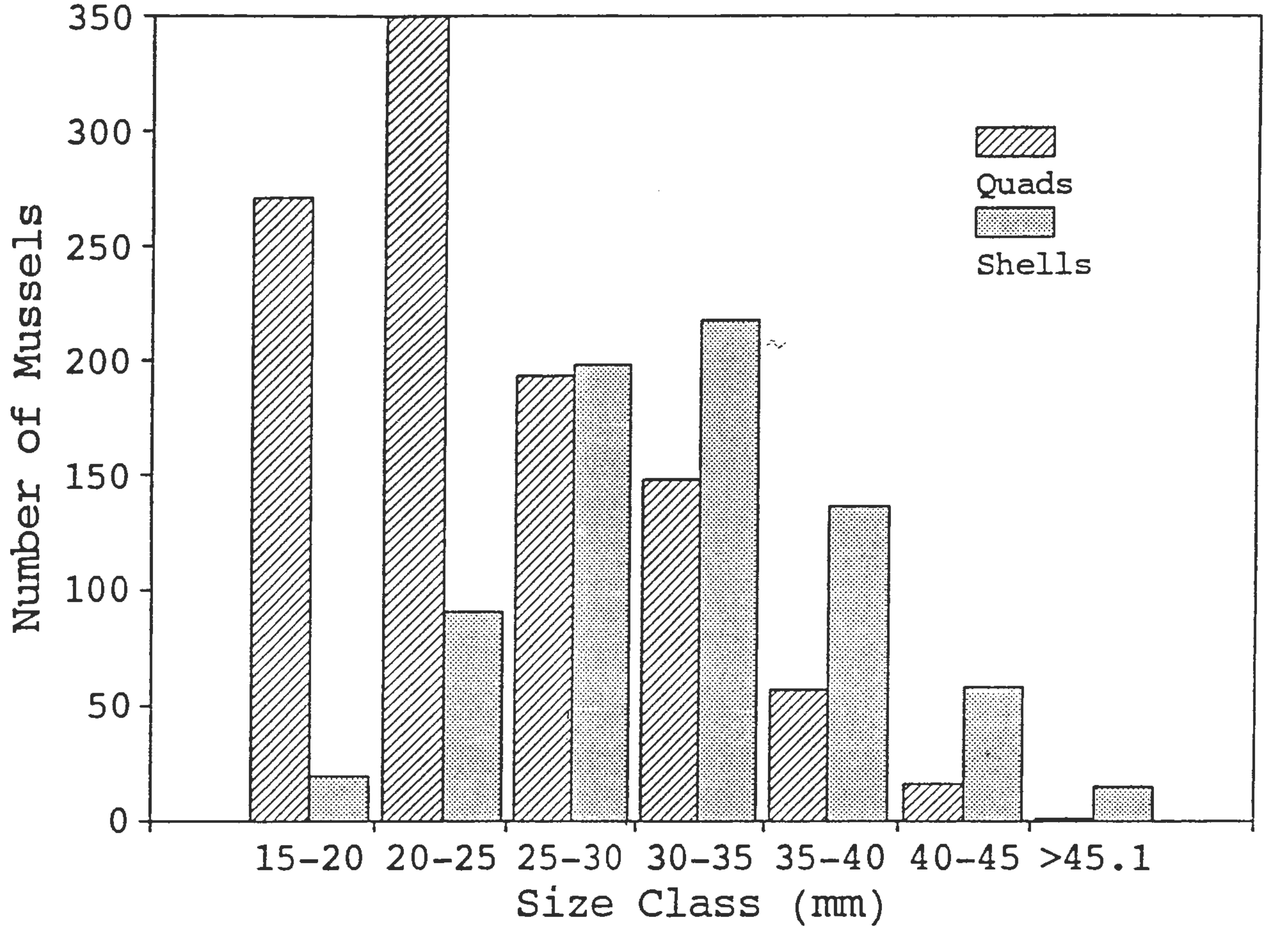


Figure 8. Size selection of mussels by foraging PWS oystercatchers

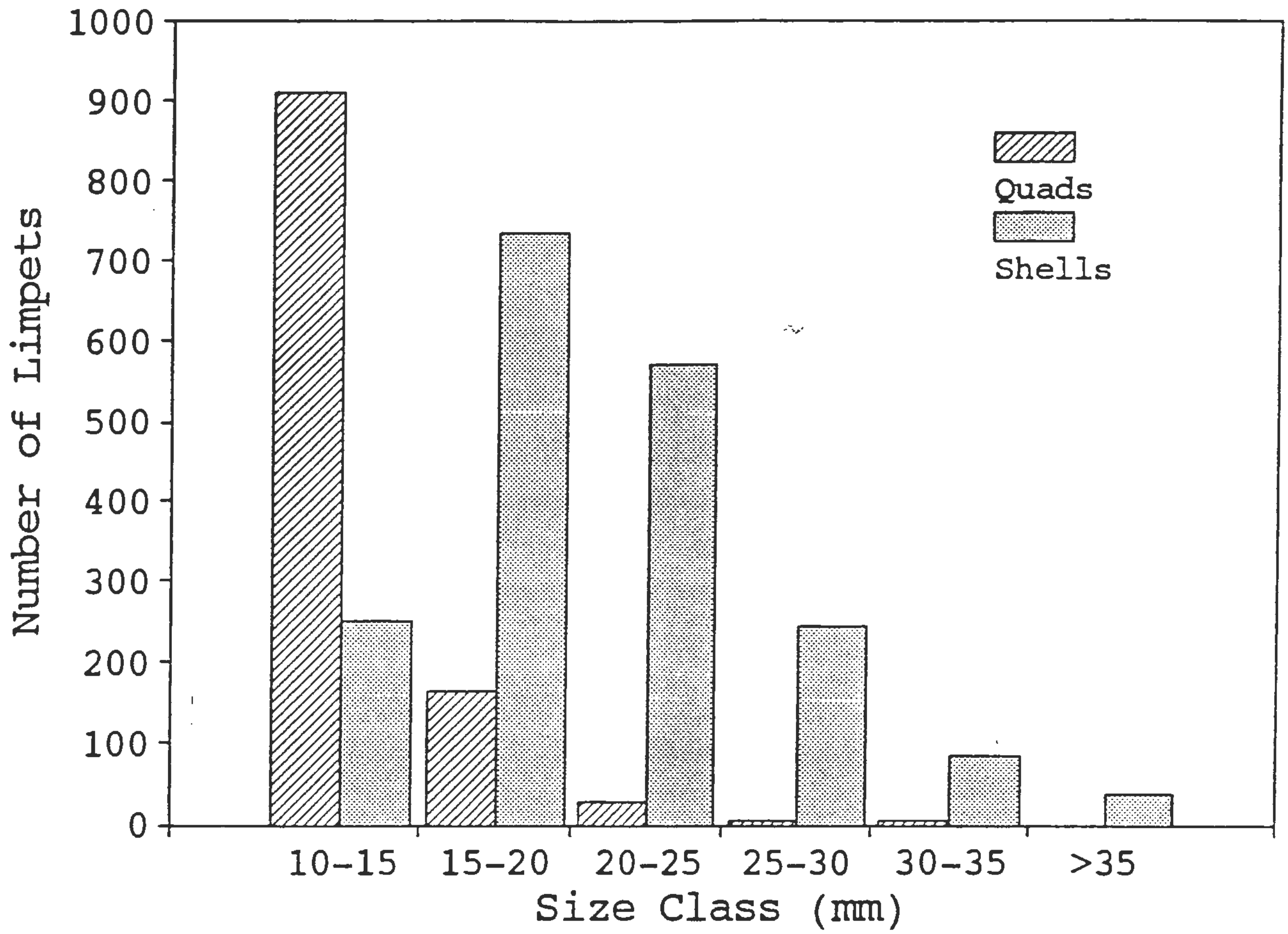


Figure 9. Size selection of limpets by foraging PWS oystercatchers

Table 1. Oil impact and shoreline distance of BLOY study areas - 1991.

Site	Impacted?	Shoreline Km
Green Island	Yes	45.45
Little Green Island	Yes	2.79
Channel Island	No	1.97
Montague Island	No	37.12
Eleanor Island	Yes	37.90
Ingot/Disk Island	Yes	26.41
Northeastern/Eastern Knight Island	Yes	33.38
Bay of Isles	Yes	31.48
Marsha Bay	Yes	11.26
Herring Bay	Yes	42.27
Western Knight Island	Yes	102.25
Lower Herring Bay	No	24.73
Johnson Bay	No	14.83
Drier Bay	No	36.16

Table 2. Length-weight regressions for dominant prey items of black oystercatchers in Prince William Sound.

	Regression Equation	R^2	Tissue:Shell
Clams (Saxidomus, Protothaca)	ln(wt) = -11.724 + 3.471 ln(lg)	0.996	0.872
Mussels (Mytilus edulis)	ln(wt) = -10.851 + 2.783 ln(lg)	0.974	0.876
Chitons (Katharina, Mopalia)	ln(wt) = -3.789 + 0.118 (lg)	0.987	0.435
Limpets (L. pelta, T. persona)	ln(wt) = -9.831 + 2.993 ln(lg)	0.988	0.757
Limpets T. scutum	ln(wt) = -11.705 + 3.456 ln(lg)	0.988	0.735

Table 3. Habitat characteristics of and BLOY reproduction on Knight and Green/Montague Islands

Characteristic	Knight	Green/Montague
Total shoreline (km)	361	87
Proportion of gravel shoreline	0.24	0.68
Average elevation (m)	154.82 (6.46)	26.36 (2.18)
Breeding pair density	0.07 (0.03)	0.62 (0.17)
Proportion of renests	0.29	0.71
Clutch size	2.30 (0.13)	2.39 (0.09)
Hatching success	0.44 (0.08)	0.76 (0.06)
Average number hatched	1.87 (0.24)	1.97 (0.12)
Fledging success	0.53 (0.13)	0.91 (0.05)
Average number fledged	1.75 (0.31)	1.61 (0.14)
Average brood reduction prop. lost CL --> FL	0.78 (0.07)	0.33 (0.07)
Average number of predators/nest-site	4.51 (0.86)	5.11 (1.08)

* Values in parentheses are standard errors.

Table 4. Black oystercatcher reproduction by shoreline habitat type.

	Shoreline Type		
	Exposed Rocky	Sheltered Rocky	Gravel Beach
Prop. of area n=448 km	0.28	0.40	0.32
Prop. of nests n=90	0.24	0.18	0.58
Prop. of renests n=14	0.21	0.14	0.64
Clutch size	2.36 (0.15)	2.28 (0.20)	2.39 (0.09)
Prop. hatched	0.68 (0.10)	0.44 (0.13)	0.65 (0.07)
Prop. fledged	0.85 (0.10)	0.67 (0.19)	0.83 (0.07)
Prop. of fledged young produced n=64	0.33	0.11	0.56

* Values in parantheses are standard errors.

Table 5. Effects of oil-impact and site on estimates of reproductive parameters.

	Knight Island		Green/Montague Island	
	Impact	No impact	Impact	No impact
No. of nests 89	-	-	14	23
No. of nests 91	10	26	26	28
Average clutch size 1989	-	-	2.54 (0.13)	2.43 (0.14)
Average clutch size 1991	2.36 (0.15)	2.25 (0.27)	2.48 (0.12)	2.29 (0.12)
Prop. of nests hatched 1989	_	_	0.77 (0.12)	0.53 (0.12)
Prop. of nests hatched 1991	0.58 (0.10)	0.10 (0.09)	0.76 (0.09)	0.88 (0.07)
Average number hatched 1989	_	_	1.80 (0.25)	1.87 (0.29)
Average number hatched 1991	1.87 (0.26)	2.00	2.17 (0.19)	1.80 (0.16)
Prop. of nests fledged 1991	0.71 (0.12)	_	0.88 (0.08)	0.94 (0.06)
Average number fledged 1991	1.75 (0.31)	_	2.00 (0.22)	1.25 (0.11)
Average number of predators	5.48 (1.15)	2.50 (0.40)	2.59 (0.38)	7.54 (2.02)
Prop. of all sites that produced young	0.40 (0.10)	0.00	0.63 (0.05)	0.70 (0.12)
Ave. no. of young produced from all sites	0.56 (0.19)	0.00	1.25 (0.24)	0.87 (0.15)

* Values in parentheses are standard errors.

Table 6. Proportional brood reduction (clutch to hatch) of oystercatcher nesting heavily oiled, moderately oiled and unoiled sites on Green and Montague Islands - 1989, 1991.

Oiling	1989	1991
Heavy	0.467 (0.122)	0.083 (0.083)
Moderate	0.333 (0.136)	0.167 (0.075)
No oil	0.125 (0.125)	0.219 (0.058)

* Values in parentheses are standard errors.

7. Dolly Varden and Cutthroat Trout Populations in Prince William Sound

1991 #7

RESTORATION SCIENCE STUDY
DRAFT 1991 INTERIM REPORT

Project Title:	Technical Support Study for the Restoration of Dolly Varden and Cutthroat Trout Populations in Prince William Sound
Study ID Number:	Restoration Science Study #7
Lead Agency:	Alaska Department of Fish and Game Division of Sport Fish
Principle Investigators:	Andrew G. Hoffmann, Project Leader Suzanne McCarron, Project Assistant
Assisting Personnel:	Kelly Hepler, Area Management Biologist Patricia Hansen, Biometrician
Date Submitted:	November 20, 1991

TABLE OF CONTENTS

	Page
LIST OF TABLES	ii
LIST OF FIGURES	iii
LIST OF APPENDIX TABLES	iv
EXECUTIVE SUMMARY	1
INTRODUCTION	2
OBJECTIVES	3
METHODS	4
Identification and Categorization of Potential Survey Sites	4
Ground Surveys and Sampling	7
Development of Fishery Matrices	8
Evaluation of Stock Structure	9
Estimates of Relative Stock Density	10
RESULTS	12
Identification and Categorization of Potential Survey Sites	12
Ground Surveys and Sampling	12
Development of Fishery Matrices	16
Evaluation of Stock Structure	21
Estimates of Relative Stock Density	21
RESTORATION PROJECT STATUS AND RECOMMENDATIONS	23
Identification and Categorization of Potential Survey Sites	25
Ground Surveys and Sampling	25
Development of Fishery Matrix	26
Evaluation of Stock Structure	26
Estimates of Relative Stock Density	26
REFERENCES	27
APPENDIX	29

LIST OF TABLES

Table Page

1. Site selection matrix.................................. 13

2. Fishery matrix for Zone 1 streams........................ 17

3. Fishery matrix for Zone 2 streams........................ 18

4. Fishery matrix for Zone 3 streams........................ 19

LIST OF FIGURES

Figure | Page

1. Location of geographic zones in Prince William Sound...... 6

2. Location of sites where ground surveys were completed during 1991... 15

3. Catch curve for Dolly Varden in Eyak River, 1991.......... 22

4. Schematic of components needed and tentative time frame for development of a Dolly Varden and cutthroat trout management plan for Prince William Sound................. 24

LIST OF APPENDIX TABLES

Appendix Table — Page

1. Mean catch-per-unit-effort for Dolly Varden at Zone 1 sites, 4 - 15 August, 1991 30
2. Mean catch-per-unit-effort and site ranking for Dolly Varden at Zone 1 sites, 3 - 16 September, 1991 31
3. Mean catch-per-unit-effort and site ranking for Dolly Varden at Zone 2 sites, 24 July - 13 August, 1991 32
4. Mean catch-per-unit-effort for Dolly Varden at Zone 2 sites, 24 September - 4 October, 1991 33
5. Mean catch-per-unit-effort and site ranking for cutthroat trout Zone 2 sites, 24 July - 13 August, 1991 34
6. Mean catch-per-unit-effort for cutthroat trout at Zone 2 sites, 24 - 27 September, 1991 35
7. Mean catch-per-unit-effort and site ranking for Dolly Varden at Zone 3 sites, 19 - 29 August, 1991 36
8. Relative stock densities (RSD) for Dolly Varden caught by hook and line by geographic zone, 1991 37
9. Mean length of Dolly Varden and cutthroat trout caught by hook and line by geographic zone, 1991 38

EXECUTIVE SUMMARY

The ultimate goal of this project is the rational development of a management plan for Dolly Varden and cutthroat trout in Prince William Sound (PWS). This plan will provide for responsible and orderly management of these fisheries through modification of human use and replacement of lost fishing opportunities in PWS. This plan will aid in the recovery of these species from the impacts of the Exxon Valdez oil spill (EVOS) as well as protecting the biological integrity of wild stocks.

This report summarizes the first year of activities of a restoration project to restore Dolly Varden and cutthroat trout populations and fishing opportunities in Prince William Sound lost as a result of the Exxon Valdez oil spill. This restoration project was initiated in response to the results of the Natural Resource Damage Assessment (NRDA) Study #5, Injury to Dolly Varden and Cutthroat Trout in PWS (Hepler 1989, 1990). The NRDA project measured the effects of oil on growth and survival of these two species. It conclusively documented injury to these species in the year following the Exxon Valdez oil spill and also provided evidence that injury to oiled stocks persisted between 1990 and 1991. These injuries have resulted in an overall loss of opportunities for recreational anglers in PWS.

Sixty-one stream systems in non-oiled locations in PWS that support populations of Dolly Varden or cutthroat trout were identified. These sites were categorized by geographic zones based on remoteness and accessibility. Information about these sites was incorporated into a site selection matrix and sites were scored according to their potential to support fisheries for Dolly Varden or cutthroat trout. Thirty-two of these sites, selected based on these matrix scores, were sampled during the 1991 open water season, 1 May through 4 October. Catch rate and size information, as well as information about the characteristics of the streams, collected during ground surveys were incorporated into fishery matrices for each of the three geographic zones. In addition to the ground surveys, field data collection for estimating abundance of Dolly Varden and cutthroat trout at the first of six sites, Eyak River, was begun. Abundance and relative stock density information from these sites will also be incorporated into the fishery matrices. The fishery matrices are dynamic by nature and will continue to be developed through the life of this project, approximately 1996. These fishery matrices will provide the basis from which a Dolly Varden and cutthroat trout management plan will be developed.

INTRODUCTION

This report provides a status summary for the first year of a multi-year plan to restore Dolly Varden and cutthroat trout fishing opportunities, lost as a result of the Exxon Valdez oil spill (EVOS), to sport fish anglers in Prince William Sound (PWS). This restoration project was initiated in response to the results of the Natural Resource Damage Assessment (NRDA) Study #5, Injury to Dolly Varden and Cutthroat Trout in PWS (Hepler 1989,1990). The NRDA project measured the effects of oil on growth and survival of these two species. It conclusively documented damage to these species in the year following the Exxon Valdez oil spill and also provided evidence that injury to oiled stocks persisted between 1990 and 1991. These injuries have resulted in an overall loss of opportunities for recreational anglers in PWS.

Since Dolly Varden and cutthroat trout are both important components of the recreational fisheries in PWS, the Division of Sport Fish, Alaska Department of Fish and Game (ADF&G) recommends replacing lost recreational opportunities by directing human use. However, the Department does not want to exacerbate the stock status of Dolly Varden and cutthroat in PWS by increasing effort on populations of fish that cannot sustain increased sport harvest. Information collected by this project will provide the basis for the rational development of a management plan for these species to meet these concerns. This plan will provide for responsible and orderly management of fisheries which will protect the biological integrity of wild stocks and provide recreational benefit to all users. At the present time there is a paucity of data available on the stock status of Dolly Varden and cutthroat trout populations in PWS except for the five populations sampled during the NRDA Study # 5. It is imperative to collect stock status data from an increased number of Dolly Varden and cutthroat trout populations in order to develop a meaningful management plan.

At the conclusion of this project, a number of Dolly Varden and cutthroat trout fisheries will be identified in non-oiled areas of PWS, that can provide the sport fishing public with a range of desirable angling opportunities. These sites are being identified through a systematic process that addresses a number of criteria. The range of angling opportunities will be categorized into three geographic zones based on remoteness and accessibility. Additionally, data collected from this project could be used to identify further restoration opportunities for these stocks such as identifying possible sites for the placement of fish passes or critical habitat areas that could be protected through the purchase of private inholding or mineral rights.

OBJECTIVES

The overall goal of this project is to develop a restoration plan that modifies human use and replaces lost fishing opportunities in PWS. This goal will be met by accomplishing the following objectives and associated tasks.

Objective 1:

Identify and categorize stream systems in non-oiled locations in PWS that support populations of Dolly Varden or cutthroat trout.

Task:

A. Inventory known locations of Dolly Varden and cutthroat trout in the non-oiled locations in PWS and categorize them into three sport fishing zones based on remoteness and accessibility.

B. Visit approximately 21 (seven per zone) of the sites identified and sample for Dolly Varden and cutthroat trout during the peak of the sport fishery, July through September. Determine relative abundance of each species using catch- per-unit-effort (CPUE) as an index, and length distribution using relative-stock-densities (Gablehouse 1984).

C. Prepare a matrix of fishery characteristics by stream using information from tasks A and B. The matrix will be used in selecting stream systems for potential stock structure evaluation and for evaluating potential as an alternative sport fishery for Dolly Varden and cutthroat trout fisheries outside the oil impacted area of PWS.

Objective 2:

Evaluate stock structure of overwintering populations of Dolly Varden and cutthroat trout at two sites in each of the three sport fishing zones. (Studies on Eyak lake will begin in 1991 other sites will begin in 1992).

Task:

D. Estimate abundance of Dolly Varden and cutthroat trout ≥200 mm in two sites within each of the three sport fisheries zones, such that the estimate is within 25% of the true value 95% of the time.

E. Estimate the relative stock densities (RSD) of Dolly Varden and cutthroat trout in two sites within each of the three sport fisheries zones, such that all proportions are within 5 percentage points of the true values 95% of the time.

METHODS

The methods employed this season to achieve the stated goals and objectives of this project are stated in detail below. The overall approach is summarized here. The approach is one of gathering information about stocks of Dolly Varden and cutthroat trout in PWS in successive steps and in each successive step the number of sites decreases but the detail of information about the stocks increases. The first step was to gather as much information as possible about any locations where Dolly Varden and cutthroat trout were known to occur in non-oiled areas of PWS and adjoining areas. This information was put into a site selection matrix. From this matrix, the most promising sites were chosen for further investigations. Ground surveys of these chosen sites provided additional information about these sites and the stocks of Dolly Varden and cutthroat trout that are present. This information, along with information acquired in the first step was incorporated into fishery matrices. These matrices will help to choose sites where population abundance and stock structure research needs to be conducted. There was one site, Eyak Lake, chosen prior the development of either matrix. It was chosen due the fact that it supports major fisheries for both Dolly Varden and cutthroat trout in an unoiled area of PWS. At this site, a mark-recapture tagging program was initiated during the spring of 1991.

Identification and Categorization of Potential Survey Sites

An inventory of potential Dolly Varden and cutthroat trout systems was compiled using available information gained by prior studies conducted within PWS. Sources for information included; the Alaska Statewide Sport Fisheries Harvest Report (Mills 1985 - 1989), data from the NRDA Fish/Shellfish Study #1 Injury to Salmon Spawning Areas in PWS (Sharr personal communication), and the Field Data Summary for Copper River and Prince William Sound Lake Investigations (Barto 1982, 1983, Pellissier 1984, 1985). Specific local information about Valdez and northeastern PWS was obtained through interviews with hatchery personnel (Morgan personal communication) and tackle shop personnel (Winney personal communication). Finally, information about recreational facilities and land status was collected from the United States Forest Service (USFS).

All sites for which there was information available were listed in the site selection matrix. Information about facilities, land ownership, sport harvest, and locations where Dolly Varden and cutthroat trout were know to occur in PWS and adjoining areas, was incorporated into the matrix using the following criteria.

1. USFS Cabin: a value of 1 was given to sites where a USFS cabin was present, and 0 if there was no cabin.

2. Land Status: a value of 1 was assigned if the stream system was located on public land, and 0 if on private.

3. ADF&G Stream survey data: a value of 3 was given to those sites where AD&G personnel, doing either ground or aerial surveys had seen more than 500 Dolly Varden; 2 where 101 - 500 were seen; 1 where 1 - 100 Dolly Varden had been seen; and 0 for sites surveyed but no Dolly Varden were seen.

4. Statewide Harvest Survey: a value of 3 was given to sites where the average 1985-1989 estimated harvest of Dolly Varden exceeded 50 fish but was less than 100, 1 for sites where it exceeded 1 but was less than 50, and 0 for those sites that had no reported harvest for 1985-1989.

5. Length data from Lake Investigations: a value of 1 was assigned to those sites where Dolly Varden or cutthroat trout caught were over 200 mm in length.

6. CPUE data from Lake Investigations: a value of 3 was assigned to those sites having a CPUE statistic of 1.5 or greater, 2 for sites where CPUE for either species ranged between 0.5 and 1.5, and 1 for sites where CPUE for either species was greater than 0 but less than 0.5.

7. Valdez references: Valdez Fisheries Development Association personnel, and a salesperson for a tackle shop in Valdez were interviewed. They were asked to quantify their observations of Dolly Varden and cutthroat trout in local streams and in northeastern PWS streams. From their observations a value of 3 was given to those sites where they had seen more than 500 Dolly Varden or cutthroat trout, 2 where 101 - 500 were seen, and 1 where 1 - 100 Dolly Varden or cutthroat trout had been seen.

There was not information available for every category at each site, therefore, a percentage score was calculated for each stream. The calculation was the sum of the values assigned divided by the sum of the highest possible value for each category for which information was available.

Streams listed in the site selection matrix were then placed into one of three geographic zones (Figure 1). Each of these zones is defined by accessibility and suggests various types of sport fishing experiences. Zone 1 consists of systems accessible by road. Zone 2 are those areas accessed by single day boat trips (within a 25 mile radius from Whittier, Valdez or Cordova). Zone 3 includes remote systems accessible by boat or plane where anglers usually stay for more than one day.

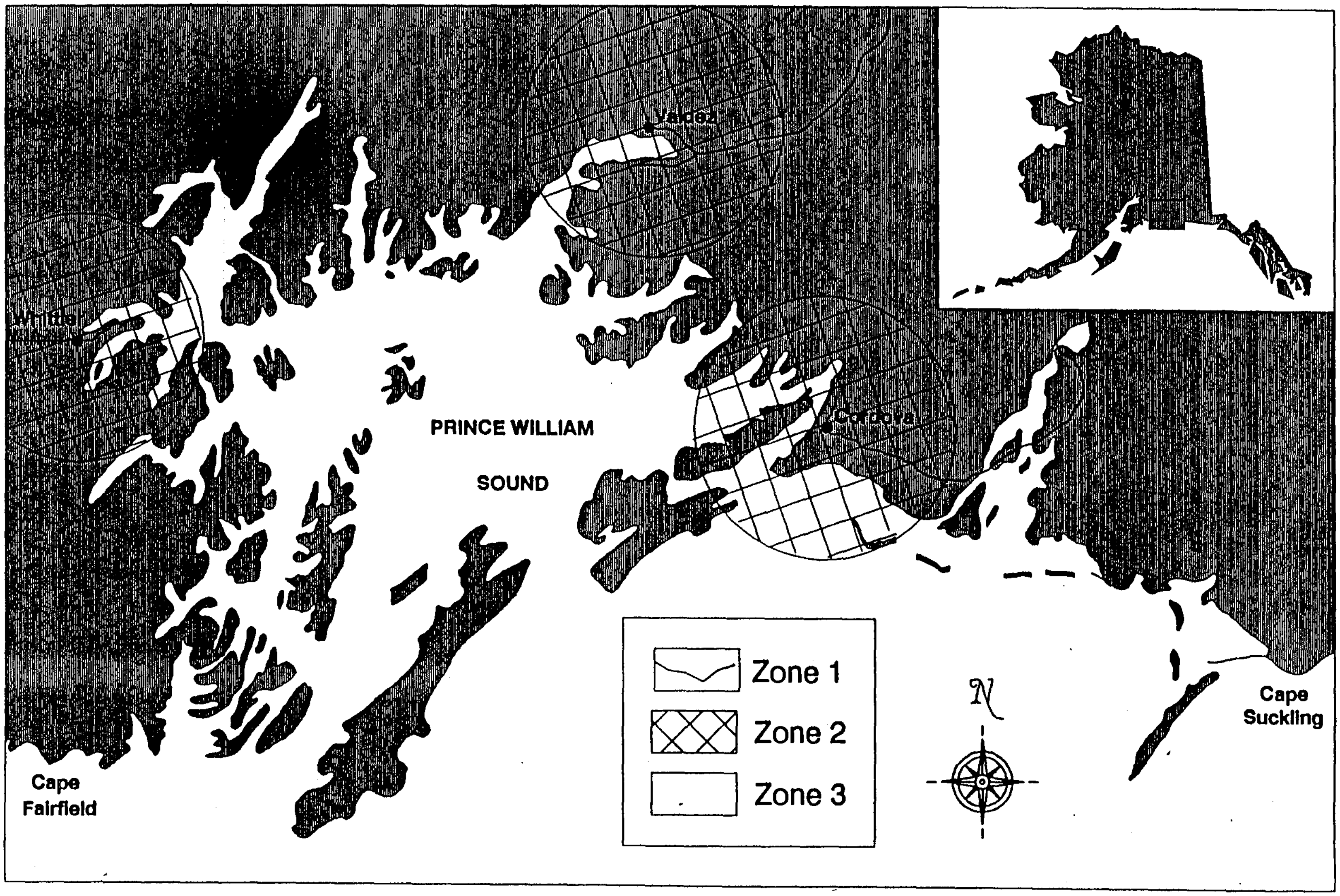


Figure 1. Location of geographic zones in Prince William Sound.

Ground Surveys and Sampling

The seven highest scoring streams in the site selection matrix were selected for ground surveys. Exceptions to this rule were streams or lake systems that were geographically close to the highest scoring streams that could also be sampled within a one week time period. In addition, the two unoiled sites studied in the NRDA project (Makarka Creek and Fish Creek in Boswell Bay) were sampled because of the availability of overwintering abundance and length data from the NRDA study. All selected sites within a zone were sampled within a two-week period of time to reduce the chance that differences in abundance or stock structure could be attributed to time of year sampled.

Ground surveys of 28 stream systems were conducted from 24 July through 4 October. The information collected at each site was: the amount of time spent sampling; location; the gear used to collect samples of target species; number of target and non-target species caught; number of fish observed but not caught; stream morphology and water character; riparian and intertidal structure of surveyed area; access to the site; existing trails and facilities; and amount of human use observed or suspected.

Common sport tackle (flies, lures or bait) was used to obtain catch-per-unit-effort information. Hook and line gear was also used as the capture method for obtaining samples for RSD statistics. Beach seines were used when possible to augment insufficient sample sizes collected with hook and line techniques.

All Dolly Varden and cutthroat trout greater than 199 mm were measured (fork length) to the nearest 1 mm and tagged with an individually numbered Floy FD-68 anchor tag inserted at the base of the dorsal fin. All Dolly Varden and cutthroat trout were checked for tag scars and missing adipose fins (natural or inflicted), tags, or tag scars from other tagging studies. In addition, the left ventral (pelvic) fin was partially clipped to provide a secondary mark to estimate tag loss. Date, location, species, tag number, type of hook and line gear used, and sex (if identifiable from external maturation characteristics) were recorded for each fish over 199 mm in length on revised tagging mark sense forms. Scale smears were taken from all cutthroat trout captured and otoliths were taken from all Dolly Varden mortalities.

The mean CPUE for each site by gear (fly, lure or bait) for each sampling period was calculated using the formula:

$$\overline{CPUE_j} = \frac{\sum_{i=1}^{n} CPUE_{ij}}{n_j} \qquad (1)$$

where:

$CPUE_{ij}$ = the catch of angler i using gear j divided by the effort expended by angler i using gear j.

n_j = number of sampling events where j gear was used at each site.

RSD statistics were calculated, as described by Gabelhouse (1984), for sites where the sample size was greater than 30. Mean length of fish sampled at a site was calculated for sample sizes greater than ten.

Development of Fishery Matrices

Information collected from ground surveys and the inventory of available information was incorporated into a fishery matrix for each zone. The highest possible values for each category were based on the relative importance of the particular piece of information. The two most heavily weighted pieces of information in the matrices were estimated annual harvest of either species, and the site's CPUE rank.

1. Access: for Zone 1 sites, a value of 2 was assigned to those sites that are road accessible, 3 for those sites that are both road and accessible by boat. For Zone 2 and 3 sites, a value of 2 was given to those sites where access is limited by tide, and 3 if there is a landing strip or good mooring site present.

2. Land Status: a value of 0 was assigned if the land surrounding the lake or stream is privately owned, and 3 if the land surrounding the lake or stream is publicly owned.

3. Lake System: a value of 0 was given to non-lake systems, 2 to closed lake systems, and 3 for open lake systems.

4. Salmon Species: a value of 0 if no preferred salmon species, sockeye and coho, are available; a value of 2 if sockeye or coho salmon are present; and a value of 3 if both sockeye and coho salmon are present.

5. Average Dolly Varden harvest: the average of the 1985-1990 estimated annual harvest of Dolly Varden (Mills 1985 -1990) was multiplied by a conversion factor in order to give it a weight similar to that of CPUE rank. The conversion factor equals the average annual harvest estimates for each species, multiplied by the quotient of the number of sites per zone with CPUE greater than zero, divided by the highest annual harvest estimate of any site within that zone.

6. <u>Average cutthroat trout harvest</u>: the average of the 1985-1990 estimated annual harvest of cutthroat trout (Mills 1985 -1990) multiplied by a conversion factor (see above).

7. <u>Dolly Varden CPUE</u>: the rank of the CPUE values from the most representative ground survey.

8. <u>Cutthroat trout CPUE</u>: the rank of the CPUE values from the most representative ground survey.

9. <u>Length Score</u>: the value is the mean length (fork length in millimeters) divided by one hundred for sites where 10 or more target species were caught. The mean length of target species caught at a site was divided by one hundred so that the mean length score carries the approximate weight of other values in the fishery matrix.

10. <u>Target species</u>: a value of 2 was assigned to sites where one of the target species was present, and 3 if both target species were present.

11. <u>Water Character</u>: a value of 2 was assigned to streams that had widths of less than 20 ft, or overhanging vegetation with few gravel bars from which to fish; and a value of 3 was assigned to stream that were wider than 20 ft for at least a quarter of a mile, and that were easy to fish, and had good riffle-pool configuration.

<u>Evaluation of Stock Structure</u>

Eyak Lake was chosen for study as a Zone 1 location prior to development of the fishery matrix because the harvests of Dolly Varden and cutthroat trout comprise a significant portion of the total harvest of these two species in PWS (20 to 30% for both species in 1988 and 1989), and because road accessibility to lakes that support overwintering populations of both Dolly Varden and cutthroat trout are rare in PWS.

A sampling strategy was designed so that either a modified Petersen two event mark-recapture estimator (Seber 1982), or the generalized Jolly-Seber estimator (Seber 1982) as modified by Buckland (1980) could be used to estimate the abundance of Dolly Varden and cutthroat trout greater than 199 mm (FL) overwintering in Eyak Lake.

The timing of the first event for both estimators was 9 May, 1991 through 19 July, 1991. This time period was selected based on observations of Dolly Varden and cutthroat trout emigrations at five sites in PWS (Hepler 1989, 1990), and the fact that cutthroat trout in Eyak lake spawn during April, May, and through early June and leave the lake immediately after spawning (Professional Fishery Consultants 1984).

Fyke nets, hoop traps, and an improvised weir were used as capture methods in the spring of 1991. On 9 May, six baited fyke nets (3'x3'x 13' with 3'x30' wings) were placed approximately 200 yards downstream from the lake outlet. From 11 May through 23 May, another 6 fyke nets were placed approximately one mile downstream to serve as the recapture event for the Petersen estimator. On 18 May, the upstream fyke nets were replaced with an improvised weir made up of two 8'x 300' beach seines and three fyke nets arranged so that approximately 80% of Eyak River was weired off. An eight foot gap was left open during the day to accommodate river boat traffic. This improvised weir served as the primary capture device during the remainder of the emigration. The outlet of the lake was also sampled with eight sunken baited hoop nets (2' diameter x 7' length) from 30 May through 21 June, and 7 fyke nets arranged so that effectively 50% of the lake outlet was blocked from 14 June - 25 June. These were in place to increase the number of fish caught during the emigration.

All Dolly Varden and cutthroat trout over 199 mm were measured to the nearest 1 mm fork length (FL) and tagged with individually numbered Floy FD-68 anchor tag inserted at the base of the dorsal fin. All Dolly Varden and cutthroat trout were checked for tag scars and missing adipose fins (natural or inflicted), tags, or tag scars from other tagging studies. In addition, the left ventral (pelvic) fin was partially clipped to provide a secondary mark to estimate tag loss. Date, location, species, tag number, and sex (if identifiable from external maturation characteristics) was recorded for each fish over 199 mm FL on revised tagging mark sense forms. Scales smears were taken from all cutthroat trout captured and otoliths were taken from all Dolly Varden mortalities.

Estimate of Relative Stock Density

Length distribution data for emigrants from Eyak lake were evaluated using RSD. The RSD statistic is a length-categorization system used to describe the length characteristics of a population of fish in terms of preferences of sport anglers (Gabelhouse 1984). Minimum lengths for each length category for Dolly Varden and cutthroat trout are: quality 200 mm, preferred 254 mm, memorable 305 mm, and trophy 381 mm. Proportions of each species within specific length categories were calculated for each system.

Where the proportion of each species in the sample that belong to length category j was estimated by:

$$\hat{p}_j = \frac{y_j}{n} \quad (2)$$

where:

y_j = the number of fish of length category j sampled; and,

n = the total number of fish sampled.

The unbiased variance of this proportion is estimated by:

$$V[\hat{p}_j] = \frac{\hat{p}_j (1 - \hat{p}_j)}{n - 1} \qquad (3)$$

RESULTS

Identification and Categorization of Potential Survey Sites

Existing information about populations of Dolly Varden and cutthroat trout in PWS and the adjacent Copper River Basin was examined. Sixty-one sites, and the information associated with them, was entered into a site selection matrix (Table 1). Each lake or stream system was classified as a Zone 1, 2, or 3 study site depending on its distance from either Cordova, Whittier, or Valdez. Zone 1 consisted of 14 lakes and stream systems that are within those city's boundaries or are accessed by a road system. Zone 2 consisted of 19 lake and stream systems located within a 25 mile radius of one of the above mentioned cities. Zone 3 was comprised of 28 remote lakes and stream systems. Thirty-two of these 61 systems were chosen for on-site surveys in 1991.

Ground Surveys and Sampling

From 16 August through 4 October, surveys were conducted for six Zone 1 sites, 17 Zone 2 sites and nine Zone 3 sites (Figure 2). Appendix Tables 1 through 7 detail CPUE data for each site sampled, and Appendix Tables 8 and 9 detail length data gathered at each site. The following summary of catch and length data for each zone emphasizes sites having the highest catch rate statistics (all hook and line gear combined) and RSD results for sites where more than 30 Dolly Varden or cutthroat trout were caught by hook and line.

Zone 1:

Zone 1 sites were surveyed during the first two weeks in August and also during the first two weeks of September. Catch-per-unit-effort for each site during both time periods are reported in Appendix Tables 1 and 2. The Alaganik Slough/McKinley lake system had the highest Dolly Varden catch rates, 4.33 fish per hour, followed by the Eyak River system, 2.92 fish per hour, for the August sampling period. The two sites having highest catch rates for the September sampling period were Power Creek, a tributary to Eyak lake, 5.49 fish per hour, and Clear Creek 4.32 fish per hour.

The RSD for the Dolly Varden caught in Salmon Creek (n = 31), a tributary to Alaganik Slough, was 9.7% preferred (254 - 304 mm), 48.4% memorable (305 - 380 mm), and 41.9% trophy (381 mm and larger). Relative Stock Density of the Dolly Varden caught at Power Creek (n = 149) was 1.3% preferred, 29.5% memorable, and 69.1% trophy. The RSD of Dolly Varden caught at Clear Creek (n = 76) was 3.9% Memorable and 96.1% Trophy.

Zone 2:

Thirteen Zone 2 sites were surveyed during the last two weeks in July and into early August. Of those, five were sampled again and

Table 1. Site selection matrix.

STREAM NAME	ZONE	LOCATION	USFS CABIN	LAND STATUS	STREAM SURVEYS	HARVEST SURVEYS	LAKE SURVEYS LENGTH	CPUE	VALDEZ REFERENCES	POINTS	SCORE
Eyak Lake complex	1	Eyak Lake	1	0	3	3				7.0	87.5
Clear Creek	1	Copper River Delta	0	1	3	3				7.0	87.5
McKinley Lake Complex	1	Copper River Delta	1	1	3	2				7.0	87.5
Robe River	1	Valdez	0	1		3			3	7.0	87.5
Alaganik Slough	1	Copper River Delta	0	1		2				3.0	60.0
Ptarmigan Creek	1	Tsina River	0	1		2				3.0	60.0
Lowe River	1	Valdez	0	1		2			0	3.0	60.0
Rainbow Creek	1	Tonsina River	0	1		2				3.0	60.0
Pipeline Lakes	1	Copper River Delta	0	1		2				3.0	60.0
Elsner River	1	Copper River Delta	0	1	3	0				4.0	50.0
Tsina River	1	Tiekel River	0	1		1				2.0	40.0
Cabin Lake	1	Copper River Delta	0	1		1				2.0	40.0
Mineral Creek	1	Valdez	0	1		1			1	3.0	37.5
Hartney Creek	1	Hartney Bay	0	0	1	1				2.0	25.0
Eccles Creek	1	Orca Inlet	0	0	1	0				1.0	12.5
Lake Shrode	2	Culross Passage	1	1		3		3		8.0	100.0
Halferty Creek	2	Cochrane Bay	0	1			1	3		5.0	83.3
Canoe Pass Lake	2	Hawkins Island	0	0		3				3.0	80.0
Shoestring Creek	2	Shoestring Cove	0	1		0		3		4.0	80.0
Swanson Creek	2	Pigot Bay	1	1	2	1				5.0	62.5
Paulson Creek	2	Cochran Bay	1	1	2	0				4.0	60.0
Raspberry Lake	2	Culross Island	0	1		2				3.0	60.0
Simpson Bay	2	Orca Bay	0	0		3				3.0	60.0
Naomoff River	2	Jack Bay	1	1	0	0			2	4.0	50.0
Hawkins Creek	2	Hawkins Island	0	1	3	0				4.0	50.0
unnamed Creek	2	Port Wells	0	1			1	1		3.0	50.0
Devish Lake	2	Valdez	0	1		1				2.0	40.0
Vlasoff Creek	2	Jack Bay	0	1	0	0			2	3.0	37.5
Stellar Creek	2	Valdez Arm	0	1	2	0				3.0	37.5
Esther River	2	Wells Passage	0	1		0	1	1		3.0	33.3
Allen Creek	2	Sheep Bay	1	0	1	0				2.0	25.0
Twin Lakes Creek	2	Simpson Bay	0	0	1	0				1.0	12.5

Table 1. Continued.

STREAM NAME	ZONE	LOCATION	USFS CABIN	LAND STATUS	STREAM SURVEYS	HARVEST SURVEYS	LAKE SURVEYS LENGTH	LAKE SURVEYS CPUE	VALDEZ REFERENCES	POINTS	SCORE
Katalla River	3	Katalla Bay	0	0	3	3				6.0	87.5
Martin River	3	East of Copper River	1	1	3	2				7.0	87.5
unnamed Creek	3	Columbia Bay	0	1			1	3		5.0	83.3
Coghill River	3	College Fjord	1	1		2				4.0	80.0
Bering River	3	Controller Bay	0	1		3				4.0	80.0
Beach River	3	Montague Island	1	0		2				3.0	80.0
MacLeod Creek	3	Macleod harbor	0	0	2	3				5.0	62.5
Silver Lake	3	Valdez Arm	0	0		3				3.0	60.0
King's River	3	King's Bay	0	1		2				3.0	60.0
Swamp Creek	3	Montague Island	0	1	3	0				4.0	50.0
Hells's Hole	3	Port Gravina	0	0		1			3	4.0	50.0
Princeton Creek	3	Icy Bay	0	1		0	1	1		3.0	50.0
Edwards River	3	Controller Bay	0	1	3	0				4.0	50.0
Martin River Slough	3	East of Copper River	0	1	3	0				4.0	50.0
Tokun Lake	3	Martin River	0	1		1				2.0	40.0
Cook Creek	3	Double Bay	0	1	2	0				3.0	37.5
Nellie Martin River	3	Patton Bay	1	0	1	1				3.0	37.5
Hanning Creek	3	Hanning Bay	0	1	2	0				3.0	37.5
Quadra Creek	3	Hanning Bay	0	1	2	0				3.0	37.5
Nuchek Creek	3	Port Etches	0	1	2	0				3.0	37.5
Jonah Creek	3	Jonah Bay	0	1	2	0				3.0	37.5
Irish Creek	3	Port Fidalgo	0	0	3	0				3.0	37.5
Dog Salmon Creek	3	Port Etches	0	1	1	0				2.0	25.0
Captain Creek	3	Double Bay	0	1	1	0				2.0	25.0
Cabin Creek	3	Port Chalmers	0	1		0				1.0	20.0
Patton River	3	Patton Bay	0	0		1				1.0	20.0
Double Creek	3	Double Bay	1	1	0	0				2.0	18.2
Whalen Creek	3	Whalen Bay	0	0	1	0				1.0	12.5

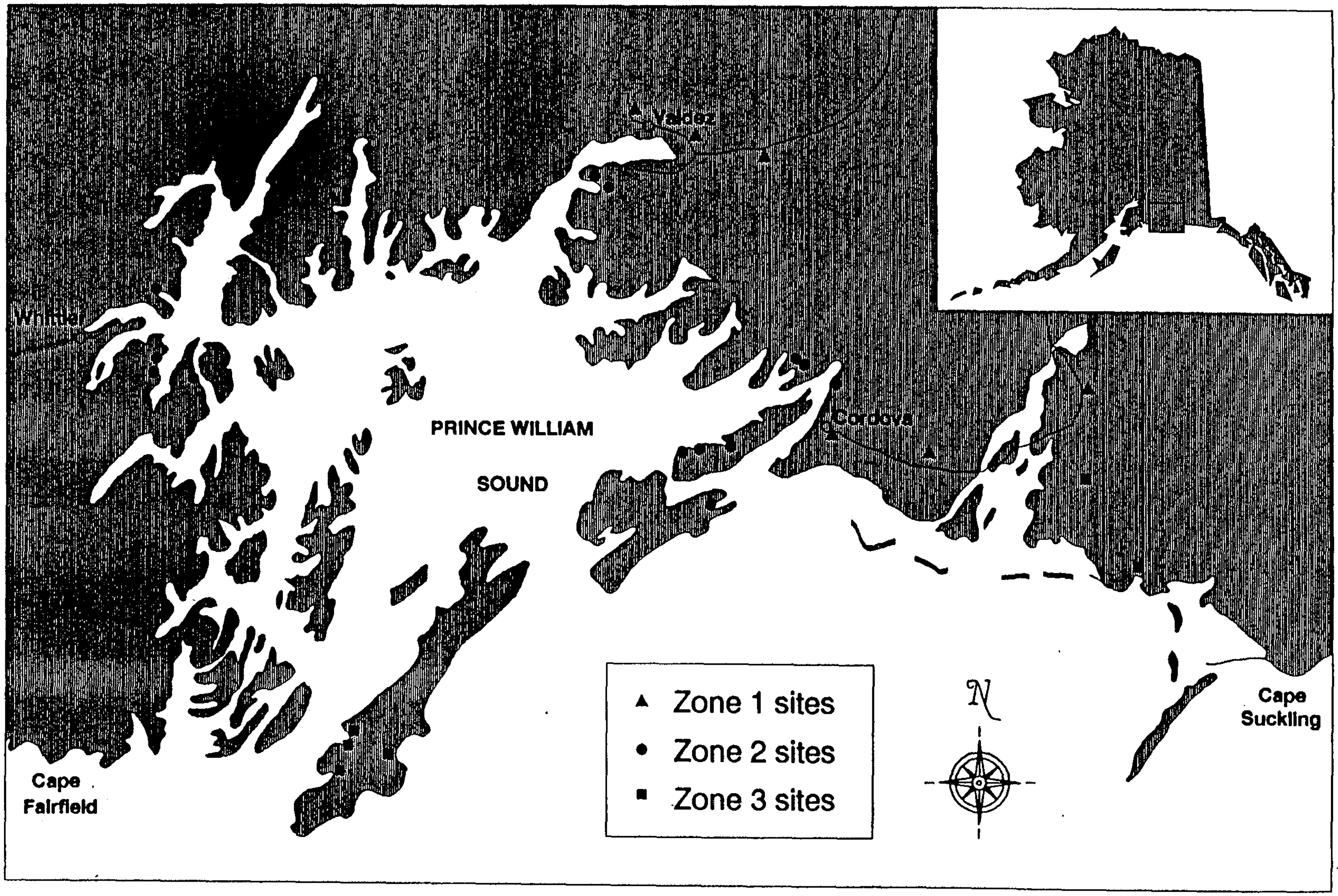


Figure 2. Location of sites where ground surveys were completed during 1991.

an additional site was sampled during the last two weeks of September and into early October. Catch-per-unit-effort statistics for each site for both time periods and for each species are reported in Appendix Tables 3 - 6. The top three sites for Dolly Varden catch rates were Halferty Creek, 1.65 fish per hour, Makarka Creek 1.07 fish per hour, and Naomoff Creek 0.92 fish per hour. The top three sites for cutthroat trout CPUE in August were Makarka Creek 1.92 fish per hour, Boswell Creek 1.60 fish per hour, and Hawkins Creek 1.52 fish per hour. The September sampling at Zone 2 sites resulted in low catch rates for Dolly Varden and the only site where cutthroat trout were caught in September was Makarka Creek where the catch rate was 1.75 fish per hour. RSD analysis was not calculated for any Zone 2 sites, this is due to insufficient sample sizes collected at these sites.

Zone 3:

Seven Zone 3 streams were surveyed in the latter part of August (Appendix Table 7). The sites with the highest Dolly Varden catch rates, using all types of hook and line gear combined, were Quadra Creek, 4.44 fish per hour, and Swamp Creek, 4.03 fish per hour. However, these CPUE statistics were driven by the high catch rates achieved when bait was used, for example, the mean CPUE for all anglers using bait at Quadra Creek was 10.27 fish per hour, and was 7.56 fish per hour at Swamp Creek. The ranking procedure eliminated this bias against sites where bait was not used as a gear type, which resulted in Quadra and Hanning creeks being ranked the highest.

The RSD for Dolly Varden caught at Martin River (n = 61) was 6.6% Quality, 47.5% Preferred, 44.3% Memorable and 1.6% Trophy. The RSD for Quadra Creek (n = 34) was 11.8% Preferred, 44.1% Memorable and 44.1% Trophy.

<u>Development of Fishery Matrices</u>

The information gathered in the inventory and ground surveys was incorporated into fishery matrices for each zone (Tables 2 - 4). The following is a summary of pertinent information in these matrices.

Zone 1:

The two systems scoring the highest in the fishery matrix for Zone 1 (Table 2) are the Eyak lake system and the Robe lake system. Eyak River, which drains Eyak Lake has consistently ranked as one of the top three sites of freshwater harvest for both cutthroat trout and Dolly Varden, (Mills 1985 -1990). Power Creek, a tributary of Eyak Lake, had the highest CPUE of all sites in Zone 1. Other traits that make it desirable are that it is accessible by boat and road, and also supports viable coho and sockeye salmon sport fisheries. Robe Lake system achieved the second highest

Table 2. Fishery matrix for Zone 1 streams.

					Dolly Varden			Cutthroat			
	Access	Land Status	Lake System	Salmon Species	Average Harvest	CPUE Rank	Length Score	Average Harvest	Target Species	Water Character	Matrix Score
Eyak River	3	3	3	3	2.02	5	4.24	5.00	3	3	0.92
Robe River	2	3	3	3	5.00	1	2.5		2	2	0.73
Clear Creek	3	3	0	3	0.52	4	4.4	0.25	3	3	0.65
Alaganik Slough	3	3	3	3	0.18	*	3.77	2.09	3	3	0.64
Lowe River	2	3	0	3	0.30	2			2	3	0.55
Mineral Creek	2	3	0	2	0.05	3			2	2	0.50

Dolly Varden estimated annual harvest conversion factor = .003396
Cutthroat trout estimated annual harvest conversion factor = .025125

*The September sampling period was chosen for ranking CPUE statistic, however Alaganik was not sampled due to high water levels.

Table 3. Fishery matrix for Zone 2 streams.

	Access	Land Status	Lake System	Salmon Species	Dolly CPUE Rank	Cutthroat CPUE Rank	Cutthroat Length Score	Target Species	Water Character	Matrix Score
Makarka Creek	2	3	3	3	4	5	3.16	3	3	0.97
Boswell Creek	2	3	3	3	0	4		3	3	0.78
Halferty Creek	2	3	2	2	5	0		2	3	0.70
Hawkins Creek	2	3	0	2	2	3	3.04	3	3	0.70
Lake Shrode	3	3	3	3	*	*		2	3	0.63
Canoe Pass Lake	3	0	3	2	0	2	2.47	3	3	0.61
Naomoff Creek	3	3	0	2	3	0		2	3	0.59
Vlasslof Creek	2	3	0	2	1	0		2	3	0.48
Swanson Creek	2	3	0	2	0	0		2	3	0.44
Paulson Creek	2	3	0	2	0	0		2	2	0.41
Twin Lakes	2	0	2	0	0	1		2	3	0.37
Raging River	2	0	0	0	0	0		3	3	0.30
Rogue River	2	0	0	0	0	0		3	2	0.26
Humpback Creek	2	0	0	0	0	0		2	2	0.22

* The August sampling period was chosen for ranking the CPUE statistic, however Lake Shrode was not sampled during the August sampling period.

Table 4. Fishery matrix for Zone 3 streams.

	Access	Land Status	Lake System	Salmon Species	Dolly Varden			Target Species	Water Character	FS Cabin	Matrix Score
					Average Harvest	CPUE Rank	Length Score				
Martin River	3	3	3	3	2.49	5	3.04	3	3	3	0.81
Hanning Creek	3	3	0	2		6	3.82	2	3	0	0.71
Quadra Creek	3	3	0	2		7	3.77	2	2	0	0.71
Swamp Creek	2	3	0	2		3	4.05	2	2	3	0.66
Nellie Martin	3	3	0	3	1.20	2	2.97	2	3	3	0.59
Katalla River	3	0	0	3	7.00	1		3	3	0	0.57
Macleod Creek	3	0	0	2		4		2	3	0	0.50

Dolly Varden estimated annual harvest conversion factor = 0.03004 score in Zone 1. This high score was driven in part by the historically high catches of Dolly Varden caught at this site. The annual sport harvest of Dolly Varden from Robe River has been in decline since 1986, down from an estimated 3,104 in 1985 and 4,449 in 1986, to 98 in 1990. The probable reason for this decline is that Robe Lake has become choked with aquatic vegetation in recent years due to the diversion of two streams that previously drained into the lake (Koenings 1985). Robe Lake still supports viable sport fisheries for coho and sockeye salmon. Large numbers of Dolly Varden were not found during ground surveys, the catch rate statistics for the August and September sampling periods were, 0.28 fish per hour in August, and 0.0 fish per hour in September. Although water characteristics of Robe Lake and River are not desirable now, Robe Lake and River do have road access and are on public land, therefore, this system is a good candidate for further research or its own restoration project as recommended by Koenings.

Zone 2:

The two highest scoring sites in the fishery matrix for Zone 2 (Table 3) were Makarka Creek and Boswell Creek. The reasons for their high ranks is that they had the highest cutthroat trout catch rates of all Zone 2 sites, and they are both lake systems that provide overwintering habitat for both target species. They also support viable runs of sockeye and coho salmon. The next two highest scoring sites were Lake Shrode and Halferty Creek. Lake Shrode is accessible by float plane or by boat to Long Bay. There is a USFS cabin on the lake and trails from it that lead down to Long Bay. It also supports runs of sockeye and coho salmon. While the catch rates experienced at this site were low, several hundred Dolly Varden were seen at the outlet of the lake in late September. Halferty Creek had the highest Dolly Varden CPUE rank in Zone 2 and the water characteristics are very conducive to angling. Halferty Creek also supports coho salmon and is on public land.

Zone 3:

The fisheries matrix for Zone 3 (Table 4) indicates that Martin River initially looks promising as a remote fishery location for Dolly Varden and cutthroat trout. The on-site survey of Martin River verified that there were abundant numbers of Dolly Varden in the Preferred (47%) and Memorable (44%) length categories in Martin River itself as well as Trophy size individuals in the lake (mean length 448 mm, n = 19). Cutthroat trout were also found in Martin River although they were less abundant than Dolly Varden. There were also abundant coho, pink and red salmon in the system. According to Mills (1977-1990) there was a limited harvest of both Dolly Varden and cutthroat trout occurring annually at this site. This range of fish species diversity coupled with a Forest Service cabin; the stream being enjoyable to fish; spectacular scenery and wildlife, make this site an ideal sport fishing destination.

Hanning and Quadra creeks, located on the western side of Montague Island, received the second highest scores for Zone 3 sites. Both of these sites are located on USFS land (public), and have good mooring sites available in Hanning Bay. Of the seven sites surveyed, Quadra Creek had the highest catch rate and Hanning Creek had the third highest catch rate. Hanning Creek had the highest mean length of any Zone 3 site (462 mm n = 27).

Evaluation of Stock Structure

A total of 512 Dolly Varden and 16 cutthroat trout greater than 200 mm were caught in Eyak River. All 16 cutthroat trout were tagged and 511 of the Dolly Varden were tagged in Eyak River from 9 May through 19 July 1991. Of the total number of Dolly Varden tagged, 56 were caught in the fyke nets closest to the lake outlet (upstream fyke nets), five were caught in the fyke nets (downstream fyke nets) set approximately 1 mile below the upstream nets, and 451 were caught at the improvised weir. None of the five Dolly Varden caught in the downstream fyke nets was a recapture from either the weir or the upstream fyke nets. There were no Dolly Varden or cutthroat trout greater than 200 mm caught in the fyke nets or hoop traps set in the lake. Of the total number of cutthroat trout caught, three were caught in the upstream fyke nets and 13 were caught at the weir.

Examination of the catch curve (Figure 3) indicates that the peak of migration occurred prior to our sampling effort. The spike observed beginning on May 17 corresponds to when the upstream fyke nets were replaced by the improvised weir which was a more efficient capture device.

Estimates of Relative Stock Density

The Relative stock density for all emigrating Dolly Varden over 200 mm FL from Eyak Lake (based on 508 lengths) caught in either the fyke nets or the weir was 80.5% Quality (200 - 253 mm), 17.6% Preferred (254 - 304 mm), and 2.0% Memorable (305 -380 mm). There were no Trophy (381 and larger) size Dolly Varden caught. The sample size for Eyak Lake system cutthroat over 200 mm in length was insufficient to perform RSD analysis.

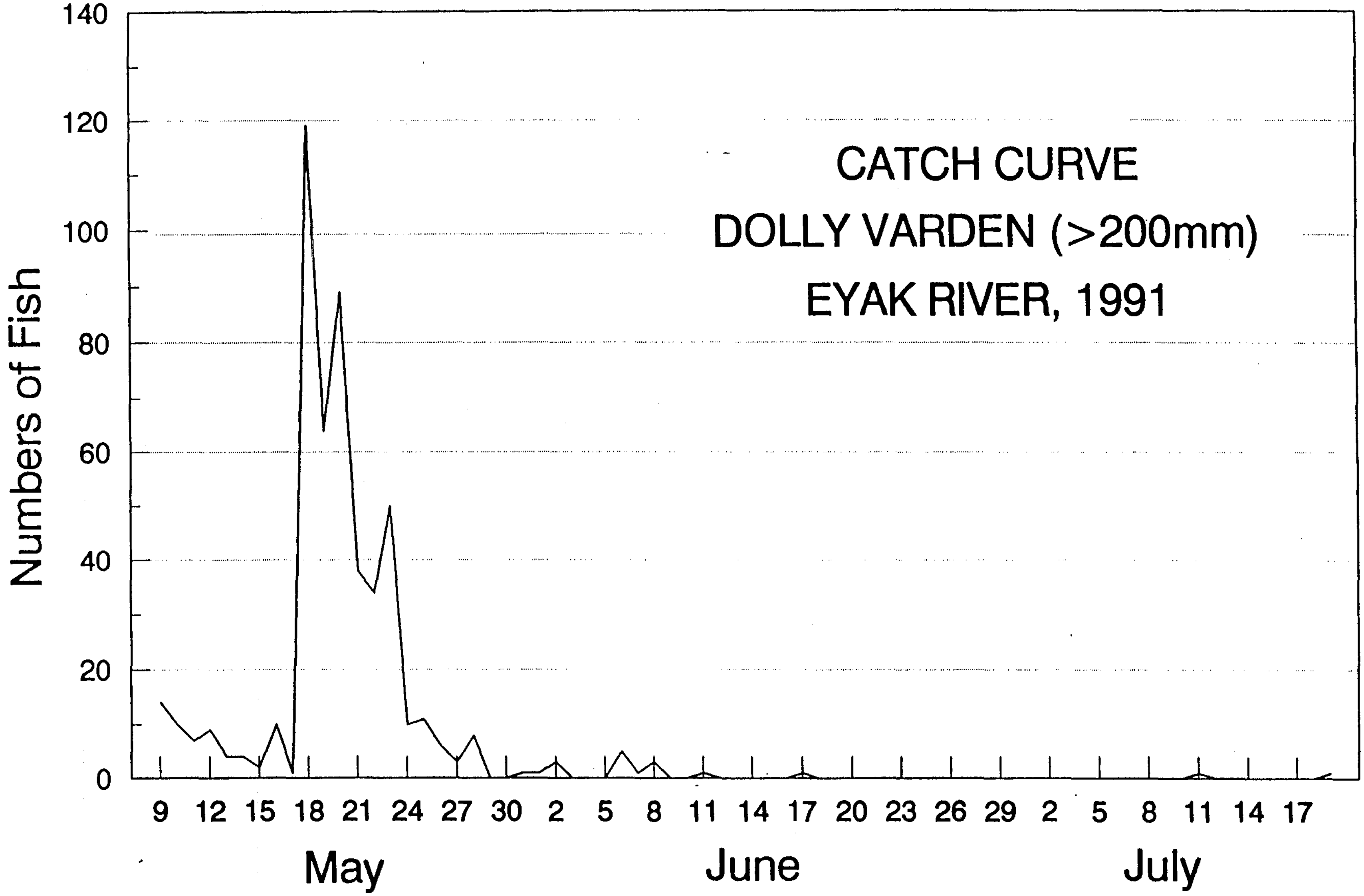


Figure 3. Catch curve for Dolly Varden in Eyak River, 1991.

RESTORATION PROJECT STATUS AND RECOMMENDATIONS

The ultimate use of information from this project is for the rational development of a management plan for Dolly Varden and cutthroat trout in PWS. The development of a specific management plan is the logical endpoint of the initially stated intention of this project to "provide information which can be used for making management decisions". This plan will provide for responsible and orderly management of these fisheries through modification of human use and replacement of lost fishing opportunities in PWS, while aiding in the recovery of these species from the impacts of the Exxon Valdez oil spill (EVOS) as well as protecting the biological integrity of wild stocks. This plan will address biological issues which could include setting desired harvest and participation levels, or determining whether time or area closures are needed. It will also address social issues, such as providing for a diversity of fishing experiences (e.g. fly fishing only areas, as well as areas where anglers can use any type of tackle). The information needed to address these types of issues include, stock size, length distribution, geographic distribution, migration, current effort and harvest levels, and spawning stock identification, also information such as access, land status, catch rates, watershed characteristics and other species present will be needed (Figure 4).

The present paucity of data on the stock status, life history and distribution of Dolly Varden and cutthroat trout populations in PWS is being greatly enhanced by this project. It is imperative to complete the collection of this information for an increased number of Dolly Varden and cutthroat trout populations in order to develop a meaningful management plan. This study was designed to collect data over a several year time period. The rational for this is that the evaluation of potential sites requires the collection of detailed field information and the estimation of abundance may require several years of data. 1992 field studies will be comprised of the continuation of reconnaissance in Zone 3, the continuation of the Eyak River abundance estimates and stock structure evaluation, and the initiation of abundance estimate sampling at least two additional sites. Consideration of the needs of developing a comprehensive management plan has lead to the conclusion that this process is necessary in the oiled areas of PWS in addition to those proposed in the unoiled areas. These considerations will be addressed in the 1992 operational plan.

The Dolly Varden and cutthroat trout (DVCT) restoration science project is integrated with several other restoration projects and proposals, and an ongoing damage assessment project. Information gained or field and logistic support from this study will complement objectives listed in some of these studies, and is essential for others. From the other perspective, information and logistics from some of these other projects and proposals will be beneficial to this project. The field logistics provided by this

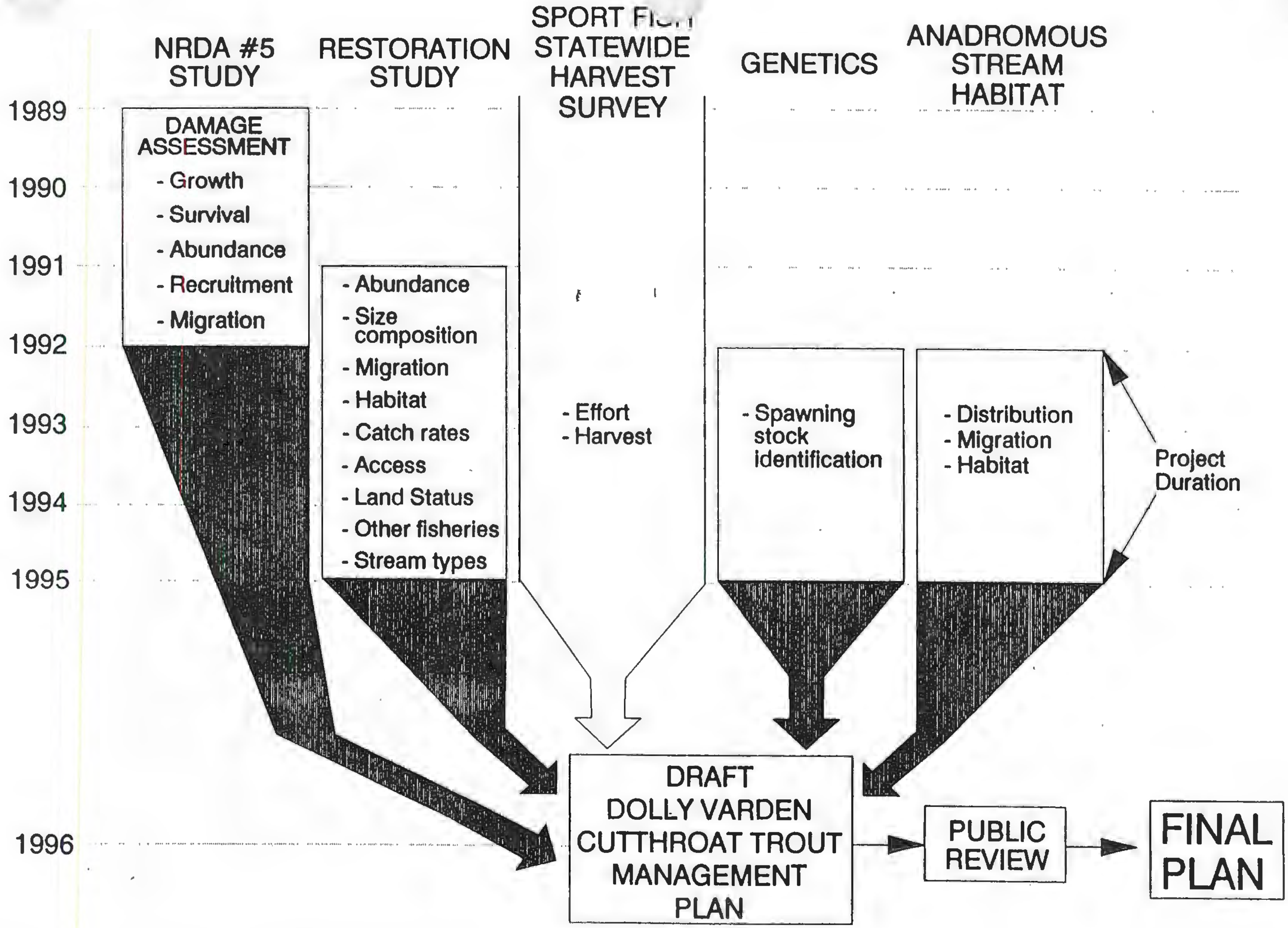


Figure 4. Schematic of components needed and tentative time frame for development of a Dolly Varden and cutthroat trout management plan for Prince William Sound.

study are essential to a Restoration Science Study proposal "Genetics Studies of Salmonids". This study will provide information about reproductively isolated populations of Dolly Varden and cutthroat trout that will be valuable to the development of a management plan. The Restoration Science proposal "Anadromous Fish Stream Habitat Assessment" (AFSHA) has objectives that are indirectly addressed by this project. The objectives of the AFSHA are directed toward documenting anadromous fish distribution and habitat characteristics in impacted areas; identifying critical habitat areas important to the recovery of anadromous fish; and examining land use activities that conflict with the recovery of anadromous fish. The DVCT project has already identified additional anadromous streams and has collected information about stream habitat characteristics and critical habitat areas that will be useful to the AFSHA project. Information gained by the AFSHA study about the distribution of Dolly Varden and cutthroat trout as well as the recovery of fish tagged as part of the DVCT restoration and NRDA projects will be extremely valuable in understanding the movements and distribution of these species. The continuation of the NRDA study of Dolly Varden and cutthroat trout will document the extent to which injury persists to these species and recapture information will help in documenting movements and overwintering areas of fish tagged during the DVCT restoration study. Finally, the continuation of ground surveys by the DVCT restoration study will document additional areas critical to Dolly Varden and cutthroat trout, which could be considered for protection, enhancement or acquisition. This is a need identified by the Restoration Planning Work Group, as well as a specific objective of the DVCT and AFSHA restoration projects.

Identification and Categorization of Potential Survey Sites.

The development of the site selection matrix is a dynamic process and as such the current matrix, while instrumental in conducting this years ground survey studies, should continue to be updated as new information becomes available and additional sources of information are found. Also, oiled areas are recommended for study in 1992, information for a number of sites within oiled areas of PWS was gathered during the inventory phase and can be easily incorporated into site selection matrix prior to site selection.

Ground Surveys and Sampling

Ground surveys need to be continued in 1992 for some of the remaining Zone 3 sites and for important sites within oiled areas. These surveys provide information such as catch rate, water character, and length distribution that will not be available otherwise. This information along with the information collected during the inventory is forming the groundwork for a better understanding of the Dolly Varden and cutthroat trout fisheries in PWS.

Development of Fishery Matrices

From the matrices developed in 1991 there are more than 2 sites in Zone 1 that can be considered for further stock assessment work and there are also several lake systems (both closed and open) in Zone 2 that can be considered for stock assessment work. With current information, there is only one Zone 3 site that can be considered for stock assessment work. Therefore, other Zone 3 sites such as Irish Creek, Whalen Creek or Silver Lake that were mentioned in the site selection matrix but were not visited in 1991 should be considered for sampling in 1992.

Evaluation of Stock Status

During the first year of the project one site, Eyak River, was sampled for estimating abundance. Five hundred and twelve Dolly Varden and 16 cutthroat trout were tagged during the field season. No recaptures were made at the downstream capture site therefore no Petersen estimate could be made this year. Therefore, we will be depending on either a complete census or a Jolly-Seber estimator to determine the abundance of overwintering fish in Eyak Lake. Sampling at this site in 1992 will begin in April as soon as sampling devices can be installed in order to catch the peak of the emigration which was probably missed in 1991. The data collected in 1991 will be used as the first capture event for calculating the Jolly-Seber abundance estimator.

Estimates of Relative Stock Densities

The RSD statistics show that the Dolly Varden emigration from Eyak River in 1991 lacked trophy sized fish and had very few memorable size fish. This is surprising considering the high proportions of trophy and memorable fish caught in Power Creek the major spawning tributary of Eyak Lake. This could be a result of missing the peak or early part of the emigration as indicated by the catch curve (Figure 3). The RSD analysis following the second year of study should be able to confirm this provided that sampling devices can be installed early enough. Another theory could be that these large spawners in Power Creek leave in the fall and over-winter in another system. This could be determined by tag recapture information.

REFERENCES

Barto, D. L., and V. L. Nelson. 1982. Field data summary for Copper River and Prince William Sound lake investigations, 1982. [Produced by] Alaska Department of Fish and Game [for] Prince William Sound Aquaculture Corporation, Cordova. 268 pp.

Barto, D. L., V. L. Nelson, and R. F. Pellissier. 1983. Field data summary for Copper River and Prince William Sound lake investigations, 1983. [Produced by] Alaska Department of Fish and Game [for] Prince William Sound Aquaculture Corporation, Cordova. 213 pp.

Buckland, S. T. 1980. A modified analysis of the Jolly-Seber capture-recapture model. Biometrics 36:419-435

Buckland, S. T. 1982. A mark-recapture survival analysis. Journal of Animal Ecology. 51:833-847

Gabelhouse, D. W. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273-285.

Hepler, K., A. Hoffmann, and P. Hansen. 1989. Injury to Dolly Varden char and cutthroat trout in Prince William Sound. State/Federal Natural Resource Damage Assessment Preliminary Status Report Draft, January 1990. Fish/Shellfish Study Number 5. Alaska Department of Fish and Game, Sport Fish Division, Anchorage. 52 pp.

Hepler, K., A. Hoffmann and P. Hansen. 1990. Injury to Dolly Varden char and cutthroat trout in Prince William Sound. State/Federal Natural Resource Damage Assessment Preliminary Status Report Draft, January 1990. Fish/Shellfish Study Number 5. Alaska Department of Fish and Game, Sport Fish Division, Anchorage. 47 pp.

Keonings, J. P., D. Barto, G. Perkins, and P. McCollum. 1985. Robe Lake diagnostic/feasibility study: phase I of the EPA clean lakes program. Alaska Department of Fish and Game, Soldotna, Alaska and Valdez Fisheries Development Association, Valdez, Alaska. 108 pp.

Mills, M.J. 1986. Alaska statewide sport fish harvest studies (1985). Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1985-1986, Project F-10-1, 27 (RT-2). 137 pp.

______. 1987. Alaska statewide sport fisheries harvest report (1986). Alaska Department of Fish and Game, Fishery Data Series No. 2. 140 pp.

______. 1988. Alaska statewide sport fisheries harvest report (1987). Alaska Department of Fish and Game, Fishery Data Series No. 52. 142 pp.

______. 1989. Alaska statewide sport fisheries harvest report (1988). Alaska Department of Fish and Game, Fishery Data Series No. 122. 142 pp.

______. 1990. Harvest and participation in Alaska sport fishing during 1989 (1990). Alaska Department of Fish and Game. Fishery Data Series No. 90-44. 152 pp.

______. 1991. Harvest, catch, and participation in Alaska sport fisheries during 1990. Alaska Department of Fish and Game, Fishery Data Series No. 91-58. 184 pp.

Morgan, K. 1991, Personal communication. Valdez Fisheries Development Association. Valdez.

Pellissier, R. F., D. L. Barto, M. A. Somerville, J.C. Woodruff and J. B. Todd. 1985. Field data summary for Copper River and Prince William Sound lake investigations, 1984. [Produced by] Alaska Department of Fish and Game [for] Prince William Sound Aquaculture Corporation, Cordova. 98 pp.

Pellissier, R. F. and M. A. Somerville. 1985. Field data summary for Copper River and Prince William Sound lake investigations, 1985. [Produced by] Alaska Department of Fish and Game [for] Prince William Sound Aquaculture Corporation, Cordova. 149 pp.

Professional Fishery Consultants. 1984. Eyak Lake AMSA, Cooperative Management Plan, Public Review Draft. Prepared for the Eyak Lake AMSA Study Team.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. 2nd ed. Charles Griffin and Company Limited. Charles Griffin House, Credon Street, High Wycombe Bucks, HP13 6LE, England. 654 pp.

Sharr, S. 1991. Personal communication. Alaska Department of Fish and Game. Cordova.

Winney, D. 1991. Personal communication. Hook Line and Sinker. Valdez.

APPENDIX

Appendix Table 1. Mean catch-per-unit-effort and site ranking for Dolly Varden at Zone 1 sites, 4 - 15 August, 1991.

Location	Mean CPUE			
	Bait	Fly	Lure	All
Clear Creek	0.00	0.00	0.10	0.06
Eyak River / Power Creek	IT	4.50	1.87	2.92
Alaganik Slough / Salmon Creeek	IT	9.00	3.25	4.33
Mineral Creek	1.00	NU	NU	1.00
Lowe River	0.00	NU	NU	0.00
Robe River	0.35	NU	0.00	0.28

IT = Insuffficent time sampled. (Less than 1 hour)
NU = Gear not used

Appendix Table 2. Mean catch-per-unit-effort and site ranking for Dolly Varden at Zone 1 sites , 3 - 16 September, 1991.

	Mean CPUE				Rank				
Location	Bait	Fly	Lure	All	Bait	Fly	Lure	Rank Score	Final Rank
Clear Creek	5.96	4.47	IT	4.32	2	1		0.6	4
Power Creek	7.57	7.35	1.00	5.49	3	2	3	1.0	5
Alaganik Slough			(no fishing due to high water conditions)						
Mineral Creek	0.37	NU	0.05	0.41	1		1	0.33	3
Lowe River	0.00	0.00	0.51	0.34	0	0	2	0.25	2
Robe River	0.00	0.00	0.00	0.00	0	0	0	0.00	1

IT = Insufficent time sampled. (Less than 1 hour)
NU = Gear not used

Appendix Table 3. Mean catch-per-unit-effort and site ranking for Dolly Varden at Zone 2 sites, 24 July - 13 August, 1991.

Location	Mean CPUE			Rank		Final Score	Final Rank
	Fly	Lure	All	Fly	Lure		
Swanson Creek	NU	0.00	0.00		0	0.00	0
Halferty Creek	NU	1.98	1.65		5	1.00	5
Paulson Creek	NU	0.00	0.00		0	0.00	0
Makarka Creek	0.00	1.60	1.07	0	4	0.80	4
Hawkins Creek	0.00	0.89	0.51	0	2	0.40	2
Vlassloff Creek	NU	0.17	0.17		1	0.20	1
Canoe Pass Lake	0.00	0.00	0.00	0	0	0.00	0
Twin Lakes	0.00	0.00	0.00	0	0	0.00	0
Rogue River	NU	0.00	0.00		0	0.00	0
Raging River	NU	0.00	0.00		0	0.00	0
Boswell Creek	0.00	0.00	0.00	0	0	0.00	0
Naomoff Creek	NU	0.92	0.92	0	3	0.60	3
Humpback Creek	IT	0.00	0.00		0	0.00	0

IT = Insufficent time sampled. (Less than 1 hour)
NU = Gear not used
* Bait was used only at 2 sites for .75, and.5 hrs, Bait CPUE was 0.0 for both

Appendix Table 4. Mean catch-per-unit-effort by gear type for Dolly Varden at Zone 2 sites, 24 September - 4 October, 1991.

Location	Mean CPUE			
	Bait	Fly	Lure	All
Lake Shrode	0.33	NU	0.20	0.23
Halferty Creek	NU	NU	0.00	0.00
Naomoff Creek	0.00	NU	0.00	0.00
Makarka Creek	0.00	0.00	NU	0.00
Hawkins Creek	1.00	0.38	NU	0.38

NU = Gear not used

Appendix Table 5. Mean catch-per-unit-effort and site ranking for cutthroat trout Zone 2 sites, 24 July - 13 August, 1991.

Location	Mean CPUE			Rank		Rank	Final
	Fly	Lure	All	Fly	Lure	Score	Score
Makarka Creek	2.00	1.88	1.92	3.5	5	0.94	5
Boswell Creek	2.00	2.00	1.60	3.5	4	0.83	4
Hawkins Creek	1.33	1.67	1.52	2.0	3	0.56	3
Canoe Pass Lake	1.50	1.00	1.17	1.0	2	0.33	2
Twin Lakes	0.00	0.84	0.56	0.0	1	0.11	1
Swanson Creek	NU	0.00	0.00		0	0.00	0
Halferty Creek	NU	0.00	0.00		0	0.00	0
Paulson Creek	NU	0.00	0.00		0	0.00	0
Raging River	NU	0.00	0.00		0	0.00	0
Humpback Creek	0.00	0.00	0.00	0.0	0	0.00	0
Naomoff Creek	NU	0.00	0.00		0	0.00	0
Vlassloff Creek	NU	0.00	0.00		0	0.00	0

NU = Gear not used

* Bait was used only at 2 sites for .75, and.5 hrs, Bait CPUE was 0.0 for both

Appendix Table 6. Mean catch-per-unit-effort by gear type for cutthroat trout at Zone 2 sites, 24 September - 4 October, 1991.

Location	Mean CPUE			
	Bait	Fly	Lure	All
Lake Shrode	0.00	NU	0.00	0.00
Halferty Creek	NU	NU	0.00	0.00
Naomoff Creek	0.00	NU	0.00	0.00
Makarka Creek	1.50	1.00	NU	1.75
Hawkins Creek	0.00	0.00	NU	0.00

NU = Gear not used

Appendix Table 7. Mean catch-per-unit-effort and site rankings for Dolly Varden at Zone 3 sites, 19 - 29 August, 1991.

Location	Mean CPUE				Rank			Rank Score	Final Score
	Bait	Fly	Lure	All	Bait	Fly	Lure		
Quadra Creek	10.27	IT	2.14	4.44	3		6	0.90	7
Hanning Creek	NU	2.71	0.80	2.33		4	5	0.82	6
Martin River	IT	1.00	3.01	2.37		1	7	0.73	5
McCleod Creek	NU	2.33	0.75	1.81		3	4	0.64	4
Swamp Creek	7.56	NU	0.50	4.03	2		3	0.50	3
Nellie Martin River	0.27	1.67	0.30	0.66	1	2	2	0.36	2
Katalla River	0.00	IT	0.06	0.04	0		1	0.10	1

IT = Insufficent time sampled. (Less than 1 hour)
NU = Gear not used

Appendix Table 8. Relative stock densities (RSD) for Dolly Varden caught by hook and line by geographic zone, 1991.

Site	RSD	Sample Proportion	Std. Error
ZONE I			
Power Cr. (n = 149)	Preferred	1%	1%
	Memorable	30%	4%
	Trophy	69%	4%
Clear Cr. (n = 76)	Memorable	4%	2%
	Trophy	96%	2%
Salmon Cr. (n = 31)	Preferred	1%	1%
	Memorable	48%	1%
	Trophy	41%	1%
ZONE III			
Martin R. (n = 61)	Quality	7%	3%
	Preferred	47%	7%
	Memorable	44%	7%
	Trophy	2%	2%
Quadra Cr. (n = 34)	Preferred	12%	6%
	Memorable	44%	9%
	Trophy	44%	9%

Appendix Table 9. Mean length of Dolly Varden and cutthroat trout caught by hook and line by geographic zone, 1991.

Site	Sample Size	Mean Length (mm)	Std. Dev.
<u>ZONE I</u>			
<u>Dolly Varden</u>			
Power Cr.	149	424	67
Robe R.	13	250	36
Clear Cr.	76	440	38
Salmon Cr.	31	477	51
<u>ZONE II</u>			
<u>Dolly Varden</u>			
Hawkins Cr.	14	196	42
<u>Cutthroat trout</u>			
Makarka Cr.	17	316	50
Canoe Pass L.	11	247	21
<u>ZONE III</u>			
Martin L.	19	448	36
Martin R.	61	304	38
Nellie Martin R.	12	297	19
Swamp Cr.	14	410	35
Hanning Cr.	27	462	41
Quadra Cr.	34	377	50

8. Salmon Coded-Wire Tagging in Prince William Sound

STATE/FEDERAL NATURAL RESOURCE DAMAGE ASSESSMENT
DRAFT PRELIMINARY STATUS REPORT

Project Title:	CODED-WIRE TAG STUDIES ON PRINCE WILLIAM SOUND SALMON
Study ID Number:	Fish/Shellfish Study Number 3 Restoration Study Number 8
Lead Agency:	State of Alaska, ADF&G
Cooperating Agency(ies):	NOAA, UA State: DNR
Principal Investigator(s):	Samuel Sharr, Comm. Fish. Division Mark Willette, FRED Division
Assisting Personnel:	Carol Peckham, Dan Sharp, Jodi Smith
Date Submitted:	November 20, 1991

TABLE OF CONTENTS

LIST OF TABLES ii

LIST OF FIGURES iii

EXECUTIVE SUMMARY 1

OBJECTIVES 2

INTRODUCTION 3

METHODS 6
- 1991 Tagging 6
  - Tagging of Hatchery Stocks 6
  - Tagging of Wild Stocks 7
- 1991 Tag Recovery 8
  - Commercial and Cost Recovery Harvests 8
  - Brood Stock Harvests 9
  - Wildstock Streams 11
- 1991 Catch and Contribution 11

RESULTS 12
- Previous Findings 12
- 1991 Tagging 13
  - Tagging of Hatchery Stocks 13
  - Tagging of Wild Stocks 13
- 1991 Tag Recovery 13

STATUS OF INJURY ASSESSMENT 28

LITERATURE CITED 30

LIST OF TABLES

TABLE — Page

1. Hatchery tagged stocks returning to Prince William Sound in 1991 14

2. Coded-wire tagging results for hatchery stocks released in Prince William Sound, 1991 15

3. Coded-wire tagging results and dates of weir operation for wild stocks released in Prince William Sound, 1991 . 16

4. Recovery results for tagged wildstock pink salmon, 1991 19

5. Tags recovered in wildstock streams by hatchery or stream of origin 21

6. Summary of hatchery contributions to the PWS pink salmon fishery using tag expansions at release and adjustment factors from the broodstock or cost recovery 22

7. Total hatchery contribution (adjusted and unadjusted) to the PWS pink salmon fishery by harvest type 25

8. Summary of results of coded-wire tag studies on pink salmon in Prince WIlliam Sound, 1987-1991 27

LIST OF FIGURES

FIGURE		Page
1.	Map of Prince William Sound showing fishing districts and hatcheries	4
2.	Map of Prince William Sound showing location of pink and sockeye salmon weir sites	5
3.	Percent tags recovered in broodstock and total catch	10
4.	Timing and magnitude of pink salmon fry outmigrations from three oiled streams in Prince William Sound	17
5.	Timing and magnitude of pink salmon fry outmigration from three unoiled streams in Prince William Sound	18
6.	Hatchery contribution to the 1991 PWS pink salmon commercial fishery by district	23
7.	Total hatchery contribution to the 1991 PWS pink salmon commercial fishery for all districts combined	24
8.	Pink salmon survival rates by hatchery, tagcode, and treatment	26

EXECUTIVE SUMMARY

The study is part of an integrated group of Natural Resources Damage Assessment Fish/Shellfish Studies (NRDA F/S Studies 1,2,3,4, and 28) and Restoration Studies (8 and9), being conducted to quantify damage to wild Pacific salmon from the *MV Exxon Valdez* oil spill and restore damaged stocks to health. To determine how adult returns are affected, accurate appraisals of catch and spawning escapement are needed. NRDA F/S Study 3 is designed to estimate catch contributions and survival rates for both wildstock and hatchery salmon in oiled and unoiled areas of Prince William Sound (PWS). It is also designed to provide tags of known origin for recovery in NRDA F/S Study 4, Early Marine Salmon Injury Assessment. Restoration Study 8 integrates with NRDA F/S Study 3 as the tag application portion of the wildstock analyses and is summarized in this report.

Contribution of wild and hatchery pink salmon (*Oncorhynchus gorbuscha*) to the 1991 PWS commercial, cost recovery, special (discarded and donated pink salmon), and brood stock harvests were estimated from tagged fish released from 6 streams and 4 PWS hatcheries in 1990. Nineteen percent of the pink salmon harvest and 90% of the wildstock pink salmon carcasses in 46 selected streams were scanned for coded-wire tags. Out of 14,409 pink salmon heads sent to the Juneau Tag Lab, 8253 tags were recovered. The preliminary maximum estimate of wildstock contribution to the PWS pink salmon fishery is 6.8 million fish out of a total catch of 38.3 million fish (82% hatchery contribution). Estimated pink salmon survival, unadjusted for tag loss or tagging mortality, for the 6 tagged wildstock streams was 2.2%. Estimated maximum pink salmon survival for all hatcheries combined was 5.1%. The 1989 and 1990 hatchery average survival rates were 4.02% and 7.02%. Adjustment factors used in the hatchery contribution estimates ranged from 1.4 to 1.9.

Approximately 42% of the chum (*O. keta*), sockeye (*O. nerka*), coho (*O. kisutch*), and chinook (*O. tshawytscha*) salmon catch was scanned for tags, and 64, 4872, 1236, and 21 tags were recovered. Marine survival rates for these 4 species will be calculated as the many age classes return. Coho salmon brood stock sampling has just been completed and contribution estimates are incomplete.

Approximately 60,000 wild sockeye salmon in 3 streams and 319,400 wild pink salmon in 6 streams were tagged in 1991. Over 800,000 of the 535 million pink salmon fry and 473,000 hatchery produced chum, coho, sockeye, and chinook salmon released from PWS hatcheries in 1991 were also tagged.

Examination of the wild stock tagging data for differences in survival due to oiling is underway but not yet completed. Analysis of hatchery returns from oiled and unoiled areas is also being addressed.

OBJECTIVES

1. Estimate catch and survival rates of pink, chum, sockeye, coho, and chinook salmon released from five hatcheries in Prince William Sound; two hatcheries are in heavily oiled areas, and three are not.

2. Estimate survival rates of wild pink salmon from three streams with contaminated estuaries and three streams with uncontaminated estuaries using outmigration, catch, and escapement (provided by stream surveys).

3. Estimate survival rates of wild sockeye salmon from two watersheds with contaminated estuaries and one watershed with an uncontaminated estuary using outmigration, catch, and escapement (provided by operating weirs).

4. Provide marked salmon of known origin and oil exposure history for recovery by researchers studying early marine existence and migration of juvenile salmon (NRDA F/S Study 4).

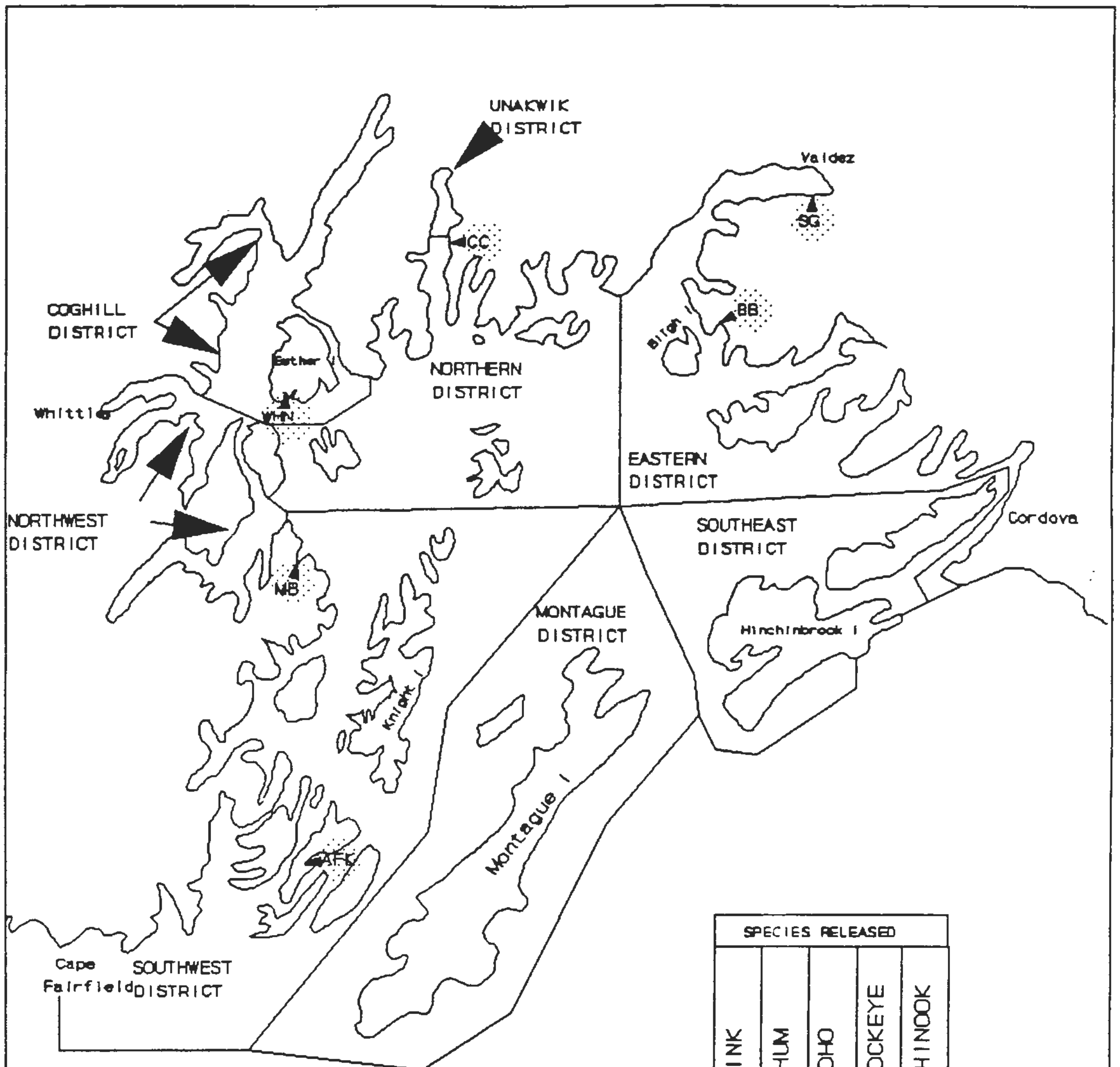
5. Identify relevant injuries for which methods of restoring lost use, populations, and habitat must be developed.

INTRODUCTION

Wild pink salmon returns to Prince William Sound (PWS) have averaged 8 million fish since 1961. Hatchery produced pink salmon have been a significant component of the total return since 1985 and now average over 20 million fish. Hatchery fry have been tagged since 1986 to estimate contributions of wild and hatchery fish to the commercial catch and to estimate survival rates for release groups. Hatchery contribution estimates are necessary to estimate the wildstock catch and production. Estimates of catch and escapement for both wild and hatchery fish are needed to assess effects of oil and possible loss of production.

NRDA F/S Study 3 applies tags to all species of salmon produced at 6 hatcheries (Figure 1). Restoration Study 8 applies tags in wild sockeye salmon in 3 streams, and wild pink salmon in 6 streams (Figure 2). Results of the tagging and recovery are used to examine the relationship between oil exposure and survival rates and to document any loss of production. Pink salmon fry are produced at the Valdez Fisheries Development Association (VFDA) Solomon Gulch Hatchery and at three Prince William Sound Aquaculture Corporation (PWSAC) hatcheries: A.F. Koernig, W.H. Noerenberg, and Cannery Creek. The W.H. Noerenberg and Solomon Gulch hatcheries also produce chum and coho salmon. Chinook salmon are produced at the W.H. Noerenberg hatchery and sockeye salmon are produced at the Main Bay hatchery, which is also operated by PWSAC. The Ft. Richardson hatchery, a Fisheries Rehabilitation, Enhancement Department (FRED) facility, produces coho salmon smolts for release in Whittier and Cordova. Wild sockeye salmon were tagged at Jackpot, Coghill, and Eshamy Rivers. Wild pink salmon were tagged at Herring, Hayden, Loomis, Cathead, O'Brien, and Totemoff Creeks.

Tags were recovered at fish processing plants in Cordova, Valdez, Anchorage, Whittier, Kenai, and Kodiak. Recovery of tags from carcasses occurred at 6 wildstock pink salmon streams which had adult weirs and at 40 other streams surveyed as part of NRDA F/S 1. Broodstock scanning was conducted at all PWS hatcheries. A significant number of tags were recovered, allowing accurate contribution estimates and survival rates for hatchery and wildstock pink salmon in oiled and unoiled areas.



			SPECIES RELEASED				
			PINK	CHUM	COHO	SOCKEYE	CHINOOK
SG	=	SOLOMON GULCH	X	X	X		X
BB	=	BOULDER BAY *	X				
CC	=	CANNERY CREEK	X				
WHN	=	WALLACE H. NOERENBERG	X	X	X		X
AFK	=	ARMIN F. KOERNIG	X				
MB	=	MAIN BAY				X	

*REMOTE RELEASE SITE FOR SOLOMON GULCH HATCHERY

Figure 1. Map of Prince William Sound fishing districts and hatcheries.

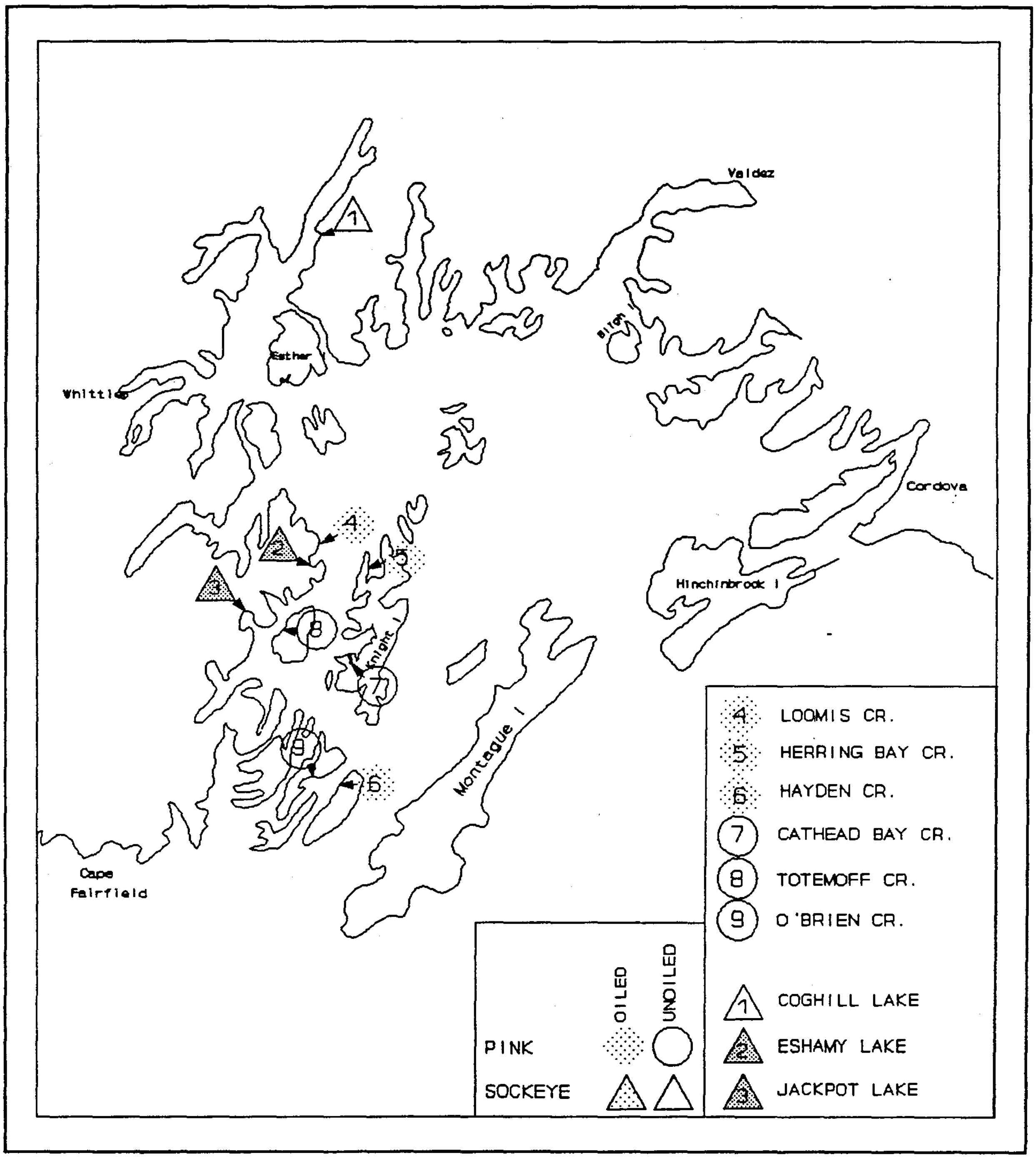


Figure 2. Map of Prince William Sound pink and sockeye salmon weir sites.

METHODS

Tagging

Tag recovery rates vary by district, week, and processor (Peltz and Geiger 1988). Tagging goals are set to ensure tags can be recovered in sufficient numbers to estimate the contribution of each release group to each district, week, and processor stratum. This degree of precision is required to estimate differences in production for oiled and unoiled groups of wild salmon (when NRDA F/S 1, 2, 3, and 28 are synthesized). Hatchery release groups represent differences in fry treatment or timing (i.e., fed vs. unfed, early vs. late fry emergence). Tagging rates were held as constant as possible.

Tagging of Hatchery Stocks

Pink and chum salmon fry to be tagged were randomly selected as they emerged from incubators. Fry were then anesthetized in a 1 ppm solution of MS-222, adipose fin clipped, and tagged. A random sample of 20 clipped fish was graded for clip quality during each tagging shift. The proportion of bad clips was used to discount the daily release of tagged fish. Clipped fish were tagged and passed through a quality control device (QCD) to test for tag retention. Rejected fish were held and retested later in the day. If rejected a second time, they were killed to minimize the number of untagged but clipped fish in the release. Fry which retained tags were held overnight to determine short-term mortality. An overnight tag retention rate was estimated by randomly selecting 200 fish and testing them with the QCD before release into saltwater rearing pens. Tag placement was checked periodically but not quantified.

Methods of handling tagged fry prior to release differed slightly between PWSAC and VFDA facilities. Fry tagged at Solomon Gulch hatchery were held in freshwater incubators until all tagging within a single tag code was completed. They were then moved to saltwater pens. Fry tagged at PWSAC facilities were introduced into saltwater net pens once the initial 24 hour waiting period after tagging had passed. Tagged fry at all facilities were placed in small net pens suspended within the larger salt water rearing pens they represented for at least 3 days. This allowed tagged fry time to recover from tagging and handling before being mixed with their unmarked cohorts. By deducting both the short-term tagging and saltwater rearing mortalities from the number tagged, the total number of fry with valid tags was estimated for each release group as:

$$T_{vt} = (T_t - M_{ot} - M_{sw})\ (1 - L_{ot})\ C\ ,$$

where

M_{sw} = saltwater rearing mortality,
T_t = total number of group *t* fish tagged,
M_{ot} = overnight mortality of tagged group *t* fish,
L_{ot} =overnight tag loss rate of group *t* fish,
C = good clip rate for group *t* fish.

Unmarked fry entering the salt water rearing pens were counted with fry counters at PWSAC hatcheries. At Solomon Gulch, the numbers of unmarked fry entering salt water net pens were estimated from counts of eggs loaded into incubators minus egg mortalities. Chum fry at Solomon Gulch Hatchery were transferred to salt water after emergence while those at W.H. Noerenberg Hatchery were reared in fresh water. At all facilities, fry mortalities in the large pens were estimated visually prior to release. Mortality rates determined from visual estimates were applied equally to tagged and untagged fish. The timing of hatchery releases was determined by the goals of the rearing experiment.

Sockeye, coho, and chinook salmon smolts were tagged using nearly identical methods as described for pink salmon fry tagging. The major differences were that full-length tags were used instead of half-length tags and fin clip inspections and discounting for poor clips were unnecessary because of the size of fish being tagged. After tagging, smolts were returned to freshwater before being transferred to either saltwater pens or remote release locations.

Tagging of Wild Stocks

In 1991, coded wire tags were applied to wild pink salmon at the same six streams examined in 1990 as part of NRDA Fish Study 3. Tags were also applied to the same three wild stocks of sockeye salmon examined in 1989 and 1990. Intertidal fry weirs, inclined-plane traps, and smolt weirs were used to capture and enumerate outmigrating juvenile salmon. A portion of the outmigration from each site was marked with an adipose fin clip and a coded wire tag was applied. Length, weight, and age information were collected to characterize the outmigration at each site. At Herring Creek, an upstream weir was operated in conjunction with an intertidal weir to separately enumerate and tag the pink fry production from both stream components.

Intertidal weirs were designed to provide a total enumeration of outmigrating pink salmon fry. Weirs were fished continuously and outmigration counts were summed for each low tide. Fry were counted using electronic fry counters or by individually tallying fry using thumb counters. Each day, a random sample of fry were set aside for tagging. Of these, approximately 150 to 200 fry were measured and weighed to quantify size differences between creeks and within individual creeks over time. Fry to be tagged were anesthetized in an MS-222 solution, their adipose fin clipped, and injected with a half-length coded wire tag. Tagged fry were held for 24 hours to measure short term tag-loss and mortality rates. Each tagging day, a sample of 20 clipped fry were graded for fin clip quality to determine a good fin clip rate. Tag placement was also checked daily. After tag retention checks, fry were introduced into salt water net pens and held for up to 24 hours prior to release. The total number of fry with valid tags was estimated as:

$$T_{vt} = (T_t - M_{ot})\ (1 - L_{ot})\ C \quad ,$$

where

T_t = total number of fish tagged from group t,
M_{ot} = overnight mortality of tagged group t fish,
L_{ot} = overnight tag loss rate of group t fish,
C= good clip rate.

Tagging at each site was temporally stratified. The number of strata ranged from 3 to 5 depending on the magnitude and duration of the run. Tag codes for each stream were unique.

Smolts from wild stocks of sockeye salmon at Coghill, Eshamy, and Jackpot rivers were enumerated and a random sample were coded wire tagged. Inclined plane traps were used to capture smolt at all locations. A 1.22 m x 1.22 m fyke net was also used at the Eshamy weir. Smolts were anesthetized with an MS-222 solution and their adipose fins were clipped. Smolts were tagged and held for at least 24 hours to determine short term mortality and tag loss rates. The number of valid tags released was calculated the same as for pink salmon fry without discounting for bad fin clips.

1991 Tag Recovery

Commercial and Cost Recovery Harvests

Salmon delivered to sixteen land based processors and two floating processors were sampled for coded wire tags during the 1991 PWS fishery. All five species of salmon were sampled. Catches of salmon were scanned for coded wire tags by visual and tactile methods as the fish were off-loaded from tendering vessels. Each sample was from a specific tender, and the following data were recorded: sampler name, port, harvest type (i.e., commercial or cost recovery catch), catch date, delivery date, processor, tender or boat name, fishing district(s) where fish were caught, number of fish examined, number of fish with adipose fin clips found, identification numbers for fish heads recovered, and the quality of adipose clip on each recovered fish. District and subdistrict information for each tender load was obtained from tender crews, processor records, and fish tickets. Heads of clipped fish were frozen and sent to the ADF&G Coded-Wire Tag Processing Lab in Juneau along with sample data. The tag lab processed the heads, recording each head's tagcode when a tag was recovered. This information along with the information from the data sheets was entered into the Juneau tag lab database and sent to Cordova on a weekly basis to aid in-season editing and analysis.

Scanning commercial pink salmon catches for coded-wire tags involves visually selecting adipose clipped fish from a mixture of unclipped and clipped fish on a conveyor belt. Samplers select fish on the basis of whether they have a good view of the adipose fin region; negative sampling bias is possible by consistent exclusion of tagged fish. This possible sampling bias was tested by comparing the tag recovery rates of sampled fish to recovery rates in a complete census of the sampled load of fish.

Brood Stock Harvests

A technician was stationed at each of the 5 PWS hatcheries to scan the broodstock during egg take for all five species of salmon. After the salmon were manually spawned, technicians used visual and tactile methods to scan approximately 95% of the fish. When an adipose clipped fish was found, the head was removed and marked with a uniquely numbered cinch tag. Total number of fish scanned and total number of fin-clipped fish found were recorded on a daily basis. Heads and their corresponding data sheets were picked up weekly from each hatchery and returned to Cordova for editing and shipping to the Juneau Tag Lab.

Broodstock scanning is an important part of estimating hatchery contributions. Due to differential mortality between tagged and untagged fish as well as differential tag loss between release groups the tag expansion factor at release may no longer accurately reflect the tag expansion factor in the adult population. Theoretically, brood stock is 100% hatchery fish and representative of returns from each fry and smolt release group (Figure 3). Based on this assumption, tag recovery rates from brood stock can be used to adjust the initial tag expansions for each hatchery. Salmon sold for cost recovery are taken from terminal harvest areas directly in front of the hatcheries. Therefore, these fish are expected to be of primarily hatchery origin. Therefore, a similar analysis to that of the broodstock is performed for the cost recovery harvest.

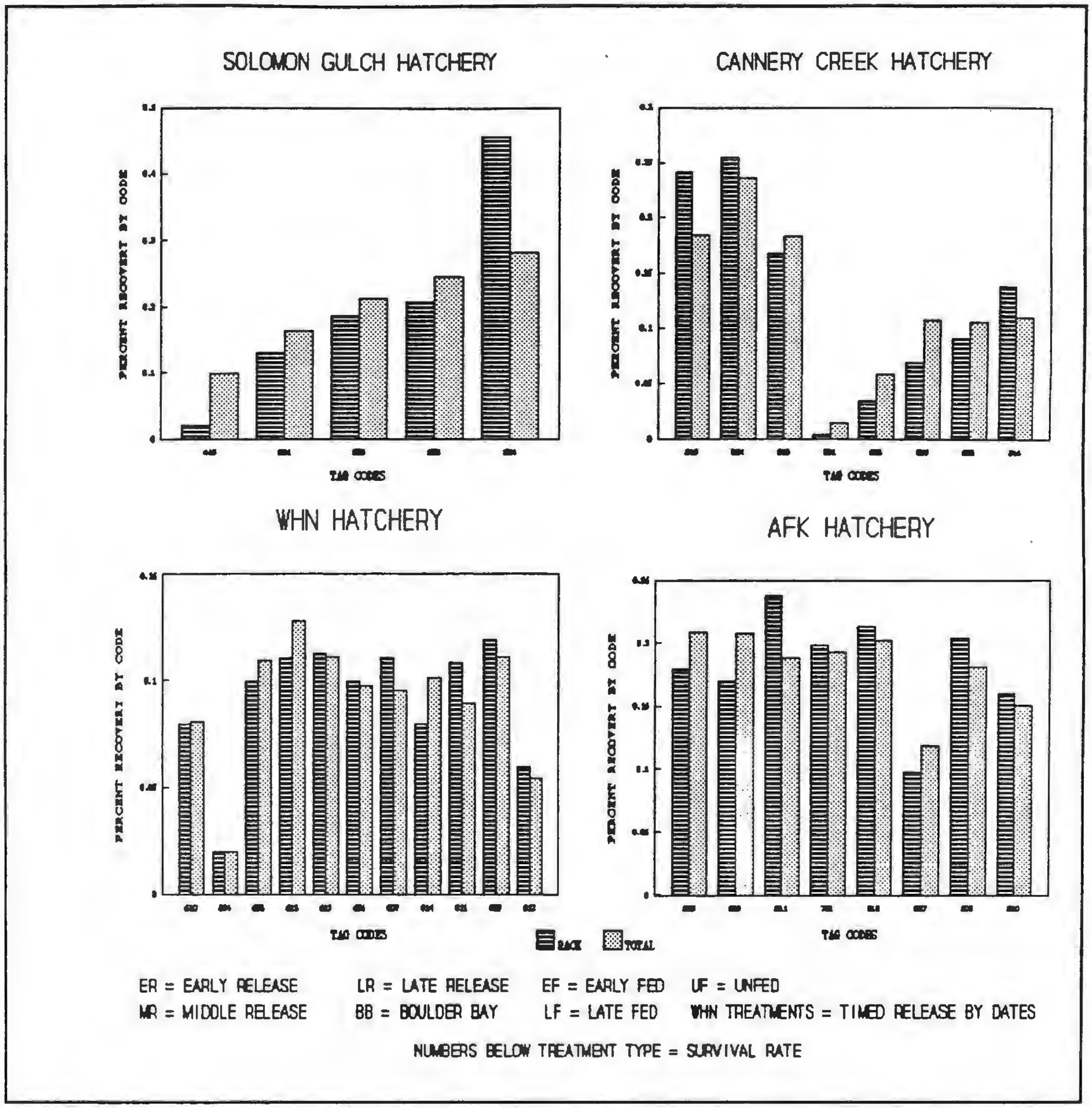


Figure 3. Percent tags recovered in broodstock and total catch, 1991.

Wildstock Streams

Carcasses were scanned for coded-wire tags at the six tagged wildstock streams: Loomis, Cathead, Herring, Totemoff, O'Brien, and Hayden, and at an additional 40 streams surveyed as part of NRDA F/S 1. Only carcasses with a visible adipose region were counted. Heads were removed from the adipose clipped carcasses, soaked in a brine solution, and put into plastic bags. Total number of carcasses and total number of adipose clipped fish were recorded on a daily basis for each stream surveyed. Heads and their corresponding data sheets were picked up on a regular basis and returned to Cordova for editing and shipping to the Juneau tag lab.

Catch and Contribution

The 1986-87 tagging study indicated catch allocations for each hatchery should be stratified by district, week, and processor (Peltz and Geiger 1988). Processors tend to obtain fish from specific sub-areas within each district. In 1988, most fishing effort was restricted to terminal areas (close to the hatcheries) to prevent harvest of wild stocks. With this fishing pattern, it was not found necessary to stratify by processor when calculating the Solomon Gulch Hatchery contribution, presumably because tenders for each processor were in close proximity (Geiger and Sharr 1989). In 1989, fishing effort was again restricted to terminal areas due to the presence of oil in portions of PWS, but processor differences, though small, were found significant, suggesting that contribution estimates should be stratified by processor even when the fishery is conducted in terminal areas. The 1990 hatchery contribution estimates were therefore stratified by district, week and processor. Stratification differences have not yet been analyzed for the 1991 data and hatchery contribution estimates remain stratified by district, week, and processor.

Catches were obtained from summaries of fish sales receipts (fish tickets) issued to fishermen. The total hatchery contribution (C) to each harvest type is the sum over all release groups of theestimated contributions for each release group over all week, district, and processor strata:

$$\hat{C} = \Sigma_t \ \Sigma_i \ X_{ti} \ (N_i \ / \ S_i \ p_t) \quad ,$$

where

X_{ti}= number of group t tags recovered in ith strata,
N_i= number of fish caught in ith strata,
S_i= number of fish sampled in ith strata,
p_t= proportion of group t tagged.

A variance approximation which ignores covariance between release groups was calculated for sampled strata (Geiger 1988):

$$V(\hat{C}) = \Sigma_t \ \Sigma_i \ X_{ti} \ [\ (N_i \ / \ S_i \ p_t)^2 - (N_i \ / \ S_i \ p_t) \ ].$$

The average tag recovery rate for all processors in a week and district was used to estimate hatchery contribution in catches delivered to processors not sampled that district and week. Variances associated with unsampled strata are not calculated.

RESULTS

Previous Findings

In 1986, 625,000 of 200.5 million pink salmon fry released (1 out of 320) from 3 of the 4 Prince William Sound pink salmon hatcheries were tagged with half-length coded-wire tags and marked with adipose fin clips (Peltz and Miller 1988). These tags were recovered in 1987 by scanning catches at four processors and scanning the hatchery brood stock. Analysis of the 2,274 tag recoveries suggested the 3 hatcheries contributed approximately 10.2 million pink salmon to the total PWS harvest of 26.1 million pink salmon (Peltz and Geiger 1988). Survival of tagged hatchery stocks was approximately 6.3%.

In 1987, roughly 178,000 of the 60 million pink salmon fry released from Solomon Gulch hatchery were tagged, an average of 337 fish per tag. They were recovered by sampling commercial catches and hatchery brood stock in 1988. Approximately 300,000 pink salmon out of the total PWS commercial pink salmon catch of 11.8 million were attributed to Solomon Gulch returns. The survival rate for the stock was estimated at 0.5%.

Approximately 893,000 of the 521 million pink salmon fry released from all hatcheries in 1988 were tagged, an average of 583 fish per tag. Approximately 8,000 PWS pink salmon heads were sent to Juneau where 4,821 legible tags were removed and decoded. Tag expansions adjusted by tag recovery rates from brood stock collections yielded a maximum estimate of 20.3 million hatchery fish in the total harvest of 21.8 million fish which indicated a wildstock failure. Based on this estimate, survival of pink salmon from all hatcheries combined was 4.1%.

In 1989, over 1 million of the 506.6 million pink salmon fry released from PWS hatcheries were tagged, an average of 480 fish per tag. Approximately 182 thousand of the 3.68 million coho salmon smolts released from Solomon Gulch, Esther, and Ft. Richardson hatcheries, and 100 thousand of the 2.6 million sockeye salmon smolts released from the Main Bay hatchery were tagged. Over 8,500 tags were recovered in the 1990 season. The maximum catch contribution estimate was 36.5 million hatchery pink salmon out of a total catch of 45 million (8.5 million wildstock fish). The average survival rate for hatchery pink salmon stocks was 7.2%.

1991 Tagging

Tagging of Hatchery Stocks

Total releases and number of tagged fish for each stock returning to the PWS fishery in 1991 are shown in Table 1. Tables 2 and 3 summarize tagging of hatchery and wild stocks in 1991. Efforts to maintain a constant tagging rate for hatchery produced pink salmon fry were successful with PWSAC hatcheries having a release to tagged ratio of approximately 600. Solomon Gulch was not as successful and had a lower tag ratio of 544.

Over 800,000 of the 535 million pink salmon released from PWS hatcheries were tagged, as were almost 473 thousand hatchery produced chum, coho, sockeye, and chinook salmon.

Tagging of Wild Stocks

Dates of operation and tagging results for the wild pink salmon fry and sockeye salmon smolt weirs are shown in Table 3. Timing and magnitude of pink salmon fry outmigrations for 1990 and 1991 are shown in Figures 4 and 5. Each pink salmon fry weir was at some time inoperable due to extremely high water or ice flows. Tide series outmigration sounts for times when the weirs were inoperable will be estimated using regression models of outmigrations on surrounding tide series. Over 319,000 wild pink salmon fry and approximately 60,000 wild sockeye salmon smolt were tagged.

1991 Tag Recovery

Twelve percent of the pink salmon common property catch was scanned for coded wire tags. Thirty percent of the cost recovery harvest, 7% of the special harvest and 93% of the pink salmon brood stock were scanned. Forty-two percent of the sockeye, chum, coho, and chinook catches were scanned. An average of 90% of the wildstock pink salmon carcasses at each surveyed stream was examined.Over 15,000 tags were recovered from almost 34,000 heads sent to the Juneau tag lab.

The preliminary unadjusted contribution estimate of the 6 tagged wildstock streams to the PWS pink salmon fishery is 47,077 fish. Survival rates ranged from .24% to 3.40% with an overall average of 2.2%. It appears that fry emigrating at the peak of outmigration timing had the highest survival rates (Table 4). This may be due to lessened effects of predation on larger groups of fry. Survival rates for the oiled streams (2.1%, 2.7%, 2.6%) were fairly consistent, while the survival rates for the unoiled streams

Table 1. Hatchery tagged stocks returning to Prince William Sound in 1991.

Salmon Species	Hatchery	Year of Releas	Valid Tags[a]	Total Release[a]	Tag Ratio
Pink	A.F. Koernig	1990	193	113,844	590
	W.H. Noerenberg	1990	395	235,379	596
	Cannery Cr.	1990	240	143,663	599
	Solomon Gulch	1990	205	122,242	596
Chum	Main Bay	1986	120	5,109	42
	Main Bay	1987	110	76,537	696
	Solomon Gulch	1987	36	3,437	95
	Solomon Gulch	1989	28	2,921	104
Coho	W.H. Noerenberg	1989	101	2,600	26
	W.H. Noerenberg	1990	70	2,460	35
	Solomon Gulch	1989	31	980	32
	Solomon Gulch	1990	34	787	23
	Ft. Richardson	1989	51	100	2
	Ft. Richardson	1990	29	143	5
Sockeye	Main Bay	1988	42	309	7
	Main Bay	1989	100	2,645	26
	Main Bay	1990	141	2,747	19

[a] Thousands of fish.

Table 2. Coded wire tagging results for hatchery stocks released in Prince William Sound, 1991.

Salmon Species	Hatchery	Valid Tags[a]	Releases[a]	Tag Ratio	Tag Codes
Pink	A.F. Koernig	195	109,131	598	16
	W.H. Noerenberg	371	12,523	583	18
	Cannery Cr.	237	141,514	596	14
	Solomon Gulch	241	131,295	544	10
Chum	W.H. Noerenberg	178	77,949	459	4
	Solomon Gulch	20	1,736	87	2
Coho	W.H. Noerenberg	73	5,142	70	4
	Solomon Gulch	36	1,956	55	3
Sockeye	Main Bay	115	3,726	32	8
Chinook	W.H. Noerenberg	41	411	10	2

[a] Thousands of fish.

Table 3. Coded wire tagging results and dates of weir operation for wild stocks in Prince William Sound, 1991.

Salmon Species	Treatment	Stream	Date	Valid Tags[a]	Seaward Migration[a]	Tag Ratio
Pink	Control	Cathead Creek	4/18 - 5/25	40	158[b]	4
		O'Brien Creek	4/22 - 5/26	28	298[c]	10
		Totemoff Creek	4/17 - 5/24	43	734[d]	17
Pink	Oil	Hayden Creek	4/23 - 5/28	43	391[e]	9
		Herring Creek	4/13 - 6/3	43	399[d]	9
		Loomis Creek	4/18 - 6/1	45	211[e]	5
Sockeye		Eshamy River	4/4 - 6/25	21	683	33
		Jackpot Creek	4/14 - 6/1	5	20	4
		Coghill River	4/5 - 5/30	0	4	0

[a] Thousands of fish.
[b] Interpolated 5 days data.
[c] Interpolated 1 day data.
[d] Interpolated 3 days data.
[e] Interpolated 4 days data.

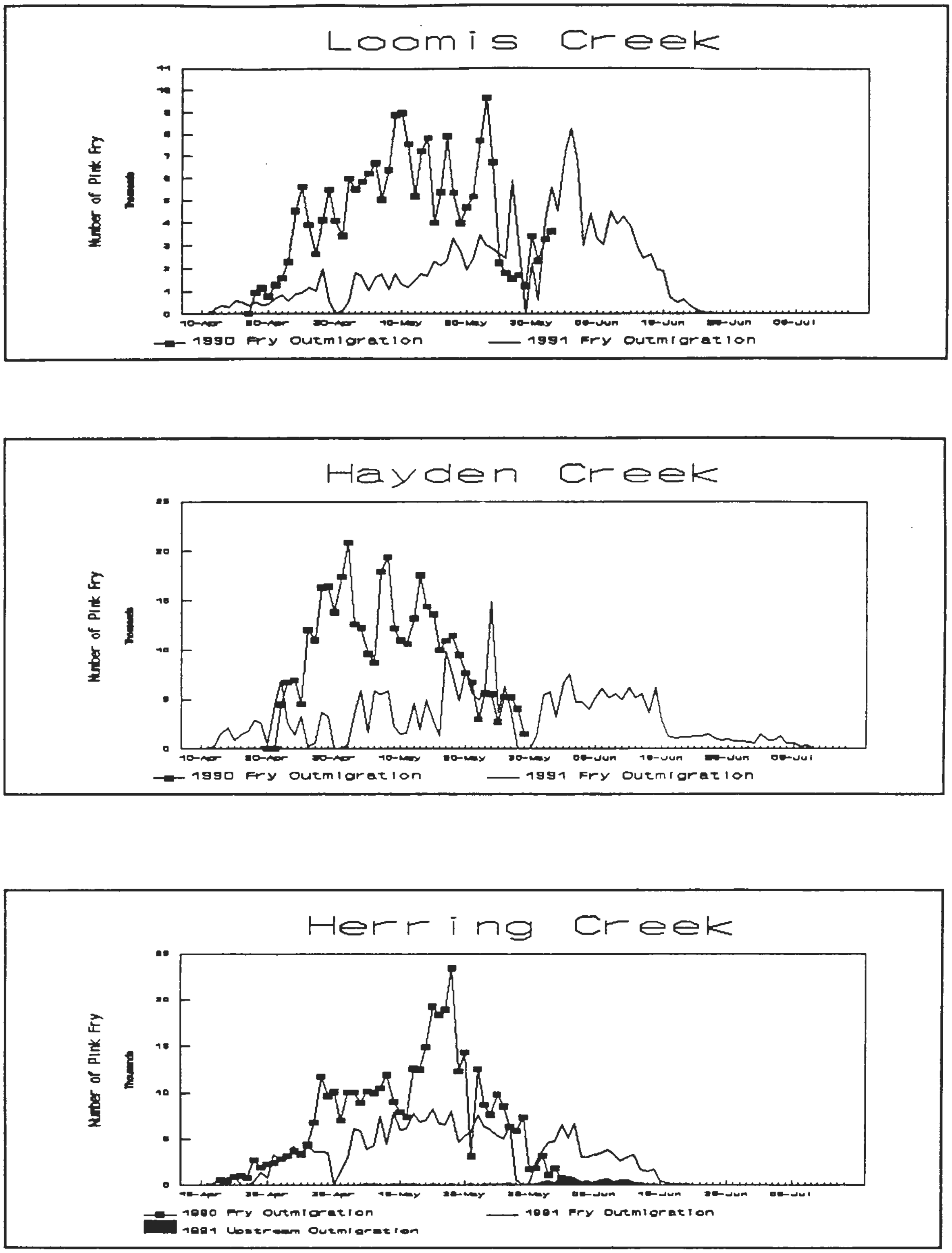
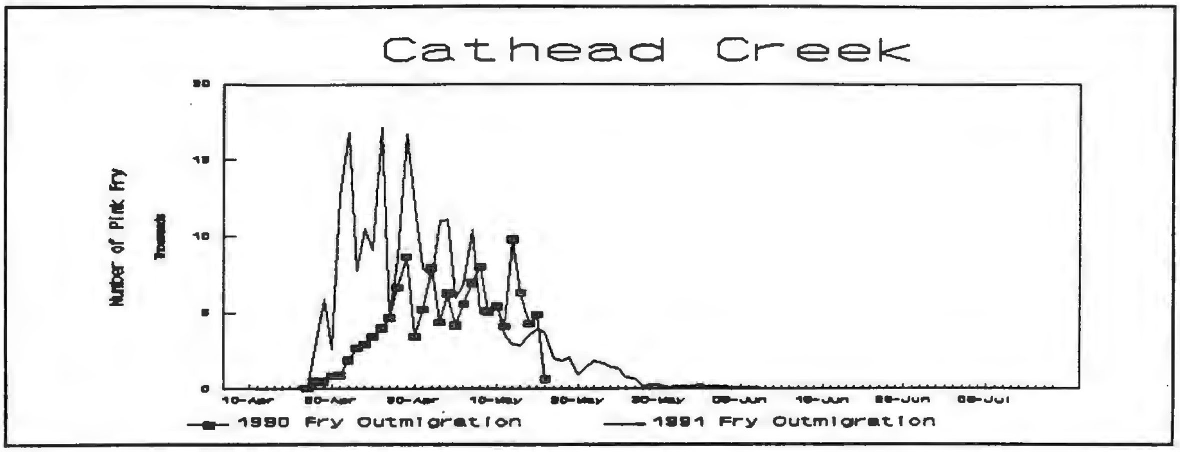
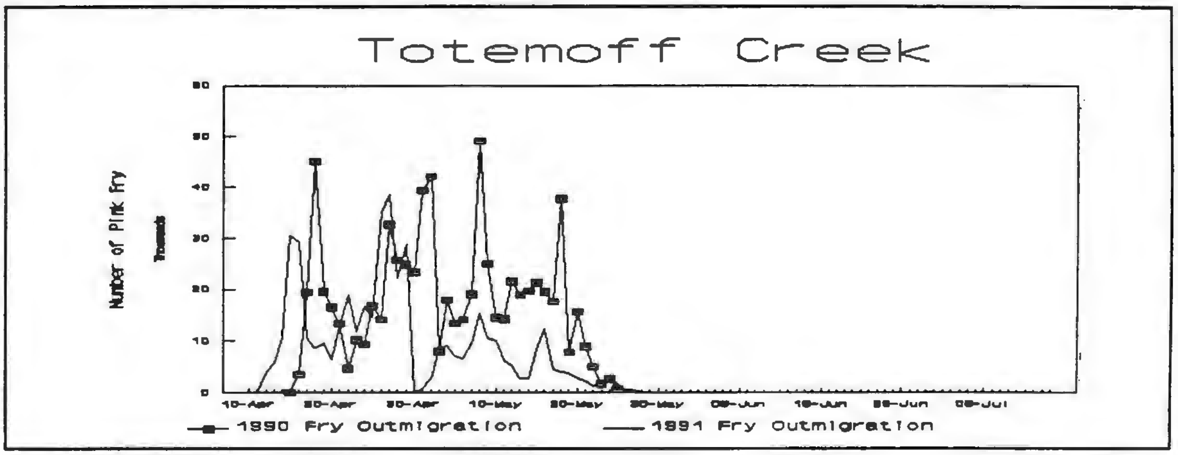


Figure 4. Timing and magnitude of pink salmon fry outmigrations from three oiled streams in Prince william Sound





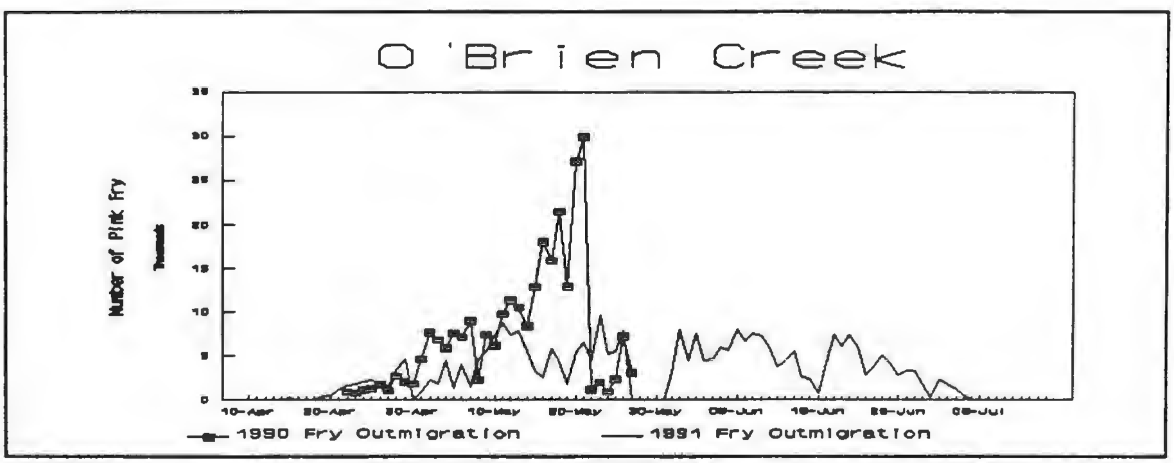


Figure 5. Timing and mignitude of 1990 and 1991 pink salmon fry outmigrations from three unoiled streams in Prince william Sound.

Table 4. Recovery results for tagged wildstock pink salmon, 1991.

	WILDSTOCK STREAM	TAG CODE	TOTAL RELEASED	TOTAL TAGGED	TAG EXPANSION	TOTAL TAGS RECOVERED	TOTAL CONTRIBUTION	SURVIVAL RATE(%)
OILED	HAYDEN	802	275,233	30,574	9.002	154	7,457	2.71
		803	89,804	12,584	7.136	24	467	0.52
	HERRING	715	84,184	27,747	5.622	22	663	0.79
		801	309,229	14,974	11.144	193	10,004	3.24
	LOOMIS	707	130,586	27,132	4.812	219	4,396	3.37
		708	72,729	17,571	4.139	42	869	1.19
UNOILED	O'BRIEN	712	207,366	22,831	9.082	69	3,688	1.78
		711	82,342	5,358	15.368	1	197	0.24
	TOTEMOFF	713	440,358	25,457	17.298	189	10,881	2.47
		714	274,101	17,535	15.631	37	3,409	1.24
	CATHEAD	709	125,326	30,047	4.170	180	4,266	3.40
		710	29,051	9,617	3.020	35	780	2.68

(1.34%, 2.0%,3.3%) varied. There was an apparent failure in the return of one O'Brien tagcode, 711, (one recovery) which influenced the overall O'Brien survival rate (Table 4). Some straying of hatchery and wildstock pinks is indicated by the 1991 tag recovery data (Table 5.). Tagged wildstock pink salmon were recovered in cost recovery and broodstock harvests as well as the common property fishery, and hatchery pinks were recovered in many of the wildstock streams. This suggests possible genetic mixing between and among the wild and hatchery pink salmon.

The preliminary estimate of maximum hatchery contribution to the 1991 catch of 37,037,118 pink salmon is 30,358,793 (6.7 million wild) with Solomon Gulch contributing 18%, W H Noerenburg 38%, A F Koernig 16%, and Cannery Creek 28% (Table 6). Figures 6 and 7 show contribution results stratified by district and week. Total hatchery contribution to each harvest type ranges from 80% (Common Property) to 92% (Broodstock) (Table 7). Pink salmon survival for all hatcheries combined is 5.2% (Figure 8). A. F. Koernig hatchery, located in a heavily oiled area, had the lowest survival rate (4.56%) of the 3 PWSAC hatcheries. Summary results for hatchery releases from 1987 through 1991 are listed in Table 8.

Tag expansion factors for 1990 releases from each hatchery were multiplied by adjustments between 1.38 and 1.92, based on tag recovery rates in cost recovery and brood stock samples. Tagging related mortality and tag loss may lower the incidence of tagged fish in hatchery returns and necessitate increasing tag expansion factors calculated for fry releases. Among adult returns, 100% of the fish in a hatchery broodstock are assumed to have originated from the releases at the hatchery. If no tag loss or tagging related mortality occur, the fraction of tagged fish in the broodstock should closely approximate the fraction observed in fry releases. Observed decreases in the fraction tagged are assumed to be related to tag loss or taggging related mortalities and a tag expansion factor calculated from tagging and release data are adjusted according to the tag rates observed in the broodstock. Tag rates in the broodstock were used to adjust tag expansions for AFK and WHN hatcheries in 1991, but not for Solomon Gulch and Cannery Creek hatcheries. At the latter 2 hatcheries, tag rates were much lower than those observed in fry releases, but were also much lower than those observed in hatchery cost recovery harvest. The low occurrence of tagged fish in these broodstocks relative to rates observed in the cost recvery harvests is puzzling. The problem could be related to sampling error (missed clips during scanning), but this seems unlikely since scanning procedures are uniform for all hatcheries. Low rates of tag occurrence may also be due to wildstock dilution of broodstock. Wild fish in the broodstock may originate from natural spawning regularly observed in streams adjacent to Solomon Gulch and Cannery Creek hatcheries. These streams also provide the hatcheries with water and provide olfactory cues to both hatchery and wild fish returning to these

Table 5. Tags recovered in wildstock streams by hatchery or stream of origin.

RECOVERY STREAM	TAG ORIGIN: WILDSTOCK STREAM: LOOMIS	TOTEMOFF	O'BRIAN	HAYDEN	HERRING	CATHEAD	HATCHERY: AFK	CCH	WHN	SGH	TOTAL TAGS
LOOMIS	150	2	0	0	14	0	1	1	18	0	186
TOTEMOFF	3	108	0	0	4	8	1	1	6	0	131
O'BRIEN	0	1	26	3	1	3	10	0	5	1	50
HAYDEN	0	0	0	84	1	1	5	1	2	0	94
HERRING	2	0	0	1	54	1	1	0	3	0	62
CATHEAD	0	0	0	0	0	36	1	0	1	0	38
16949	0	0	0	0	2	3	0	0	1	0	6
500	0	0	0	0	1	0	0	0	0	0	1
507	0	1	0	0	0	0	0	0	0	0	1
508	2	3	0	0	20	2	3	0	2	0	32
510	1	4	0	0	1	2	0	2	4	0	14
511	0	1	0	0	3	2	0	1	1	0	8
515	0	0	0	0	1	0	0	0	2	0	3
516	2	1	1	0	2	0	0	0	5	0	11
601	0	1	0	0	2	1	1	0	4	0	9
602	0	1	0	0	1	1	0	1	1	0	5
604	1	11	0	0	1	5	0	0	2	0	20
612	0	1	0	0	0	0	0	0	0	0	1
618	1	0	0	1	3	0	1	0	1	0	7
623	0	3	1	0	0	3	1	1	2	0	11
628	0	0	0	0	1	1	1	2	2	0	7
636	1	0	0	0	0	0	0	0	0	0	1
665	0	0	0	1	3	0	3	0	1	0	8
670	0	0	0	1	0	1	1	0	0	0	3
673	0	0	1	2	0	0	1	1	0	0	5
678	0	0	0	0	0	0	1	0	0	0	1
695	0	0	0	1	2	2	0	1	0	0	6
697	0	0	0	0	0	1	0	0	1	0	2
76	0	0	0	0	0	0	1	0	0	2	3
80	0	1	0	0	0	0	0	1	0	0	2
93	0	0	0	0	0	0	0	0	0	3	3
94	0	1	0	0	0	0	0	0	0	0	1
TOTAL TAGS	163	140	29	94	117	73	33	13	64	6	732

Table 6. Summary of hatchery contributions to the PWS Fishery using tag expansions at release and adjustment factors calculated from the broodstock or cost recovery.

	Contribution Unadjusted	Contribution Adjusted
SOLOMON GULCH HATCHERY		
Common Property	2,074,973	2,544,914
Cost Recovery	2,075,455	2,872,737
Special [1]	0	0
Broodstock	146,239	218,852
Total Return	4,296,667	5,636,503
Total Release	122,242,297	
Marine Survival	3.51	4.61
CANNERY CREEK HATCHERY		
Common Property	3,964,731	6,978,131
Cost Recovery	392,141	682,124
Special [1]	430,854	760,306
Broodstock	155,690	299,275
Total Return	4,943,416	8,719,836
Total Release	143,662,511	
Marine Survival	3.44	6.07
W.H. NOERENBERG HATCHERY		
Common Property	5,313,197	8,084,192
Cost Recovery	710,399	1,044,032
Special [1]	1,651,081	2,444,692
Broodstock	294,715	453,103
Total Return	7,969,392	12,056,019
Total Release	235,378,496	
Marine Survival	3.39	5.11
ARMIN F. KOERNIG HATCHERY		
Common Property	2,922,811	4,011,573
Cost Recovery	478,981	645,966
Special [1]	213,865	290,126
Broodstock	181,358	244,589
Total Return	3,797,015	5,192,254
Total Release	113,843,914	
Marine Survival	3.34	4.56

[1] Special includes the pink salmon that were discarded and donated.

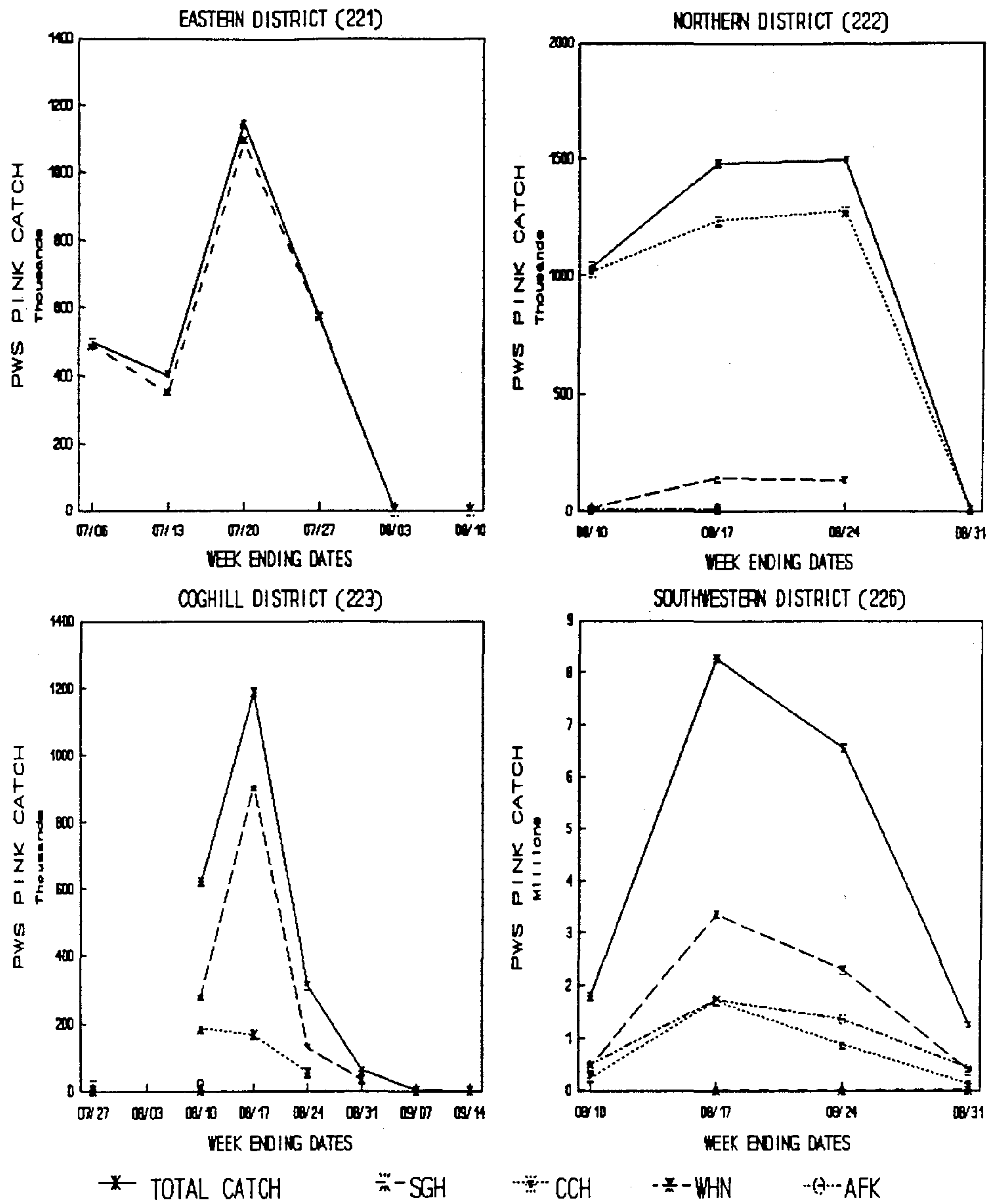


Figure 6. Hatchery contribution to the 1991 PWS pink salmon commercial fishery by district.

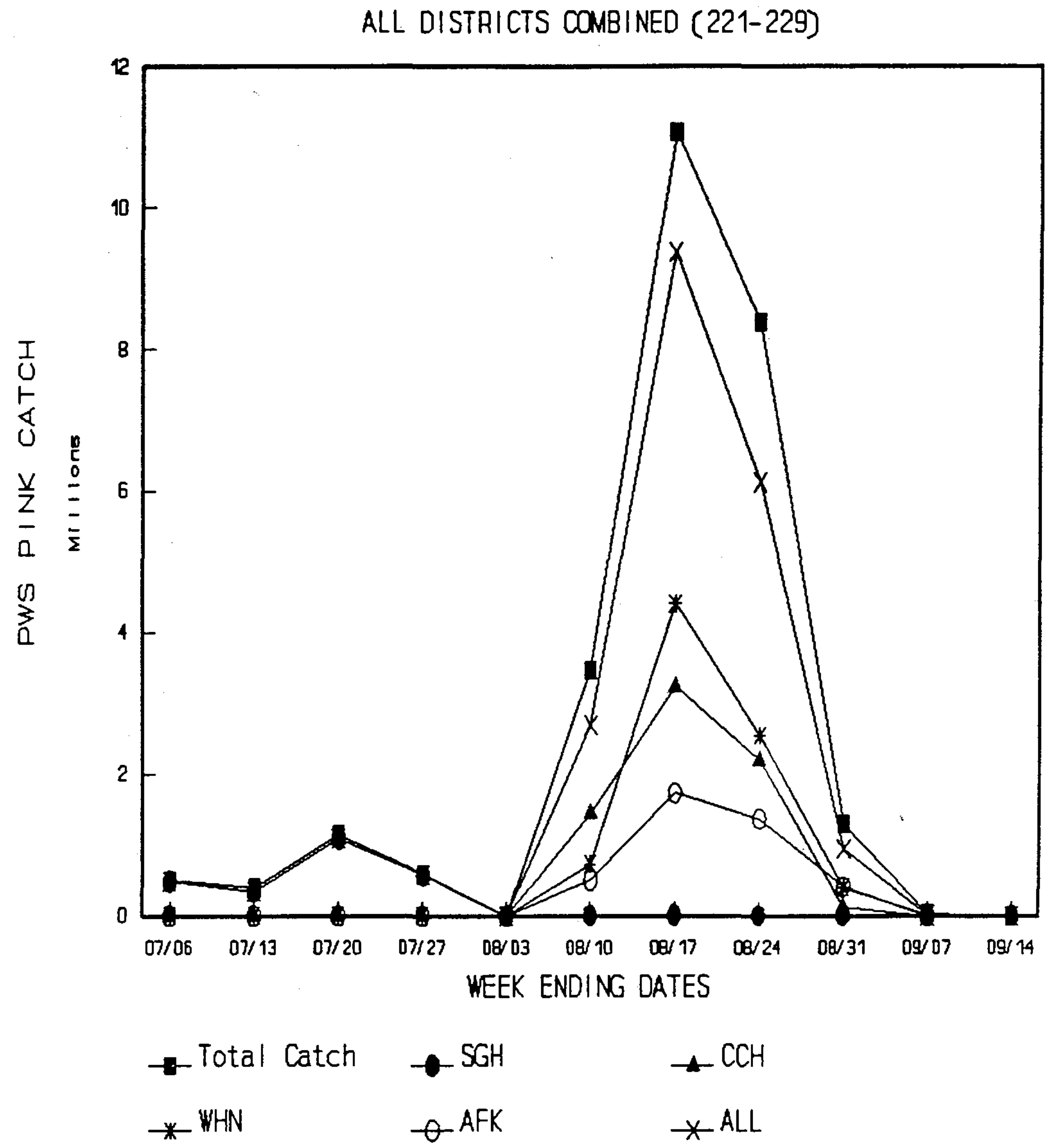


Figure 7. Total hatchery contribution to the 1991 PWS pink salmon commercial fishery for all districts combined.

Table 7. Total hatchery contribution (adjusted and unadjusted) to the Prince William Sound pink salmon fishery by harvest type.

HARVEST TYPE	TOTAL CATCH	CONTRIBUTION (UNADJUSTED)	PERCENT CONTRIBUTION	CONTRIBUTION (ADJUSTED)	PERCENT CONTRIBUTION
COMMON PROPERTY	26,894,679	14,275,712	53.08	21,618,810	80.38
COST RECOVERY	6,094,282	3,656,976	60.01	5,244,859	86.06
*SPECIAL	4,048,157	2,295,800	56.71	3,495,124	86.34
BROODSTOCK	1,317,708	778,002	59.04	1,215,819	92.27
TOTAL	38,354,826	21,006,490	54.77	31,574,612	82.32

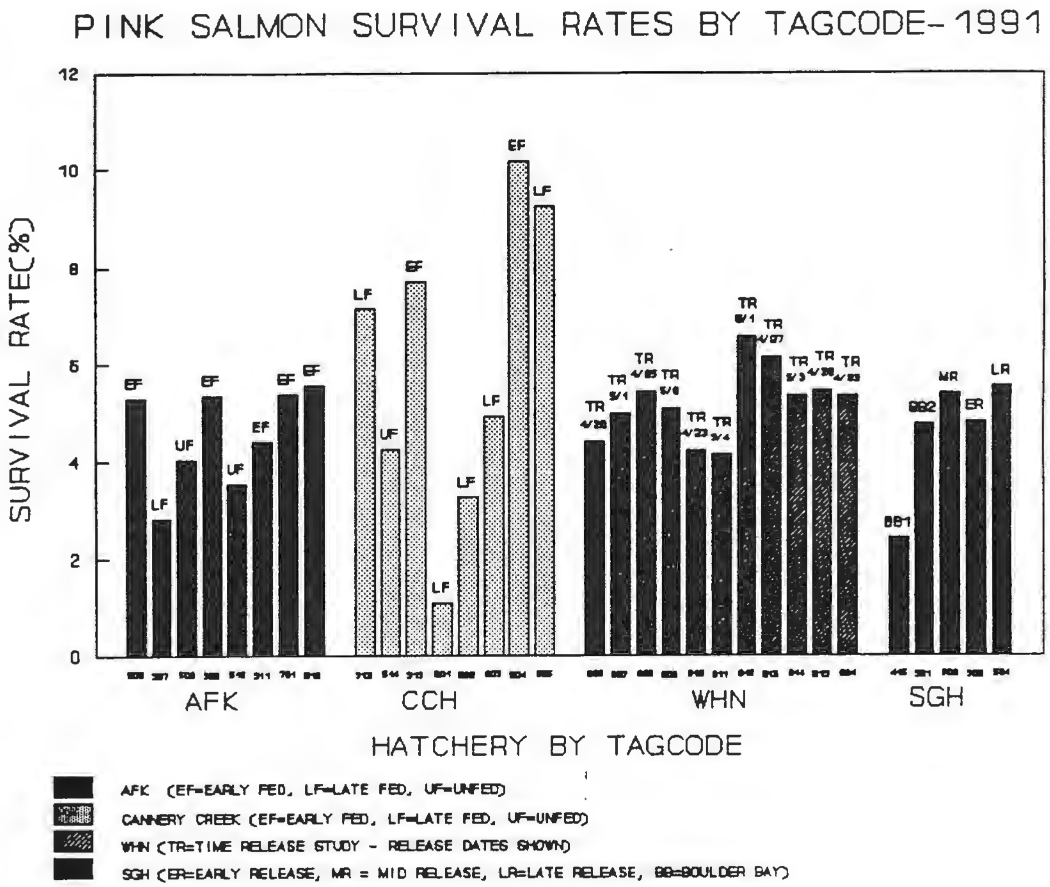


Figure 8. Pink salmon survival rates by hatchery, tagcode, and treatment.

Table 8. Summary of results of coded wire tag studies on pink salmon in Prince William Sound, 1987-1991. Results of 1991 tag recoveries are preliminary.

Hatchery	Year	Releases[a]	Returns[a]	Survival Rate	Adjustment Factor[b]
A. F. Koernig	87	112,528	7,614	6.8	.96
	88				
	89	110,037	2,736	2.5	1.31
	90	160,487	7,159	4.5	1.56
	91	109,131	5,192	4.6	1.38
W. Noerenberg	87	34,437	3,032	8.8	1.18
	88				
	89	195,608	7,092	3.6	1.90
	90	159,714	14,833	9.3	1.26
	91	12,523	12,026	5.1	1.55
Cannery Cr.	87	56,200	2,123	3.8	2.22
	88				
	89	95,571	7,099	7.4	1.87
	90	58,970	3,245	5.5	1.87
	91	141,514	8,720	6.1	1.92
Solomon Gulch	87				
	88	130,827	300	.5	2.35
	89	60,000	3,405	2.6	1.15
	90	128,500	11,278	8.8	1.19
	91	131,295	5,636	4.6	1.50

[a] Thousands of fish.
[b] Adjusted for lost tags.

sites. In any case, tag rates in cost recovery harvest for these two hatcheries were much more consistent with rates observed at the time of fry release and were used to adjust the expansion factors. Given the high probability of at least some occurrence of wild fish in the cost recovery harvests as well, these expansion factor adjustments were probably too large.

STATUS OF INJURY ASSESSMENT

The major objective of this tagging study is to estimate differential survival of fish exposed to oil contaminated waters. Estimates of catch contributions and production from this study in conjunction with escapement (NRDA F/S 1), egg and fry survival (NRDA F/S 2), and early marine survival (NRDA F/S 4) will provide information on the extent of effects on each Pacific salmon life stage. The time frame depends on the life span of each species. Although still preliminary, we now have survival estimates for 1989, 1990, and 1991 hatchery produced pink salmon, as well as 1990 tagged wildstock pink salmon. We also have an extensive escapement database which will be modeled to determine whether differential production occurred between oiled and unoiled streams.(NRDA F/S 28)

Progress on each objective is as follows:

1. Catch and survival rates of pink salmon released from four PWS hatcheries in 1988 were estimated from 1989 recoveries. The overall survival rate for pink salmon was 4.1%. Almost 1.4 million tagged pink, chum, sockeye, and coho salmon were released from five hatcheries in 1989. Over 8,500 of the pink salmon tagged in 1989 were recovered in 1990 providing an overall hatchery survival estimate of 7.2%. Marine survival of the other 4 species will be calculated as they return. Chum and sockeye salmon began returning in significant numbers in 1991, and recovery efforts will need to continue through 1993 to encompass the majority of adult returns from the 1989 release. Approximately 1.6 million tagged pink, chum, sockeye, and coho salmon were released from 5 hatcheries in 1990 along with over 265,000 wild sockeye and pink salmon. In 1991, 8253 pink salmon tags were recovered providing an overall hatchery survival rate of estimate of 5.13%. Chinook salmon tagged in 1990 will begin returning in 1993 and continue through 1995. Sockeye, chum, and coho salmon from the 1990 release will continue to return through 1994. In 1991, approximately 473,000 tagged pink, chum, sockeye, and coho salmon were released from the 5 hatcheries.

2. Six streams (3 oiled and 3 unoiled) were selected for pink salmon fry tagging and estimation of seaward migrants in 1990 using information gathered in NRDA F/S 1 and 2. Over 240,000

wild pink salmon were tagged at the 6 streams. These fish were recovered in the 1991 harvests and escapement surveys (NRDA F/S 1), providing survival rates and production estimates. The preliminary contribution estimate is 47,077 and the average survival rate was 2.2%. In 1991, 319,400 wild pink salmon were tagged at these same six streams.

3. Over 90,000 sockeye salmon smolts were tagged at Eshamy and Coghill Rivers in 1989. These fish will began returning in 1991. In 1990, 25 thousand tags were applied to sockeye salmon smolts in the Jackpot and Eshamy Rivers. Fish from the Coghill River were not tagged due to low smolt abundance. The sockeye salmon tagged in 1990 will begin returning in 1993. In 1991, approximately 60,000 tags were applied to sockeye salmon in the Eshamy, Jackpot, and Coghill Rivers. Weirs operated by ADF&G Commercial Fisheries and OSIAR Divisions are in place to monitor the escapements.

4. Almost 1.4, 1.6 million and 1.3 million Pacific salmon were tagged and released in 1989, 1990, and 1991 providing fish of known origin for NRDA F/S 4 (early marine life history) and this study.

5. The analysis of spatial trends in the recent and historic catch and escapement data suggest that alternative strategies for managing the commercial fleet may be the first and most effective step in restoring full production to PWS in the wake of the Exxon Valdez oil spill. A comprehensive escapement enumeration and stock identification projects, which are designed to improve the accuracy of current management strategies, have been proposed.

LITERATURE CITED

Geiger, H.J. 1988. Parametric bootstrap confidence intervals for estimates of fisheries contribution in salmon marking studies. Proceedings of the international symposium and educational workshop on fish-marking techniques. University of Washington Press, Seattle. In press.

Geiger, H.J., and S. Sharr. 1989. A tag study of pink salmon from the Solomon Gulch Hatchery in the Prince William Sound fishery, 1988. Alaska Department of Fish and Game, Division of Commercial Fisheries. In press.

Peltz, L., and H.J. Geiger. 1988. A study of the effect of hatcheries on the 1987 pink salmon fishery in Prince William Sound, Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries. In press.

Peltz, L., and J. Miller. 1988. Performance of half-length coded-wire tags in a pink salmon hatchery marking program. Proceedings of the international symposium and educational workshop on fish-marking techniques. University of Washington Press, Seattle. In press.

9. Prince William Sound Pink Salmon Escapement Enumeration

STATE/FEDERAL NATURAL RESOURCE DAMAGE ASSESSMENT
DRAFT PRELIMINARY STATUS REPORT

Project Title:	INJURY TO SALMON SPAWNING AREAS IN PRINCE WILLIAM SOUND (NRDA) and ADULT ESCAPEMENT ENUMERATION (RESTORATION)
Study ID Number:	Fish/Shellfish Study Number 1 and Restoration Study Number 9
Lead Agency:	State of Alaska, ADF&G; Commercial Fisheries Division
Cooperating Agency(ies):	Federal: NPS, USFS, USFWS State: DNR
Principal Investigator(s):	Samuel Sharr Dan Sharp
Assisting Personnel:	Brian Bue Penny Saddler Todd Rosen
Date Submitted:	November 20, 1990

TABLE OF CONTENTS

Page

LIST OF TABLES . . . iii

LIST OF FIGURES . . . iii

LIST OF APPENDICES . . . vi

EXECUTIVE SUMMARY . . . 1

OBJECTIVES . . . 3

INTRODUCTION . . . 4

STUDY METHODOLOGY . . . 5

Study Design . . . 5

Total Enumeration Studies . . . 5
Ground Surveys of Escapements . . . 5
Aerial Surveys . . . 9
Stream Life Studies . . . 10
Documentation of Oil Contamination . . . 11
Hydrocarbon Sampling . . . 11
Histopathology, Cytogenetic, and Electrophoretic Sampling . . . 11

Data Analysis . . . 13

Total Escapement Enumeration . . . 15
Adjustment of Aerial and Ground Counts . . . 15
Stream Life Data . . . 15
Estimates From Tagging . . . 16
Estimates Using Fish Days and Total Escapement . 16
Estimates From Run Timing . . . 17
Escapement Estimates Based on Aerial Survey Data . 18
Escapement Estimates Based on Ground Survey Data . 18
Hydrocarbon and Histopathology Analyses . . . 19

RESULTS . . . 19

Oil Survey . . . 19

Total Escapement Enumeration Through Weirs . . . 19
Pink Salmon . . . 19
Sockeye Salmon . . . 22

Adjustment of Aerial and Ground Counts . . . 22

TABLE OF CONTENTS (continued)

Page

Stream Life 34

Estimates Based on Tagging 34
Estimates Using Fish Days and Total Escapement . . 37
Estimates From Run Timing 37

Total Escapement Estimates From Aerial Surveys 38

Hydrocarbon and Histopathology Analysis 39

Restoration Strategies 39

STATUS OF INJURY ASSESSMENT 42

LITERATURE CITED 45

APPENDICES 46

LIST OF TABLES

TABLE — Page

1. Weir counts, carcass counts, and stream life estimates for 10 pink salmon streams in Prince William Sound, 1991. Stream life estimates are based on tagging, fish days and total escapement, and run timing 20

2. Comparisons of 1990 and 1991 aerial escapement estimates to results from weirs and comparisons of traditional estimation procedures used in Prince William Sound versus procedures incorporating correction factors for bias in the aerial method and revised stream life values. 21

LIST OF FIGURES

FIGURE — Page

1. Map showing the locations of streams included in the traditional aerial and ground survey programs for pink and chum salmon escapements in Prince William Sound, 1960-1991 6

2. Map showing the locations of streams weired to enumerate salmon escapements and additional streams where ground surveys and tagging studies were conducted on pink salmon in Prince William Sound, 1991. 7

3. Map showing the locations of streams where tissue samples taken from adult pink salmon for histopathological and cytogenetic examination and MFO analyses 12

4. Map showing sites where tissue samples were taken from pink salmon and sockeye salmon for electrophoretic analyses 14

5. Regression of 1991 aerial counts and ground counts of pink salmon against concurrent weir and carcass counts 23

6. Daily numbers of fish in Irish Creek based on weir, ground survey, and aerial survey methods, 1991. Regression of aerial and ground counts against concurrent counts from the weir are also shown . . . 24

LIST OF FIGURES (continued)

FIGURE — Page

7. Daily numbers of fish in Loomis Creek based on weir, ground survey, and aerial survey methods, 1991. Regression of aerial and ground counts against concurrent counts from the weir are also shown 25

8. Daily numbers of fish in Totemoff Creek based on weir, ground survey, and aerial survey methods, 1991. Regression of aerial and ground counts against concurrent counts from the weir are also shown 26

9. Daily numbers of fish in Chenega Creek based on weir, ground survey, and aerial survey methods, 1991. Regression of aerial and ground counts against concurrent counts from the weir are also shown 27

10. Daily numbers of fish in Countess Creek based on weir, ground survey, and aerial survey methods, 1991. Regression of aerial and ground counts against concurrent counts from the weir are also shown 28

11. Daily numbers of fish in O'Brien Creek based on weir, ground survey, and aerial survey methods, 1991. Regression of aerial and ground counts against concurrent counts from the weir are also shown 29

12. Daily numbers of fish in Hayden Creek based on weir, ground survey, and aerial survey methods, 1991. Regression of aerial and ground counts against concurrent counts from the weir are also shown 30

13. Daily numbers of fish in Herring Creek based on weir, ground survey, and aerial survey methods, 1991. Regression of aerial and ground counts against concurrent counts from the weir are also shown 31

14. Daily numbers of fish in Cathead Creek based on weir, ground survey, and aerial survey methods, 1991. Regression of aerial and ground counts against concurrent counts from the weir are also shown 32

LIST OF FIGURES (continued)

FIGURE | Page

15. Daily numbers of fish in Hawkins Creek based on weir, ground survey, and aerial survey methods, 1991. Regression of aerial and ground counts against concurrent counts from the weir are also shown 33

16. Weekly stream life estimates and 95% confidence bounds for pink salmon in 10 weired streams, 1991. Estimates adjusted for milling time are also shown 35

17. The relative size and distribution of 1991 pink salmon escapements in Prince William Sound versus the average for odd years from 1969 through 1989 . . 40

LIST OF APPENDICES

Page

APPENDIX A: DAILY WEIR DATA

A.1. Daily and cumulative escapements of pink salmon through the weir at Irish Creek, 1991 48

A.2. Daily and cumulative escapements of pink salmon through the weir at Loomis Creek, 1991 49

A.3. Daily and cumulative escapements of pink salmon through the weir at Totemoff Creek, 1991 50

A.4. Daily and cumulative escapements of pink salmon through the weir at Chenega Creek, 1991 51

A.5. Daily and cumulative escapements of pink salmon through the weir at Countess Creek, 1991 52

A.6. Daily and cumulative escapements of pink salmon through the weir at O'Brien Creek, 1991 53

A.7. Daily and cumulative escapements of pink salmon through the weir at Hayden Creek, 1991 54

A.8. Daily and cumulative escapements of pink salmon through the weir at Herring Creek, 1991 55

A.9. Daily and cumulative escapements of pink salmon through the weir at Cathead Creek, 1991 56

A.10. Daily and cumulative escapements of pink salmon through the weir at Hawkins Creek, 1991 57

A.11. Daily and cumulative escapements of sockeye salmon through the weir at Eshamy River, 1991 58

A.12. Daily and cumulative escapements of sockeye salmon through the weir at Jackpot River, 1991 59

LIST OF APPENDICES (continued)

Page

APPENDIX B. WEEKLY STREAM LIFE ESTIMATES

B.1. Table of weekly stream life estimates for individual streams showing weekly means, standard deviations, minima, maxima, and lower and upper bounds 61

EXECUTIVE SUMMARY

Wild returns of pink (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) to Prince William Sound (PWS) have averaged approximately 8.1 million and 870 thousand fish since 1961. Both species were susceptible to the detrimental effects of the *TV Exxon Valdez* oil spill (EVOS) because much of their spawning occurs in the intertidal zone. To demonstrate injury to pink and chum salmon stocks from oil exposure, intertidal contamination must be documented, reduced survival for some life history stage associated with the oil must be demonstrated, or adult returns in oiled areas must be depressed. Natural Resources Damage Assessment Fish/Shellfish Study 2 (NRDA F/S) has demonstrated significant reductions in pink salmon egg survival in streams contaminated by oil. To determine how adult returns were affected, accurate appraisals of catch and spawning escapement are needed. The NRDA project described in this report is designed to document oil contamination of intertidal spawning habitat and provide accurate estimates of wild stock escapements.

Aerial survey estimates of fish in streams were compared with data from weirs on 10 pink salmon streams. The correlation between weir data and concurrent aerial surveys was poor ($R^2 = 0.495$). The correlation of weir and ground survey data was good ($R^2 = 0.949$) but both methods displayed negative bias (slope = 2.98 and 1.88). Differences between aerial survey counts and weir estimates became greater as numbers of salmon increased, were greater on long streams with significant upstream spawning, and were greater in 1991 than in 1990.

Average stream residence time (stream life) for pink salmon estimated in 21 streams in the ground survey and weir program in 1990, was 15.1 days. The average stream life for pink salmon returning to weired systems ranged from 9.8 to 11 days for the three most reliable estimation procedures used in 1991. Previous escapement estimates based on a 17.5 day stream life may, therefore, be too low, particularly in the western half of PWS. Comparison of escapement estimates using either aerial or ground counts to known escapements through four weirs indicated both aerial and ground estimates tended to be low. The 1990 pink salmon escapement to 209 streams included in the historic pink salmon escapement index program was 1.3 million fish based on a traditional analysis of aerial survey data. An analysis of the same data which incorporated new estimates of stream life and a correction factor for bias in the aerial method yielded an escapement estimate of 2.3 million fish.

Tissues were removed from adult pink salmon collected from 22 western PWS spawning streams in 1990 and 1991 to test for cellular abnormalities and the presence of mixed-function oxidases (MFO's), enzymes known to be induced by exposure to oil,

Stocks which sustained damage must be restored. The commercial fishery in PWS is a significant source of mortality for adult salmon. Fishery exploitation rates appropriate for healthy salmon stocks may be too high for stocks damaged by the EVOS. Restoration through altered harvest management is predicated on the ability to accurately enumerate the escapement to damaged stocks and alter fishing effort in response to escapement trends. Restoration Study 9 expands NRDA F/S Study 1 to include more streams and places greater emphasis on timely inseason analysis of escapement trends. Data from weirs and foot surveys were used inseason in 1991 to help justify restriction of fishing time and area in southwestern PWS near oil damaged streams where poor escapement trends were being observed. These time and area closures reduced fishing effort on damaged stocks and resulted in above average numbers of spawning adults in oil damaged streams despite intense pressure to fish heavily on the abundant hatchery returns in this mixed stock area.

OBJECTIVES

Although the emphasis is slightly different, Restoration Study 9 differs very little from NRDA F/S Study 1. Objectives 4 through 10 for NRDA F/S Study 1 are identical to those described for the three weirs and 12 survey streams in the Restoration Study 9.

OBJECTIVES

1. Determine the presence or absence of oil on intertidal habitat used by spawning salmon through visual observation, aerial photography, and hydrocarbon analysis of tissue samples from intertidal mussels at stream mouth.

2. Document the physical extent of oil distribution on intertidal spawning areas.

3. Document the presence or absence of hydrocarbons from the EVOS in the tissues of adult salmon originating from the fry outmigrations in 1989 and subsequent years in oiled and unoiled areas.

4. Estimate the number of spawning salmon, by species, within standardized intertidal and upstream zones for 27 streams in PWS.

5. Enumerate the total intertidal and upstream escapement of pink and chum salmon through weirs installed on seven streams which are representative of streams in the aerial and ground escapement survey programs.

6. Estimate the accuracy of aerial counts for the 218 aerial index streams by comparison of paired ground and aerial counts from the same streams on the same or adjacent survey dates and by comparison of aerial, ground, and weir counts on seven streams.

7. Estimate average stream life of pink and chum salmon in at least 27 streams in PWS using a variety of techniques.

8. Estimate 1961 through 1988 pink and chum salmon escapements to the 218 aerial index streams using the average observed error in the aerial survey method and stream life data from 1989, 1990 and, 1991.

9. Produce a catalog of aerial photographs and detailed maps of spawner distribution for the more important pink and chum salmon streams of Prince William Sound for use in

designing sampling transects in the egg deposition and pre-emergent fry studies.

10. Enumerating adult returns in streams where coded wire tags were applied to wild pink salmon stocks and assist in the spawning ground sampling for tag recovery.

INTRODUCTION

This project is an integral component of the impact study of the *Exxon Valdez* oil spill (EVOS) on Pacific salmon populations in *Prince William Sound* (PWS). Wild salmon play a major role in the PWS ecosystem. Salmon not only provide a significant source of food for many fish, bird, and mammal species but also convey needed nutrients from the marine system to the estuary, freshwater, and terrestrial environments. Although NRDA F/S Study 1 and Restoration Study 9 differ slightly, the principal objectives are very similar and the two studies will be treated as one escapement enumeration study in this report. Both are integral to the investigation and of impacts of the EVOS on Pacific salmon populations in PWS and to the restoration of those populations.

Additional NRDA and Restoration studies in PWS rely on information obtained in this study. Escapement enumeration of coded-wire tagged wild stocks and coded-wire tag recoveries in wilds stock streams are critical to the wild stock total return and survival estimates made by NRDA F/S Study 3 and Restoration Study 8. NRDA F/S Study 3 provides estimates of wild stock contributions to the catch but results of NRDA F/S Studies 1 and 3 must be combined to estimate total wild stock returns. NRDA F/S Study 28 will reconstruct stock specific returns in prior years so that historic and current returns can be compared, and stock specific damages determined. Stream life and aerial survey efficiency gained from the present study will be used in the complex reconstruction model. NRDA F/S Study #2 (injury to salmon eggs and pre-emergent fry studies) relies on spawner density and distribution information from this study .

Streams examined by this project are also a subset of the anadromous salmon streams monitored by the ongoing ADF&G aerial survey program. The results of this study will provide; 1) a total count of salmon escapement past weirs on twelve streams; 2) an adjustment factor for pink salmon escapement estimates from ground and aerial survey data based on comparisons with known escapements through 10 of the weirs; 3) adjusted current year and historic escapement estimates based on ground and aerial data for 353 streams; 4) estimates of post oil-spill spawning distribution within stream zones and among streams; 5) estimates of average stream life for pink salmon in PWS; 6) collections of histopathology samples and baseline genetic data on hatchery stocks and a cross section of wild stocks; 7) and an atlas of aerial photographs and detailed maps of important spawning sites.

STUDY METHODOLOGY

Study Design

Streams examined by this project are a subset of the anadromous salmon streams monitored by the ongoing ADF&G aerial survey program (Figure 1).

Total Enumeration Studies

A weir acts as a fence which channels the upstream migration of salmon through a small opening where they are counted visually. Total escapement was enumerated through intertidal weirs installed on two moderately large pink salmon streams in eastern PWS, eight small to medium sized pink salmon streams in western PWS, and two important sockeye salmon streams in western PWS (Figure 2). Weired pink salmon streams were selected from the list of streams included in the aerial and ground survey programs. Weirs were similar to standard picket weirs which have been employed successfully by ADF&G. Each weir was installed at the six foot tide level or as close to the downstream limit of intertidal spawning as possible. Counts were made periodically during the day in response to tides and fish movement. Weir crews conducted stream life studies at their weired stream and other assigned streams in the same geographic area.

Ground Surveys of Escapements

Field crews at eleven remote field camps in Prince William Sound plus crews stationed in Cordova and Valdez performed daily foot surveys of intertidal and upstream portions of the 10 pink salmon streams which were weired and at 47 additional pink and chum salmon spawning streams (Figure 2). As time and conditions allowed, weekly, semi-weekly and random surveys were performed on an additional 28 streams during the spawning season. Streams to be surveyed daily were selected on the following criteria:

1. The stream was included in the ADF&G aerial survey program for pink and chum salmon escapements;
2. The stream was included in the pink and chum salmon egg deposition and pre-emergent fry project (NRDA Study 2);
3. The stream was included in prior spawning ground foot survey programs;

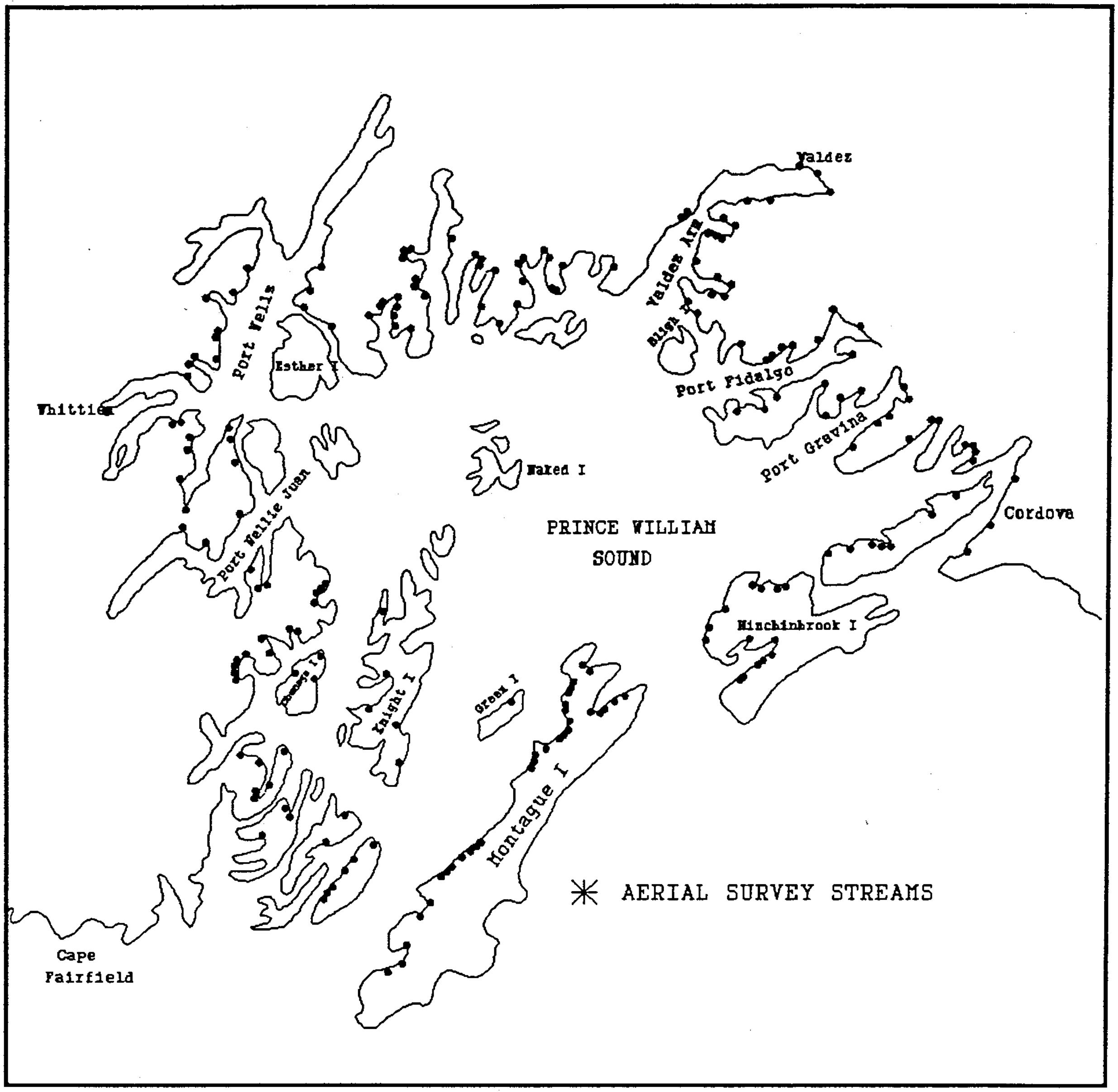


Figure 1. Map showing the locations of streams included in the traditional aerial and ground survey programs for pink and chum salmon escapements in Prince William Sound, 1960-1991.

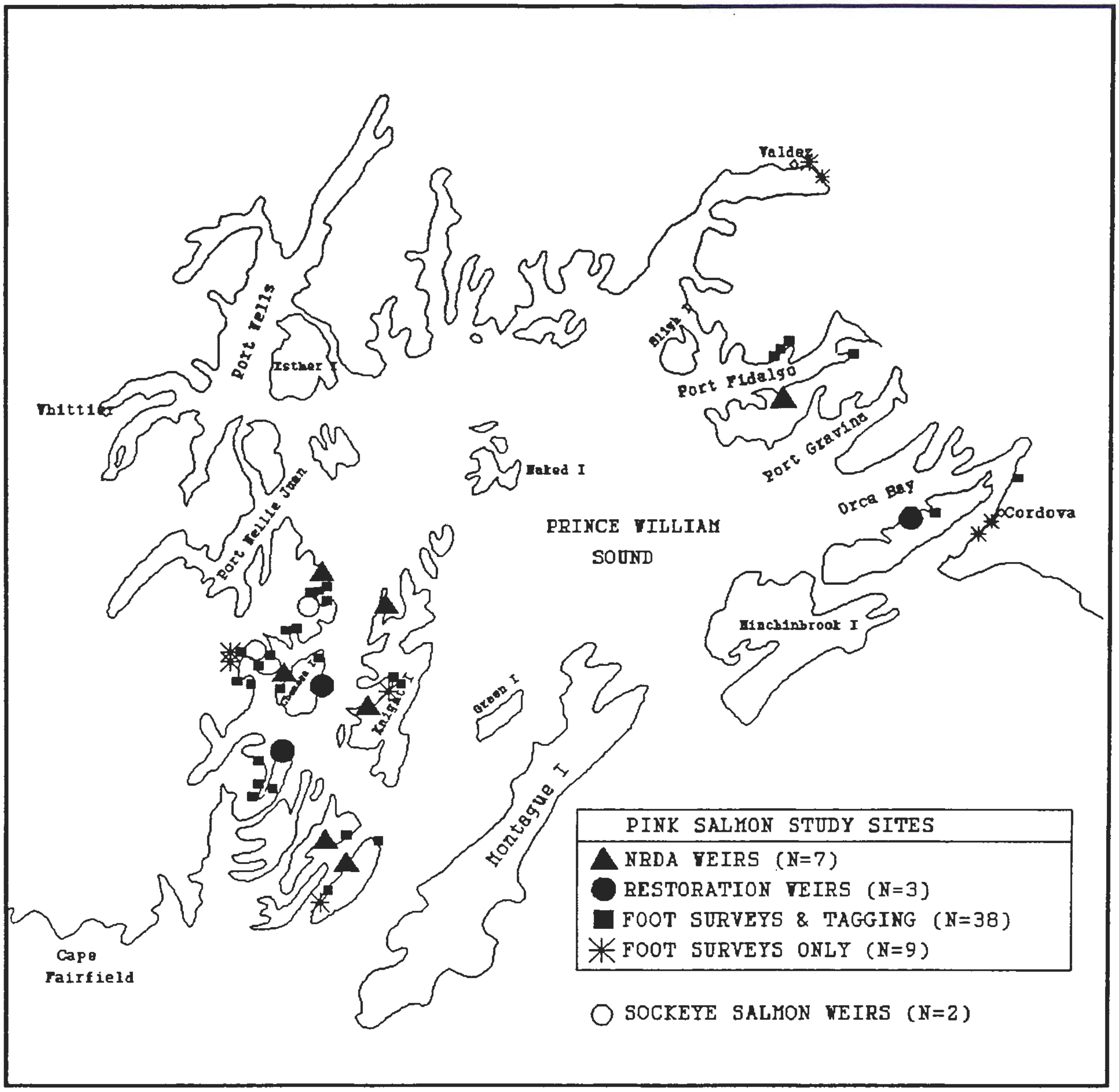


Figure 2. Map showing the locations of streams weired to enumerate salmon escapements and additional streams streams where grounds surveys and tagging studies were conducted on pink salmon in Prince William Sound, 1991.

4. The streams were representative of the early, middle, and late run pink and chum salmon stocks in PWS;
5. The streams were representative of the spatial distribution of pink and chum salmon stocks in PWS and included streams from oiled and unoiled areas.

Surveys to mark tide zones were conducted in June, prior to the return of pink and chum salmon. The locations of tide levels 1.8, 2.4, 3.0, and 3.7 m above mean low water were measured from sea level using a surveyors's level and stadia rod. Sea level at each site was referenced to mean low water with site specific, computer generated tide tables which predict tides at five minute intervals. Tide zone boundaries were delineated with color coded steel stakes.

During the escapement enumeration portion of the project, streams were surveyed visually from the ground in a systematic order. Each field crew used a skiff to travel between their respective base camps and survey streams. During each stream survey the following data were recorded for each stream on printed data forms:

1. Anadromous stream number and name (if available);
2. Date and time (24 hour military time);
3. Tide stage;
4. Observer names;
5. Counts of live and dead salmon by species for five zones; four intertidal zones between elevations of 0.0-1.8 m, 1.8-2.4 m, 2.4-3.0 m, and 3.0-3.7 m above mean low water; and one upstream zone encompassing the entire stream above 3.7 m (mean high water);
6. A record of stream life tag observations detailing tagged fish location, tag color, and individual tag number;
7. A record of adipose fin clipped carcasses recovered by time and stream location;
8. A survey condition factor in each zone based on weather, water clarity, glare, and other survey conditions. Conditions were standardized and assigned a number from 1 (excellent) to 5 (very poor).
9. A survey rating factor for each zone ranging from 1 (excellent) to 3 (poor) based on the surveyors subjective assessment. Ratings were indicative of problems associated with the conditions but also quantified other unrelated problems such lapses of concentration or difficulties associated with counting huge, mobile schools.
10. A code indicating which sections were counted together by both observers and which were counted by only one observer.

Survey patterns were adjusted using computer generated tide tables. If tide height at the beginning of the survey was at or below 1.8 m the crew started the survey at the stream mouth (ie. the point where a clearly recognizable stream channel disappeared or was submerged by salt water). Pink or chum salmon seen below the stream mouth were recorded separately as a comment on the data form. If the intertidal portion of the stream above the 1.8 m level was submerged, the crew started the survey at the upstream limit of spawning as determined by the presence of natural barriers to salmon (ie. waterfalls), the end of the stream, or the upstream limit of observed spawning.

Counts of live and dead pink and chum salmon were made by a two person crew. For streams of moderate size and having a single channel the crew members walked together but independently recorded their counts of live fish in each stream zone. To isolate and quantify observer bias, crew members were not permitted to compare or discuss counts at any time. The count for each zone was replicated a maximum of three times at the request of either observer. Upstream counts in a single channel were similarly enumerated. Long upstream zones were frequently subdivided into subsections at convenient stopping points (ie. log jams or other clear counting delineators). On large braided or branched streams, duplicate counting was not possible and each crew member counted separate channels or upstream forks. To avoid confusion with counts of live fish, counts of dead fish and tagged fish were recorded on the return leg of the stream walk or by an independent third observer. When possible, camp personnel rotated creek surveying assignments each day to avoid counting biases.

All counts were recorded on mechanical hand tallies for each stream section. At the end of each section or tide zone, counts were recorded together with other survey data on pre-printed data sheets. Data were all stored electronically on microcomputers in a relational data base (RBASE). Records in the data base were stratified by stream number, survey date, tide zone, zonal section, replicate counts, and species. Strata which were replicated by more than one observer were coded for later categorical analysis of differences between observers.

Maps of all streams to be surveyed daily in 1991 were originally prepared in 1989 from aerial photographs and improved during the course of the 1989 and 1990 field seasons. Maps were again modified and updated at the beginning of the 1991 stream surveys to include information from initial surveys regarding the location of stakes and key landmarks which identified tide zones, spawner distribution within each zone and the upstream limit of spawning. Spawner density and distribution observations were used for the 46 streams to be sampled as part of NRDA Study 2.

Aerial Surveys

Aerial survey estimates of pink and chum salmon within 209 index streams have been made since 1961 by ADF&G's commercial fisheries management biologists based in Cordova. Surveys have been flown weekly from mid-June to mid-September each year (Figure 1). Counts of salmon by species have been recorded for the bay at the terminus of each stream, the mouth of each stream, and within the stream. Prior to 1991, aerial survey counts within the stream were not stratified by tide height as they have been in the ground survey program. This year, results of aerial surveys on creeks with weirs, and on creeks that were surveyed on foot each day, were broken down into above and below the weir counts, and intertidal and upstream counts, respectively. The division between intertidal and upstream sections of surveyed streams was marked by a large orange buoy anchored at the 3.7 m tide level and visible from the air. Aerial survey methods used in PWS have been described in more detail by Pirtle (1977). In 1989, eight streams in the oiled portions of PWS were added to the survey roster. In 1990 and 1991 funds from the fishing industry and local aquaculture associations were use to approximately double the frequency of survey flights. For most weeks there were at least two observations per stream. In 1991, an additional 144 streams were added to the 209 streams examined by aerial surveyors. Added streams were selected from among all streams listed in the ADF&G Habitat Division catalogue of anadromous salmon streams (Anonymous 1990). The list of anadromous streams was stratified by area and streams were randomly selected for inclusion in the aerial survey program. The number selected from each area stratum was proportional to the total number of streams in the area.

Stream Life Studies

Stream life estimates based on tagging studies were similar to those described by McCurdy (1984), Helle et al (1964), and Sharr et al (1990). Once a week, fish from each of 38 streams (Figure 2) were captured with beach seines at the stream mouths and Peterson disk tags were applied. At larger streams, 200 tags were applied each week. At smaller streams 120 tags were applied weekly. If fewer than the desired number of fish were available, all fish captured were tagged. Tags were uniquely colored to represent day of capture, uniquely lettered to identify the stream where tags were applied, and uniquely numbered for identification of individual fish. All streams in the tagging study were included among those in the daily ground survey program. Tagged live and dead fish were tallied by color within each tide zone, and where possible individual numeric codes were recorded for live fish. Tallies of dead fish included only fish that had died since the last survey. The tail and tags, when present, were removed from all dead fish to identify carcasses which had been counted.

Independent estimates of stream life were made using two other methods which did not rely on tags. These methods incorporated daily counts of live and dead fish from the foot survey program and weir counts where available.

Documentation of Oil Contamination

In 1989 a 2-person crew conducted aerial and foot surveys to document the presence of oil in the intertidal spawning and rearing habitat of all known anadromous salmon spawning streams in western and central Prince William Sound. Most important salmon streams in the northern and eastern portions of PWS which were part of the ground escapement enumeration portion of this project and included in NRDA Study 2 were also surveyed (Sharr et al, 1990).

Hydrocarbon Sampling

In 1989 and 1990 composite samples of mussels (*Mytilus sp.*) were collected at the mouth of 135 streams for hydrocarbon analysis (Sharr 1990). Results of this analysis will be used to corroborate visual evidence of oil contamination and will be indicative of the availability of hydrocarbons to other organisms such as pink and chum salmon eggs and fry which share the same intertidal habitat for long periods of time.

Histopathology, Cytogenetic, and Electrophoretic Sampling

Histopathology. Tissue samples were removed from adult salmon for histopathological, MFO, and cytogenetic analyses. Salmon were selected for sampling according to the following criteria:

1. Equal numbers of stocks were chosen from streams in oiled and unoiled areas. Stocks in the "oiled" category represented a continuum of contamination ranging from returns to streams where large amounts of oil was visible to those where the presence of oil was only suspected;
2. Wild salmon stocks from oiled and unoiled areas were chosen from those studied in NRDA F/S Study 2 (Injury to Salmon Eggs and Fry) and NRDA F/S Study 3 (Coded-Wire Tagging Studies);
3. Stocks were selected from areas suspected of having been oiled but with mussel samples which gave ambiguous results.

Twenty two stocks were sampled in 1990 and again in 1991. Twelve stocks were from streams suspected of having oil contamination, and 10 were from unoiled sites in close geographic proximity (Figure 3). Fish were sampled immediately after entering the stream and before undergoing gross morphological changes and tissue deterioration associated with spawning. Twenty fish of each sex were sampled from each stock. Fish sampled for histopathological analyses were captured with beach seines, stored immediately on ice, and were typically sampled in the laboratory in Cordova within six hours of the time of capture. Samples of liver, spleen, posterior kidney, and olfactory tissue were remove from each animal. Liver, spleen, and kidney tissues were thin sectioned. One entire nare was removed to represent olfactory tissue. All tissues

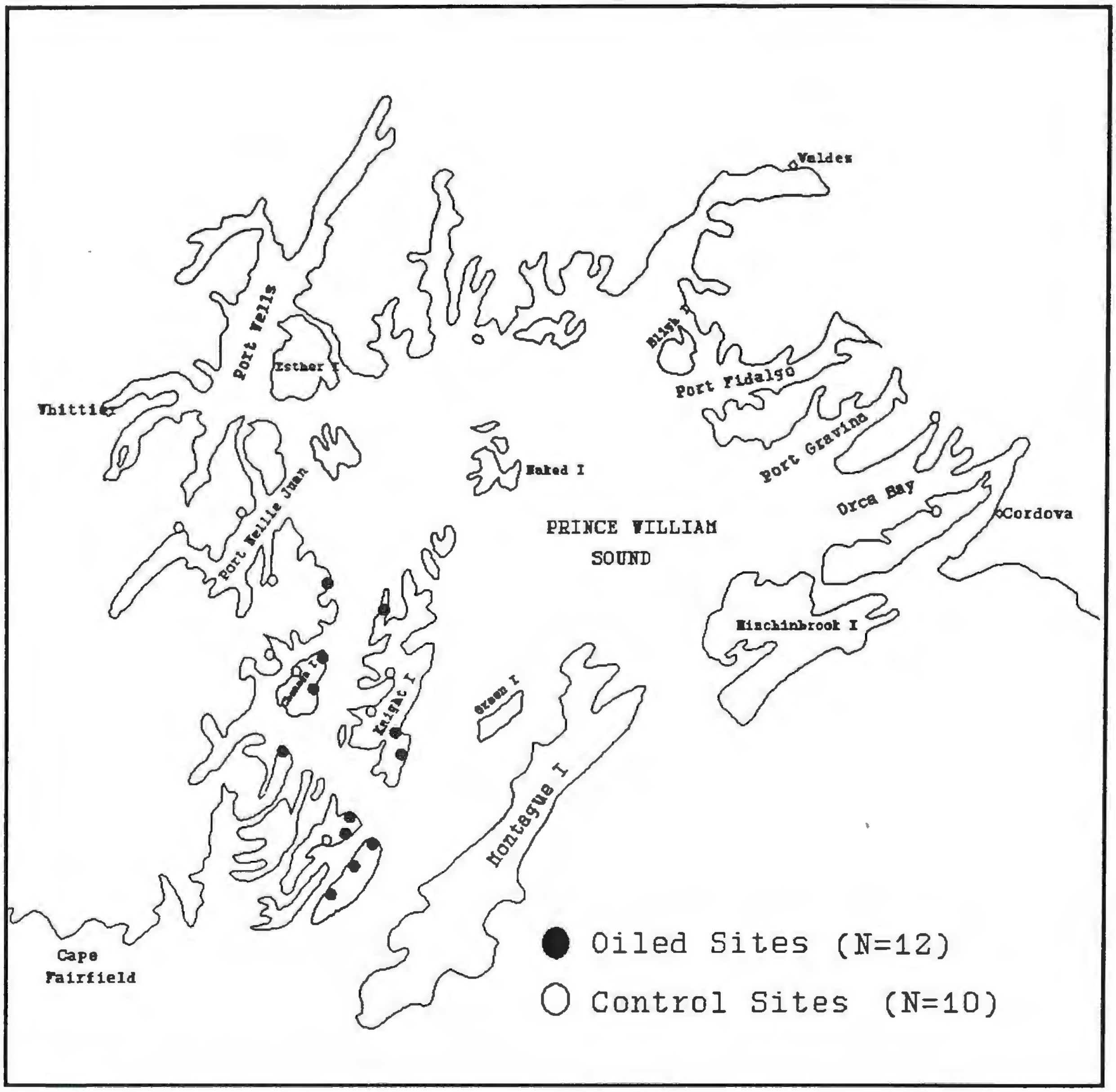


Figure 3. Map showing the locations of streams where tissue samples were taken from adult pink salmon for histopathological and cytogenetic examination and MFO analyses.

from one animal were stored in a single jar filled with 10% phosphate buffered formalin. Each sample jar was labeled inside and out with printed labels indicating species, sex, ADF&G anadromous stream number, stream name, geographic location, latitude, and longitude of the stream mouth, date, time, tissue type, preservative, and sampler(s). Corresponding information was entered on chain of custody forms. The samples were sealed with evidence tape and stored in a secure office. A subset of samples from five streams, two oiled, two control and, one suspect have been remitted to the custody of Dr. David Hinton for analysis.

Cytogenetic. Sperm samples for cytogenetic analysis were taken from all males captured at 20 of the 22 streams sampled for histopathology analyses. Males were removed live from the beach seine at each capture site and milked for sperm into cryogenic vials which were pre-labeled according to the same protocol described for histopathology samples. To avoid sample contamination by debris or other tissue types, the vent area of each fish was wiped dry prior to milking, vials used to store sperm from each male were not brought in contact with the fish, and any sample containing blood was discarded and replaced by a clean sample from another fish. Samples were transported on ice to Cordova, diluted with of phosphate buffer, frozen in liquid nitrogen, and shipped on dry ice to the Anchorage ADF&G genetics laboratory for processing.

Electrophoresis. To begin characterizing genetic stock composition of PWS pink and sockeye salmon populations, returns to thirteen pink salmon streams, three pink salmon hatcheries, two sockeye salmon streams, and one sockeye salmon hatchery were sampled for electrophoretic analysis (Figure 4). One hundred fish from each stock were sampled for tissues from the muscle, liver, heart tissue and ocular fluid. Fish were captured with beach seines at wild stock systems or removed from brood stock raceways at hatcheries, placed on ice and transported to Cordova for immediate dissection. During dissection, tissues were carefully isolated to avoid inter-fish and inter-tissue contamination. Samples were placed in pre-labeled cryogenic vials and stored, frozen in liquid nitrogen, and shipped to the ADF&G genetics lab in Anchorage.

Data Analysis

The collective data base from the ground survey program, weir projects, and stream life studies is huge and data entry alone has been a formidable task. Data editing and analyses are incomplete at this time. Many of the methods described here are proposed, are not completed, and are subject to change as analysis proceeds in the coming months.

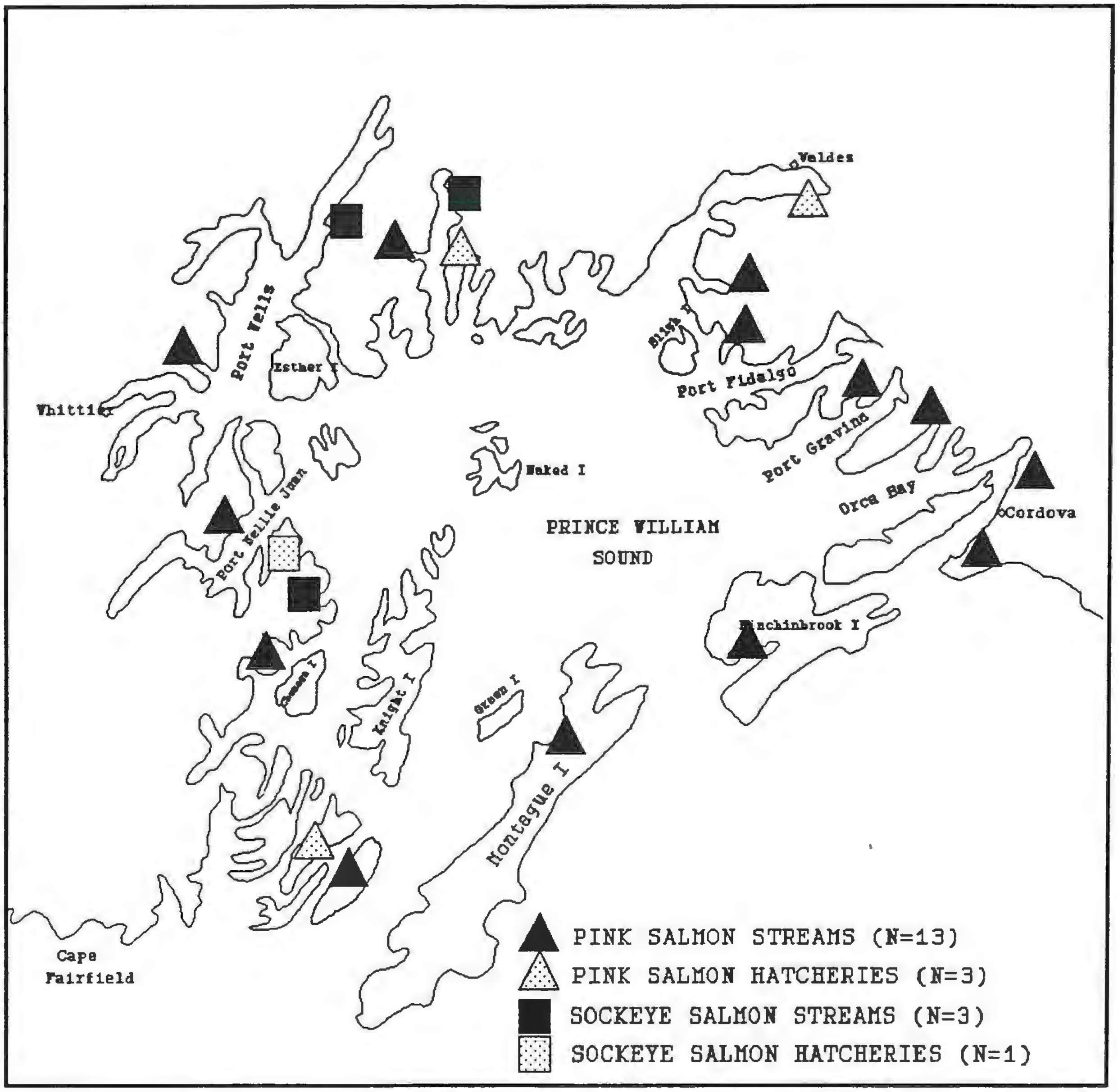


Figure 4. Map showing sites where tissue samples were taken from pink salmon and sockeye salmon for electrophoretic analyses, 1991.

Total Escapement Enumeration Data

Total escapement for streams with weirs is the summation of daily counts of fish through the weir. Very infrequently pickets at a few of the weirs had to be pulled during flooding to prevent the weir from being washed away. These periods when a weir was no longer fish tight typically lasted less than 24 hours and in most instances less than 12 hours. When they occurred, missing counts were inferred from ground counts of live and dead fish from the day preceding and the day follow the event as follows:

$$W_{(i-n)}=\Sigma((L_i-L_{(i-n)})+D_i) \quad (1)$$

where
- i = survey number,
- n = days elapsed since last survey,
- L_i = number of live fish tagged,
- D_i = number of tagged dead fish recovered on survey i,

Adjustment of Aerial and Ground Counts

Streams with weirs were used as standards to define stream categories based on stream size, extent of upstream and intertidal spawning, and other characteristics such as water clarity and extent of forest canopy. Other streams in the aerial and ground survey programs were categorized according to these same criteria. A bias adjustment function for a weired stream was applied to aerial and ground counts from unweired streams in the same category.

Daily aerial and ground counts at weired streams were adjusted for bias using the regression of survey counts to live fish in the stream by date (L_{ij}) estimated as:

$$L_{ij}=\Sigma W_{ij}-\Sigma D_{ij}, \quad (2)$$

where
- i = serial day of weir operation,
- j = stream category,
- W_{ij} = live fish passed through the weir j on day i,
- D_{ij} = count of dead fish in the stream j on day i.

Stream Life Data

Streams in the stream life study were used as standards to define stream categories based on stream size, gradient, and extent of upstream and intertidal spawning, and run timing. Other streams in the aerial and ground survey programs were categorized according to these same criteria. The stream life for a stream in the stream life study was applied to aerial and ground counts from streams in the same category which were not studied. Stream life was estimated using four methods.

Estimates From Tagging. Tagging data were used to calculate stream life values for individual fish as:

$$S=J_r-J_t \tag{3}$$

where J_t = julian date when tags were applied at the mouth of the stream.
J_r = julian date of tag recovery from the dead fish.

The stream life estimates for each stream and weekly strata were the average for individual fish in the strata. The season-average stream life estimate was the average of strata estimates. During tagging studies in 1990 (Sharr et al 1990) tagged fish were observed milling at the stream mouth. Stream life estimates calculated using the date of tag application may not accurately represent in stream residence time and may be too large. To reduce bias associated with milling time at the mouth weekly stream life estimates were adjusted as follows:

$$S=\frac{\Sigma(R_iJ_i)}{\Sigma R_i}-\frac{\Sigma[((T_i-T_{(i-1)})+R_i)J_i]}{\Sigma[(T_i-T_{(i-1)})+R_i]} \tag{4}$$

where i = survey number,
T = number of live fish tagged,
J_t = Julian date of tagging
R_i = number of tagged dead fish recovered on survey i,
J_i = Julian date of survey i.

Estimates Using Fish Days and Total Escapement. For streams with weirs, an estimate of mean stream life based on daily counts of live fish through the weir and daily dead counts in the stream will be as follows:

$$S=\frac{\Sigma[(J_i-J_{(i-1)})\Sigma(W_i-D_i)]}{\Sigma W_i}, \tag{5}$$

Where
- i = serial day of weir operation,
- J_i = Julian date,
- W_i = live fish passed through the weir on day i,
- D_i = count of dead fish in the stream on day i,
- S = stream life (in days).

Where observations for day i were missing, total live fish in the creek on day i ($\Sigma(W_i-D_i)$) was linearly interpolated. A similar, though less reliable estimate can be made using live and dead counts from ground surveys as follows:

$$S=\frac{\Sigma[(J_i-J_{(i-1)})\Sigma L_i]}{\Sigma D_i}, \tag{6}$$

Where
- i = serial day of weir operation,
- J_i = Julian date,
- L_i = count of live fish in the stream on day i,
- D_i = count of dead fish in the stream on day i,
- S = stream life (in days).

This method assumes that counts of dead fish in the stream are a reliable estimate of the total escapement. Where observations for day i were missing, total live fish in the creek on day i (L_i) was linearly interpolated.

Estimates From Run Timing. Another mean stream life estimate was calculated as the difference between the mean date of abundance of new arrivals in the stream and the mean date of abundance of daily dead counts as follows:

$$S=\frac{\Sigma D_i J_i}{\Sigma D_i}-\frac{\Sigma[((L_i-L_{(i-1)})+D_i)J_i]}{\Sigma[(L_i-L_{(i-1)})+D_i]} \tag{7}$$

where i = survey number,
L_i = number of live fish observed on survey i,
D_i = number of dead fish observed on survey i,
J_i = Julian date of survey i.

For weired systems a similar estimate was calculated using the mean date of daily weir counts as follows:

$$S=\frac{\Sigma D_i J_i}{\Sigma D_i}-\frac{\Sigma W_i J_i}{\Sigma W_i} \qquad (8)$$

Escapement Estimates Based on Aerial Survey Data

Annual spawning escapement estimates (E) for pink salmon within each surveyed stream were made using a geometric approach similar to that described by Johnson and Barrett (1986):

$$E=\frac{\sum\left[(J_i-J_{(i-1)})L_i-\frac{(J_i-J_{(i-1)})(L_i-L_{(i-1)})}{2}\right]}{S} \qquad (9)$$

Where i = survey number,
j = stream category,
J_i = julian date,
L_{ji} = survey estimate of live fish in the stream adjusted for stream category j survey bias on survey i,
S = stream life (in days).

If the maximum daily survey of live fish in the stream exceeded the total escapement estimate based on the geometric method, the maximum daily survey count was treated as the total escapement.

Escapement Estimates Based on Ground Survey Data

Ground survey counts were summarized by species, stream, survey date, the four intertidal zones and upstream zone, and by observer for all 51 streams in the study. Spawning escapement to streams surveyed from the ground was estimated using the geometric method described for aerial survey data. Frequently survey counts (L_i) were replicated as paired observations from two observers walking in tandem. The estimated number of fish in a section walked in tandem was the mean of the observations. In instances where the maximum daily sum of live and dead fish in a stream exceeds the total escapement estimate for the stream based on the geometric method, the maximum daily sum of live and dead will be the total escapement estimate.

Hydrocarbon and Histopathology Sampling

Samples of mussels for hydrocarbon analysis and tissue samples from adult salmon for MFO analysis and histopathological examination are processed by contractual agreement with Dr. David Hinton at the University of California, Davis, California. Samples for cytogenetic analysis are being processed by contractual agreement with Dr. Stan Alan at Rutgers University. Electrophoretic analyses of pink and sockeye salmon tissues will be are archived at the ADF&G Genetics laboratory in Anchorage and will be processed by that facility.

RESULTS

Oil Survey

The presence of oil on the intertidal substrate was documented at the mouths of 43 of the 411 streams surveyed in 1989 and the results were summarized by Sharr et al. (1990). The oil survey included 183 of the 211 streams enumerated by the ADF&G pink and chum salmon escapement aerial survey program, 130 of the 140 streams studied in this project, and 57 of the 58 streams sampled in NRDA Study 2. All photographs, maps and data sheets are archived in the Cordova area ADF&G office. A complete catalogue of photos, maps, and data from data sheets has been stored in both LOTUS and RBASE format on an IBM compatible microcomputer.

Total Escapement Enumeration Through Weirs

Pink Salmon

Total escapement results from weirs operated on 10 pink salmon streams in 1991 are summarized in Table 1 and Appendix A. Weirs were also operated at four of these streams in 1990 (Sharr et al 1990). Escapements in 1991 were significantly greater at three and slightly greater at the fourth. The 1991 escapement to Irish Creek was more than double that of 1990 (95,627 versus 43,564), the escapement to Totemoff Creek was more than triple that of 1990 (37,633 versus 11,454), and the escapement to Herring Creek was more than four times that of 1990 (16,723 versus 4,966) (Table 2). Only Cathead Creek had similar escapements in 1991 and 1990 (9,655

Table 1. Weir counts, carcass counts, and stream life estimates for ten Prince William Sound pink salmon streams, 1991. Stream life estimates are based on tagging (equation 3), fish days at total escapement (equations 4 and 5), and run timing (equations 6 and 7).

	Cumulative Counts		Stream Life Estimates by Method				
					Run Timing		Tagging
Stream	Live	Dead	Weir	Surveys	Weir	Surveys	
Irish Creek	95,627	94,487	16.13	9.06	15.93	9.03	13.87
Loomis Creek	17,694	18,889	5.97	5.42	6.87	5.38	6.75
Totemoff Creek	27,350	37,633	3.43	9.09	10.99	9.07	10.96
Chenega Creek	48,745	51,790	9.42	7.06	10.47	6.85	8.91
Countess Creek	15,028	14,172	9.47	6.94	8.98	6.66	8.56
O'Brien Creek	27,174	33,133	7.82	5.42	10.43	5.41	8.19
Hayden Creek	18,372	16,403	11.69	6.47	9.40	6.46	9.63
Herring Creek	16,723	13,691	13.09	10.86	10.06	10.82	9.96
Cathead Creek	9,765	8,724	11.88	8.97	10.44	8.92	10.48
Hawkins Creek	48,825	42,357	16.56	10.78	16.39	10.77	10.57
Totals	325,303	331,279					
Averages			10.55	8.01	11.00	7.94	9.79

Table 2. Comparisons of 1990 and 1991 aerial escapement estimates to results from weirs and comparisons of traditional aerial estimation procedures used in Prince William Sound versus procedures incorporating correction factors for bias in the aerial method and using revised streamlife values.

Stream Name	Stream Life	Aerial Correction Factor	Total Escapement	Aerial Escapement Estimates: Adjusted Numbers	Adjusted % Error	Traditional Numbers	Traditional % Error
1990							
Irish Creek	18.3	1.11	43,564	29,352	-32.6%	27,607	-36.6%
Totemoff Creek	7.2	0.62	16,128	13,503	-16.3%	8,961	-44.4%
Herring Creek	11.2	0.94	4,966	3,187	-35.8%	2,700	-45.6%
Cathead Creek	8.5	0.87	7,586	6,112	-19.4%	3,534	-53.4%
Totals			72,244	52,154	-27.8%	42,802	-40.8%
1991							
Irish Creek	16.13	3.51	95,627	86,376	-9.7%	22,682	-76.3%
Totemoff Creek	9.10	1.98	37,633	24,088	-36.0%	9,500	-74.8%
Herring Creek	13.90	1.87	16,723	14,382	-14.0%	5,967	-64.3%
Cathead Creek	11.88	3.85	9,765	7,583	-22.3%	1,500	-84.6%
Subtotal Totals			159,748	132,429	-17.1%	39,649	-75.2%
Loomis Creek	5.97	1.83	17,694	18,276	3.3%	3,407	-80.7%
Chenega Creek	9.42	3.01	48,745	43,421	-10.9%	7,765	-84.1%
Countess creek	9.47	1.11	15,028	6,923	-53.9%	5,400	-64.1%
O'Brien Creek	8.19	2.47	27,174	39,646	45.9%	7,512	-72.4%
Hayden Creek	11.69	1.31	18,372	7,744	-57.8%	5,000	-72.8%
Hawkins Creek	16.56	2.47	48,825	35,154	-28.0%	13,468	-72.4%
Totals			335,586	283,593	-15.5%	82,201	-75.5%

versus 7,586). The mean date of fish passage through the weirs was later in 1991 than in 1990. The largest difference (17 days) was at Cathead Creek and the smallest was at Herring Creek (2 days).

At Totemoff Creek, cumulative carcass counts from daily surveys significantly exceeded live counts through the weir (Table 1). A similar phenomenon occurred at this site in 1990 (Sharr et al. 1990). At that time it was assumed that when carcasses accumulated too rapidly on the weir, counting crews inadvertently overlooked tail clips and double counted some. It now appears more likely that the water volume, steep gradient, and loose gravel substrate in this creek resulted in frequent gaps at the bottom of weir pickets which may allow live fish to pass uncounted. In any event, estimates of live fish in the stream based on weir counts are suspect.

Sockeye Salmon

The sockeye salmon escapement through the Eshamy River weir was 46,226 fish. This was the fourth largest escapement to that system in the last 25 years and only the fifth time that the 40,000 fish escapement goal was met. The escapement of sockeye salmon to Jackpot lake was 5,495 fish.

Adjustment of Aerial and Ground Counts

Results of the regression analyses of ground and aerial counts of live fish in streams compared to estimates calculated from weir data (Equation 2) are summarized for all streams combined (Figure 5) and for individual streams (Figures 5 through 15). For all streams combined, both ground and aerial surveys were negatively biased estimators of escapement. Ground surveys were more accurate than aerial surveys at predicting fish in the stream (slope = 1.89 versus 2.98) and the fit of the regression estimates was better (R^2 =0.949 versus 0.495). This differs from 1990 results in which aerial surveys were unbiased with respect to ground surveys and is consistent with a higher proportion of spawning above the intertidal zone in the odd year cycle. Fish in upstream areas are more difficult to see from the air due to canopy and stream configuration. The fit of the regression line for ground surveys was unchanged when data points were removed for days when aerial surveys were not flown.

The results of regression analyses for individual streams are highly variable but the bias trends are the same as for all streams combined. Excluding suspect results from Totemoff Creek, the correction factor from regressions (slopes) range from 1.1 to 3.8 for aerial estimates and from 1.0 to 1.6 for the ground estimates.

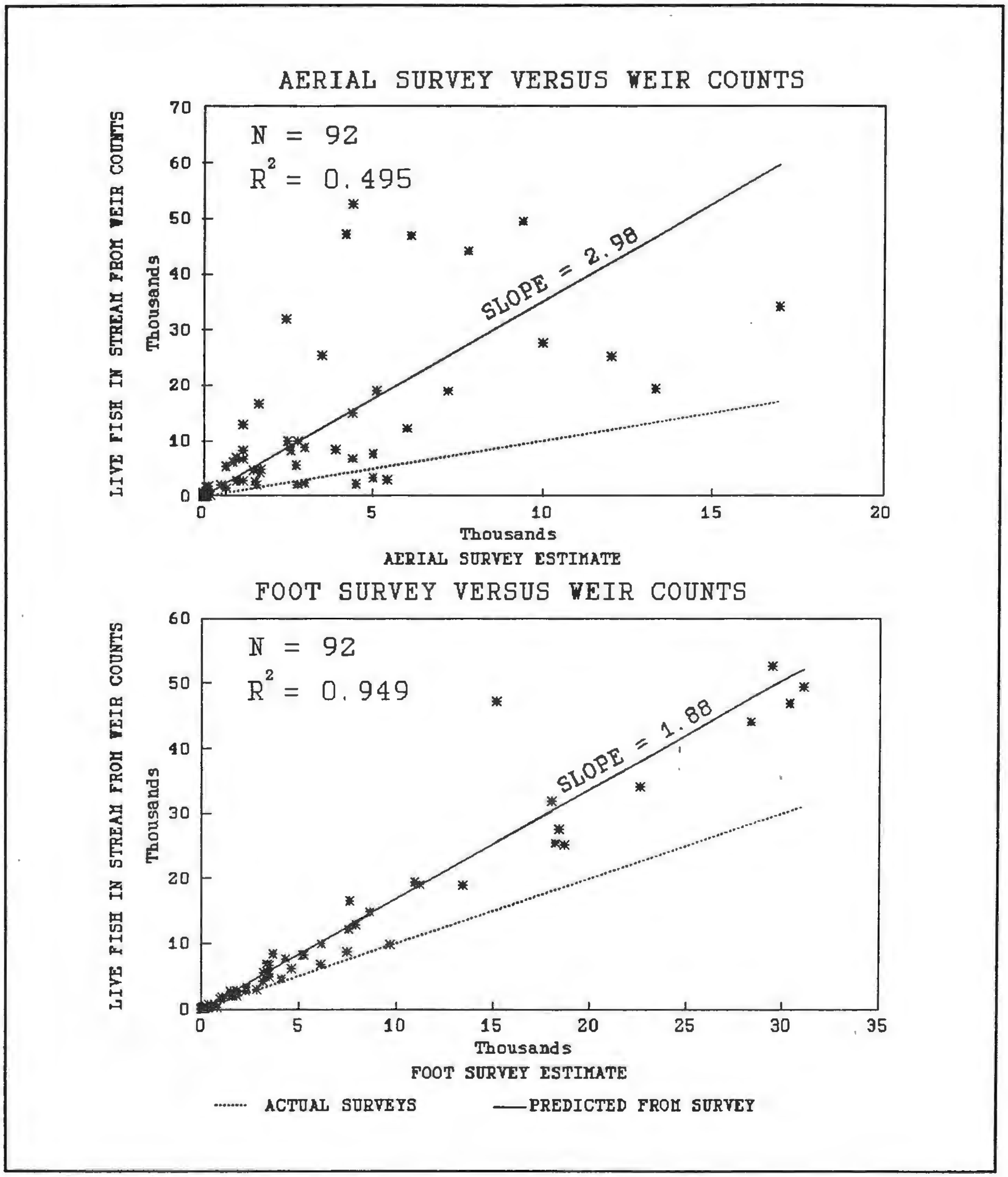


Figure 5. Regression of 1991 aerial counts and ground counts of pink salmon against concurrent weir and carcass counts.

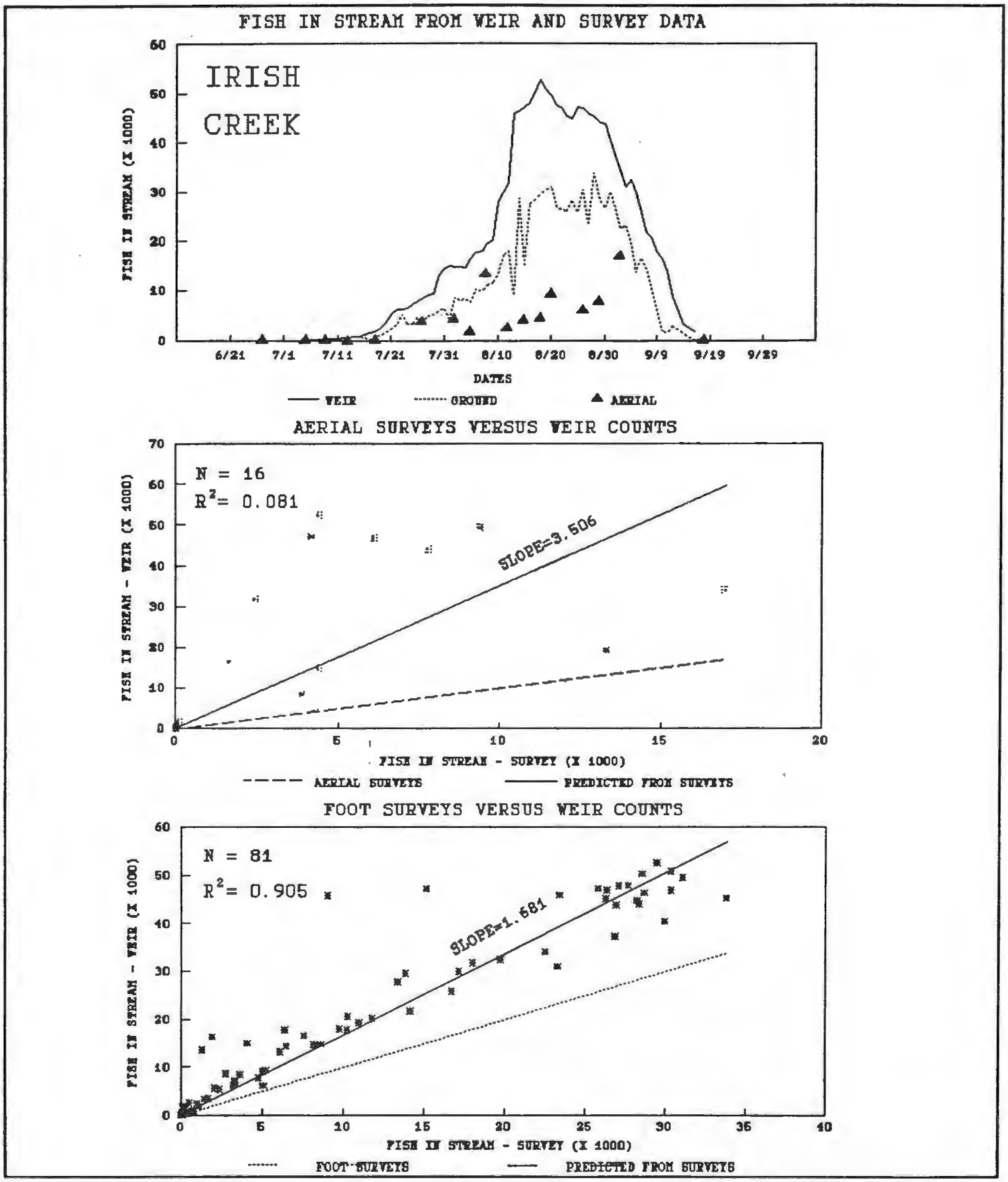


Figure 6. Daily numbers of fish in Irish Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

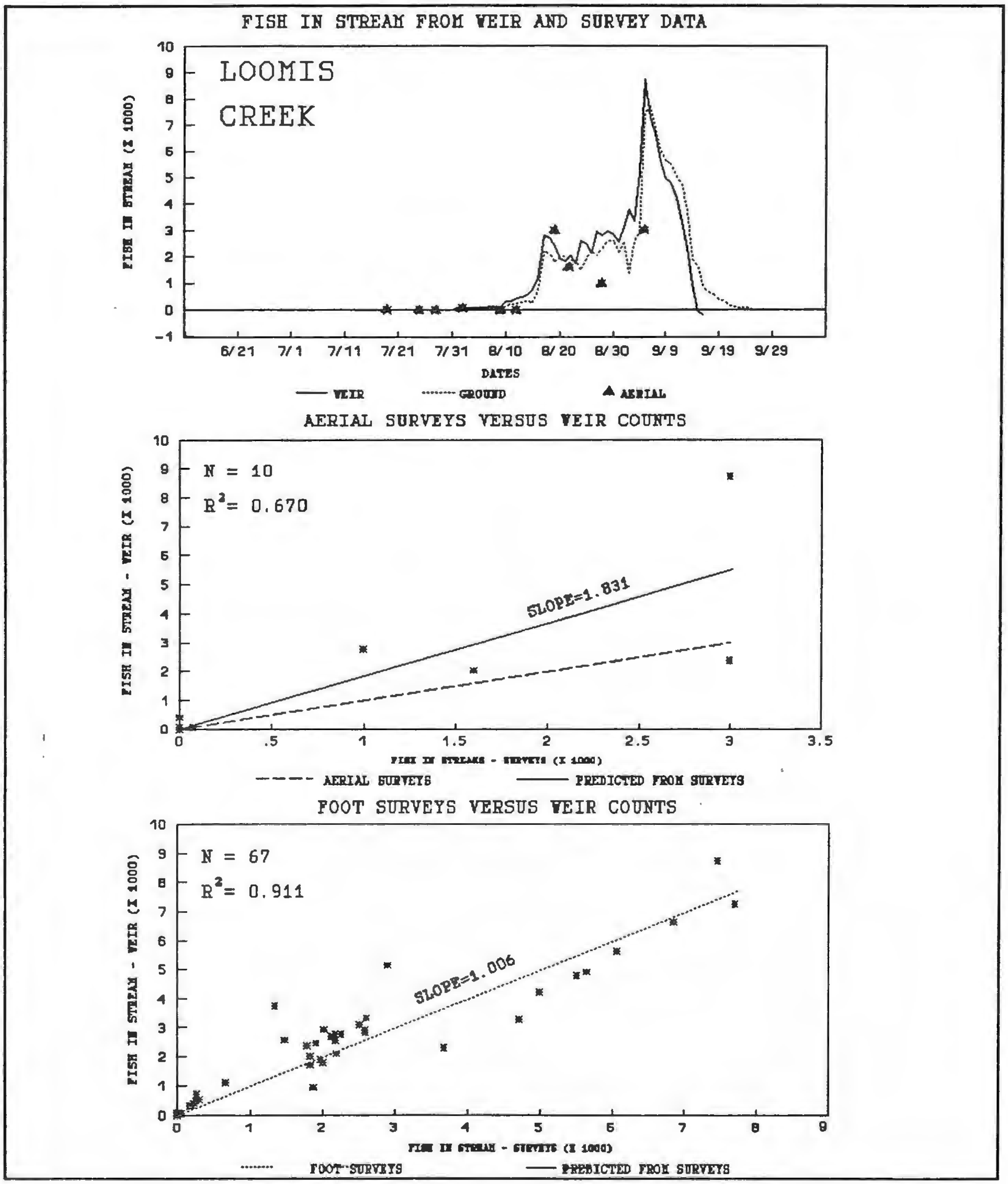


Figure 7. Daily numbers of fish in Loomis Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

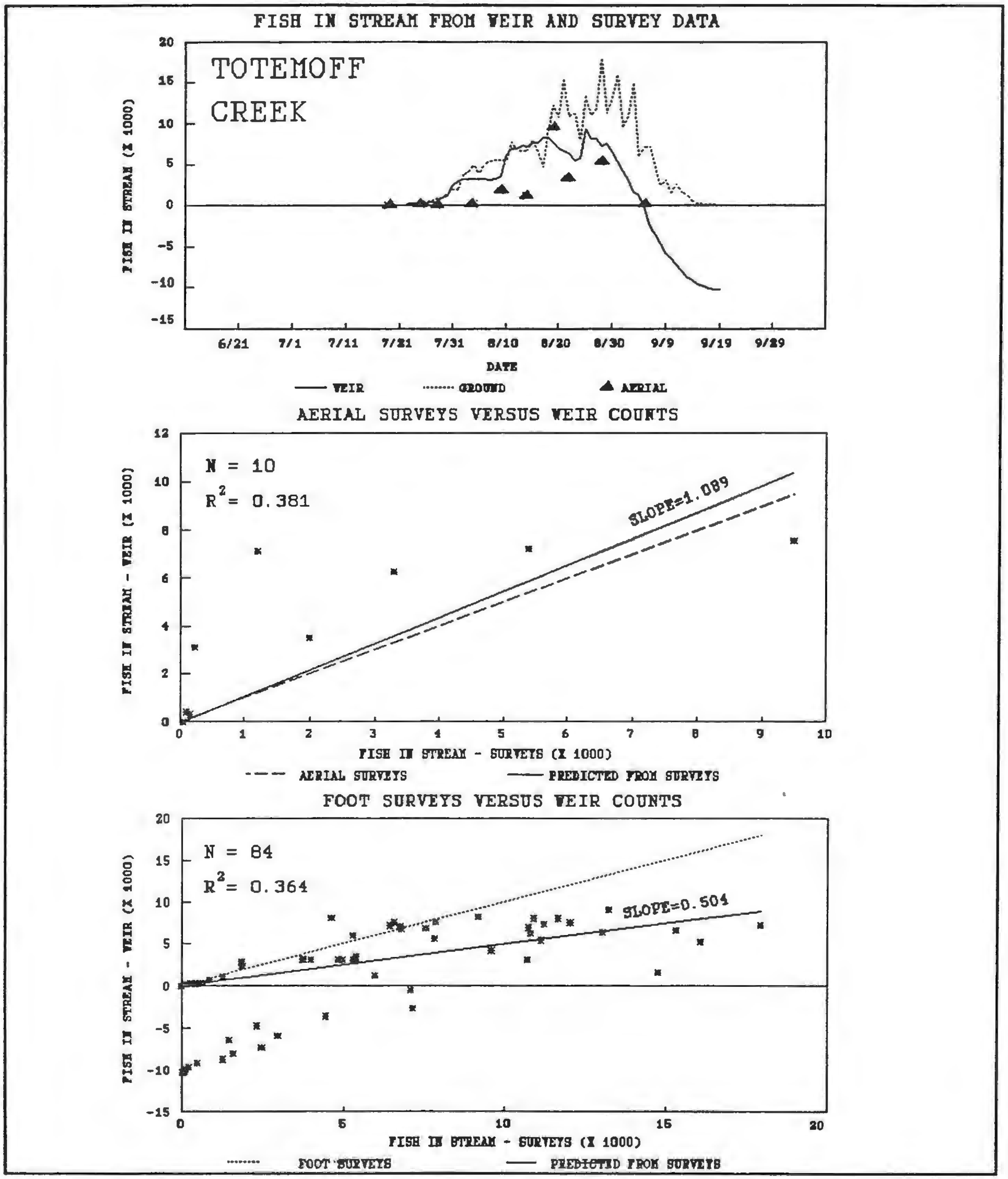


Figure 8. Daily numbers of fish in Totemoff Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

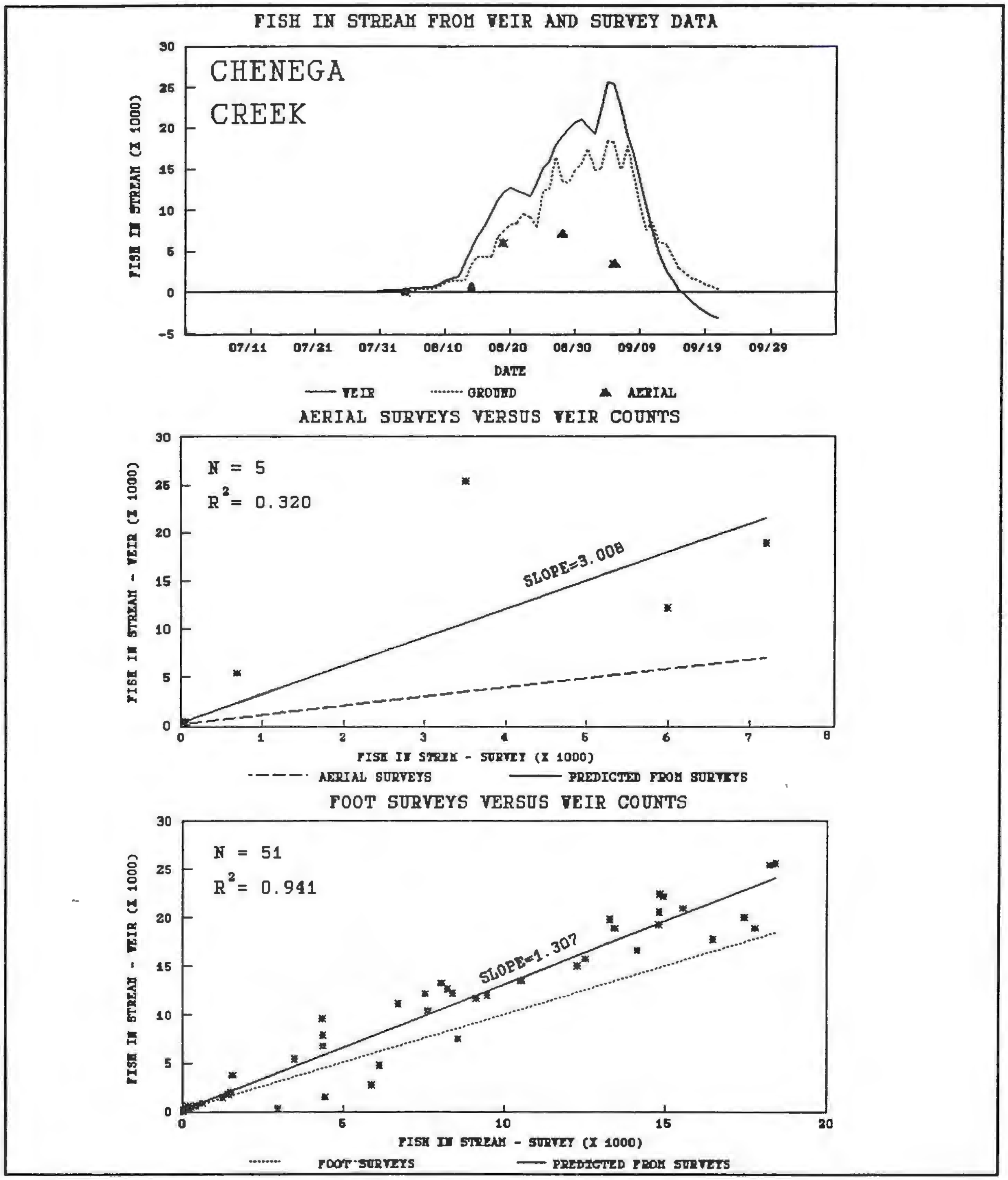


Figure 9. Daily numbers of fish in Chenega Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

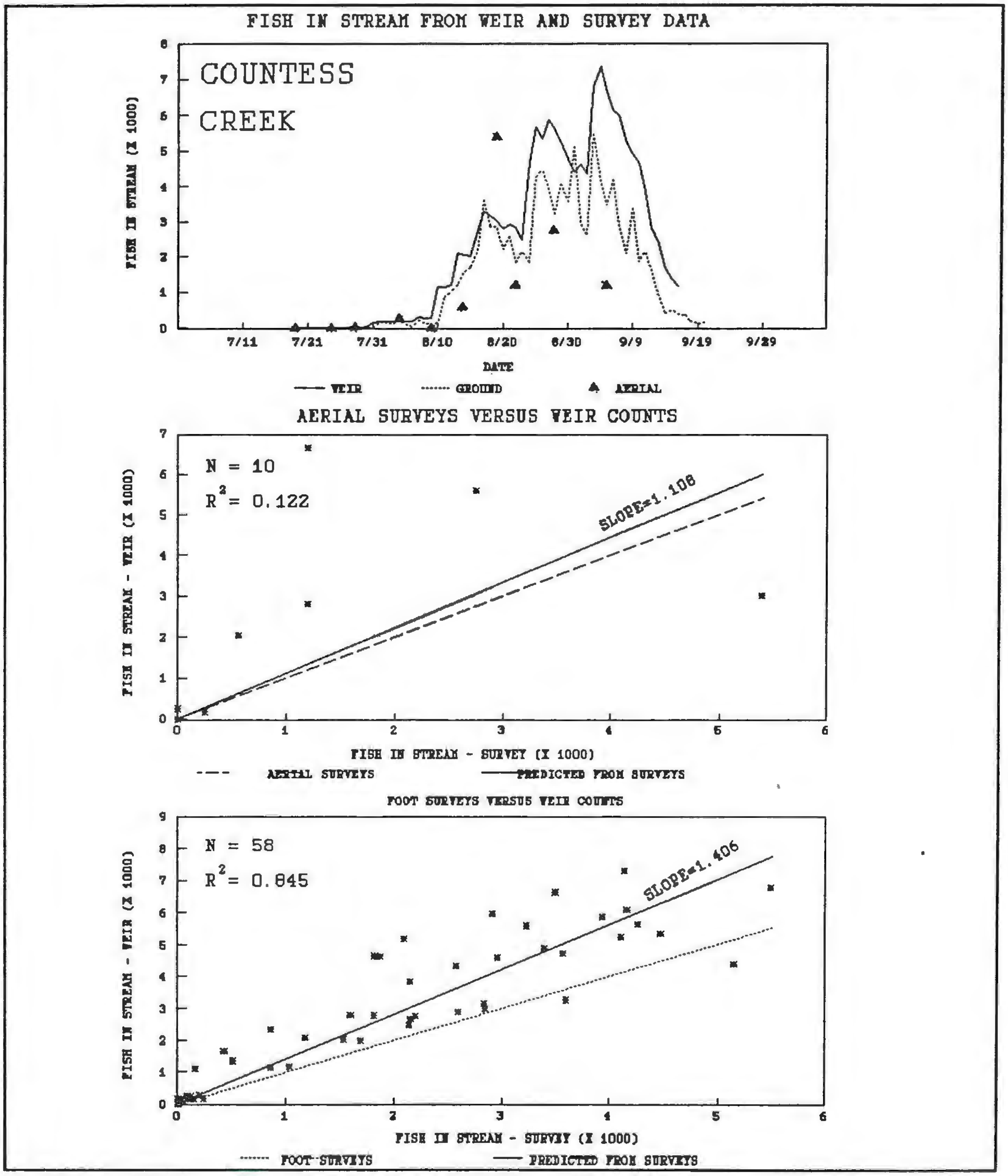


Figure 10. Daily numbers of fish in Countess Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

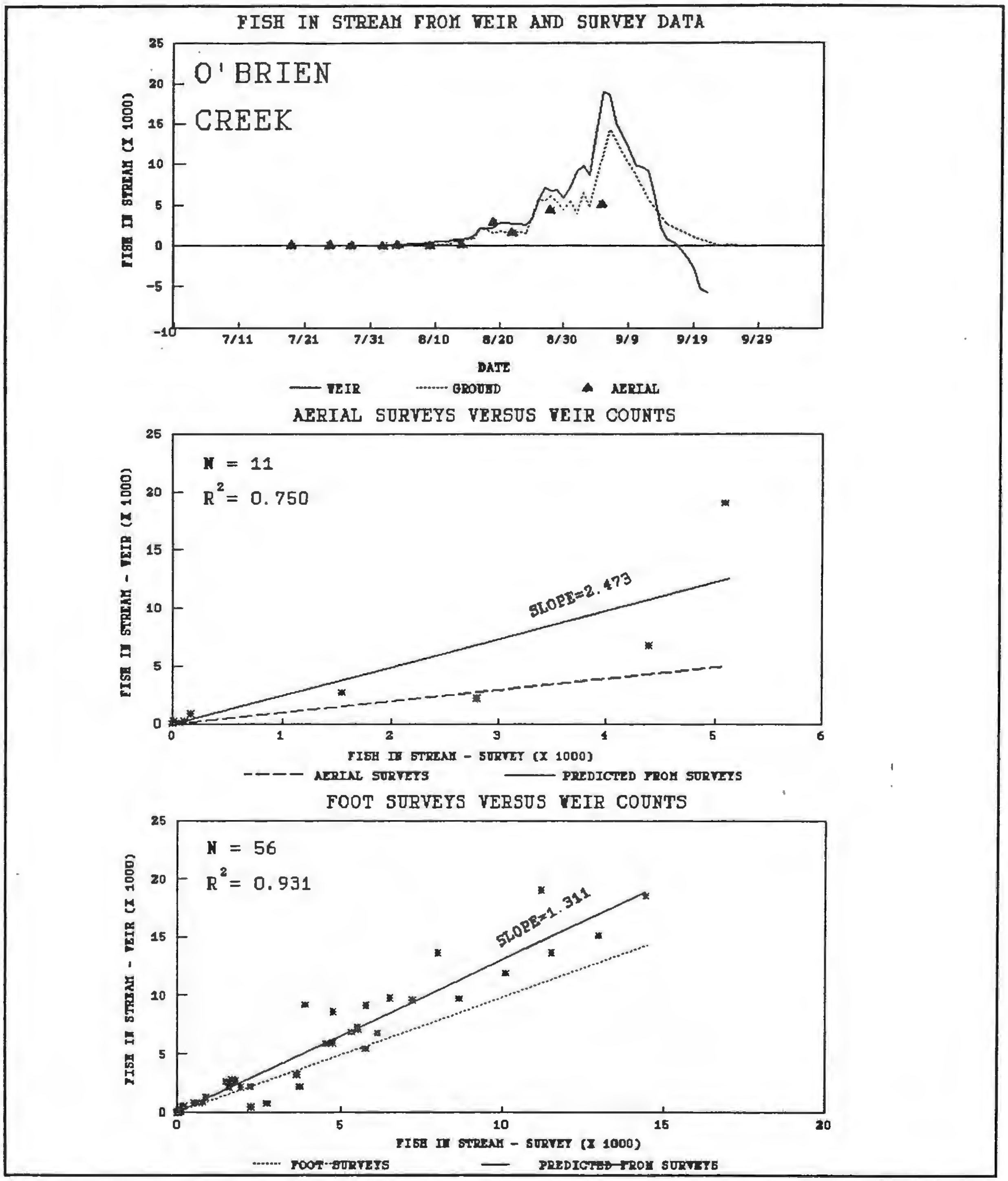


Figure 11. Daily numbers of fish in O'Brien Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

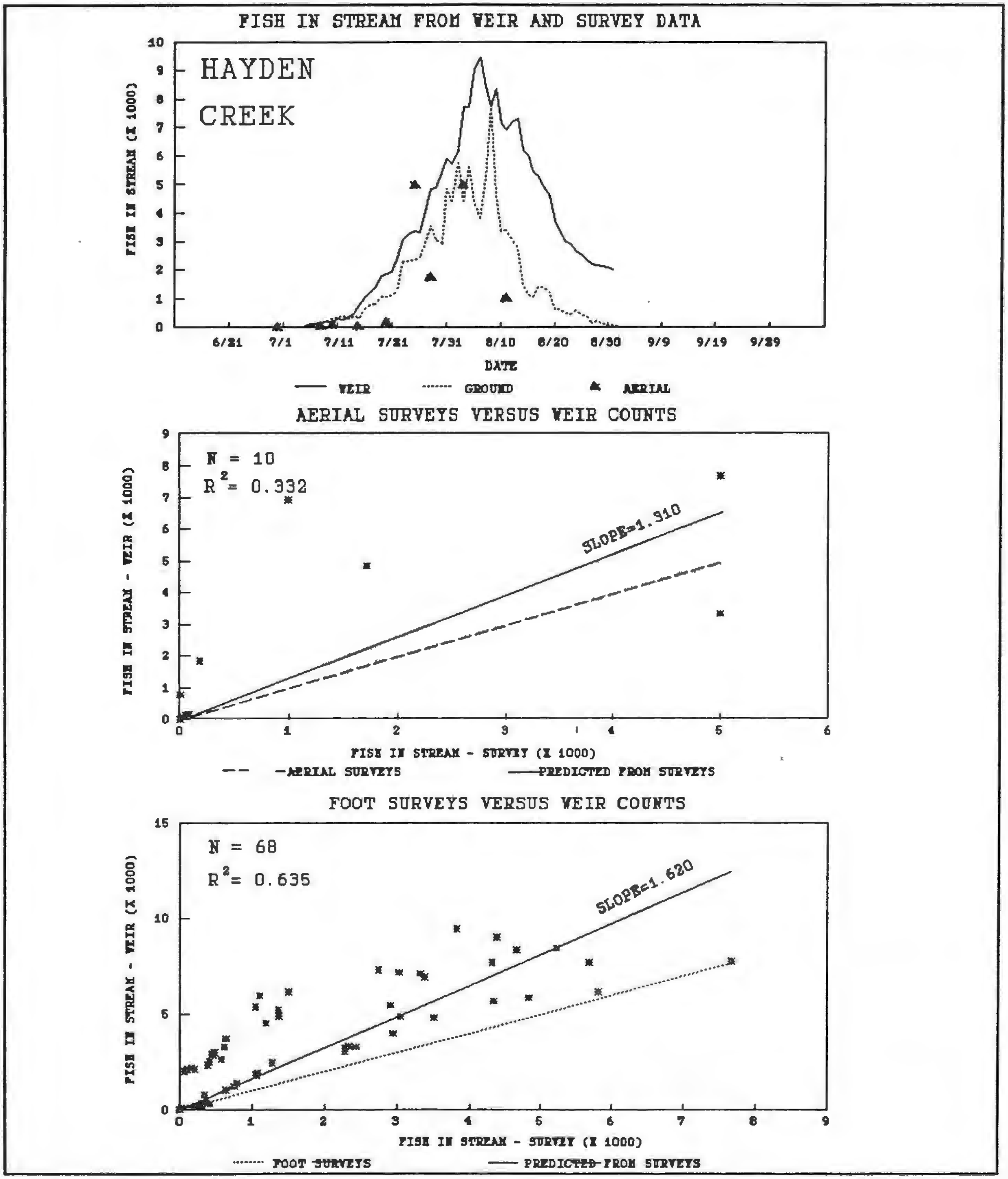


Figure 12. Daily numbers of fish in Hayden Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

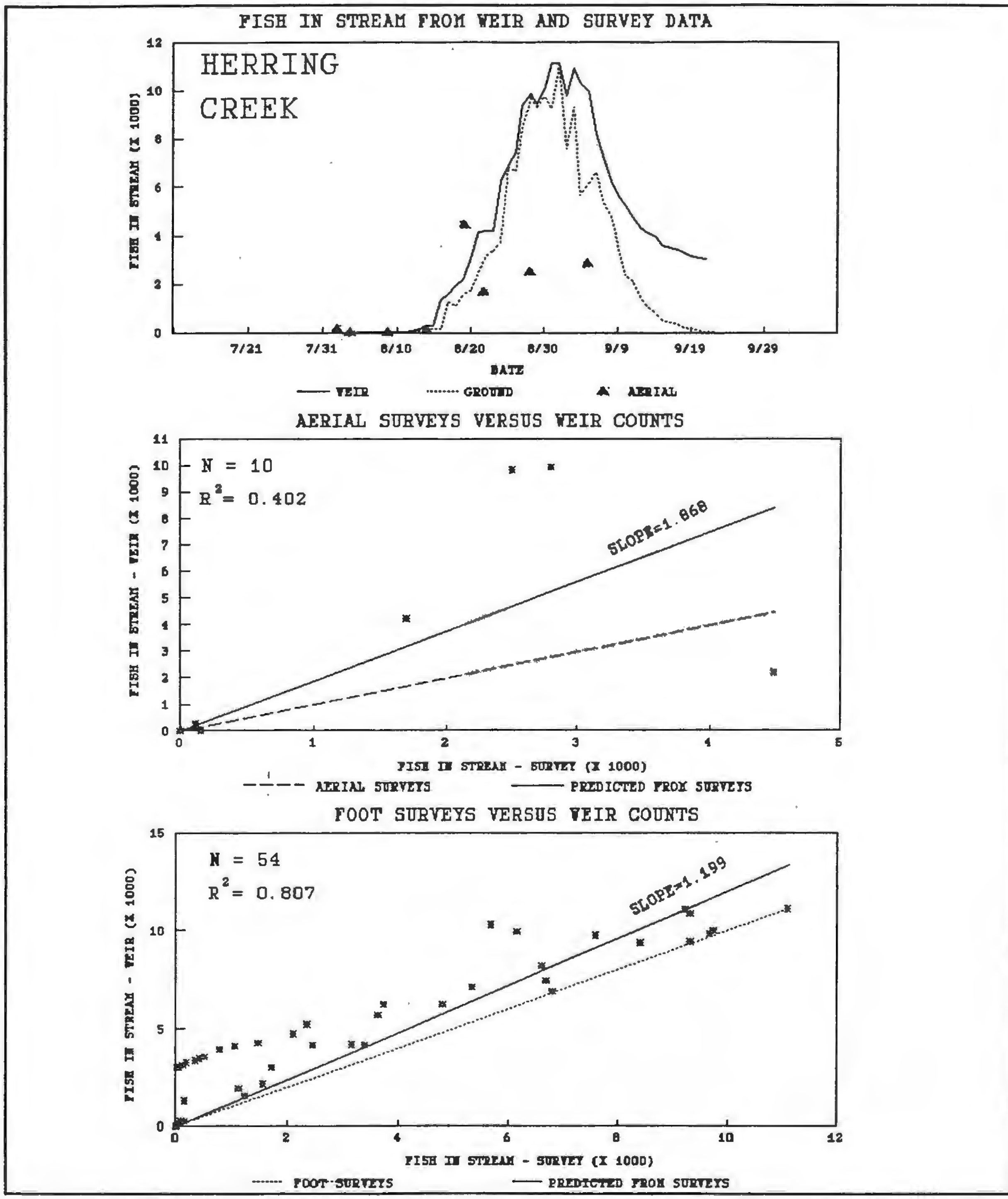


Figure 13. Daily numbers of fish in Herring Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

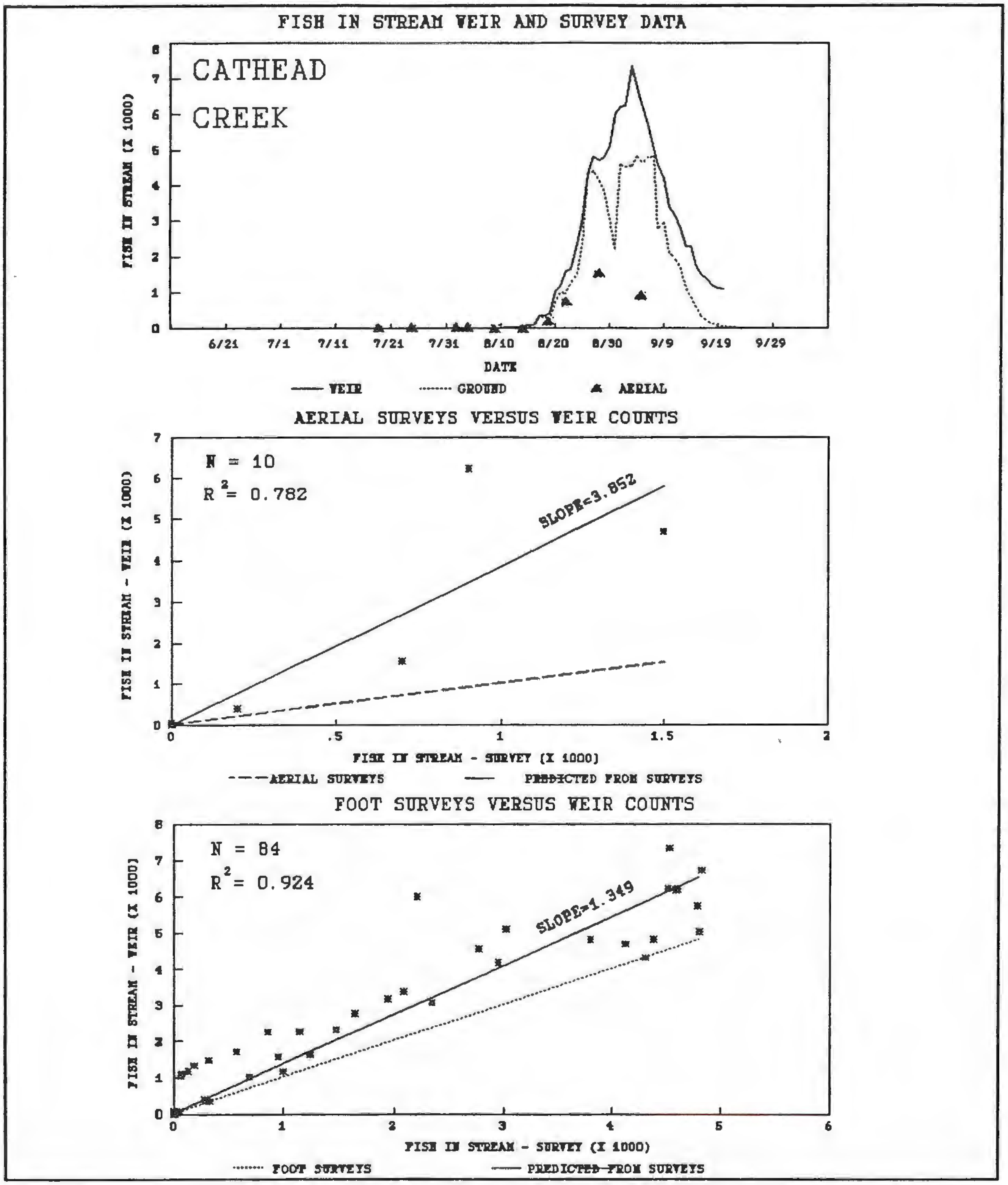


Figure 14. Daily numbers of fish in Cathead Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

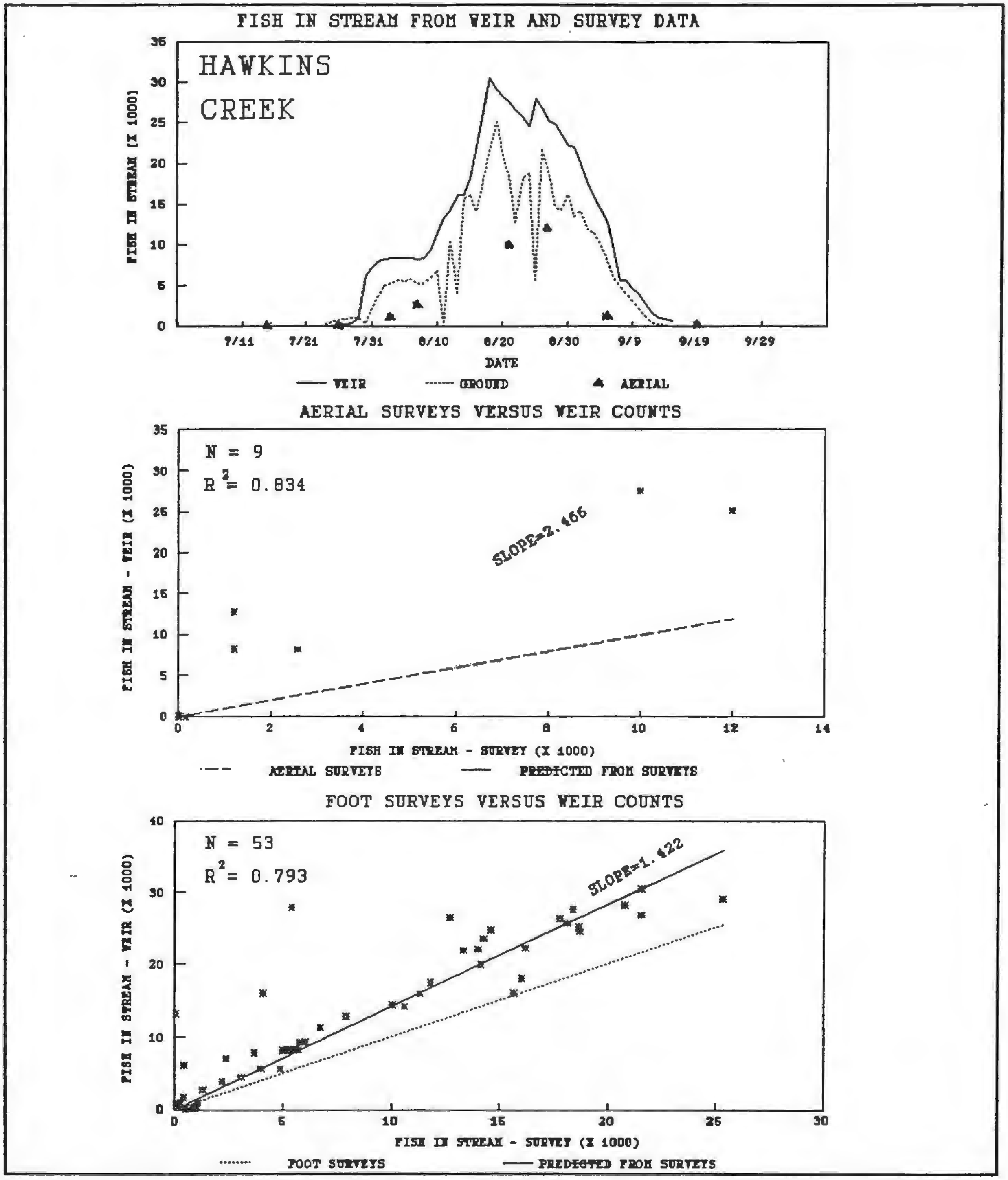


Figure 15. Daily numbers of fish in Hawkins Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

Stream Life

Some of the error associated with estimating pink and chum salmon escapements from aerial survey data may be associated with using a stream life of 17.5 days. Results of studies by McCurdy (1984) and on five of eight streams surveyed for stream life in NRDA Study 1 in 1989 suggest stream life varies among streams and the 17.5 day estimate may be too large, especially for smaller streams. Results from 21 streams studied in 1990 by NRDA F/S Study 1 (Sharr et al. 1990) also indicate stream life is variable and shorter than 17.5 days for many streams in PWS.

Estimates Based on Tagging Data

Results of temporally stratified tagging studies in 1991 are summarized in Figure 5 and Appendix B. Approximately 30,000 tags were applied at 38 streams (Figure 2). Data entry for all streams is not complete and only results for weired systems have been summarized. At the weired sites 7,893 tags were applied. Weekly tagging strata ranged from three on small streams to as many as eight on large streams. Tag recoveries spanned nine weeks. Recoveries averaged 49.7% (3,925 total recoveries) and ranged from 20.7% to 78.7% across all streams and weekly strata (Appendix B.1.).

Stream life calculated solely on tag recovery data (Equation 3) ranged from 7.2 days to 21.9 days across all streams and weekly strata (Figure 16). Stream life estimates averaged across weekly strata for each stream ranged from 9.9 to 17.1 days and had a grand mean of 13.9 days (Table 2). This is slightly shorter than the 15.1 day average reported by Sharr et al (1990) using the same method on many of the same streams in 1990 and considerably shorter than Helle's (1964) estimate of 17.5 days which was made for the middle portion of the Olsen Creek return in eastern PWS. Stream life estimates for all streams and all but one weekly strata were shorter when adjusted for milling time at the stream mouth (Figure 16; Equation 4). Adjusted mean weekly stream life estimates ranged from 3.2 to 19.6 days across all strata and streams. Across all streams season average stream life estimates ranged from 6.8 to 13.9 days and had a grand mean of 9.8 days. Milling time at stream mouths ranged from 0.0 to 9.2 days across all weekly strata and streams. Season mean milling times across streams ranged from 1.9 to 6.1 days and had a grand mean of 4.1 days.

Weekly estimates of stream life unadjusted for milling time decreased significantly through time. Both Helle (1964) and McCurdy (1984) reported similar trends. Some of the decrease in the 1991 study can be ascribed to milling time which also decreased through the season. Adjusted estimates of stream life also declined

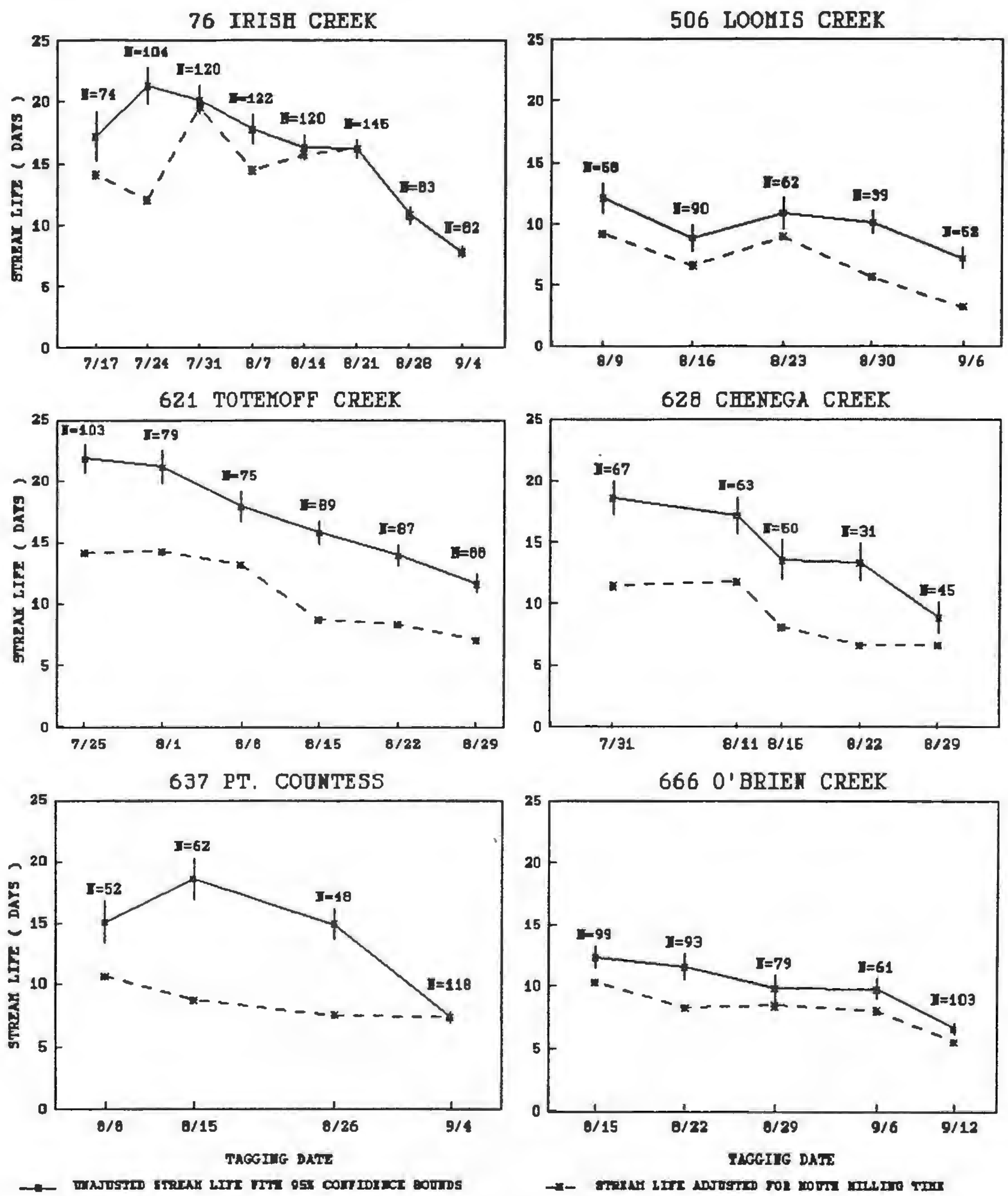


Figure 16. Weekly stream life estimates and 95% confidence bounds based on tagging studies for pink salmon in ten weired streams, 1991. Estimates adjusted for milling time are also shown.

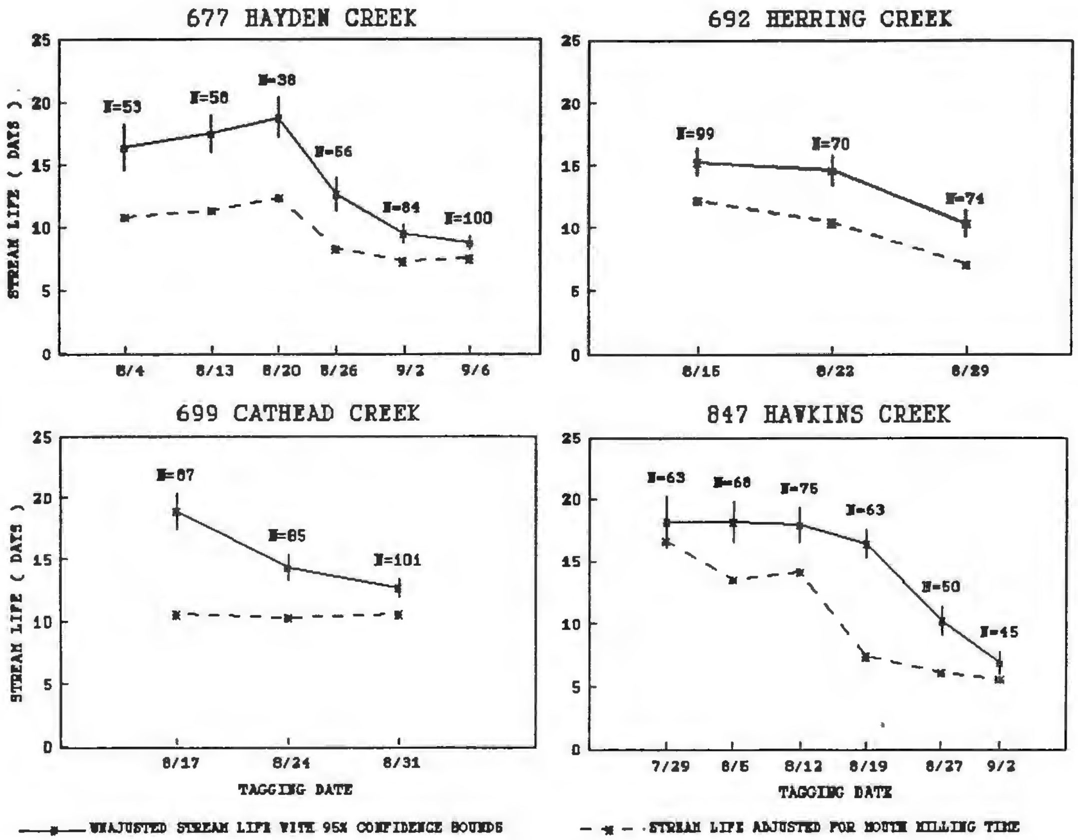


Figure 16. (continued).

significantly across the season for all but one stream (Cathead Creek, Figure 5). Mean adjusted stream life for fish tagged in all streams in the week ending 20 July was 14.1; days whereas, mean adjusted stream life was only 6.6 days for fish tagged in the week ending 7 September. Mean milling time increased slightly from the first to the second week of the study but from the week ending 21 July to the week ending 14 September declined from 8.4 days to 1.1 days. Seasonal decline in milling time was observed in all streams except Loomis Creek and Herring Creek (Appendix A).

Estimates Using Fish Days and Total Escapement

Estimates of stream life based on daily weir counts and daily counts of dead fish (Equation 5) and estimates based on daily counts of live and dead fish (Equation 6) are presented in Table 1. With the exception of Totemoff Creek, stream life estimates from weir data are larger than from ground survey data and in general correspond more closely to results from tagging. This is not surprising since negative bias associated with the ground counting method results in an estimate of fish days which is too low, hence a stream life estimate which is too low.

The stream life estimate from weir data at Totemoff Creek is only 3.4 days. The estimate from ground survey data of 9.1 days much more closely matches the 11 day estimate from tagging. These results tend to corroborate the "leaky weir" hypothesis for that stream. Low weir counts would result in an low estimate of fish days whereas the ground estimate of fish days may be fairly good.This suggests ground surveys of Totemoff Creek may have a fairly small negative bias.

Estimates From Run Timing

Estimates of stream life based on the difference between the mean dates of dead fish counts and passage of live fish through weirs (Equation 8) or the estimates of mean date of live fish counts on ground surveys (Equation 7) are presented in Table 1. With the exception of Herring Creek, stream life estimates from weir data are larger than from ground survey data and in general correspond more closely to results from tagging. The two estimates are indistinguishable at Herring Creek and very similar to the tagging estimate. Estimates based on run timing are based on relative counts between days. If counting errors at Totemoff Creek weir were independent of time, then the stream life estimate using the run timing method might be the best choice for that system in 1991.

Total Escapement Estimates From Aerial Surveys

Pink salmon escapements were estimated using the geometric method (Equation 8) applied to aerial survey data for four streams in 1990 and 10 streams in 1991 (Table 2). All streams where estimates were made had weirs. Aerial data were adjusted using regression coefficients from aerial counts versus weir data for all streams except Totemoff Creek. Stream life values used in the estimates were based on fish days and total escapement through weirs for all streams but Totemoff Creek (Equation 5).

Totemoff adjustment coefficients for aerial counts in 1990 and 1991 were from aerial count to ground count regressions. The stream life estimate for Totemoff Creek was from ground survey fish days and carcass counts (Equation 6).

A total of 72,244 pink salmon were enumerated through four weirs in 1990. Escapements through the same weirs in 1991 totaled 159,748 fish. Aerial estimates of escapement to these four streams based on the geometric method (Equation 9) were negatively biased in both 1990 and 1991. Estimates which incorporated new stream life data and adjustment factors for aerial observer bias were more accurate than estimates using the traditional uncorrected survey data and a 17.5 day stream life for all streams. In 1990, adjusted estimates were 27.8% below the weir counts whereas the unadjusted traditional estimate was 40.8 % low. The traditional method performed more poorly in 1991 (-75.2%). Given the inflexibility of this method to changes in observer bias it is not surprising it performs poorly in the odd year when significant numbers of fish spawn in upstream areas and aerial observations are difficult. Conversely, the adjusted estimate improved to -17.1% in 1991 despite the increase in upstream spawners and a doubling of the number of fish to be estimated. Analyses for the other six weired streams provided similar results.

When all streams in the aerial survey program are categorized for adjustment factors and stream life values, the departure from the traditional escapement estimate can be quite significant. Stream life values and adjustment factors are now available for 20 streams in the 1990 return. The total escapement estimate for 209 streams in the aerial survey program increased from 1.3 million to 2.1 million fish when survey data were categorized and analyzed using these stream life and adjustment factor data.

The escapement estimate for all streams in the aerial survey program is incomplete pending final analysis of stream life data from streams which were not weired. However, an estimate of escapement using a traditional analysis has been completed and the results are compared to historic odd year trends (Figure 17). The mean odd year aerial escapement estimate in 209 streams surveyed annually by ADF&G since 1969 was 1.6 million The comparable aerial estimate for the 1991 escapement was almost 1.9 million fish (Figure 17). The sum of escapements to streams on the eastern side of Prince William Sound where commercial fishing effort was minimal after 15 July was slightly above average. Escapement to streams in the southwestern corner of the Sound were also above average and escapements on the large seaward islands in the Sound were considerable greater than average. Conversely, the sum of escapement for stocks along the north, and northwestern shores of the Sound were well below average.

The better than average performance of streams in the southwestern portion of the Sound in the face of very intense fish in that area for hatchery stocks is to a large extent attributable to harvest management strategies which were altered to protect wild stocks. Fishing in the Southwestern District was prohibited in areas which the weir, ground survey, and expanded aerial survey program results indicated escapement were below average. Restoration weirs at Countess Creek and Chenega Creek provided data which helped prompt management action which protected wild stocks in the southwestern PWS.

Hydrocarbon and Histopathology Analyses

Mussel samples from six of 118 sites sampled in 1989 had positive evidence of hydrocarbon contamination. Two sites where oil was visibly present in significant quantities during the oil survey conducted by NRDA Study 1 in 1989 and during the 1989 fry dig portion of NRDA Study 2 had mussel samples for which results were negative or inconclusive. Preliminary and incomplete results from 1990 mussel samples indicate definitive evidence for hydrocarbon contamination at two sites and inconclusive results for three others. One of the sites with positive results is the weired stream at Herring Bay and the other is a ground survey stream in Sleepy Bay. Two of the three sites with inconclusive results are also study sites for the current weir and ground survey program.

Restoration Strategies

Salmon stocks in Prince William Sound which were impacted by the Exxon Valdez Oil Spill are also heavily exploited in commercial, sport, and subsistence fisheries and can most effectively be restored through stock specific management practices designed to reduce exploitation on impacted stocks. The stocks in areas heavily impacted by the spill occur in mixed stock fisheries dominated by hatchery stocks and wild stocks from unaffected areas

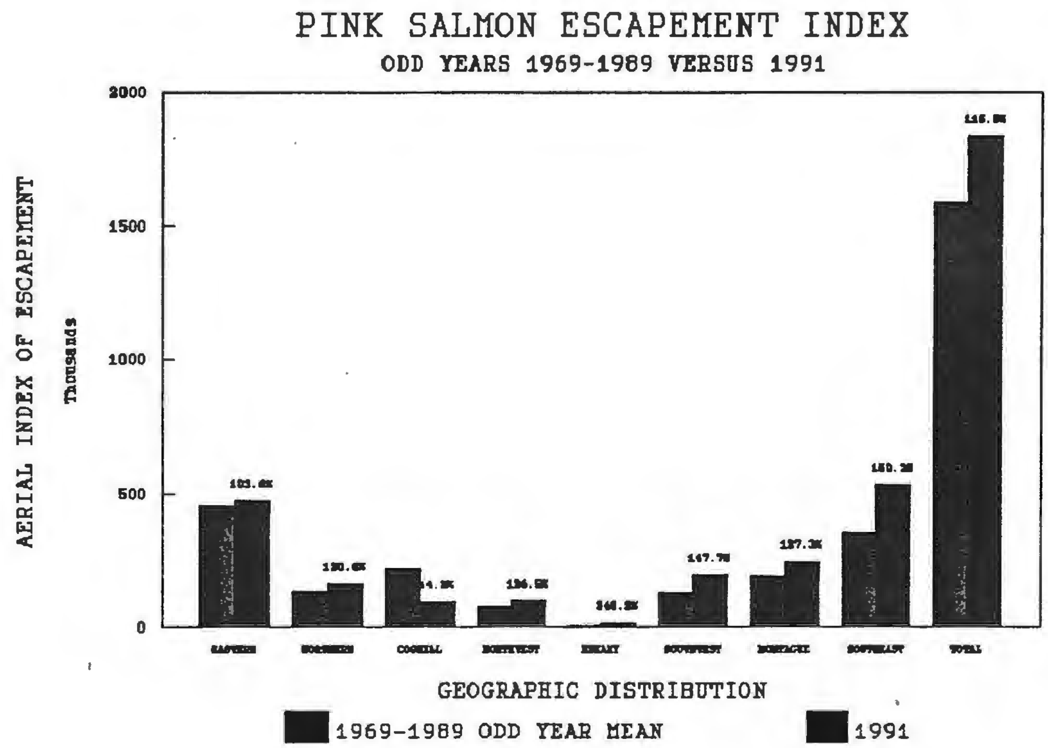


Figure 17 The relative size and distribution of 1991 pink salmon escapements in Prince William Sound versus the average for odd years from 1969 through 1989.

of the Sound. Restoration premised on stock specific management of the commercial fishery for reduced exploitation of impacted stocks will require the following:

1. Identification of impacted stocks through the NRDA process.
2. Determination of fisheries exploitation rates appropriate for facilitating the natural recovery of impacted stocks.
2. Accurate in-season escapement estimates for impacted and unimpacted wild stocks.
3. Accurate in-season estimates of the stock composition of the commercial catch by time and area.
4. Management action designed to reduce fishing effort on impacted stocks if results of escapement data and catch composition data indicate exploitation above levels desired to achieve restoration of the stock.The principal advantage of restoration strategies prefaced on more precise management are that the management framework is in place, the historic data base is sound, the research tools necessary for accurate escapement enumeration and catch stock composition estimates have been tested and established in the NRDA damage assessment arena, and regulatory mechanisms are all in place and well tested.

We have worked closely with the fisheries management and research staff of the Alaska Department of Fish and Game, Commercial Fisheries and FRED Divisions to develop a research and management package which will accomplish restoration objectives with minimal disruption of existing fisheries and fisheries management programs. Research projects have been proposed which are designed to provide the escapement estimates and catch stock composition estimates necessary for restoration predicated on improved management. A coded wire tagging and recovery project similar to NRDA F/S Study 3 is a key part of this package and will provide the catch stock composition estimates needed. An egg and fry sampling program has been suggested as an extension of NRDA Study F/S 2. In light of the demonstrated damages to this portion of the pink salmon life history in PWS the need for this program to monitor recovery is obvious.

The restoration process has already partially begun. Restoration Study 9 which resembles a scaled back version of NRDA F/S Study 1 was implemented in 1991. An expansion of the existing aerial survey program was also funded by the fishing industry. In it's first year, the program was used to implement area specific management which resulted in above average escapement to oil damaged portions of PWS despite very intense fish effort in surrounding waters.

STATUS OF INJURY ASSESSMENT

Information to complete objectives 1 of this project, the determination of presence or absence of oil on intertidal habitat used by spawning salmon, was gathered during both the 1989 and 1990 field seasons. A survey of the distribution of oil contamination was completed for 441 Prince William Sound streams and included over half of the documented intertidal salmon spawning streams. The majority of streams which were not surveyed were located in portions of PWS unlikely to have received oil. Survey data have been entered on computers and preliminary summaries of the information were presented in the 1989 preliminary status report (Sharr et al. 1990). Mussel samples taken in 1989 from the intertidal zone at the mouths of 118 streams have been analyzed. Results corroborated categorization of streams as oiled and control in all but two instances. Analyses of mussel samples taken in 1990 in the mouths of 135 streams are only partially complete but continue to support our oiled and unoiled categories.

To meet objective 2, nearly all streams surveyed in 1989 and 1990 under objective 1 were photographed, the intertidal areas of oiled streams were mapped, and the type and extent of oil contamination were recorded. Results have also been forwarded to investigators in the coastal habitat studies.

Sampling to meet objective 3 was completed at the same 22 sites (12 oiled and 10 control) in 1990 and in 1991. Some of the histopathology results are now back from David Hinton's Laboratory at the University of California, Davis. The statistical analyses of the results are not complete.

The requirements for objective 4 were exceeded for both NRDA F/S Study 1 and for Restoration Study 9. Daily ground surveys within standardized intertidal and upstream zones were completed on 51 streams in 1991. Data have been entered for all surveys and preliminary analyses of the ground survey data from weired systems is partially complete. Analysis of tidal zone spawning distribution is still pending as are comparisons of variability of counts between and within replicate surveys for individual surveyors.

The requirements of objective 5 were met for both NRDA F/S Study 1 and Restoration Study 9. Seven NRDA weirs and three Restoration weirs were constructed and operated very successfully through the 1991 season. The restoration weirs in the southwestern portion of PWS were already provided data which was used inseason to justify altered harvest management strategies. Weired streams were among those included in aerial survey, ground survey, stream life, and egg and pre-emergent fry studies. The concurrent data from all these studies is unique and has provided the first opportunity in the 30 year history of the PWS survey program to assess the accuracy of escapement estimates based on systematic survey and stream life data.

Objective 6 was related to objective 4 and was also met. In addition to the weir projects already described, a large set of paired ground and aerial observations (n=92) were made in 1990. These paired observations have been analyzed together with weir data. Estimates of escapement from aerial data were negatively biased with respect to estimates from weirs and ground survey data but negatively biased when compared to weir counts. Methods for improving aerial escapement estimates have been examined and when applied to 1990 data, removed more than 60% of the error which results from using traditional methods.

The requirements of objective 7 have been exceeded by both the NRDA and Restoration projects. Stream life studies were conducted on 48 streams in 1991. Three methods for estimating stream life using tagging data, weir counts, and daily counts of live and dead salmon have been investigated. A fourth method using only aerial counts is much more complex and is still under investigation. Analyses of 1991 data for stream life estimates are complete for 10 weired streams and underway for the remaining streams. All streams in the aerial survey index program have now been categorized as resembling at least one stream for which we have valid stream life estimates.

Objective 8 is nearly met pending final results from stream life studies on data from unweired systems in 1991. From preliminary results in 1991 it is apparent that bias correction factors for even and odd years are quite different and reflect differences in within stream spawner distributions between the two cycles. Analysis of historic odd year data will require completion of 1991 estimates of stream life and aerial bias for all 51 streams studied. A preliminary analysis of even year aerial data from 1990 has been completed. Using new stream life estimates and aerial bias correction factors, the 1990 escapement estimate was 2.1 million fish. This exceeds the estimate using traditional methods by 800,000 fish.

To meet objective 9, ground level and aerial photos were compiled for all of the 51 streams in the ground survey program and aerial photos are available for all 218 streams in the current ADF&G aerial survey program. Stream maps of the intertidal and lower upstream portions of 138 streams in the ground survey program in 1989 and 1990 and 51 streams in the 1991 NRDA and Restoration projects are complete and in most instances maps of streams in NRDA Study 2 have been annotated with information about spawner densities and distribution.

Objective number 10 was exceeded. Weir and ground survey crews recovered coded wire tags at the six weired streams where tags were originally applied and on 26 additional streams where no tags were applied. These data will provide a unique opportunity to

examine straying rates among wild stocks of pink salmon and between wild and hatchery stocks.

LITERATURE CITED

Anonymous. 1990. Catalogue of waters important for spawning, rearing or migration of anadromous fishes. Alaska Department of Fish and Game Habitat Division, Juneau.

Helle, J.H., R.S. Williamson, J.E. Bailey. 1964. Intertidal ecology and life history of pink salmon at Olsen Creek, Prince William Sound, Alaska. U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries. Special Scientific Report-Fisheries No. 483. Washington D.C.

Johnson, B.A., B.S. Barrett. 1986. Estimation of salmon escapement based on stream survey data: a geometric approach. Alaska Department of Fish and Game, Division of Commercial Fisheries. Regional Information Report No. 4K88-35. Kodiak.

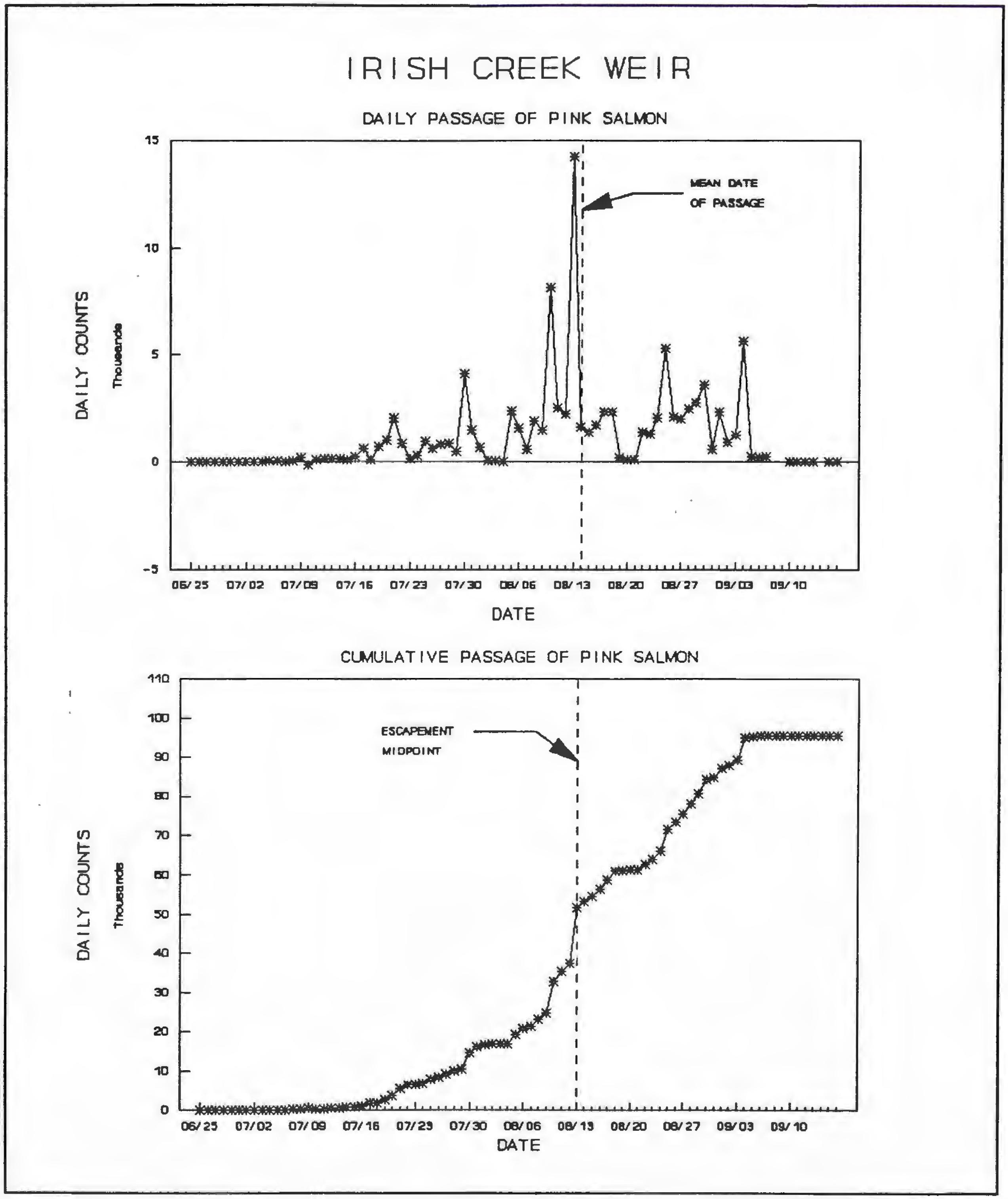
McCurdy, M.L. 1984. Eshamy District Pink Salmon Stream Life Study, 1984. Alaska Department of Fish and Game, Division of Commercial Fisheries. Prince William Sound Data Report No. 84-18. Cordova.

Pirtle, R.B. 1977. Historical pink and chum salmon estimated spawning escapements from Prince William Sound, Alaska streams 1960-1975. Alaska Department of Fish and Game, Division of Commercial Fisheries. Technical Data Report No. 35. Juneau.

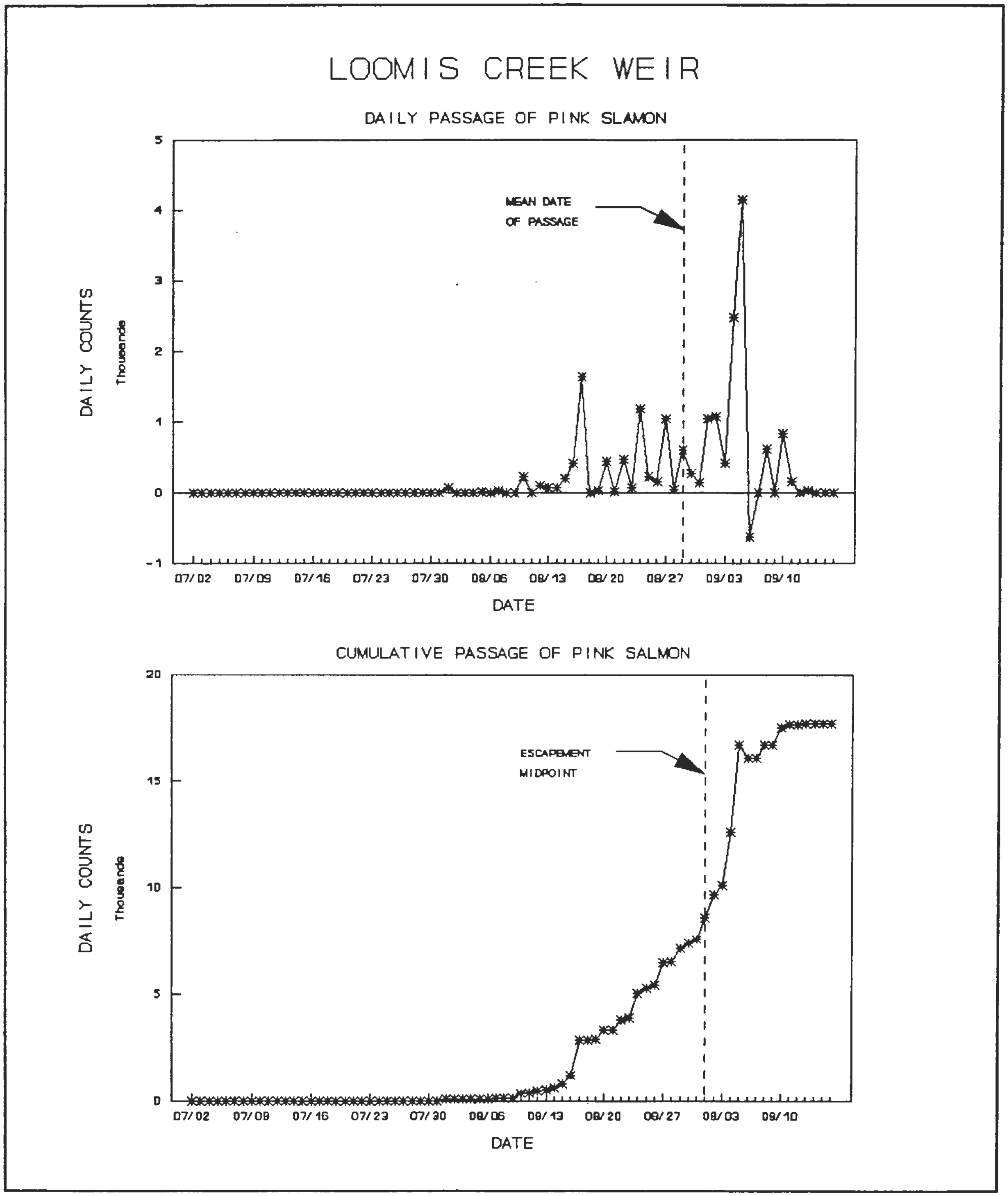
Sharr, S., B. Bue, S. Moffitt, J. Wilcock. 1990. Injury to salmon spawning areas in Prince William Sound. State/Federal Natural Resources Damage Assessment Draft preliminary Status Report. Cordova.

Sharr, S., B. Bue, M. Hausler, M. Johnson, S. Moffitt, S. Saddler. 1990. Injury to salmon spawning areas in Prince William Sound. State/Federal Natural Resources Damage Assessment Draft preliminary Status Report. Cordova.

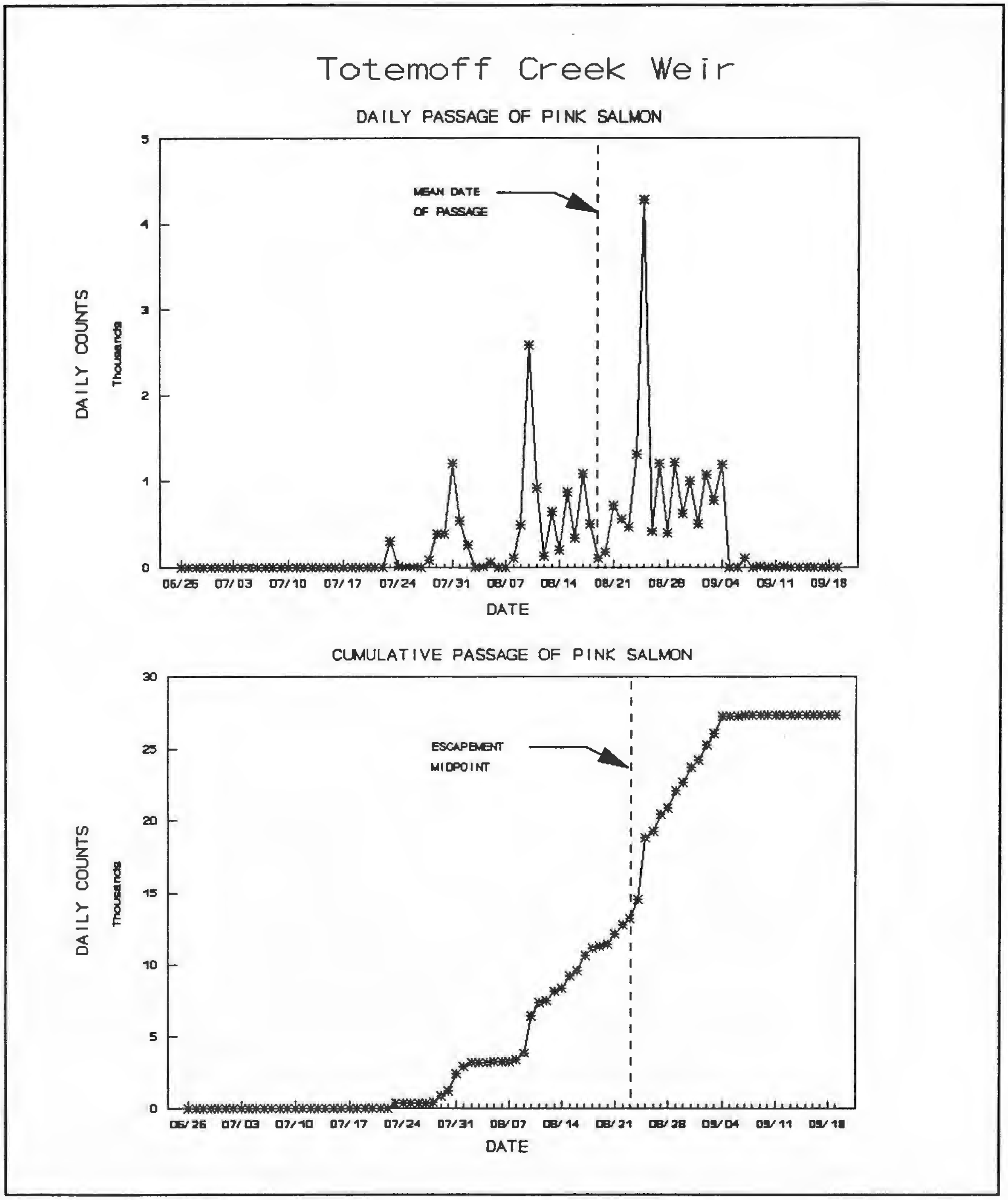
APPENDIX A. DAILY WEIR DATA



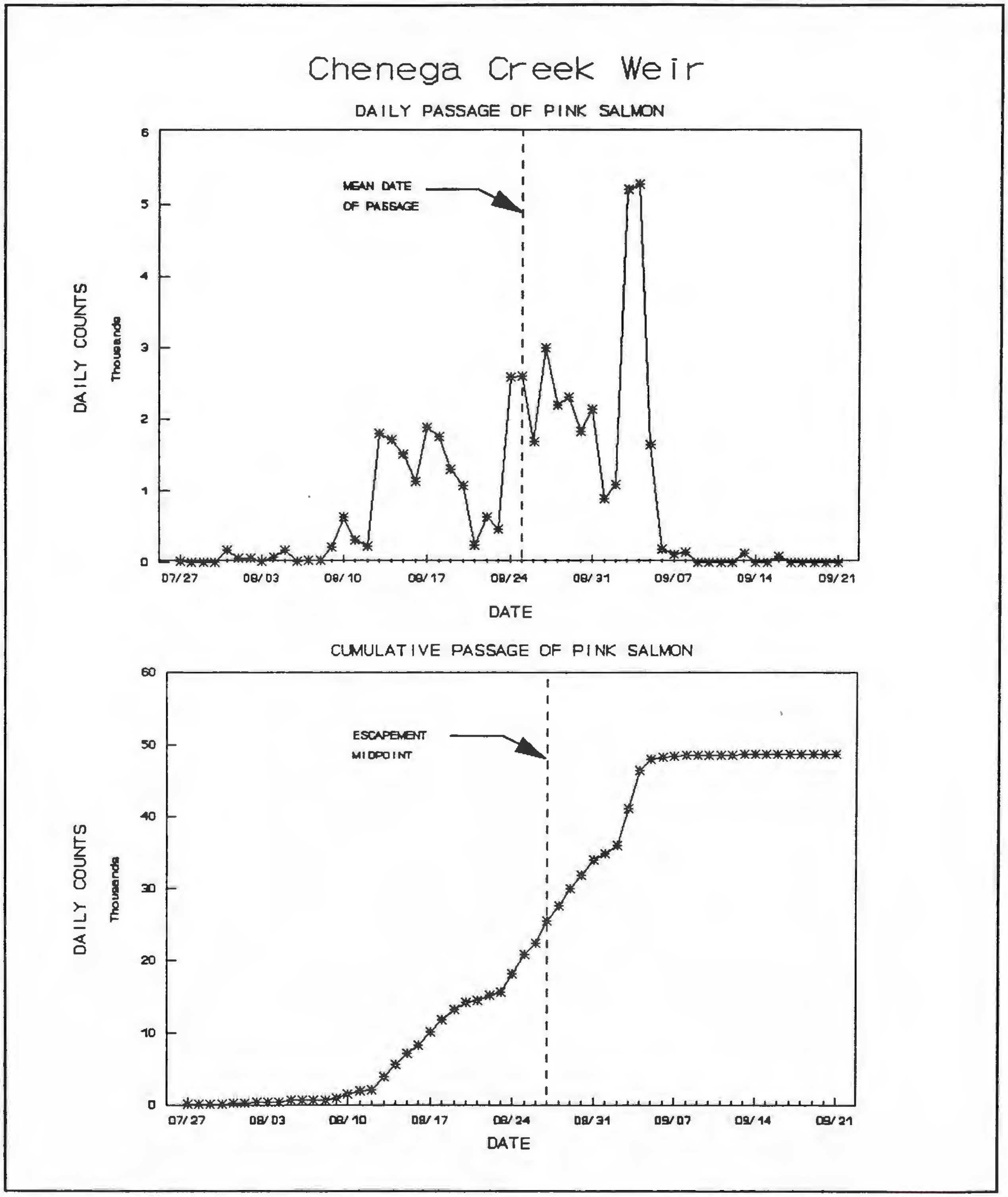
Appendix A.1. Daily and cumulative escapements of pink salmon through the weir at Irish Creek, 1991.



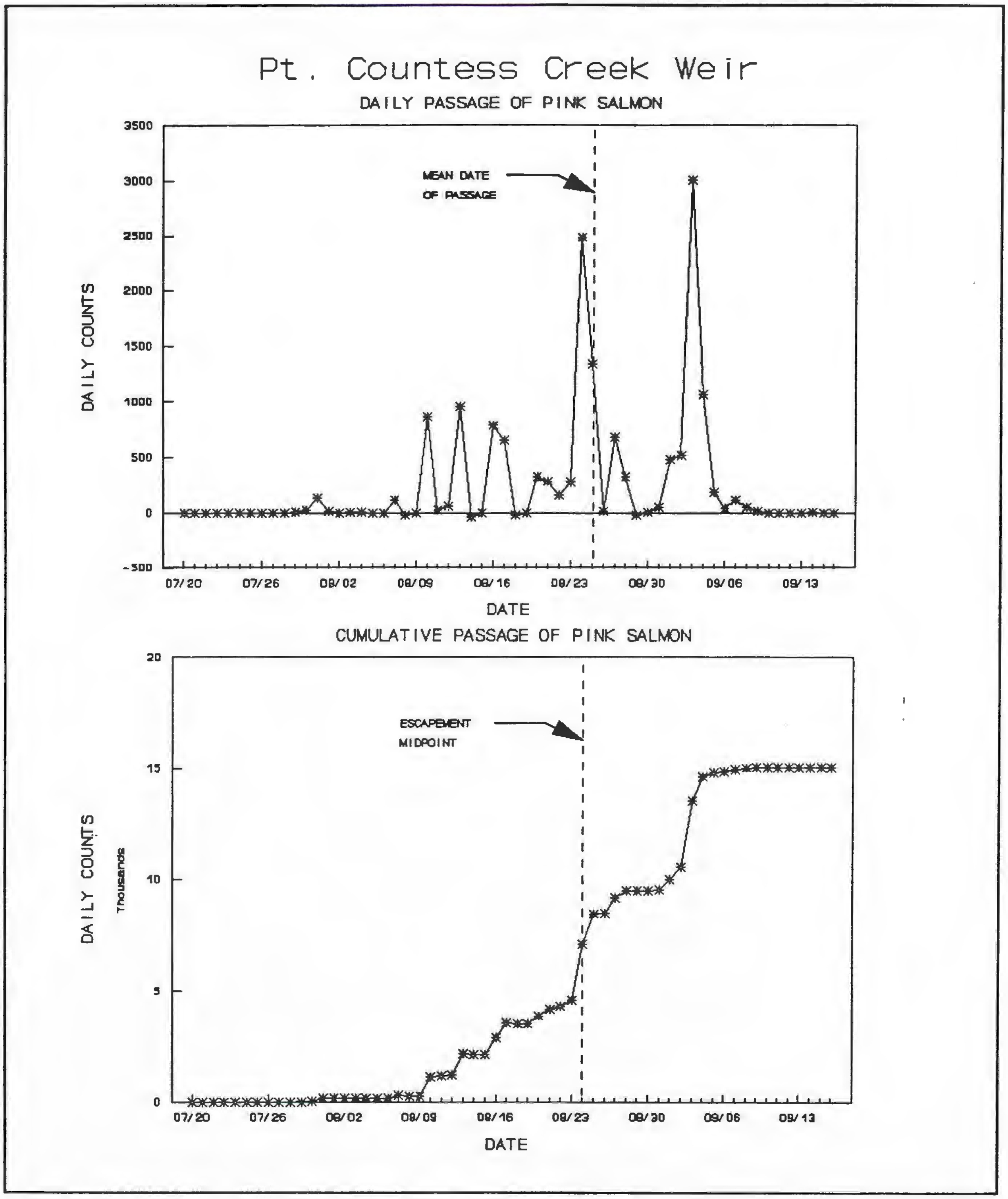
Appendix A.2. Daily and cumulative escapement of pink salmon through the weir at Loomis Creek, 1991.



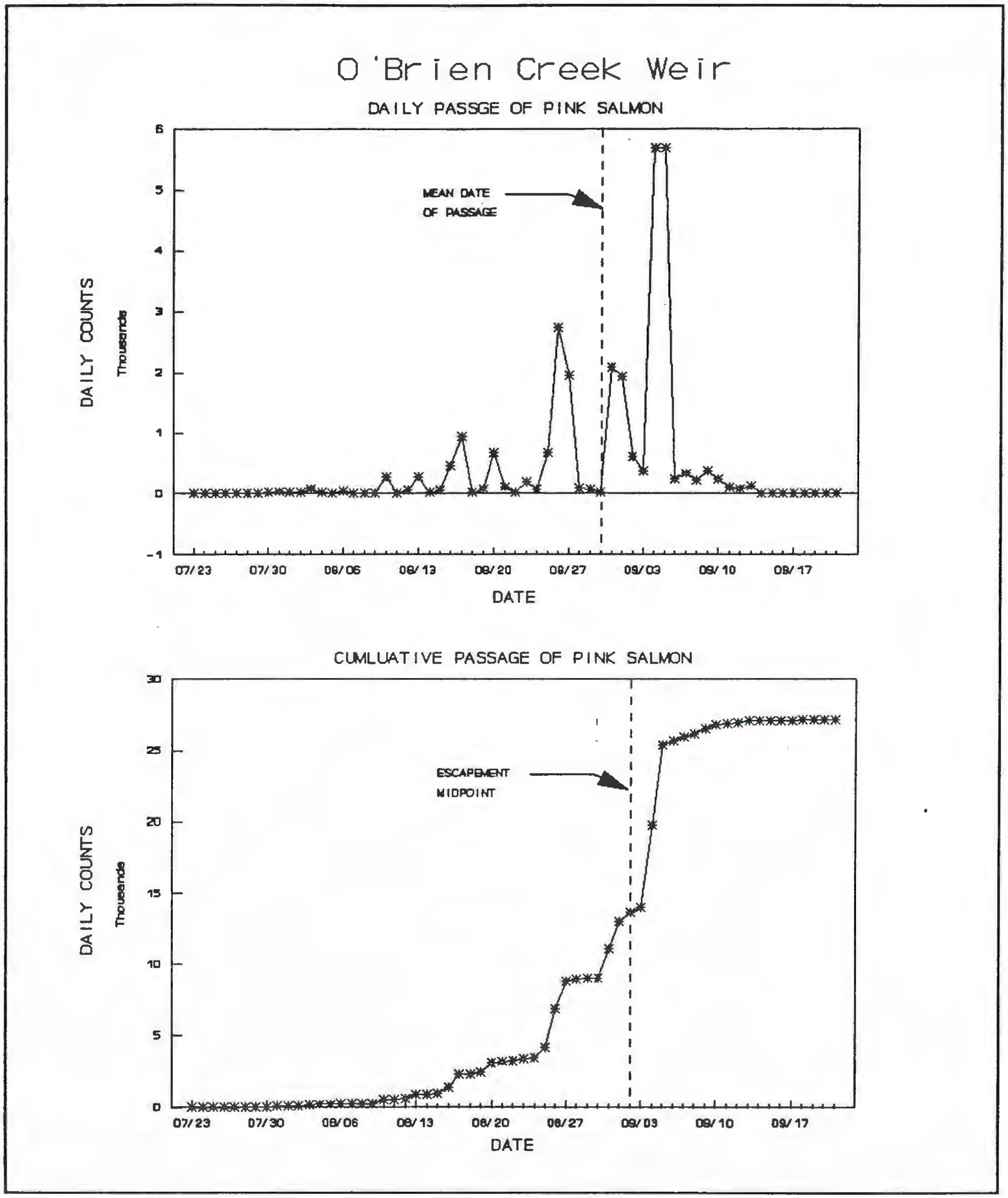
Appendix A.3. Daily and cumulative escapement of pink salmon through the weir at Totemoff Creek, 1991.



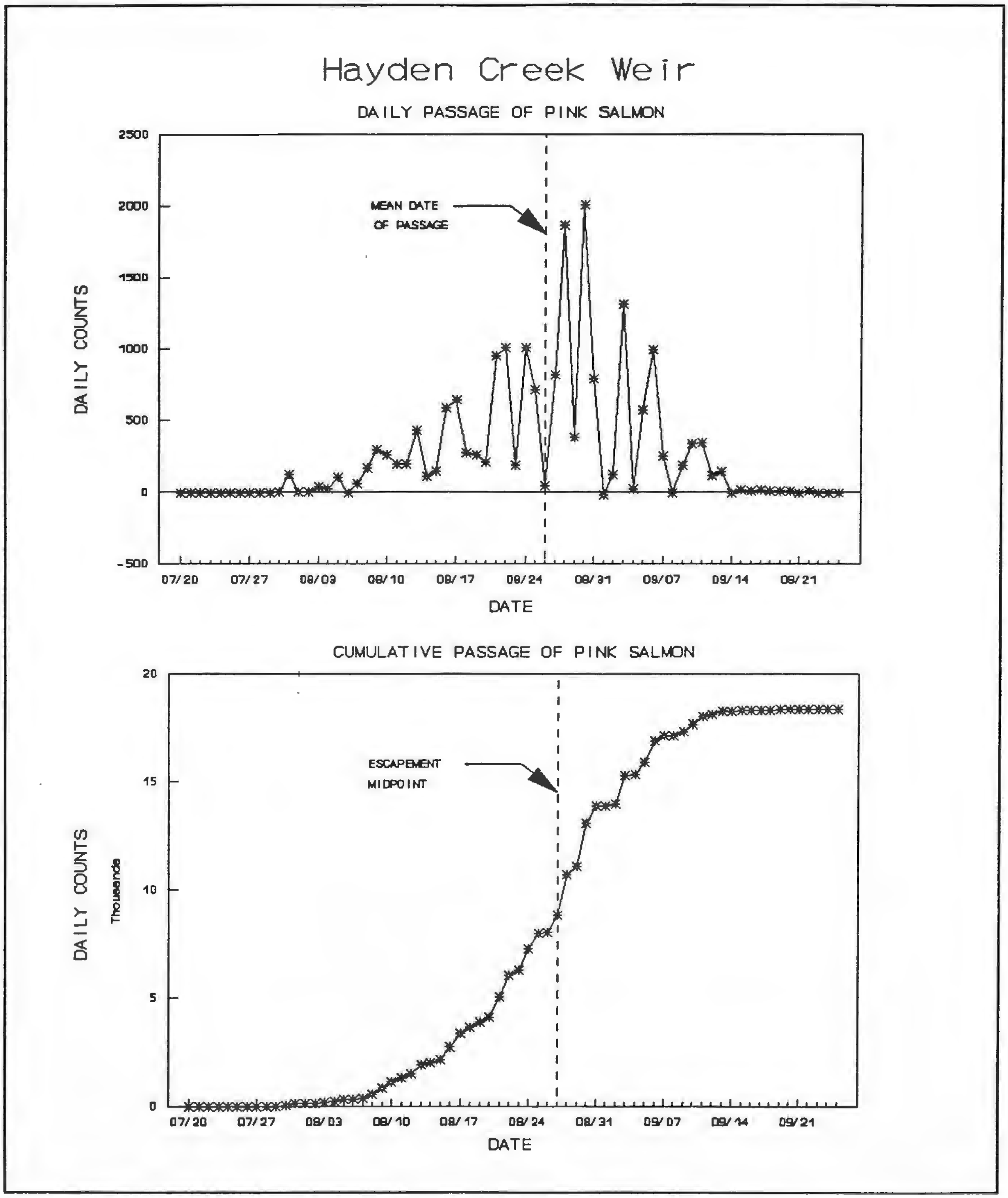
Appendix A.4. Daily and cumulative escapement of pink salmon through the weir at Chenega Creek, 1991.



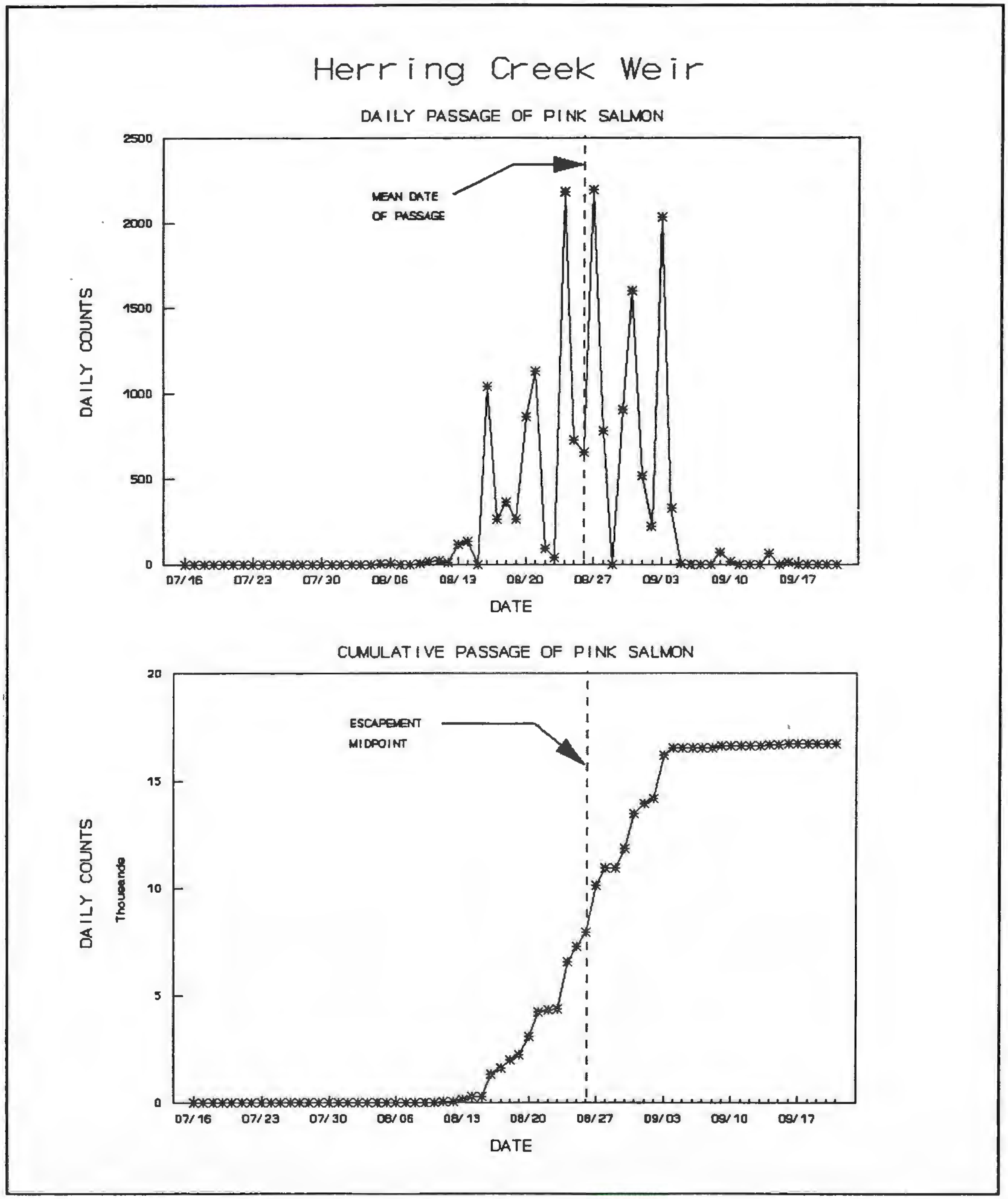
Appendix A.5. Daily and cumulative escapement of pink salmon through the weir at Countess Creek, 1991.



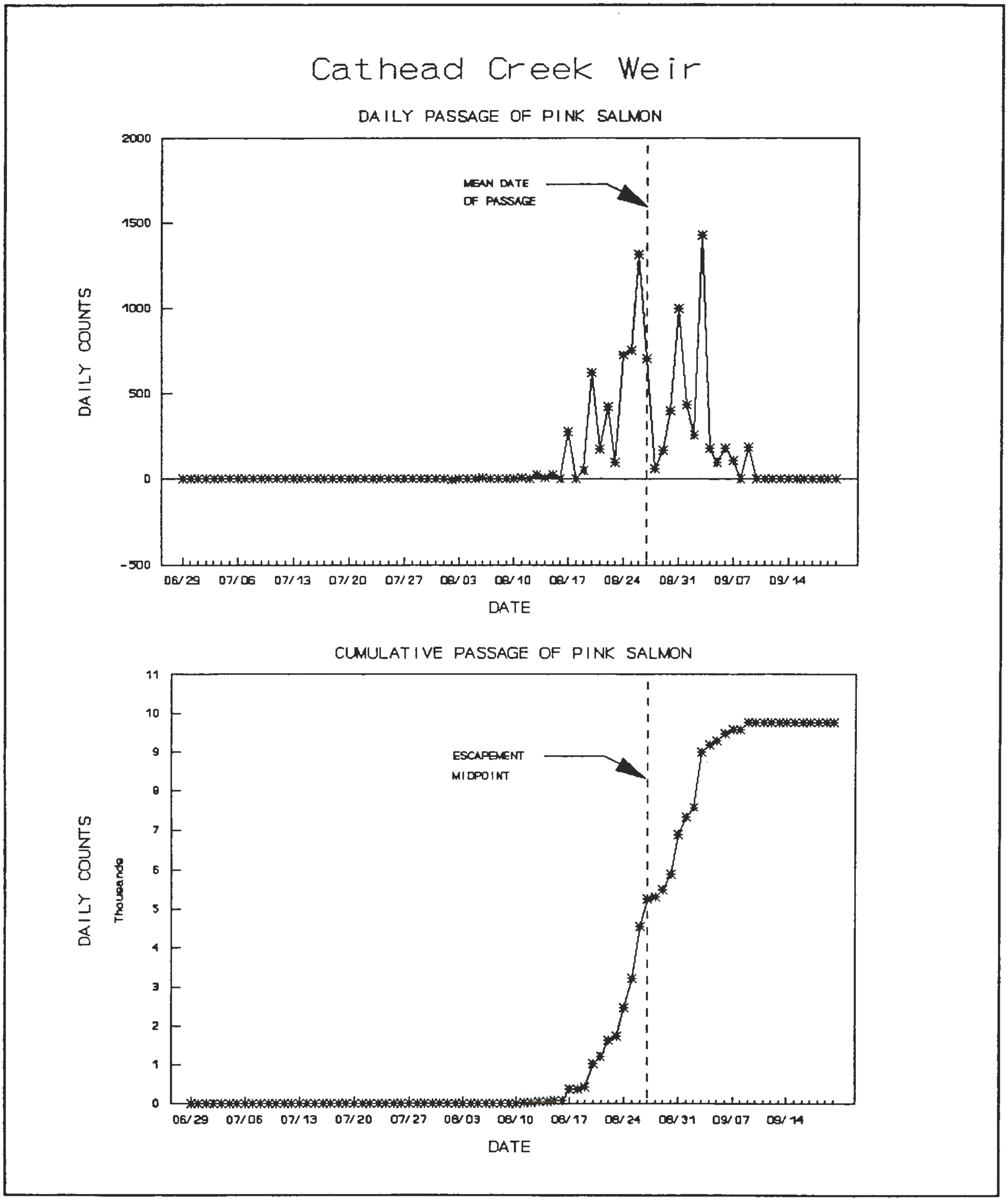
Appendix A.6. Daily and cumulative escapement of pink salmon through the weir at O'Brien Creek, 1991.



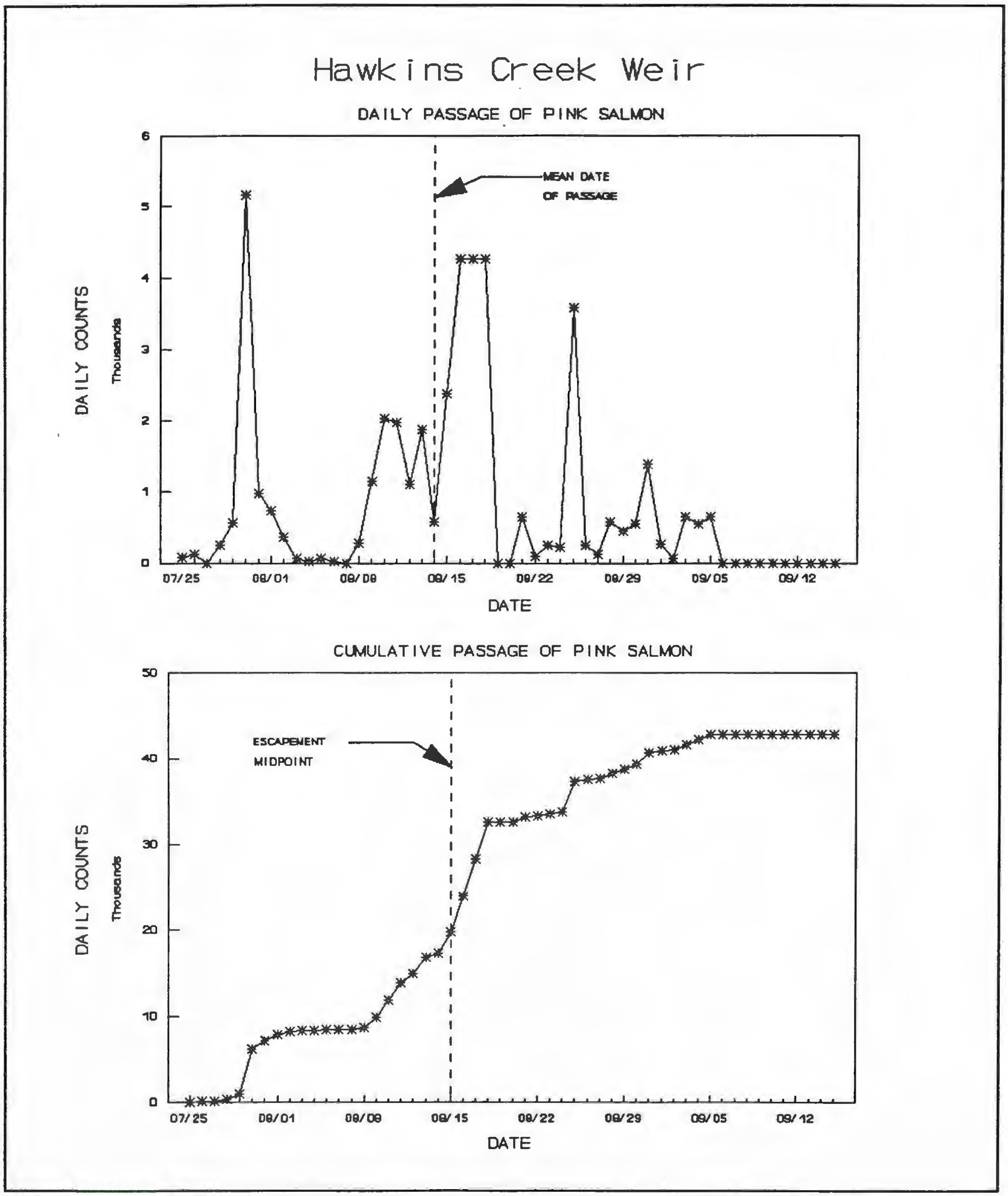
Appendix A.7. Daily and cumulative escapement of pink salmon through the weir at Hayden Creek, 1991.



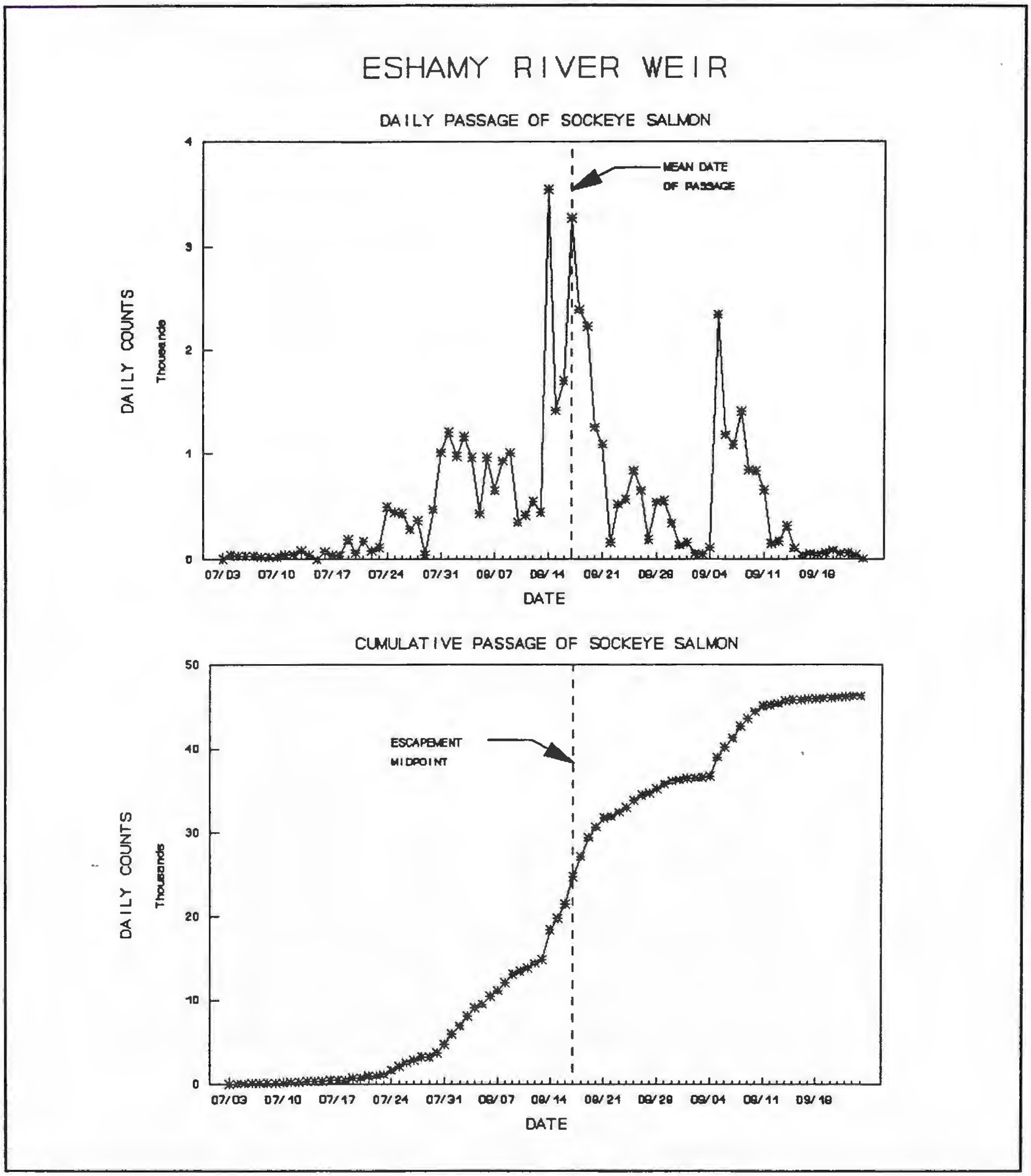
Appendix A.8. Daily and cumulative escapement of pink salmon through the weir at Herring Creek, 1991.



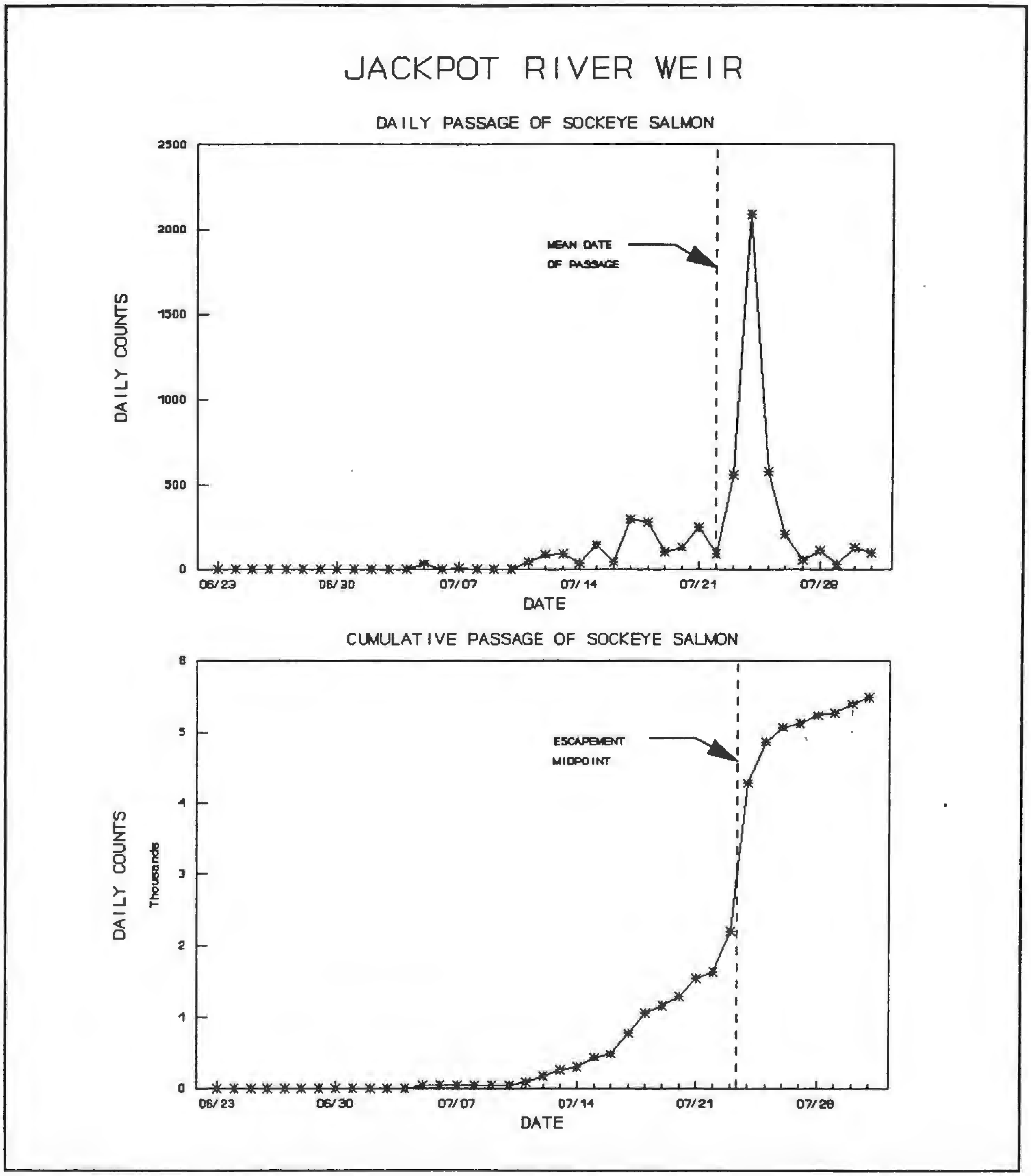
Appendix A.9. Daily and Cumulative escapement of pink salmon through the weir at Cathead Creek, 1991.



Appendix A.10. Daily and cumulative escapement of pink salmon through the weir at Hawkins Creek, 1991.



Appendix A.11. Daily and cumulative escapement of sockeye salmon through the weir at Eshamy River, 1991.



Appendix A.12. Daily and cumulative escapement of sockeye salmon through the weir at Jackpot River, 1991.

APPENDIX B. WEEKLY STREAM LIFE ESTIMATES

Appendix B.1. Mean weekly stream life estimates and their 95 % confidence intervals based on tagging studies at ten weired streams, 1991. Standard errors, errors of weekly estimates, 95 % confidence intervals around the estimates, and adjusted estimates based on estimated fish milling time at stream mouths are also shown.

	Tagging		Recoveries		Stream Life Statistics						Mouth Milling	Adjusted Stream
Stream Name	Date	Number	Total	Percent	Mean	Std	Max	Min	Lower	Upper	Time	Life
Irish Creek	07/17	198	74	37.4%	17.19	8.43	45	1	15.21	19.16	3.04	14.15
	07/24	200	104	52.0%	21.26	7.41	51	4	19.80	22.72	9.17	12.09
	07/31	200	120	60.0%	20.18	6.27	44	4	19.04	21.31	0.63	19.55 [1]
	08/07	200	122	61.0%	17.79	6.38	39	2	16.64	18.94	3.29	14.50
	08/14	200	120	60.0%	16.35	5.32	35	5	15.38	17.32	0.57	15.78 [1]
	08/21	200	145	72.5%	16.23	4.47	27	7	15.50	16.97	0.03	16.20 [1]
	08/28	150	83	55.3%	10.84	3.07	21	3	10.17	11.52	0.00	10.84 [1]
	09/04	150	82	54.7%	7.82	1.89	12	3	7.40	8.24	0.00	7.82
	Totals	1498	850	56.7%								
	Means	187	106	56.6%	15.96	5.40	34	4	14.89	17.02	2.09	13.87
Loomis Creek	08/09	150	58	38.7%	12.14	4.56	31	4	10.92	13.36	2.91	9.23
	08/16	148	90	60.8%	8.84	5.27	33	1	7.73	9.96	2.20	6.64
	08/23	150	62	41.3%	10.89	4.85	20	1	9.64	12.13	1.91	8.98
	08/30	150	39	26.0%	10.13	2.77	17	5	9.21	11.05	4.46	5.67
	09/06	150	52	34.7%	7.23	2.97	17	3	6.39	8.07	4.00	3.23
	Totals	748	301	40.2%								
	Means	150	60	40.3%	9.85	4.09	24	3	8.78	10.91	3.10	6.75
Totemoff Creek	07/25	150	103	68.7%	21.87	5.76	40	7	20.73	23.01	7.70	14.17
	08/01	150	79	52.7%	21.16	5.69	36	7	19.88	22.45	6.88	14.28
	08/08	150	75	50.0%	17.95	5.14	35	7	16.75	19.14	4.75	13.20
	08/15	150	89	59.3%	15.82	4.34	30	8	14.90	16.75	7.09	8.73
	08/22	149	87	58.4%	13.95	3.91	23	5	13.11	14.80	5.64	8.31
	08/29	150	88	58.7%	11.67	3.41	20	2	10.94	12.40	4.59	7.08
	Totals	899	521	58.0%								
	Means	150	87	58.0%	17.07	4.71	31	6	16.05	18.09	6.11	10.96
Chenega Creek	07/31	144	67	46.5%	18.60	5.44	34	6	17.26	19.94	7.16	11.44
	08/11	150	63	42.0%	17.17	5.75	32	6	15.71	18.63	5.39	11.78
	08/15	150	50	33.3%	13.56	5.50	27	2	11.97	15.15	5.47	8.09
	08/22	150	31	20.7%	13.35	4.05	21	2	11.85	14.86	6.71	6.64
	08/29	150	45	30.0%	8.87	4.04	16	1	7.64	10.10	2.26	6.61
	Totals	744	256	34.4%								
	Means	149	51	34.5%	14.31	4.95	26	3	12.89	15.74	5.40	8.91
Countess Creek	08/08	113	52	46.0%	15.12	5.93	31	5	13.44	16.79	4.46	10.66
	08/15	150	62	41.3%	18.63	6.40	32	3	16.99	20.27	9.90	8.73
	08/26	150	48	32.0%	14.94	4.17	24	3	13.71	16.17	7.40	7.54
	09/04	150	118	78.7%	7.32	2.44	12	1	6.87	7.77	0.00	7.32
	Totals	563	280	49.7%								
	Means	141	70	49.5%	14.00	4.73	25	3	12.75	15.25	5.44	8.56
O'Brien Creek	08/15	150	99	66.0%	12.39	4.43	24	4	11.50	13.29	2.01	10.38
	08/22	150	93	62.0%	11.63	4.94	30	1	10.61	12.66	3.29	8.34
	08/29	148	79	53.4%	9.90	4.59	23	1	8.86	10.94	1.40	8.50
	09/06	150	61	40.7%	9.80	3.22	17	2	8.97	10.64	1.73	8.08
	09/12	150	103	68.7%	6.63	2.21	14	2	6.19	7.07	1.00	5.63
	Totals	748	435	58.2%								
	Means	150	87	58.1%	10.07	3.88	22	2	9.23	10.92	1.89	8.19

1/ All fish tagged above the weir for these dates.

Appendix B.1. (page 2 of 2)

Stream Name	Tagging Date	Tagging Number	Recoveries Total	Recoveries Percent	Stream Life Statistics Mean	Std	Max	Min	Lower	Upper	Mouth Milling Time	Adjusted Stream Life
Hayden Creek	08/04	143	53	37.1%	16.43	6.61	38	5	14.58	18.29	5.59	10.84
	08/13	150	58	38.7%	17.52	5.59	34	6	16.02	19.01	6.15	11.37
	08/20	150	38	25.3%	18.82	4.66	28	8	17.25	20.38	6.45	12.36
	08/26	150	56	37.3%	12.68	4.90	33	3	11.34	14.01	4.34	8.34
	09/02	150	84	56.0%	9.51	3.18	17	1	8.81	10.21	2.16	7.35
	09/09	150	100	66.7%	8.79	2.69	16	3	8.25	9.33	1.25	7.54
	Totals	893	389	43.6%								
	Means	149	65	43.5%	13.96	4.61	28	4	12.71	15.21	4.32	9.63
Herring Creek	08/15	150	99	66.0%	15.30	5.26	27	3	14.24	16.37	3.06	12.24
	08/22	150	70	46.7%	14.61	4.95	30	2	13.42	15.81	4.15	10.46
	08/29	150	74	49.3%	10.41	4.28	23	1	9.40	11.41	3.23	7.18
	Totals	450	243	54.0%								
	Means	150	81	54.0%	13.44	4.83	27	2	12.36	14.53	3.48	9.96
Cathead Creek	08/17	150	87	58.0%	18.89	6.58	34	4	17.47	20.30	8.33	10.56
	08/24	150	85	56.7%	14.31	4.65	23	0	13.29	15.32	4.00	10.31
	08/31	150	101	67.3%	12.67	3.56	22	2	11.96	13.38	2.09	10.58
	Totals	450	273	60.7%								
	Means	150	91	60.7%	15.29	4.93	26	2	14.24	16.34	4.81	10.48
Hawkins Creek	07/29	150	63	42.0%	18.14	8.10	50	4	16.09	20.20	1.56	16.58
	08/05	150	68	45.3%	18.16	6.68	33	4	16.53	19.79	4.65	13.52
	08/12	150	75	50.0%	17.89	5.88	32	3	16.53	19.26	3.73	14.16
	08/19	150	63	42.0%	16.43	4.39	29	7	15.31	17.54	9.00	7.43
	08/27	150	50	33.3%	10.22	3.95	19	2	9.08	11.36	4.09	6.13
	09/02	150	45	30.0%	6.91	2.79	15	3	6.06	7.76	1.31	5.61
	Totals	900	364	67.3%								
	Means	150	61	40.4%	14.63	5.30	30	4	13.27	15.99	4.06	10.57
Streams Combined by Week Ending Dates	07/20	198	74	37.4%	17.2	8.4	45.0	1.0	15.2	19.2	3.04	14.15
	07/27	350	207	59.1%	21.6	6.6	45.5	5.5	20.3	22.9	8.44	13.13
	08/03	644	329	51.1%	19.5	6.4	41.0	5.3	18.1	21.0	4.06	15.46
	08/10	1056	491	46.5%	16.4	5.9	34.1	4.7	14.9	17.8	4.43	11.96
	08/17	1548	829	53.6%	15.5	5.5	30.8	3.9	14.3	16.8	4.85	10.67
	08/24	1399	674	48.2%	14.5	4.5	25.7	3.7	13.3	15.6	4.58	9.89
	08/31	1498	663	44.3%	11.2	3.9	21.8	2.3	10.2	12.2	3.39	7.85
	09/07	900	442	49.1%	8.1	2.7	15.0	2.2	7.4	8.8	1.53	6.57
	09/14	300	203	67.7%	7.7	2.5	15.0	2.5	7.2	8.2	1.12	6.59
Totals		7893	3912	49.6%								
Mean of weeks		877	435	50.8%	14.6	5.1	30.4	3.4	13.4	15.8	3.9	10.7
Mean of streams		152	76	49.6%	13.9	4.7	27.1	3.3	12.7	15.0	4.1	9.8

10. Monitoring Coastal Habitats at Herring Bay

COASTAL HABITAT STUDY NUMBER 1: PHASE II

DRAFT PRELIMINARY STATUS REPORT

CONFIDENTIAL

LITIGATION SENSITIVE

ATTORNEY-CLIENT WORK PRODUCT

NOVEMBER 1991

TABLE OF CONTENTS

PROJECT PARTICIPANTS iii

1. EXECUTIVE SUMMARY 1

2. GENERAL INTRODUCTION 5

3. INTERTIDAL INVERTEBRATES 6

4. INVERTEBRATE EXPERIMENTS IN HERRING BAY 411

5. INTERTIDAL FISHES 553

6. INTERTIDAL ALGAE 613

7. ALGAE EXPERIMENTS IN HERRING BAY 719

4.0 INVERTEBRATE EXPERIMENTS IN HERRING BAY

INTRODUCTION

Since 1990, the experimental station (barge) in Herring Bay has served as a platform for continuous damage assessment and restoration field studies of invertebrate and algal intertidal communities. This chapter addresses the intertidal invertebrate experiments and monitoring studies. Chapter 7 presents results for specific algal experiments. This preliminary report presents results that were incomplete at the time of the 1990 preliminary report, as well as results for the majority of experiments conducted in 1991.

The data for these studies are analyzed according to Coastal Habitat Standard Operating Procedures for data analysis. Several of the procedures involve multiple sites and sample dates and are time intensive. Consequently, not all analyses have been completed in time for this post-season report.

The following points summarize the major findings to date:

- Effects from the EVOS in Herring Bay appear to be variable, depending upon the species involved, the site condition, sample date and tidal level.
- Monitoring populations of important grazers in the intertidal, as well as several direct developing invertebrates, shows that recovery is taking place in the lower intertidal zones. However, differences in populations between oiled and control sites are still large in the upper intertidal zone.
- Oil appears to have weathered substantially since 1990 at several of the study sites, but some sites still retain oil visible as tar and asphalt in many cracks and crevices. This oil appears to be responsible for retarding colonization by barnacles in some instances, but may have a greater effect on colonization by filamentous algae.
- Results from hydrocarbon sediment and tissue sampling remain incomplete at the time of this writing.

Study Sites

Refer to the 1990 preliminary report for an explanation of procedures used in site selection in Herring Bay. In 1991 additional sites were added to several of the studies, and were selected according to the procedures used during the first season.

When the oil slick first entered Herring Bay in 1989, the southeastern portion was largely unimpacted by oil because it was heavily iced during late March and early April. Two waterfalls contribute a large volume of fresh water to this protected portion of the bay.

Thus, selection of control sites was limited to this area (Fig. 4.1). The majority of oiled sites were also located in the lower-mid and western portion of Herring Bay to match the salinity, wind, wave and solar exposure of control sites as closely as possible.

Site comparisons

Temperature and salinity

Using a CTD meter, temperature and salinity were recorded weekly during mean high high water (MHHW) at the surface, 0.5 m and 1.0-5.0 m depth intervals at all study sites. In 1990 sampling occurred from May through September, and in 1991, samples were taken from late April until early September (Fig. 4.2.1-16). The influence of fresh water in the upper water column is evident at many of the control sites, and a few of the oiled sites located near small waterfalls and streams. Fresh water may depress species richness and densities of intertidal organisms, compared to areas where salinity is more constant. Consequently, the control sites may actually provide conservative comparisons with respect to actual oil impact.

Natural Disturbance: ice scouring vs. wave energy

An additional concern in site similarity is the type and level of disturbance that may affect a study site pair. Over the winter of 1990-91 wind and wave energy from storms impacted at least one oiled study site in Herring Bay. Steel rebar stakes used to mark permanent plots were moved or destroyed by shifting cobbles along the upper intertidal zone.

Because control sites were located in more protected coves and embayments, wind and wave energy does not appear to have impacted the beaches. However, ice scouring replaces wind and wave energy in turning over substrate, and may cause a greater physical disturbance in Herring Bay. A coarse-textured site pair (2333C and 2333X; Fig 4.1) has sites located on opposite sides of the lower half of Herring Bay. The oiled site, 2333X, required reconstruction of study plots from wind and wave damage in the upper zone. However, the control site, 2333C, had a greater number of rebar stakes upturned and missing from all three tidal levels and also required reconstruction of plots. Thus, for sheltered rocky and coarse-textured intertidal communities, the location of control sites may provide conservative comparisons for natural disturbances.

History of oiling and treatment within Herring Bay

Oil was reported to have entered Herring Bay around March 29, 1989 (ADEC, personal communication). Field notes of ADEC monitors confirmed arrival of oil in the bay in early April, and skimmers were observed operating on May 18, 1989 (ADEC, aerial overflight records). Figure 4.3 shows the segments within Herring Bay that received varying degrees of oiling. Some shoreline assessments occurred during the latter part of April, but shoreline treatment was not reviewed and approved until the third week of May (ADEC, Shoreline Treatment Division).

Herring Bay was a focal point for many oil spill activities in 1989. Human activity was high and included location and operation of the solid waste incinerator, fresh water supply, and berthing vessels for staff. Shoreline treatment was also intensive within the bay, using the full range of technologies available. The hot-water, high-pressure Omni Booms focused their treatment efforts on segments KN133, KN129, and KN115 during the early part of the treatment season (G. Lewis, personal communication).

Table 4.1 presents a list of the oiled study sites and the most probable, intensive treatment technology used at each site. The exact treatment techniques used directly on our study sites cannot be stated with absolute certainty. However, the method listed is highly likely and is based upon review of State records, discussions and site visits with ADEC and shoreline treatment subcontractors in Herring Bay in 1989.

STUDY METHODS

Site Characterizations

As part of the site selection process, site pairs were sampled for presence of sediment hydrocarbon, and presence/absence of invertebrates and algae (Fig. 4.4.1).

Population Dynamics of limpets and direct developers

Monitoring five site pairs for population dynamics of limpets, *Littorina sitkana*, *Nucella* spp., and *Leptasterias hexactis* continued through the 1991 field season. Two site pairs were added to this study: an additional sheltered rocky site pair and one coarse-textured oiled beach, comparisons to be matched to an existing control site.

In addition to recording density, the five nearest individuals of each species were measured within a 1 m semicircle to the left of each quadrat (Fig. 4.4.2). For limpets, shell length and width were recorded, and distances from shell apex to siphonal canal were recorded for *Littorina* and *Nucella*. For *Leptasterias hexactis*, the diameter (arm tip to arm tip) of each starfish observed was recorded.

Settlement on oiled vs. non-oiled substrates

<u>Rock Exchange Experiment</u>

An experiment was implemented in 1990 using oiled and non-oiled halves of rocks, and oiled and non-oiled tile pairs (Fig 4.4.3). Details of the experimental design are in the 1990 preliminary report. The objectives of the experiment were to compare a) percent cover of barnacles and macro algae, b) density of recruits and c) number of grazers, i.e. limpets and littorinas.

Following the 1990 experiment, a number of rocks and tile pairs were left in place during the winter, to be monitored during the 1991 season. Unfortunately many rocks broke away from the substrate over the winter, and several of the tile pairs were lost. Oil had weathered completely from many of the remaining rocks such that oiled and non-oiled halves could no longer be distinguished. Consequently, only the tile pairs were practical to monitor during the 1991 season.

In 1991, nine new clay tile pairs (both oiled and non-oiled) were added to each of the three original site pairs. Six pairs of tarred and cleaned tiles were placed at each study site. Three of these tile pairs had 1/8" stainless steel mesh cages constructed around them to exclude grazers. The other three pairs were left uncovered.

Also, three additional tile pairs in which the "oiled" tile was painted black, were placed at each site. The painted tiles served as control for dark coloration and possible difference in temperature. All tiles were placed in those identical locations where rocks were destructively sampled during 1990.

Finally, one additional oiled tile was placed at each site and was periodically wiped with Methylene Chloride solvent. The wipes were preserved and stored to determine a rate of oil weathering, using the Gas Chromatography/Flame Ionization detection method.

Barnacle Recruitment

This study, started in 1990, is designed to determine if the presence of tar on rock faces in the upper intertidal zone reduces settlement of barnacle larvae compared to cleaned areas within the same tarred substrate. The study also tested whether the presence of tar reduces survival of barnacle juveniles, compared to non-oiled sites.

In 1990, two oiled sites and two reference sites of similar character were selected. The study was expanded in 1991 to include a total of five site pairs.

At each site, paired 10 X 10 cm plots were established. One plot of each pair was scraped to remove all visible tar. At reference sites only barnacles were removed. The horizontal length of each study site was measured, and the number of planned pairs divided into the site length to establish segment lengths. Sites contained either four or six plots, depending upon the length of tarred surface. The first plot was placed, using a random numbers table, within the first segment and remaining plots were placed at equal distances from the first. A coin was flipped to determine which 100 cm^2 area of the first pair to scrape. The remaining scraped plots were then alternated.

During the 1991 field season, the experiment was modified to add grazing exclusion cages to half of the study plots. The cages were constructed of 1/8" stainless steel hardware cloth. The sites were examined weekly for barnacle settlement, as well as germlings of *Fucus* spp.

Settlement patterns within Herring Bay

Based upon observations and results of barnacle and oiled rock studies of 1990, barnacle recruitment in the lower half of Herring Bay was noted to be patchy. Only two of the six oiled rock/tile sites received moderate to heavy barnacle recruitment. Furthermore, most heavy recruitment did not occur until July, later in the season than expected (Barnes 1956; Connell 1969).

As a supplemental study of barnacle recruitment in the lower portion of Herring Bay, a series of floating settlement stations was established in 1991. Results from this study will be used in combination with shoreline settlement results of the oiled rock/tile and barnacle settlement studies. The floating settlement stations each held

12 tiles made from marine epoxy. One tile was removed from each plate every week for twelve weeks. The settlement stations were constructed from white plastic bucket lids, with epoxy tiles affixed to the sides of the lid. Plaster-of-Paris hemispheres were molded, pre-weighed and mounted on each station. The hemispheres, by their dissolution rate, measured relative water motion, which potentially influences settlement. The hemispheres were replaced several times over the season.

Using segment maps of Herring Bay at a scale of 1:24,000, the lower half of the bay was defined as the sampling universe. From these segments five were randomly selected for the placement of the settlement plates. Each randomly selected segment was measured for total segment length, using a scale ruler. The center of the segment was determined and marked on the map. Using the map, segment centers were located in the field. Landmarks and shoreline features were used to refine the location as accurately as possible. At this point, the main habitat type was identified and constituted the subsegment where the settlement plates would be placed offshore.

During low tide, the main habitat type was then surveyed and measured along the approximate MHHW (the base of the *Verrucaria* zone). This constituted the total site length for placement of the settlement stations.

Three transect heads were randomly determined along the length of the main habitat type, following Coastal Habitat SOP #2. Flagging tape was used to mark each point so it would be visible by boat. During high tide, each site was revisited and the anchors of each settlement station were placed within 8-10 m of water and perpendicular to each transect head on shore. The settlement plates were suspended 1 m below the surface, with each lid supported by a small buoy.

Thus, each site had three subsampling stations with twelve settlement plates per station. One tile was collected from each station weekly, returned to the laboratory and examined for barnacle recruitment under a dissecting scope.

Limpet grazing: Fences and Cages

As stated in the 1990 preliminary report, studies of previous oil spills have identified the elimination of grazers within the intertidal to be of major importance to algal and intertidal community structure (Nelson-Smith 1977; Southward and Southward 1978). Two studies were implemented in Herring Bay to examine differences in algal grazing by limpets between oiled and non-oiled sites. The major hypothesis of this study was that removal of grazers by oil or treatment would affect algal community structure in recovering shorelines. Ancillary data generated during the study relate to: 1) differences in mortality of limpets between oiled and control sites, 2) differences in size and weight of these limpets, and 3) algal weights measured before and after the experiment at each site also might reveal differences caused by oiling, treatment or grazing pressure.

The 1990 preliminary report did not contain all the results of these studies because analyses were incomplete. Therefore, the 1990 results are included in this report. The studies were not continued in 1991. A detailed discussion of the materials and methods were presented in the 1990 report and are only summarized here.

Materials and Methods, Limpet Fences:

Four pairs of oiled/control sites were chosen in Herring Bay based upon algal cover within the one and two meter elevation zones below MHHW. A total of eight 625 cm^2 fences were placed randomly at each contour (Fig. 4.4.4). Algae was removed from inside 4 of the fences.

A mean density of limpets was determined per 625 cm^2 area by counts in random quadrats at several sites. More than 2,000 limpets were collected at sites away from the study areas and were tagged with unique identification numbers. Each limpet was weighed and its shell width and length was measured and recorded. Based upon size and species, limpets were randomly assigned to fences in the various treatments. Fences with and without algae had ranges of 0, one-half the mean density, the mean density, and twice the mean density of limpets per 625 cm^2.

The fences were monitored weekly, and the number of limpets remaining was recorded. Percent cover of algae in each of the fences was determined using a random point method. Percent cover of *Fucus* was estimated separately from other species of macroalgae, as it dominates the canopy and not the primary substrate in most cases. At the end of the experiment, surviving limpets were reweighed and remeasured. All algae was scraped from within each fence and total algal wet and dry weights determined.

Materials and Methods, Limpet Cages:

Because losses were high shortly after initiating the experiment, a second experiment was established which employed cages. The cages were identical to the fences but with a lid placed over the top of the fence to hold limpets inside and exclude predators.

Three different sheltered rocky site pairs were established for this study. Eight cages per site were randomly placed in algal beds along the 2 meter elevation contour, according to the procedures used for the fencing experiment.

Mussel densities between oiled and control sites

CHIA intertidal sampling in 1989 and 1990 revealed an increase in the abundance of mussels at oiled sites (see 1990 Preliminary report). This increase may be explained by certain species of filamentous algae recolonizing at oiled sites free from grazing pressure. Mussels settle preferentially on filamentous algae (Dayton 1971).

To test this hypothesis, two pairs of oiled and control sites with evidence of mussel populations were selected in Herring Bay. At each study site six transects were randomly established according to the 1990 SOP.

At the 1.6 m contour, four 25 X 25 cm plots were placed at 1 m intervals. The first two plots were cleared of all algae, and the remaining plots were marked with screws at four corners, but left uncleared.

At each cleared plot, a 25 X 25 cm fence of 1/8" stainless steel mesh (10 cm high) was constructed around the boundary of the cleared area. Plots were monitored twice weekly to ensure that all grazers were removed from inside the fences.

Two sample periods were planned over the course of the summer, removing algal subsamples from one cleared and one uncleared plot. The subsamples were to be returned to the laboratory and juvenile mussel density determined. However, algae failed to colonize in the study plots during the field season.

STUDY RESULTS

Site Characterizations

Table 4.2 presents lists of invertebrates and algae over three sample dates at many of the matched site pairs. The presence/absence listings of species do not differ to the degree that oil could be considered solely responsible. However, an increase in the number of species at oiled sites in 1991 is evident (Figs. 4.5.1, 4.5.2). These differences also might be explained by various degrees of exposure to other factors such as salinity, wave and wind energy.

Figures 4.6-4.9 show limpet lengths and weights at selected site pairs for 1990 and 1991. In 1990 both limpet lengths and weights were consistently larger at control sites in the upper intertidal zone. However, this was not the case at lower intertidal levels. In 1991 site pairs were sampled on two separate occasions, early spring and mid summer. The length and weight differences observed in 1990 in the upper intertidal zone were not evident during either of the 1991 sample periods (Fig. 4.8, 4.9). The lower levels showed small differences between the matched pairs.

Limpet size data was also collected during the 1991 population dynamics monitoring. Refer to the population dynamics section for those results.

Population Dynamics

All 20 X 50 cm quadrat data have been analyzed for differences according to statistical procedures defined in the Coastal Habitat data analysis SOP (McDonald *et al.* 1991). A Repeated Measures Analysis of Variance is being undertaken on population dynamics data, and other studies where an assessment of effect over time is appropriate. Results using this method were not completed in time for this report for most species. However, a Repeated Measures analysis was conducted on total limpets (Fig. 4.10) over seven sample periods at all sites. Limpet densities were clearly greater on control sites at 1 MVD with elements of this pattern persisting to lower tide levels. Table 4.3 presents the probabilities observed at five site pairs for the three tidal zones. An interaction effect is evident between site and date at the upper intertidal zone, but to a lesser degree at lower elevations.

Most quadrat data were analyzed using a two factor analysis of variance at each sample date, with site and oil as fixed factors. When many zeros were encountered during sampling, a randomization test was employed (Manly 1991). For the randomization tests, significance was established at the $P=0.05$ level. Very significant and highly significant differences refer to P values of 0.025 and 0.01, respectively. Figures 4.11.1–4.11.6 show mean densities of all limpets combined, and limpets separated into species at the upper intertidal zones. Differences vary among sampling dates and sites; however, the upper intertidal zone continues to show consistently larger differences among the pairs. In particular the limpet, *Tectura persona*, shows the largest difference in density among the site pairs over the majority of sample dates (Fig. 4.11.4; $P<0.1$ for 5 of 7 sample dates).

A second type of limpet density estimate was calculated from the semicircles adjacent to the permanent plots (Fig. 4.11.7-11). This estimate of density is not as precise as the permanent quadrats, but serves as a useful corroborative index. These graphs also show strong differences between oiled and control sites in the upper intertidal zone. The differences decrease at lower zones, but the general trend of higher densities at control sites persisted in most cases.

Limpet size data were also collected within semicircles adjacent to the permanent plots and the mean of ratios among site pairs determined (Fig. 4.11.12). Size data were not collected at permanent plots in 1990. These data do not show consistent size differences between oiled and control sites in 1991.

Mean densities of the periwinkle, *Littorina sitkana*, are presented in Figure 4.12. The 20 X 50 cm and semi-circle estimates show that the densities among sites and levels are variable. During several sample dates, *Littorina* densities were higher at oiled sites. The semi-circle data show higher *L. sitkana* densities at control sites in most cases.

Large numbers of *Nucella lamellosa* were only present at one of the five site pairs established in 1990, sites 1732C & 1732X (Fig. 4.13.1). The densities measured in semicircles show consistently higher numbers of *N. lamellosa* at control sites in both 1990 and 1991. A second species, *Nucella lima*, was found at one site pair (Fig. 4.13.2).

The six-armed starfish, *Leptasterias hexactis*, was found in low densities, and only in the mid and lower intertidal zone. However, the few individuals that were encountered in the study plots or adjacent semicircles were only found at control sites. *Leptasterias* is known to occur at two oiled sites, but was never observed during the Population Dynamics sampling, suggesting very low densities.

Settlement on oiled vs. non-oiled substrates

Rock Exchange Experiment

As stated previously, the rocks with oiled and cleaned halves deployed in 1990 were found to have been weathered and dislodged from the substrate over the course of the 1990-91 winter. Many of the rocks had the oil weathered completely from the sampling surface. Consequently, these units could not be sampled during the 1991 season. However, many of tile pairs that were originally placed with the rocks survived the winter, and show significantly greater algal cover on oiled than non-oiled tiles ($P<0.05$, paired t-test, Fig. 4.14). Although some oiled tiles show a high percentage of algal coverage, the species composition was very different from the non-oiled tiles. On the oiled tiles a thin, blue-green algal film was observed throughout the season. Non-oiled tiles were colonized by macro filamentous species, such as

Myleophycus sp., *Scytosiphon* sp., *Enteromorpha* and *Pillayella* (Fig. 4.15). These species were found only in very low percentages on oiled tiles.

Results of barnacle and *Fucus* recruitment on the tile pairs placed in 1991 are presented in Figures 4.16a,b, with means and probabilities presented in Table 4.4. Overall a greater number of barnacles and *Fucus* germlings recruited on non-oiled tiles. These differences varied over time. For a second season, the largest pulses of barnacle recruits occurred in early July. *Fucus* did not begin to settle on the tiles until late July and early August.

Barnacle Recruitment

A higher number of barnacles recruited on the cleaned plots of all oiled sites compared to the plots that remained oiled (Fig. 4.17). The means and probabilities over all sample dates are presented in Table 4.5. These differences were not consistent at all sample dates; but except for Site 1641A, all oiled sites showed a significant difference for barnacle recruitment on the clean plot during at least one sample period ($p=0.05$, paired T-test). These differences were very significant at two of the five oiled sites ($p<0.025$, sites 1544X; 1746X), and highly significant at three of the sites ($p<0.01$, 1343X; 1342D; 1645X).

At the control sites, differences in barnacle recruits were observed among plots with barnacle adults present ($p=0.05$). Again, these differences were not consistent throughout all sample dates. On average, barnacle recruitment was much lower at control sites compared to oiled sites. Fig. 4.17.5 shows the mean number of barnacles over all sample dates, comparing grazing exclusion cages to non-caged plots. Caged, unoiled treatments had more recruits than caged, oiled treatments and uncaged unoiled plots had more recruits than uncaged, oiled plots.

Settlement patterns within Herring Bay

The results from this experiment were inconclusive with respect to barnacle recruitment. During the experiment, the tiles were dominated by the hydroid, *Obelia* sp., and barnacle recruitment was negligible. Large numbers of juvenile mussels (> 100 individuals per 9 cm^2) were observed attached within the stalks of Obelia sp. beginning the second week of July. High mussel densities were observed through the remaining sample dates.

Limpet grazing: Fences and Cages

Results from the limpet grazing studies showed no consistent relationship between limpet density and percent algal cover. Figure 4.18 presents examples of all density treatments at site pair 1411 of the fencing experiment, and pair 1852 of the caging study. These are the typical responses observed at most sites. In the limpet fencing experiment, high mortality of limpets is evident. In the experiment using cages, survival of limpets was higher. Overall, the presence of limpets in most treatments had little effect on percent algal cover at oiled or control sites.

The mortality of limpets was also examined to determine if the enclosures with or without algae had an effect on survival of limpets. In the 1990 report, preliminary data suggested that enclosures with algae may provide limpets protection from predation or desiccation. However, no trend is evident to suggest that algal cover extended limpet survivorship (Fig. 4.19).

Net weight of limpets collected from the enclosures at the end of the experiment are variable, and some limpets lost weight at both oiled and control sites (Fig. 4.20).

Dry weights of Fucus and filamentous algae taken from fences and cages before the experiment show large differences at both tidal elevations between oiled and control sites (Fig. 4.21.1-2; $p < 0.1$, two factor ANOVA). These differences were not seen in algal dry weights taken from all fences at the termination of the experiments.

Mussel densities between oiled and control sites

Algae did not colonize inside the cleared plots to allow sampling in 1991. Consequently, the experiment was left in place over the winter and will be sampled in Spring, 1992.

LITERATURE CITED

Barnes, H. and M. Barnes. 1956. The general biology of *Balanus glandula*, Darwin. *Pacific Science.* Volume X. October 1956, pp.415-422.

Connell, J. H. 1969. A predator-prey system in the marine intertidal region. I. *Balanus glandula* and several predatory species of Thais. *Ecol. Monogr.* 40:49-77.

Dayton, P. K. 1971. Competition, disturbance and community organization: the provision and subsequent utilization of space in a rocky intertidal community. *Ecol. Monogr.* 41:351-389.

McDonald, L., D. Strickland and W. Erickson. 1991. Data analysis standard operating procedures for the coastal habitat injury assessment program. Unpublished manuscript.

Nelson-Smith, A. 1977. Recovery of some British rocky seashores from oil spills and cleanup operations. *In* Recovery and restoration of damaged ecosystems. J.Cairns, Jr., K.L.Dickson, and E.E.Herricks (eds.) International symposium on the recovery and restoration of damaged ecosystems. pp. 190-207.

Southward, A.J. and E.C. Southward. 1978. Recolonization Cornwall after use of toxic dispersants to clean up the Torrey Canyon spill. *J. Fish. Res. Board Can.*35: 682-706.

 Text continued on page 553

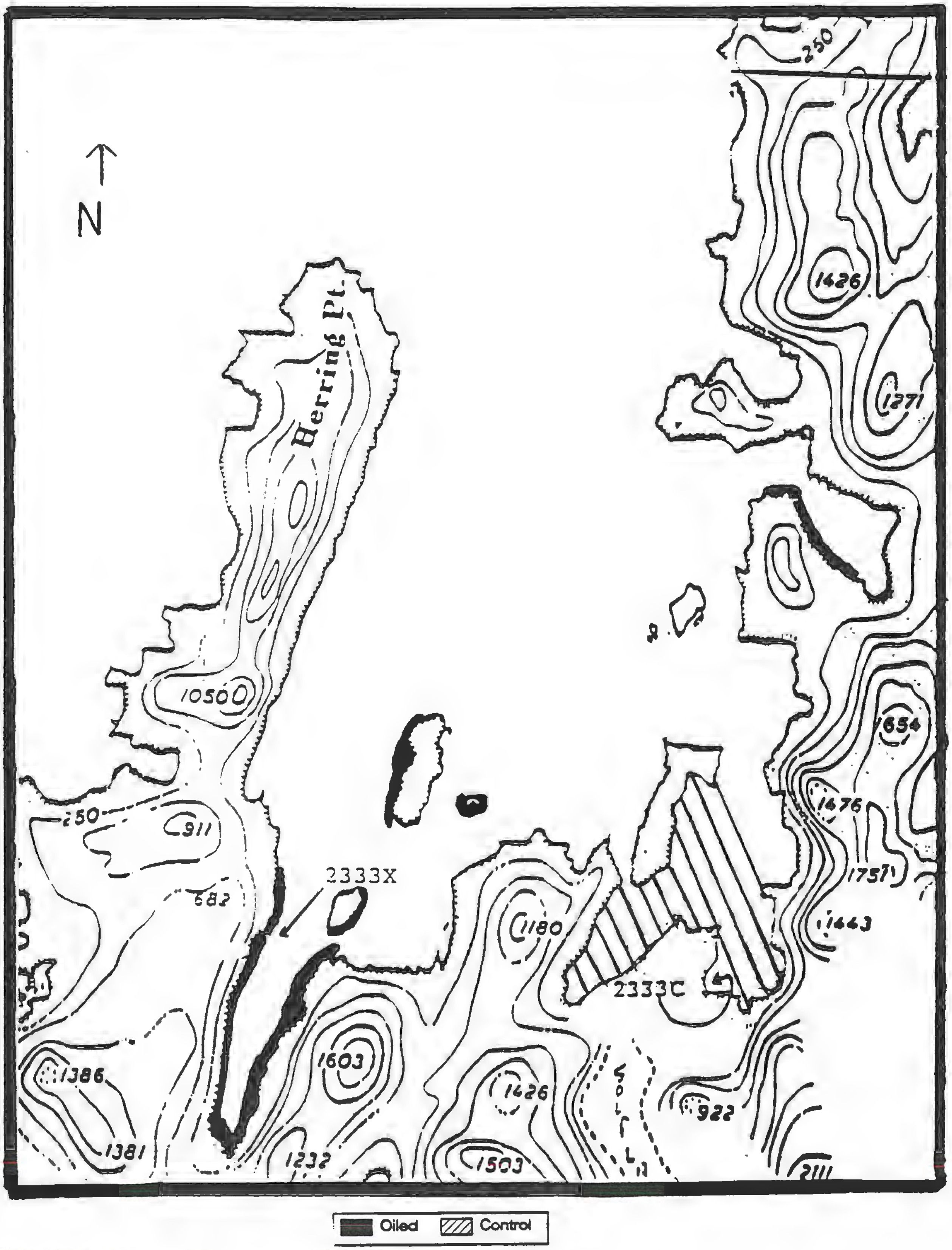


Fig. 4.1. General location of control and oiled sites in Herring Bay.

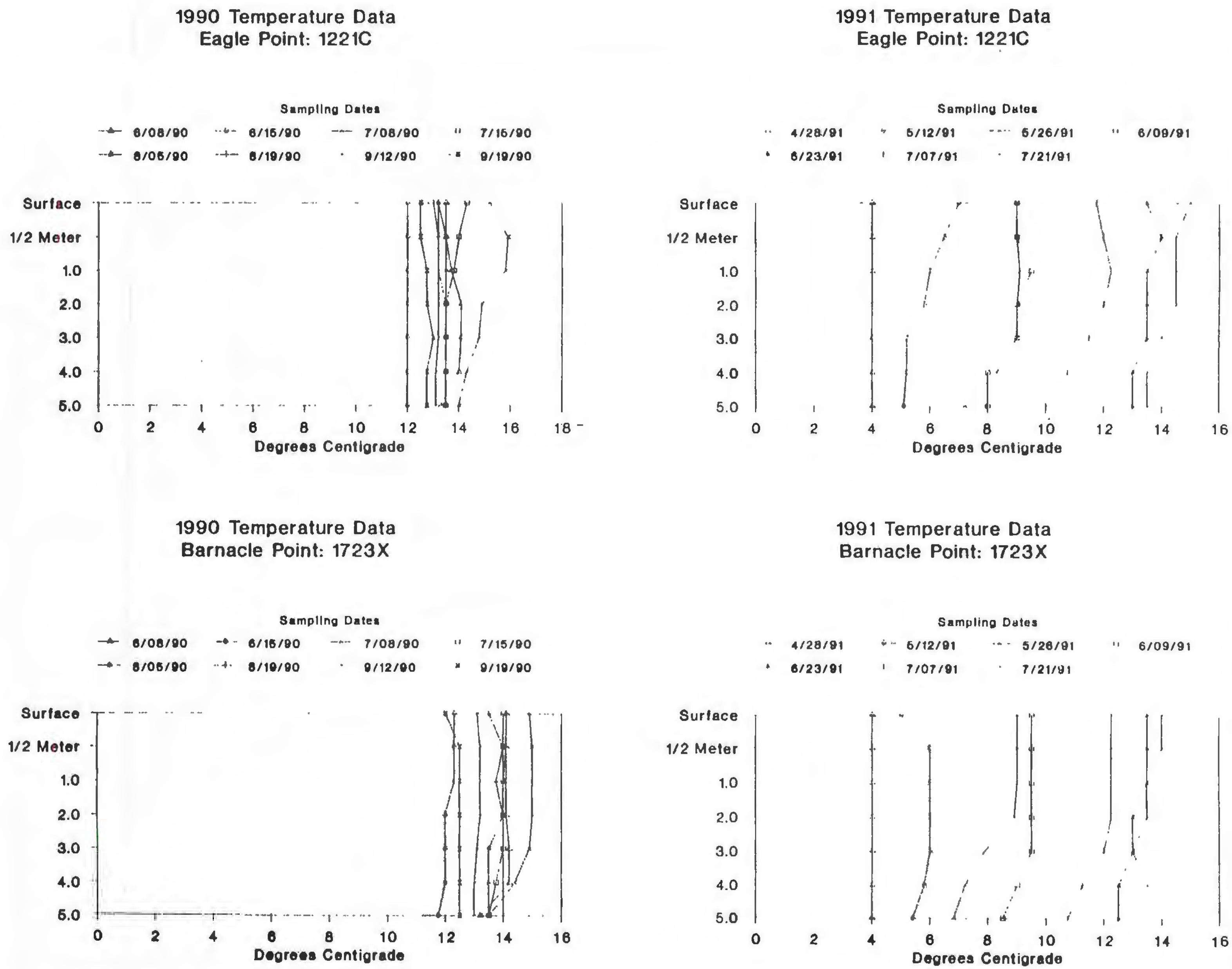


Fig. 4.2.1. Temperature at sites 1221C and 1723X during 1990 and 1991. 1723X serves as the matched pair station. The site is adjacent to 1221X.

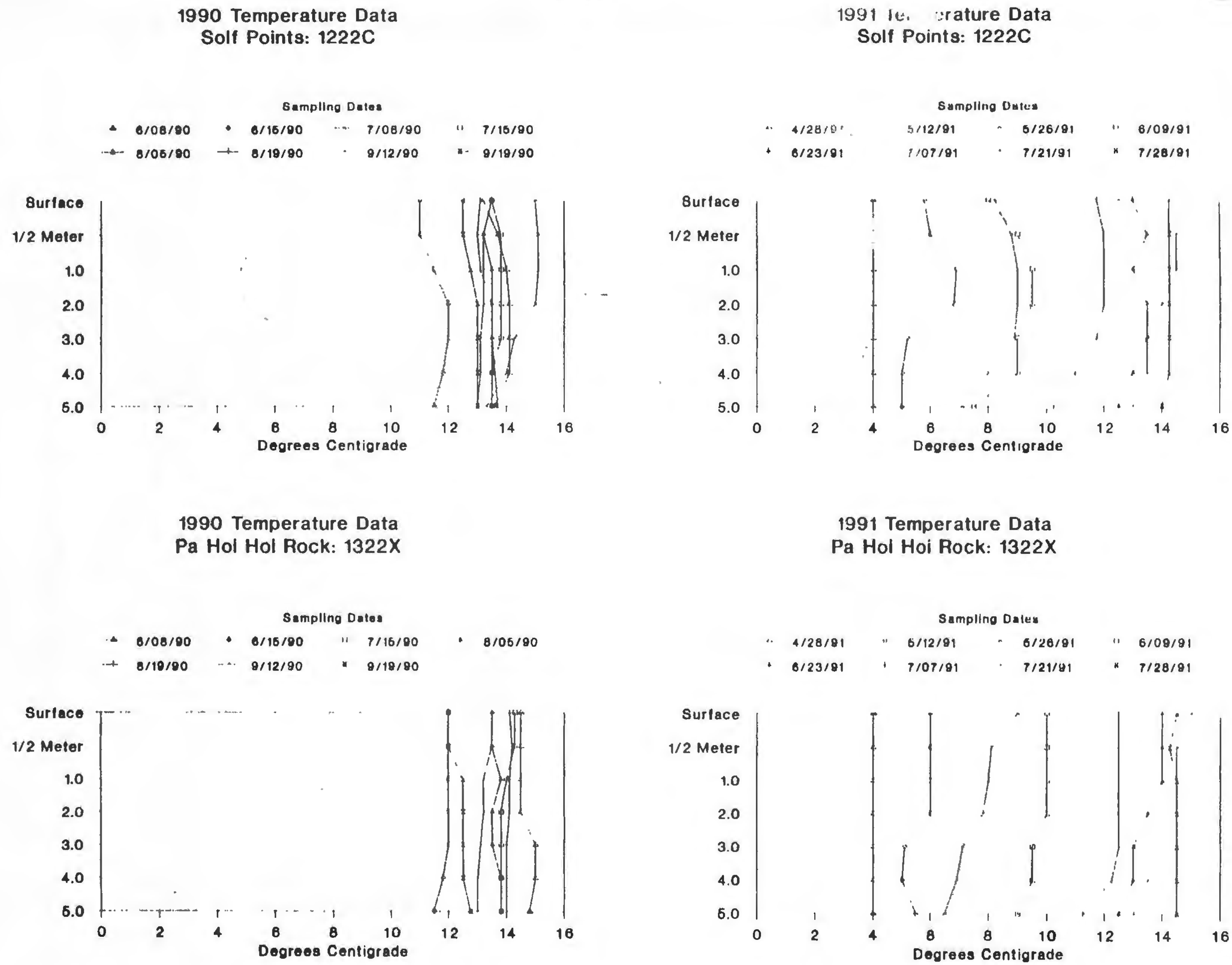
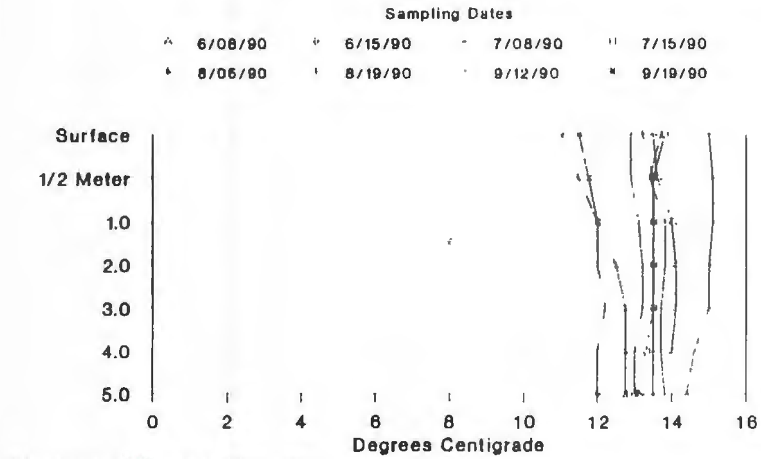


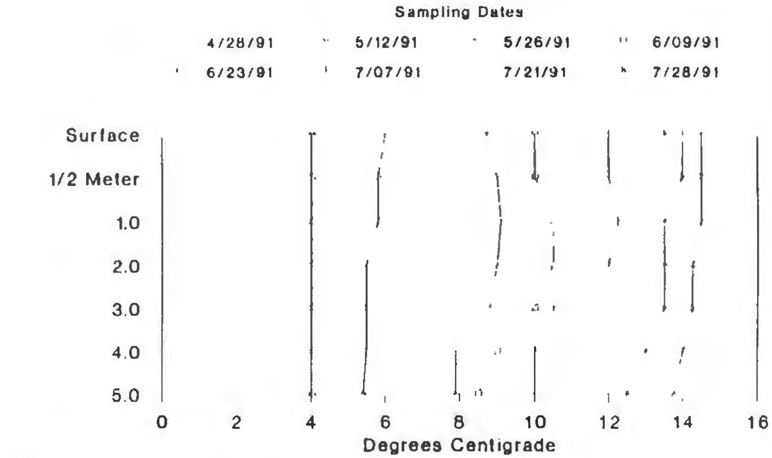
Fig. 4.2.2. Temperature at site pair 1222 during 1990 and 1991.

1990 Temperature Data
Flower Cove: 1411C



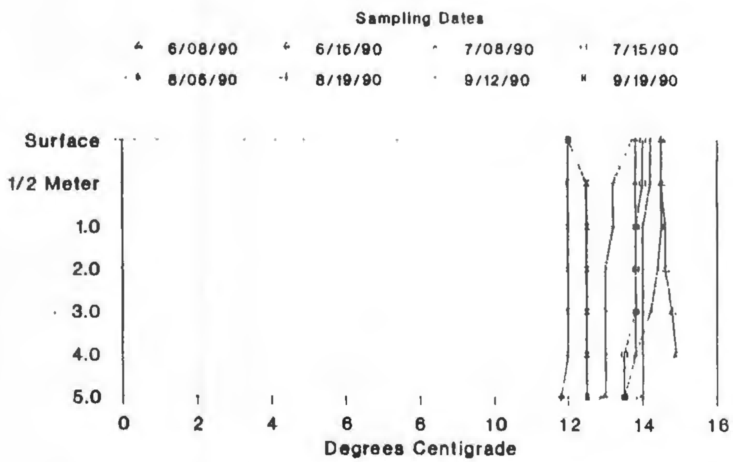
this station applies to multiple sites

1991 Temperature Data
Flower Cove: 1411C



this station serves multiple sites

1990 Temperature Data
North Shore: 1231X



1991 Temperature Data
North Shore: 1231X

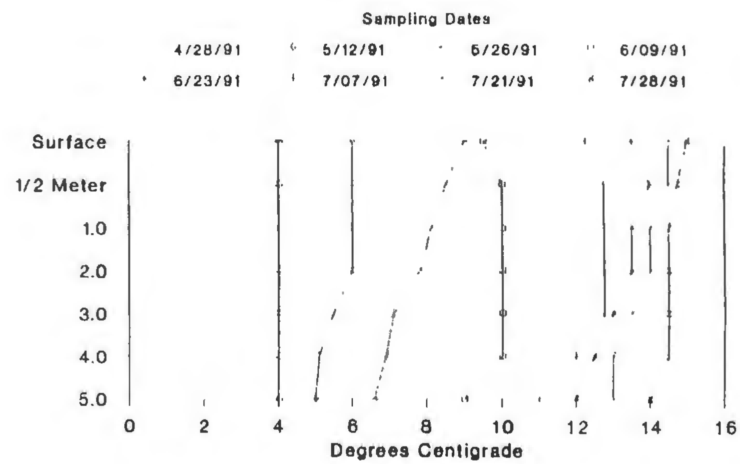


Fig. 4.2.3. Temperature at sites 1411C and 1231X during 1990 and 1991. 1411C serves as the matched pair station. The site is [illegible]ent to 1231C.

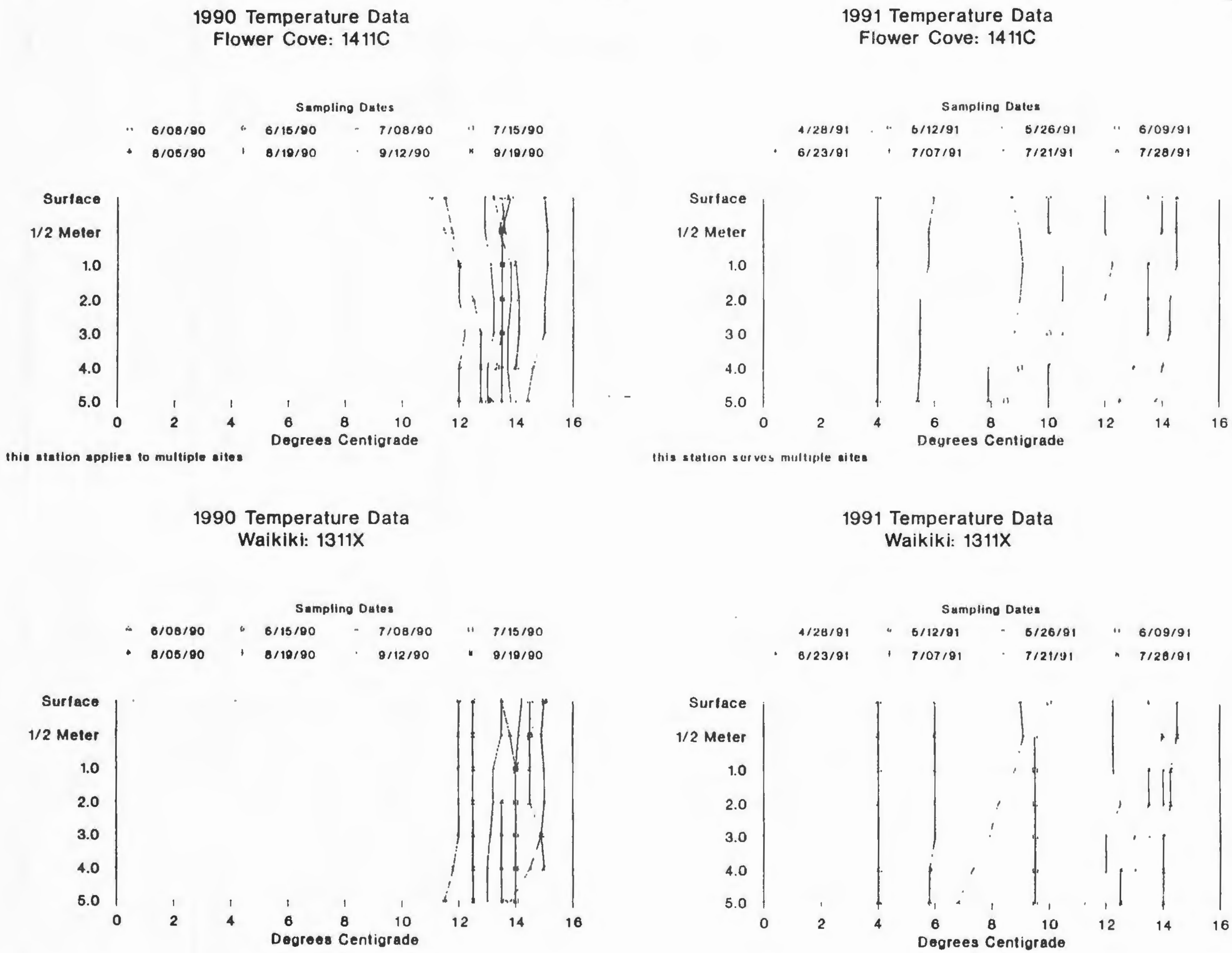


Fig. 4.2.4. Temperature at site pair 1411 during 1990 and 1991.

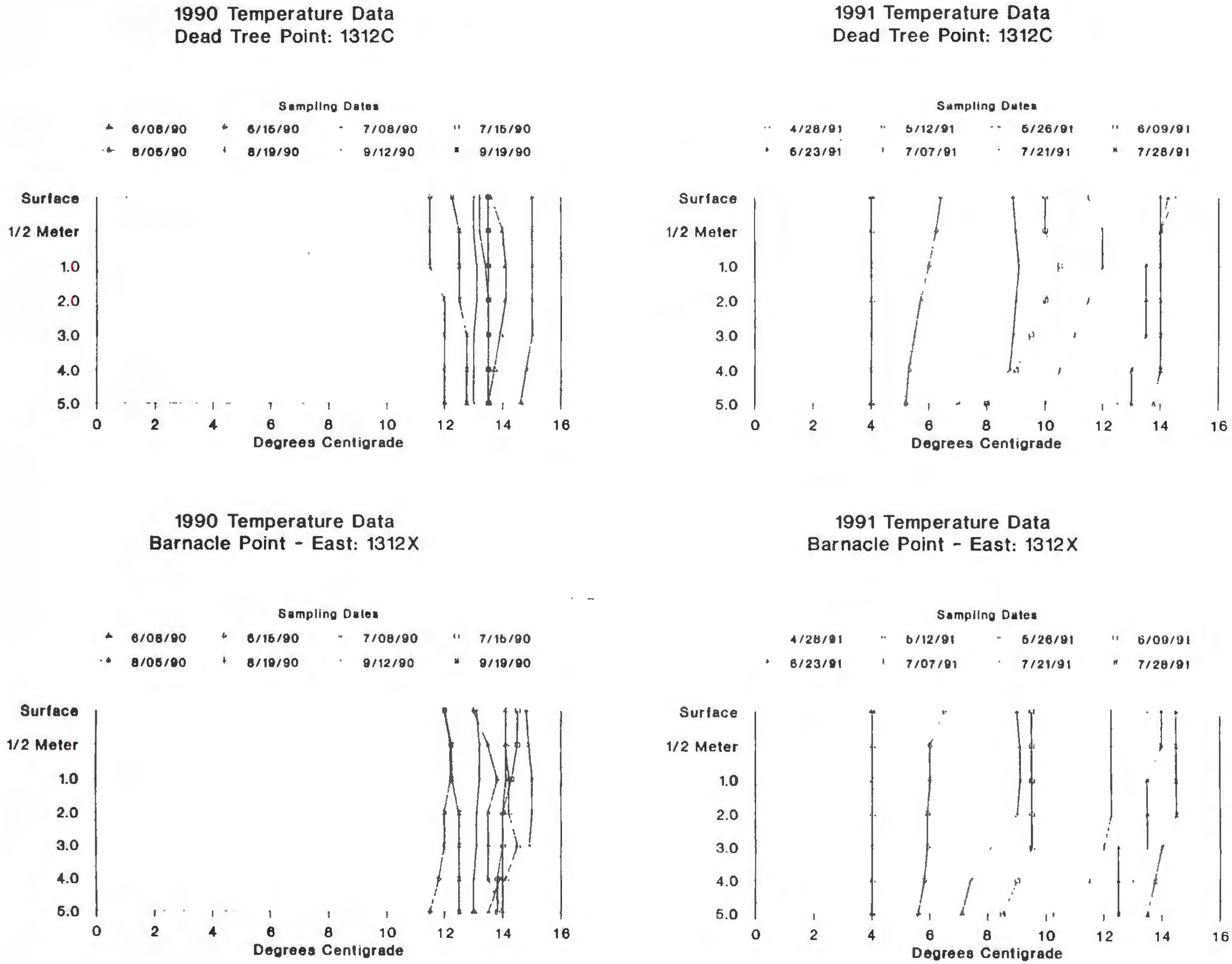


Fig. 4.2.5. Temperature at site pair 1312 during 1990 and 1991.

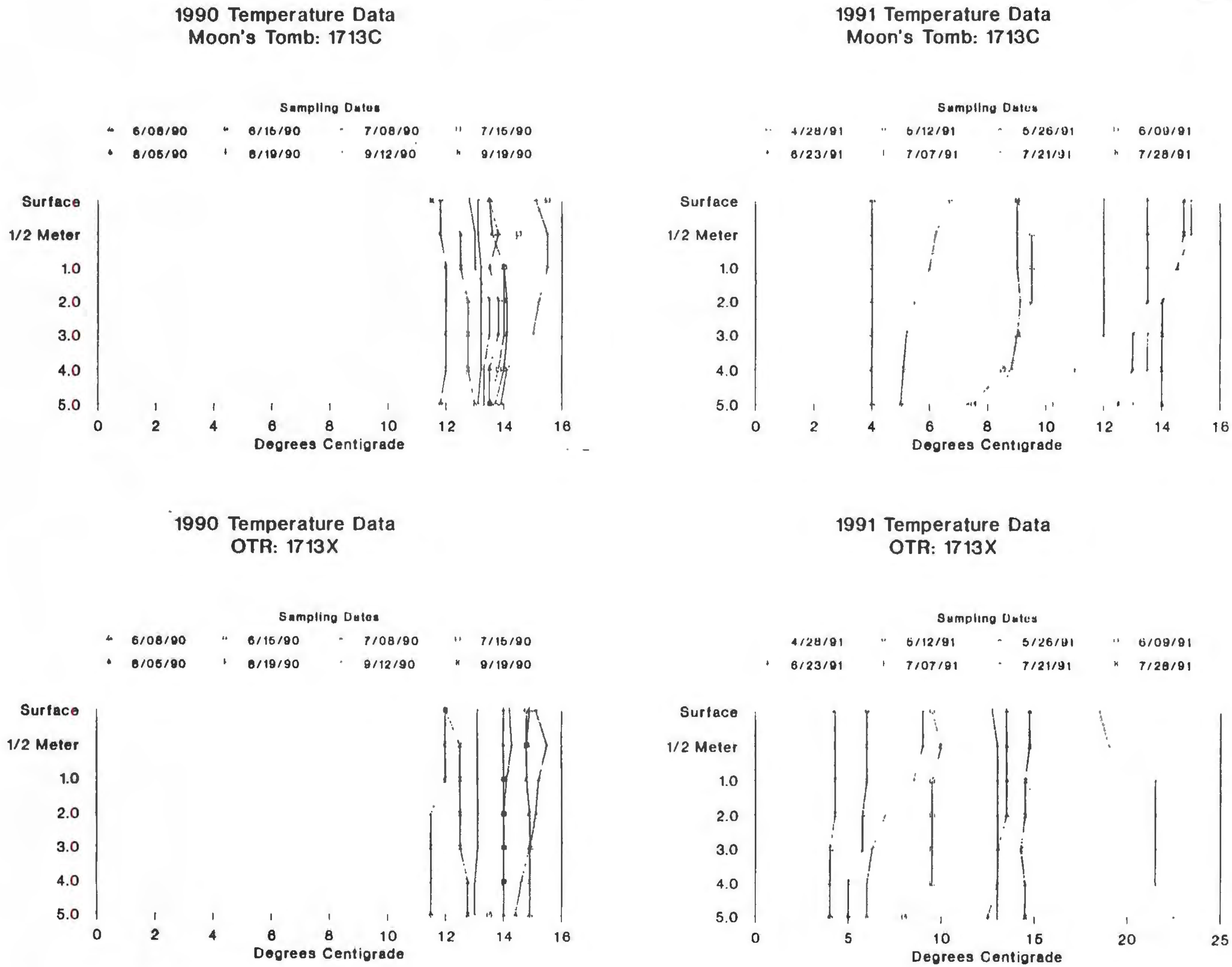


Fig. 4.2.6. Temperature at site pair 1713 during 1990 and 1991.

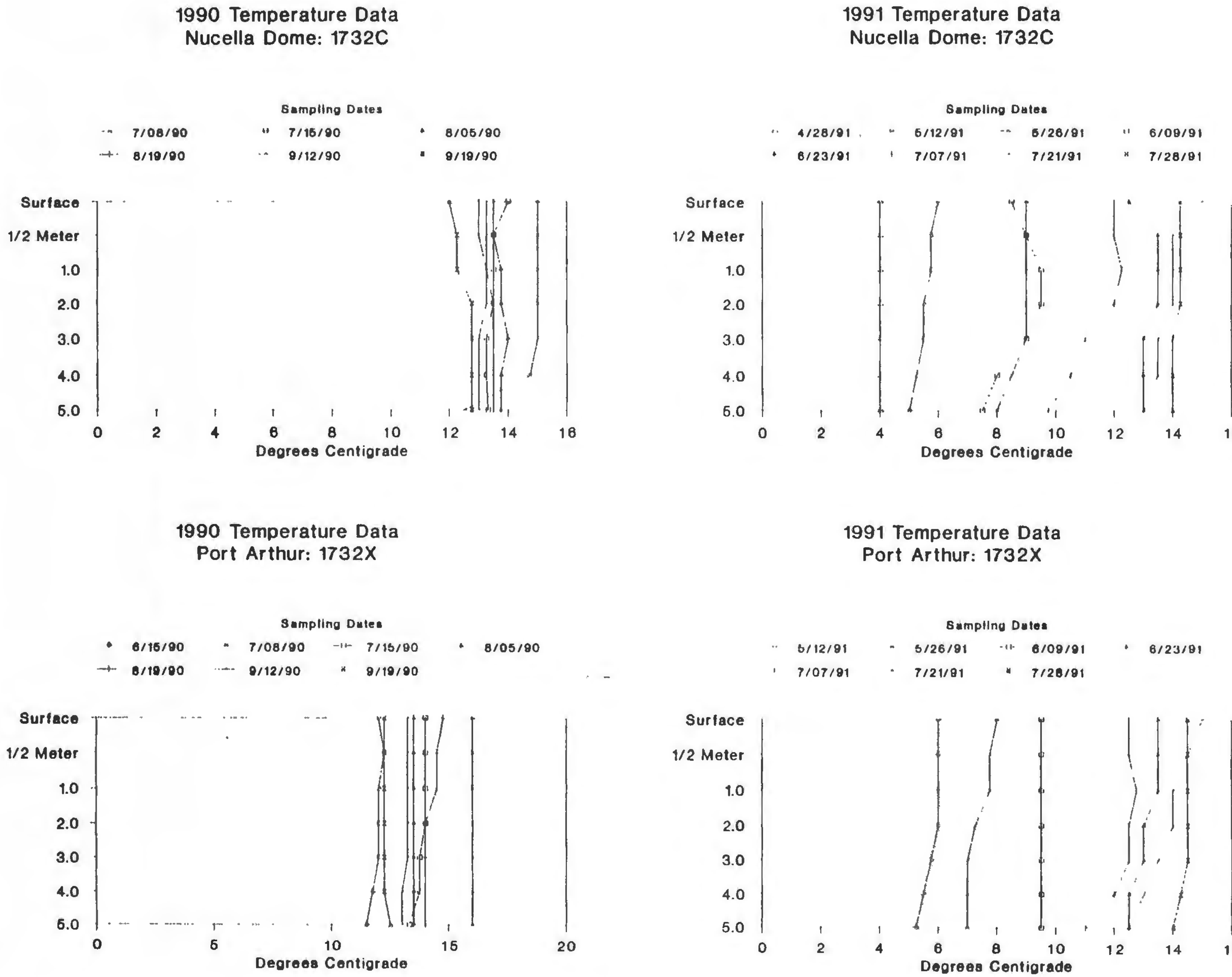


Fig. 4.2.7. Temperature at site pair 1732 during 1990 and 1991.

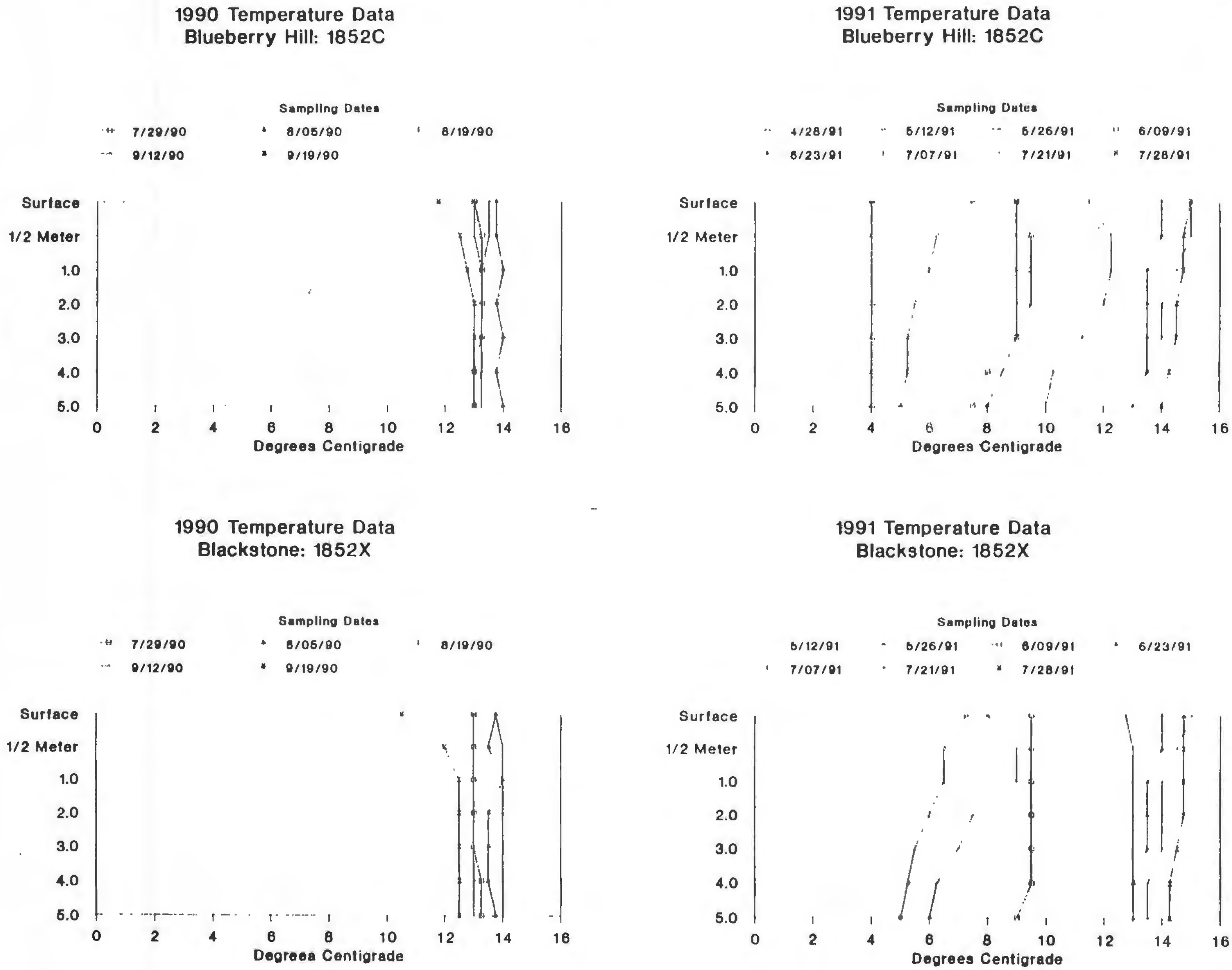


Fig. 4.2.8. Temperature at site pair 1852 during 1990 and 1991.

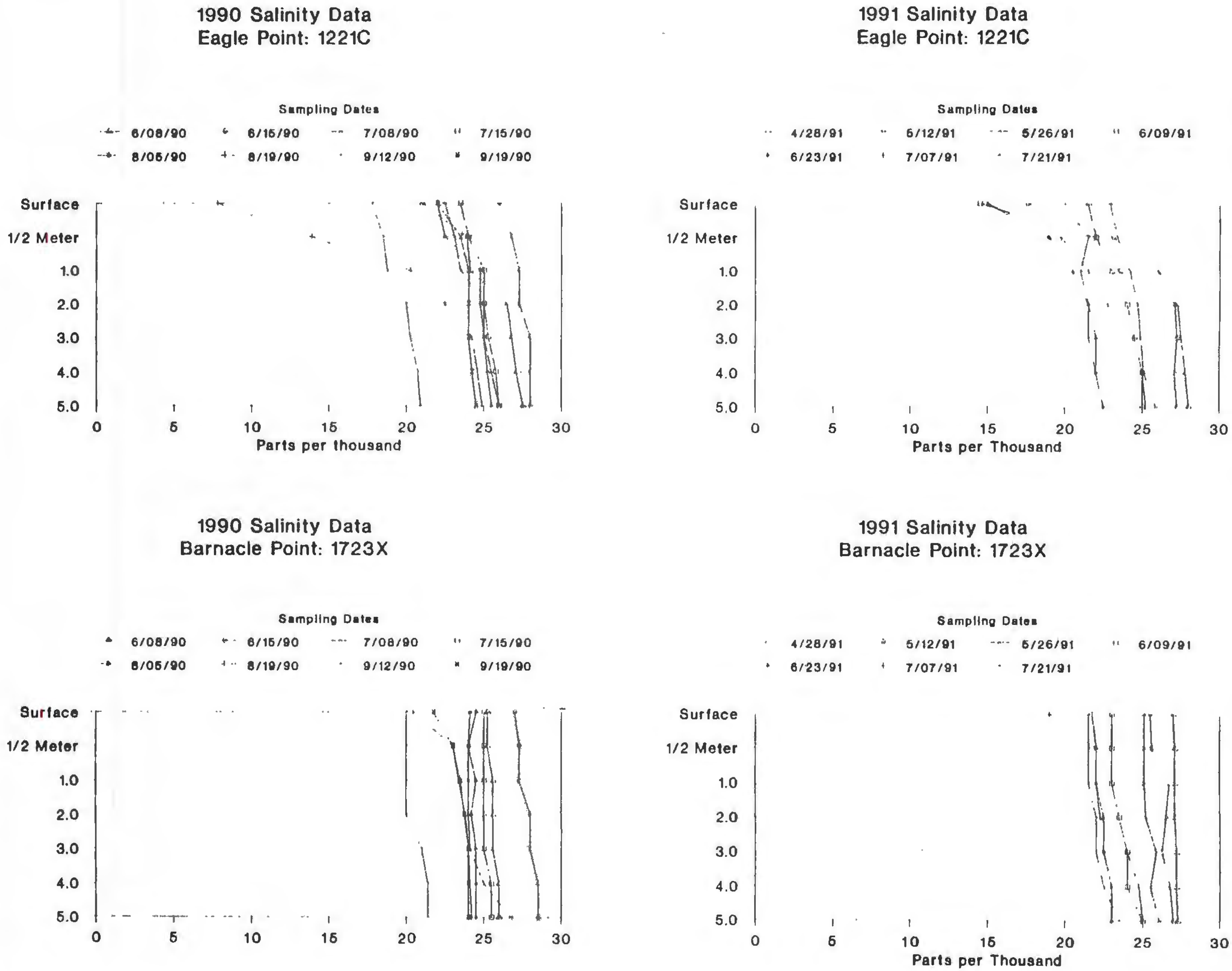


Fig. 4.2.9. Salinity at sites 1221C and 1723X during 1990 and 1991. 1723X serves as the matched pair station. The site is adjacent to 1221X.

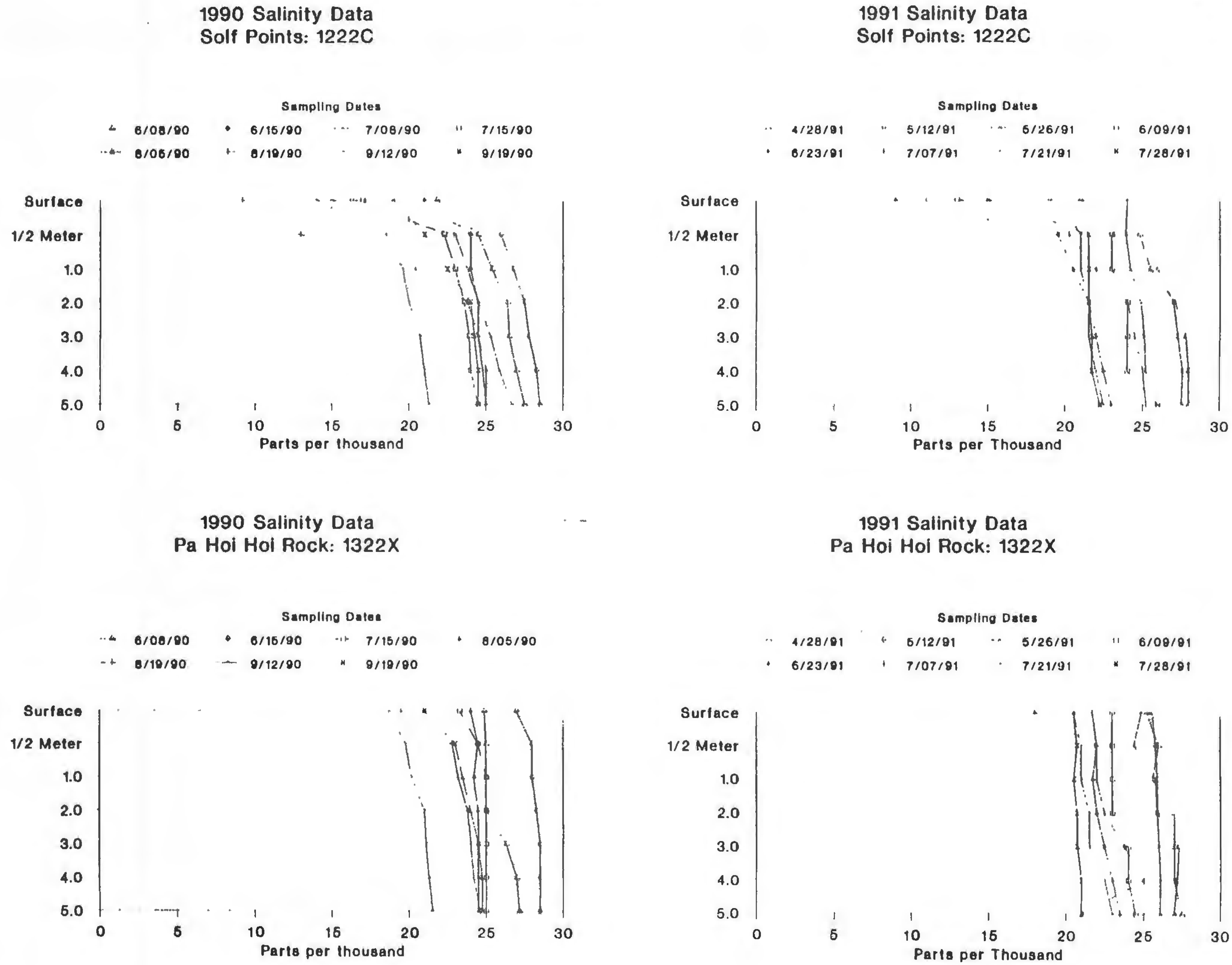


Fig. 4.2.10. Salinity at site pair 1222 during 1990 and 1991.

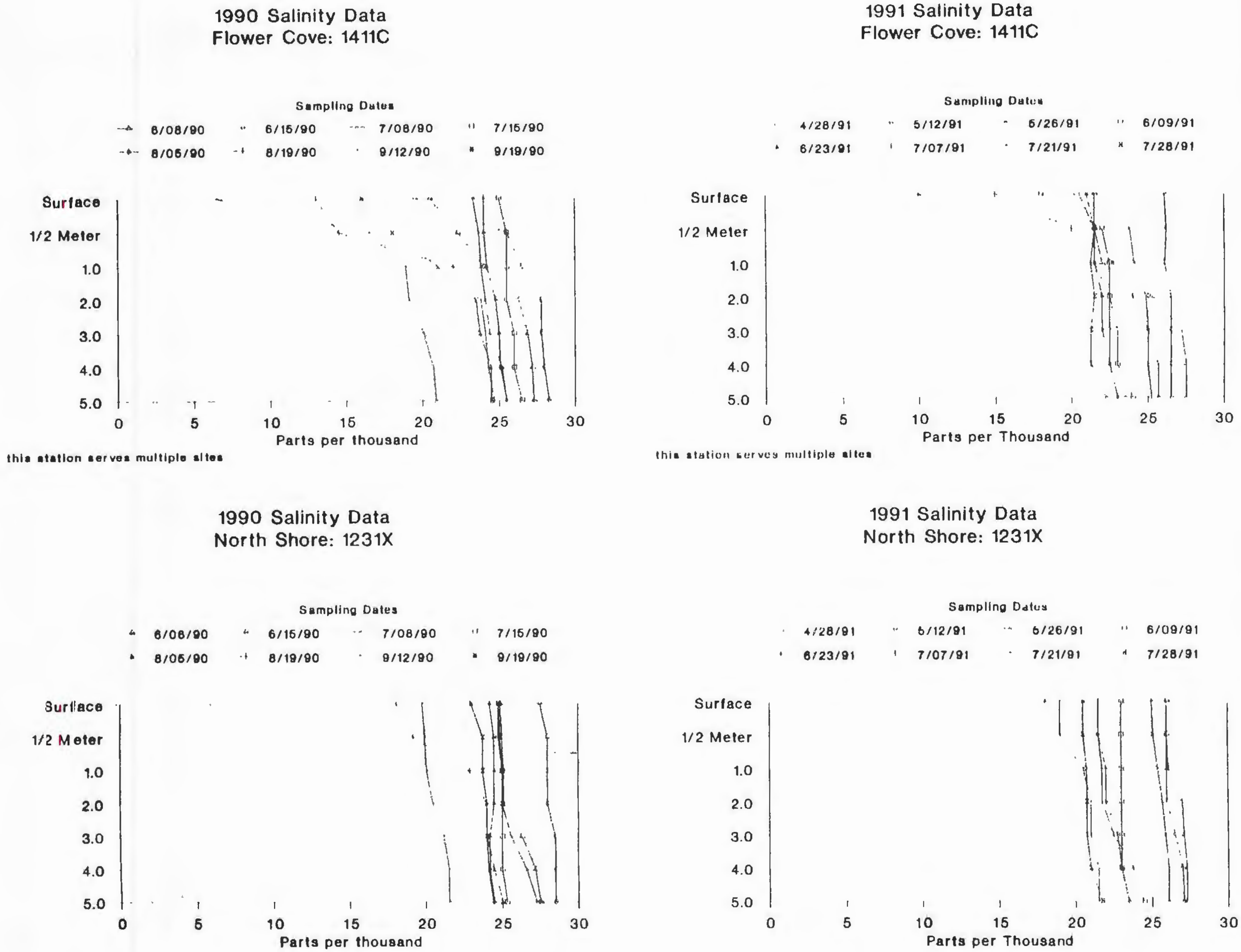


Fig. 4.2.11. Salinity at sites 1411C and 1231X during 1990 and 1991. 1411C serves as the matched pair station. The site is adjacent to 1231C.

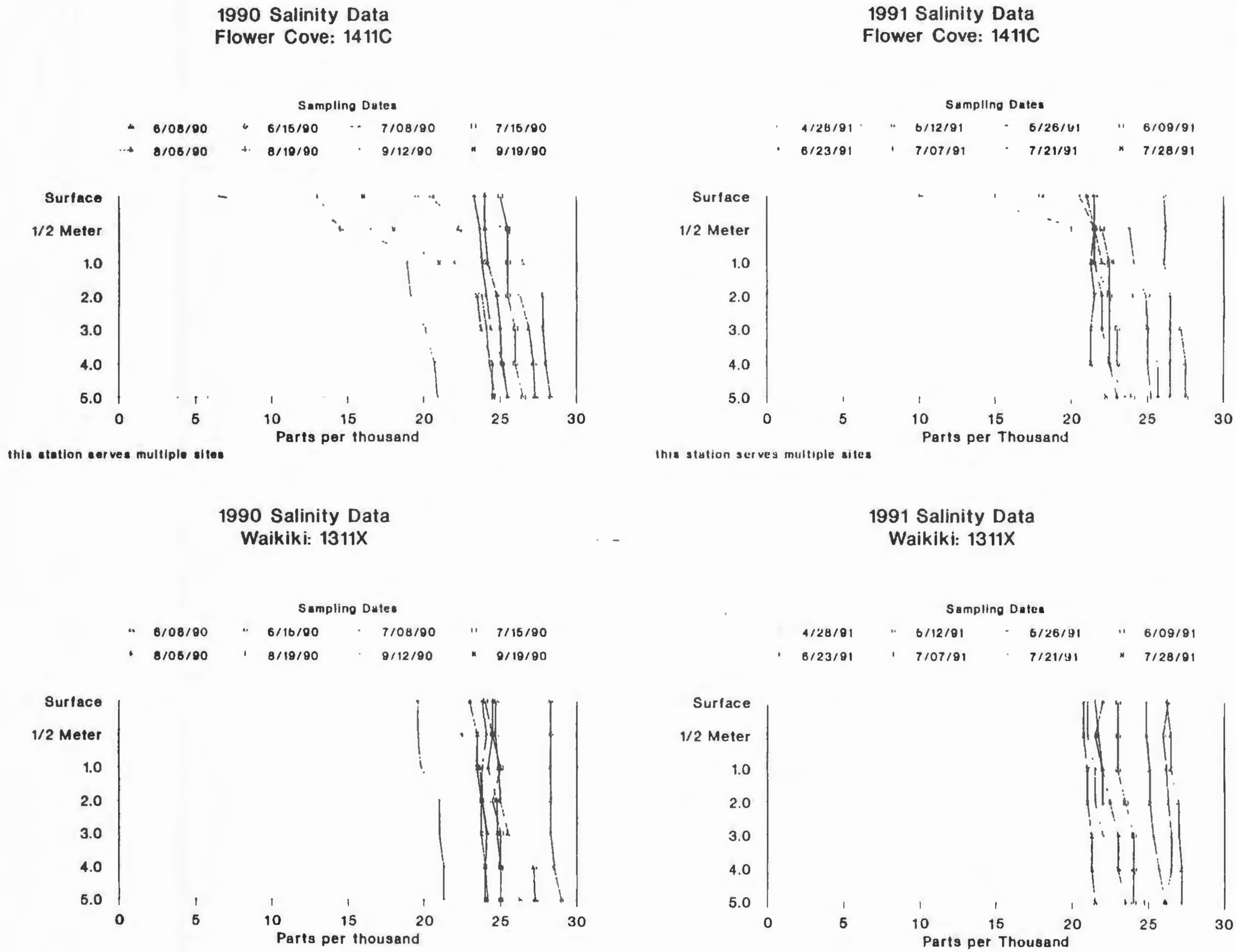


Fig. 4.2.12. Salinity at site pair 1411 during 1990 and 1991.

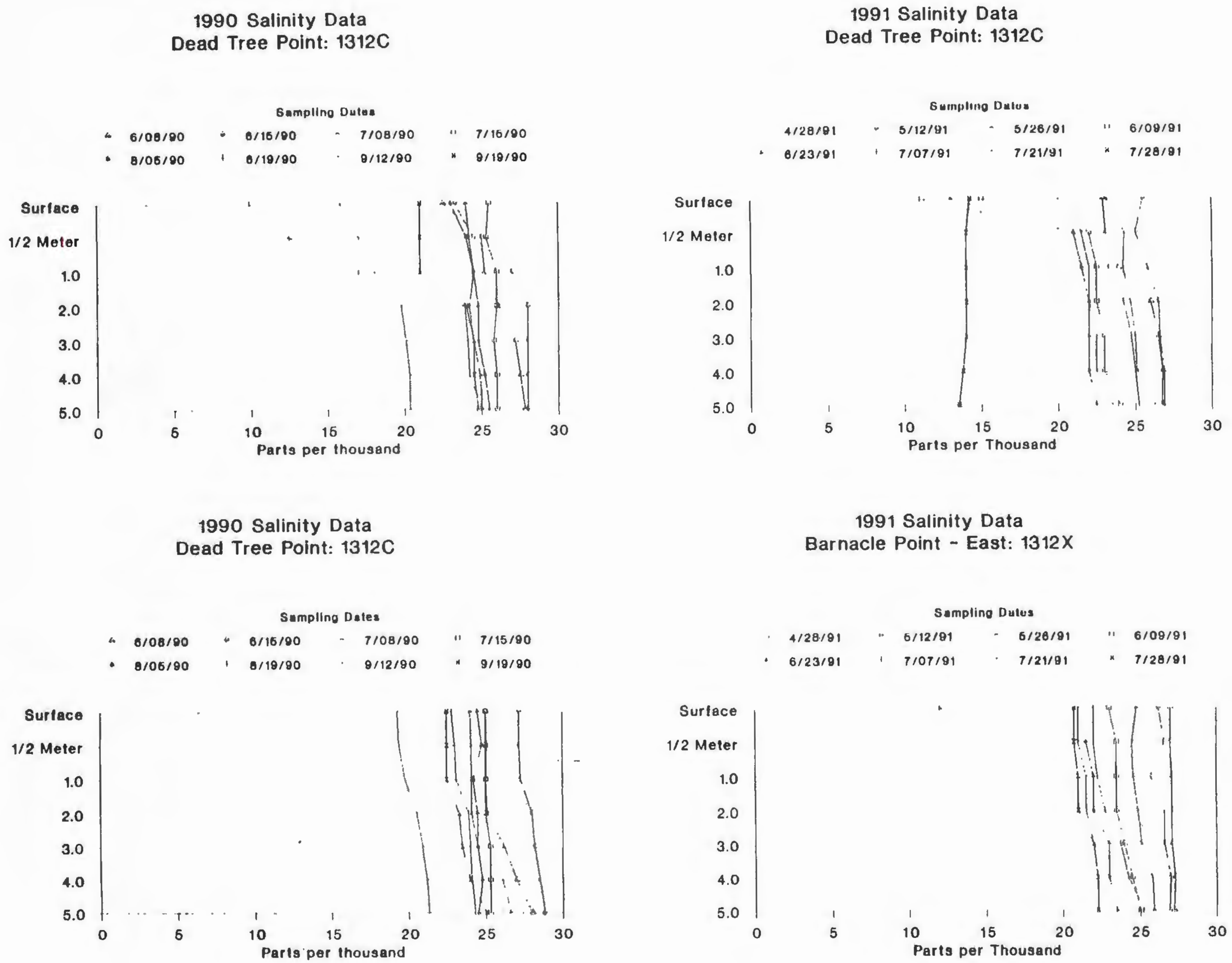


Fig. 4.2.13. Salinity at site pair 1312 during 1990 and 1991.

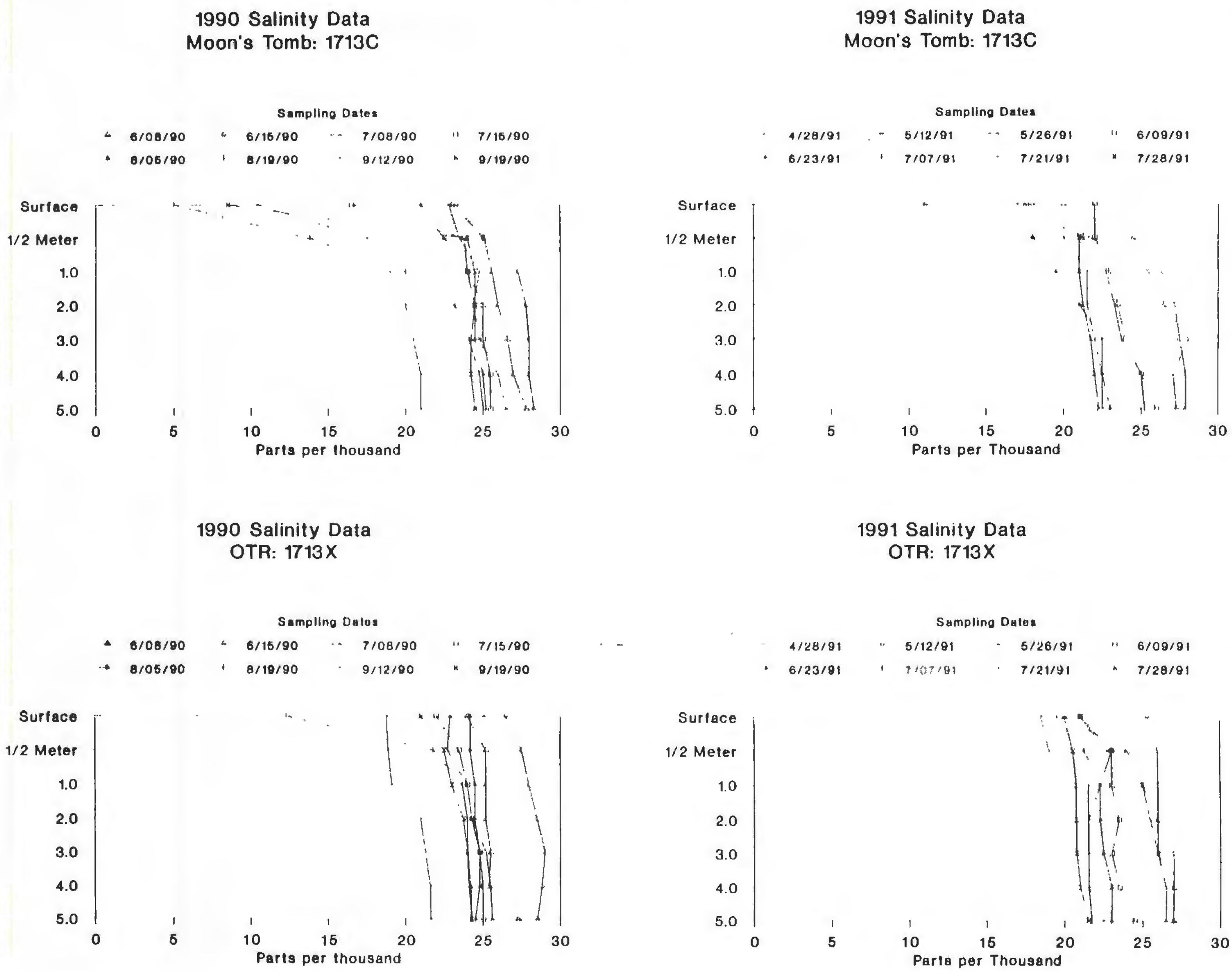


Fig. 4.2.14. Salinity at site pair 1713 during 1990 and 1991.

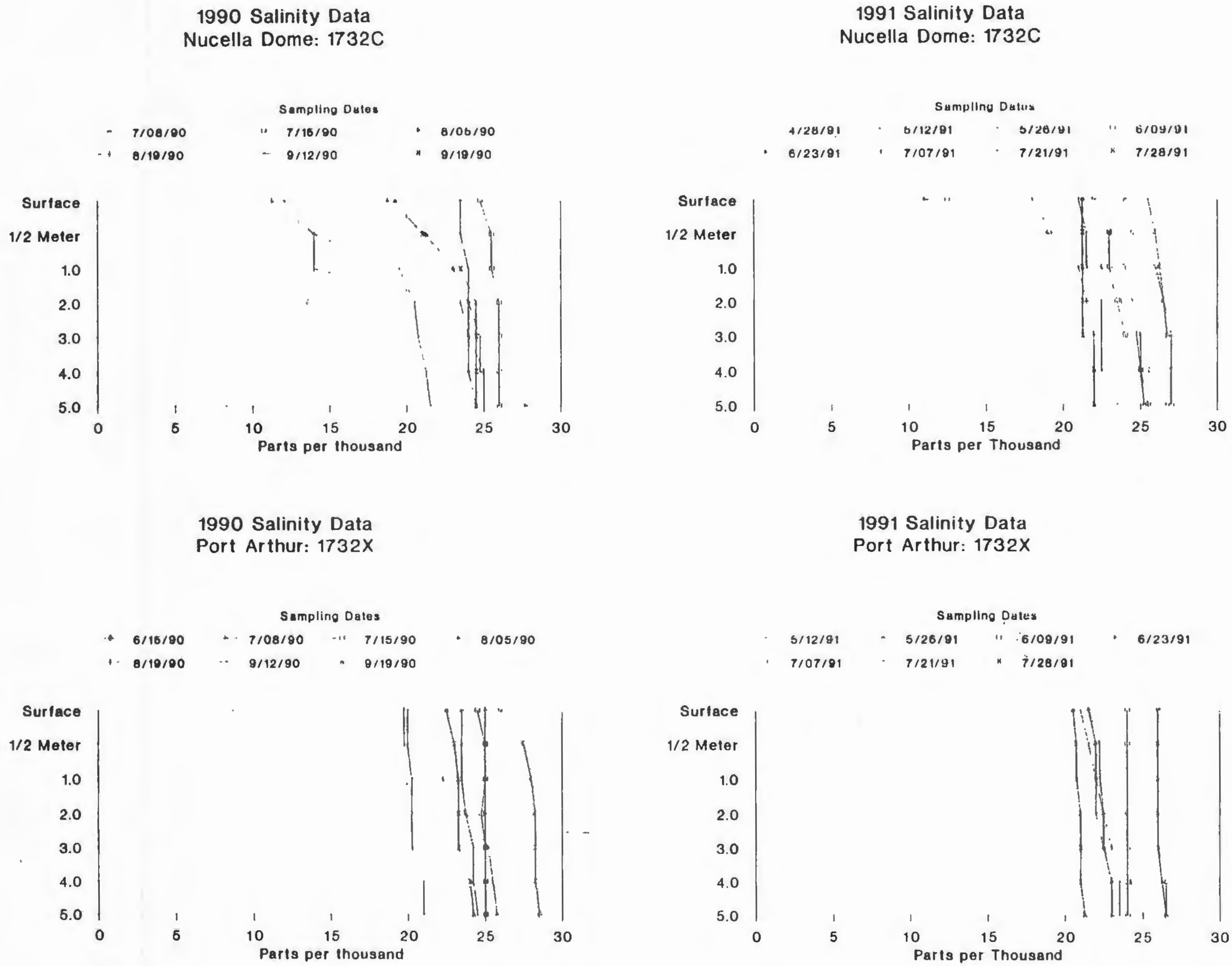


Fig. 4.2.15. Salinity at site pair 1732 during 1990 and 1991.

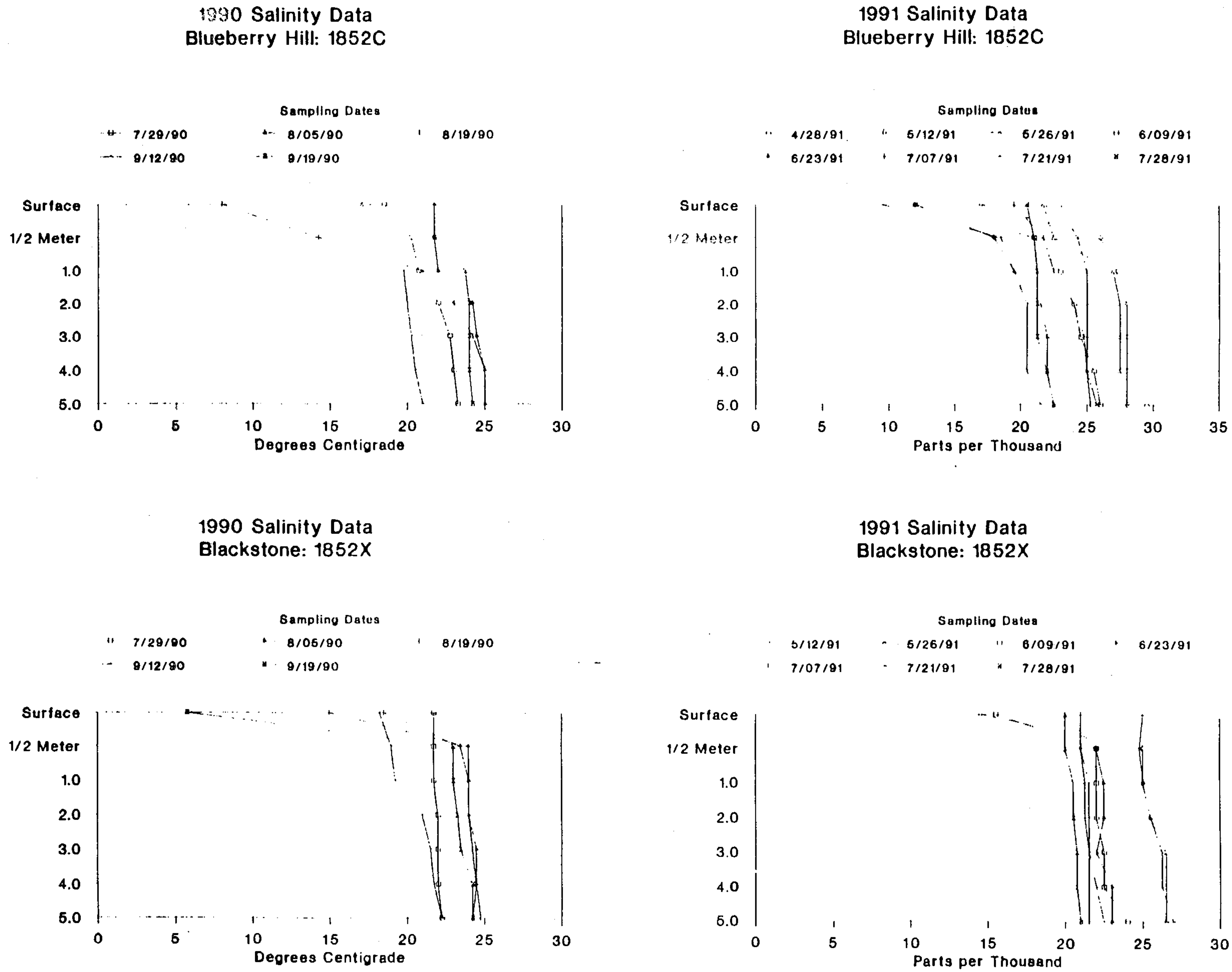
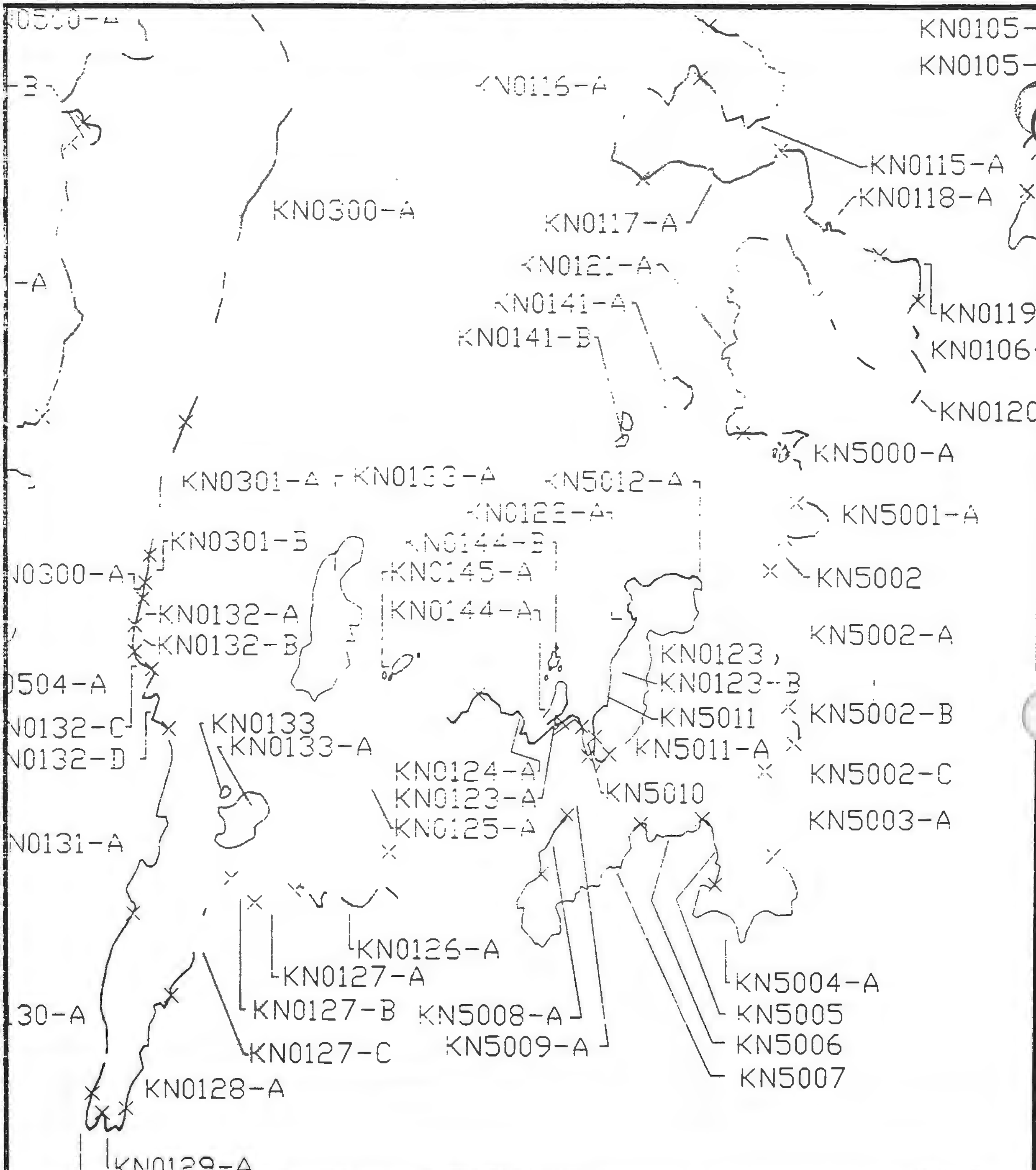


Fig. 4.2.16. Salinity at site pair 1852 during 1990 and 1991.



Alaska Department of
Natural Resources
Oil Spill Project Office
645 G st. #402
Anchorage, Alaska
99501
907-278-8012
(907) 762-2290 FAX

Figure: 4.3
Segments and 1989 Oiling levels in Herring Bay

Scale: No Scale
Drawn By: JWS
11/21/91

Heavily Oiled	——
Moderately Oiled	——
Lightely Oiled	——
Very Lightely Oiled	- - -
Not Oiled	——
Seg/Subdiv Endpoints	X

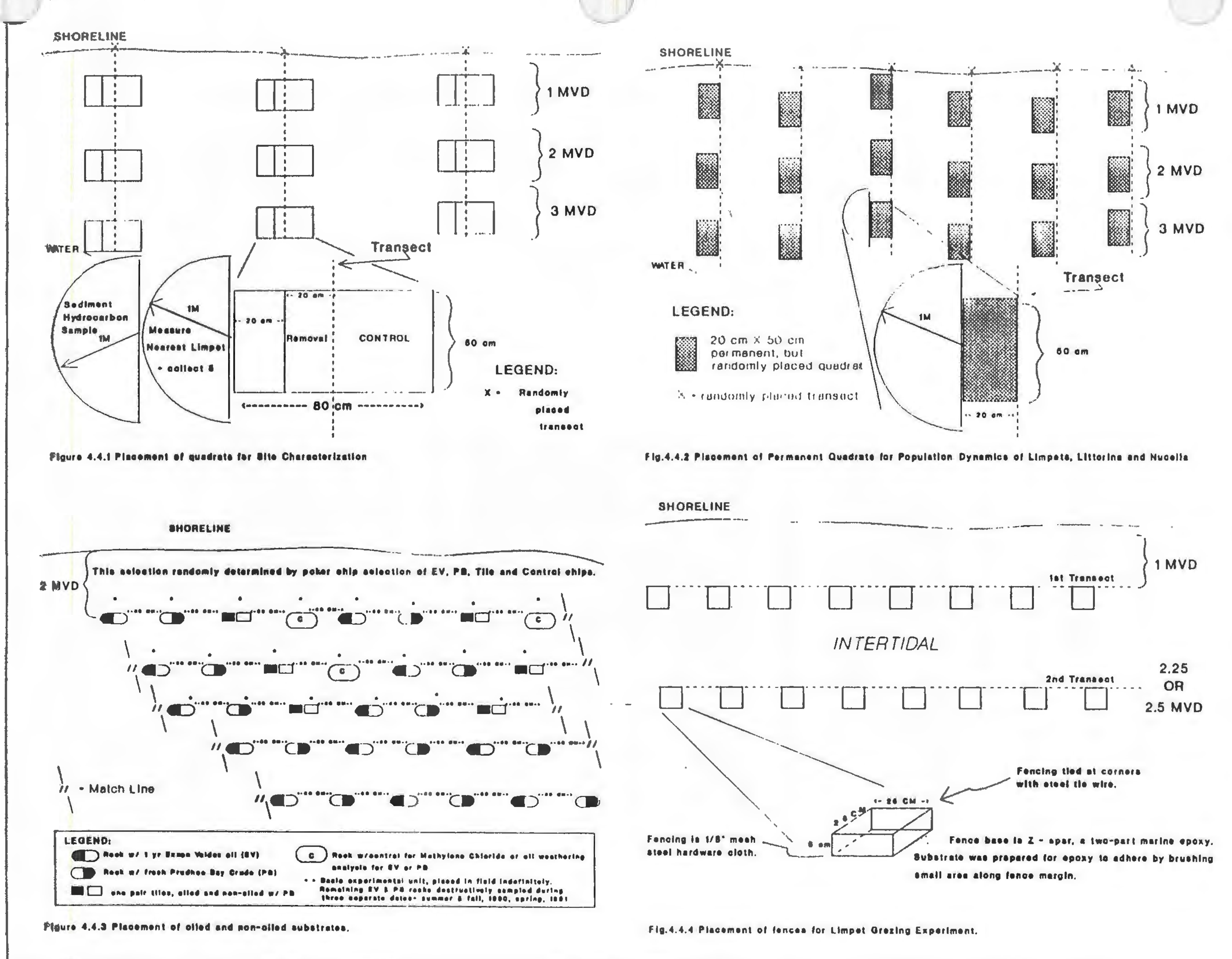


Fig. 4.4. Schematic diagrams of monitoring plots and experiments in Herring Bay.

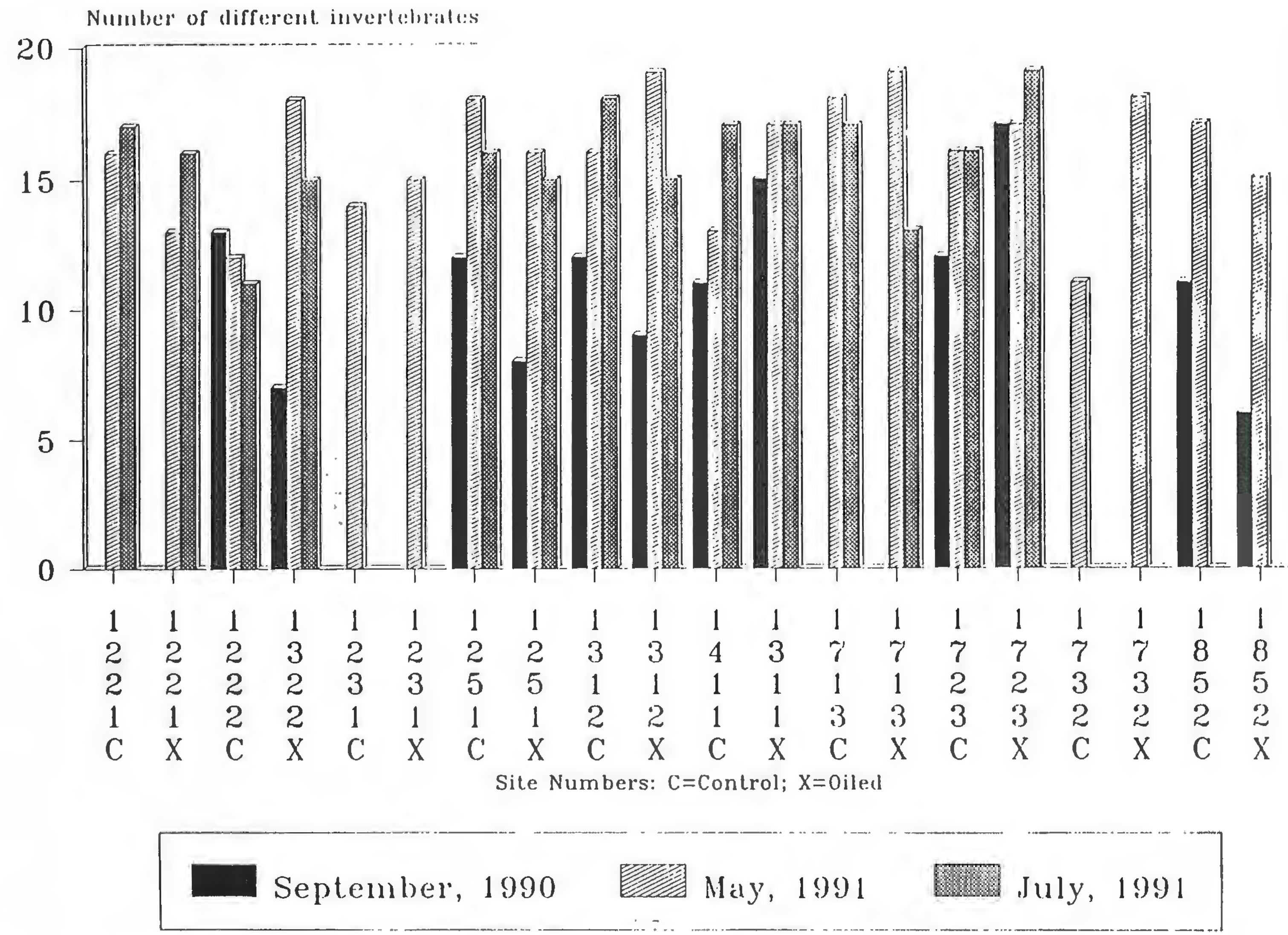


Fig.4.5.1. Number of Invertebrates at oiled & control sites. Some sites not sampled in 1990.

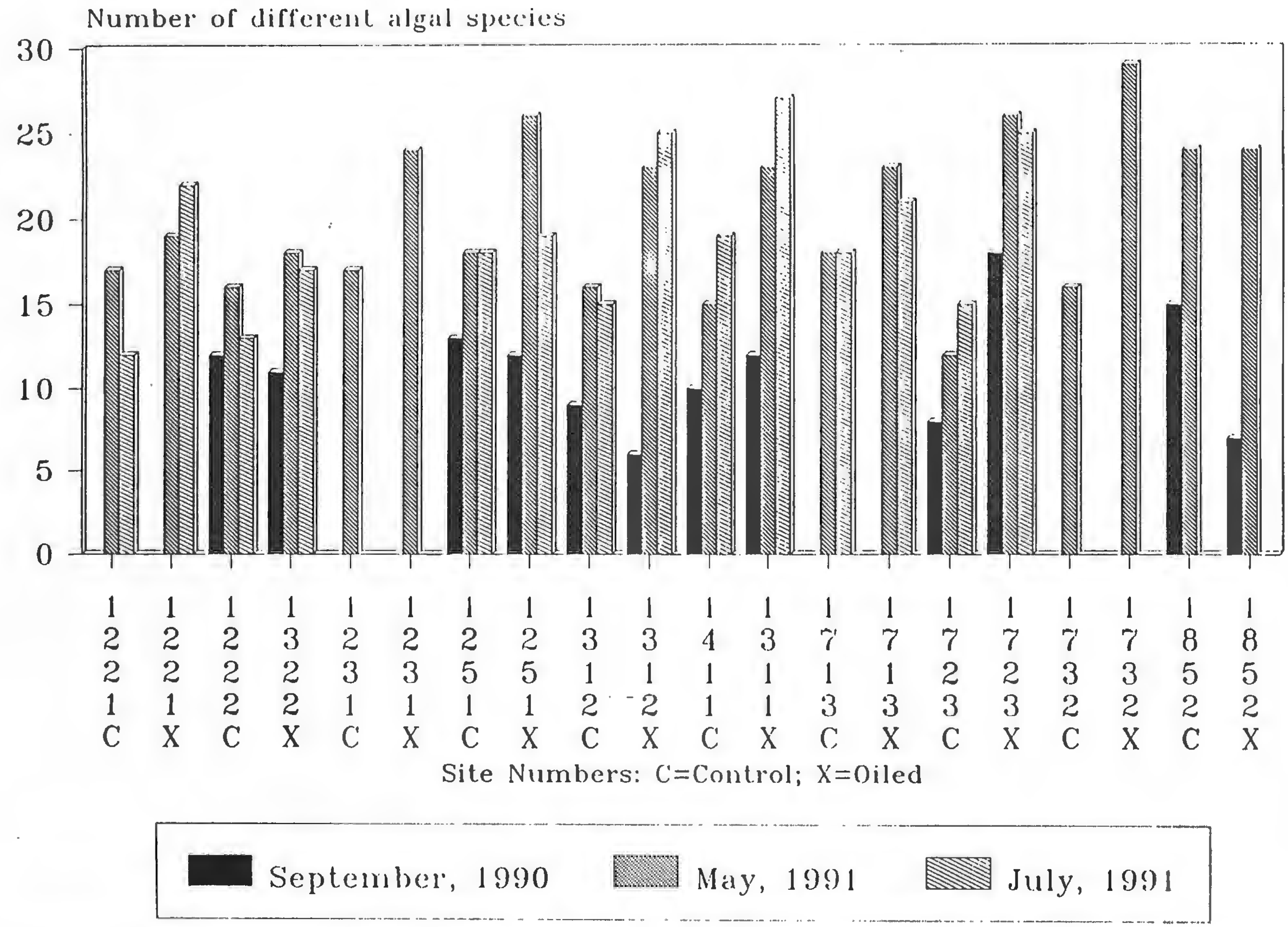


Fig. 4.5.2. Number of Algal species at oiled & control sites. Some sites not sampled in 1990.

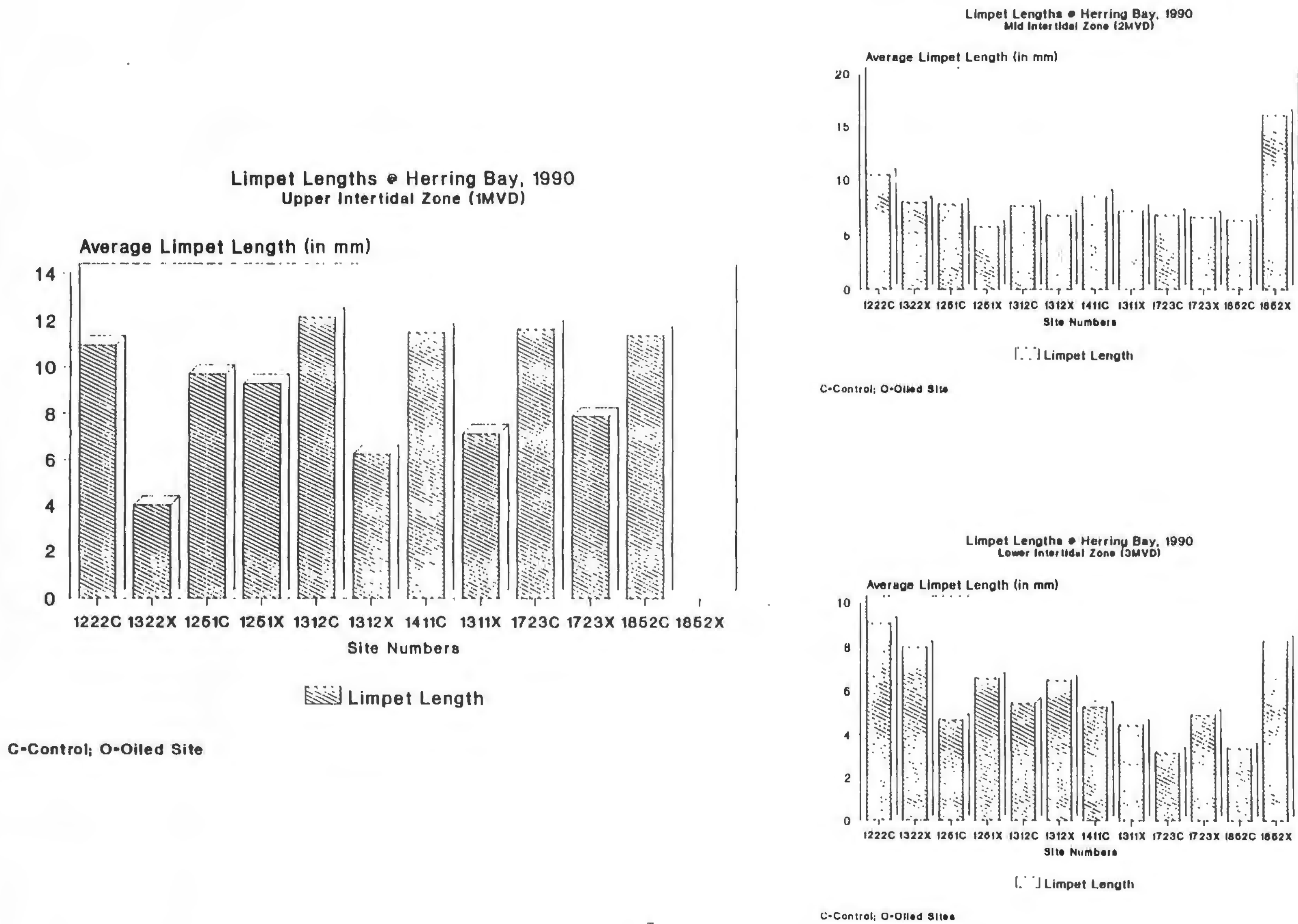
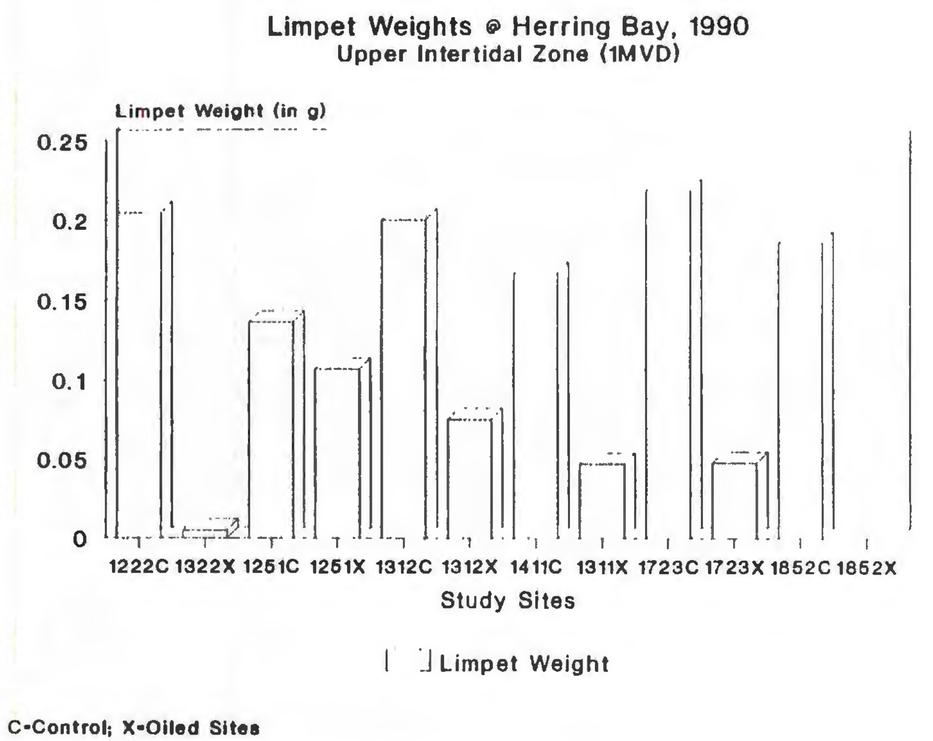
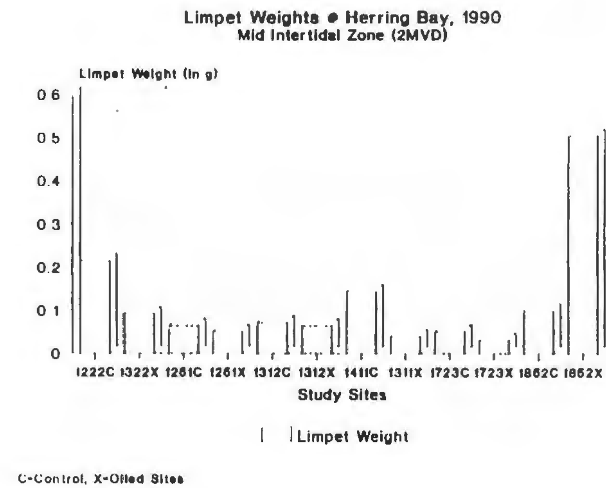


Fig. 4.6. Limpet lengths taken from Site Characterization study plots in 1990 at 3 tidal levels.





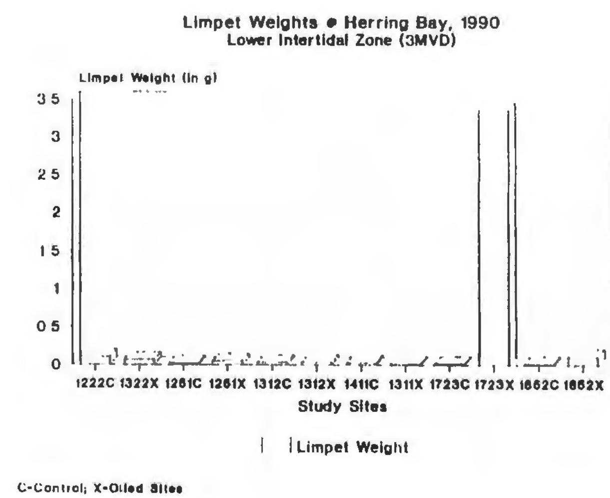


Fig. 4.7. Limpet weights taken from Site Characterization study plots in 1990 at 3 tidal levels.

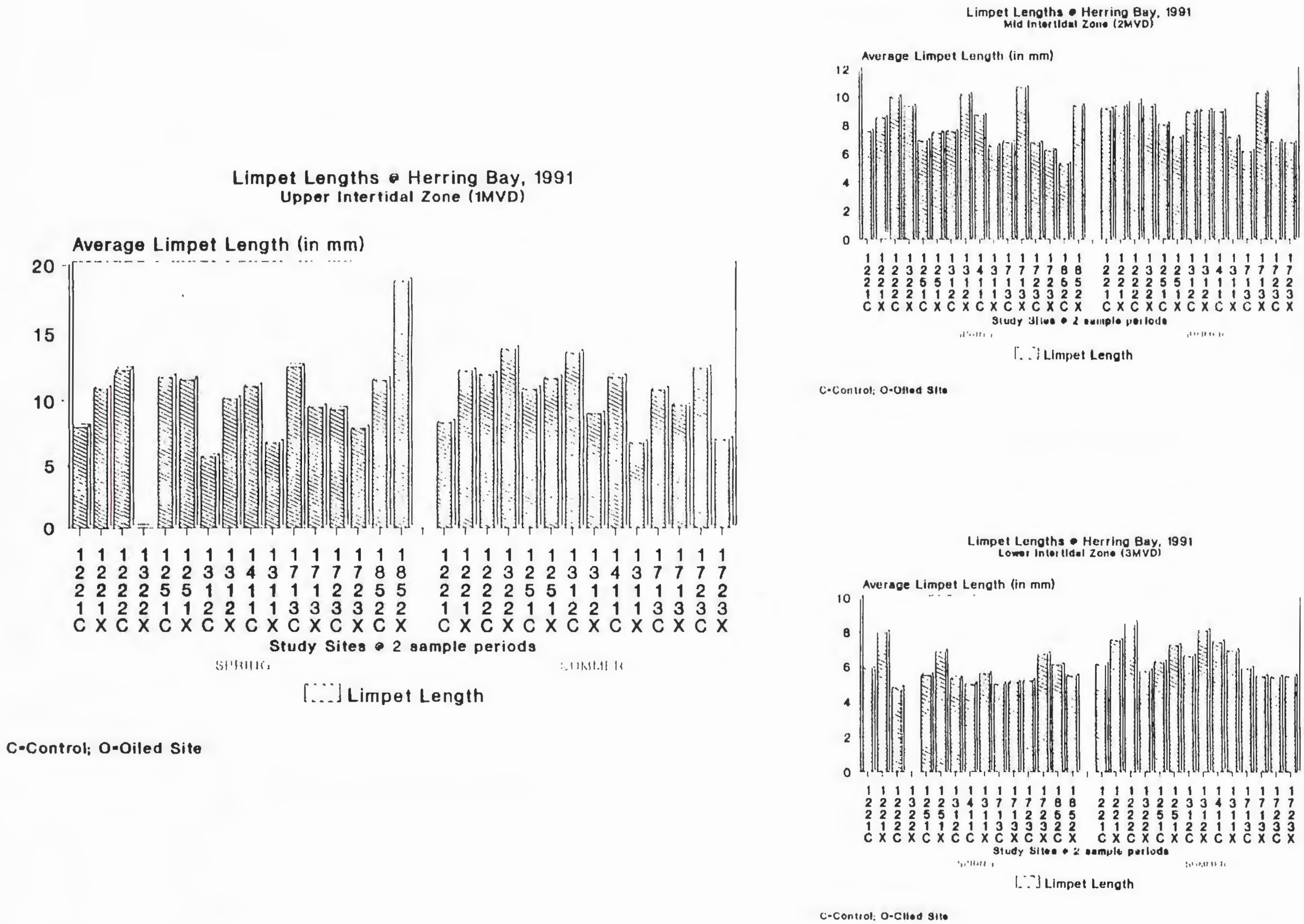


Fig. 4.8. 1991 limpet lengths taken from Site Characterization study plots. Samples are from spring and mid-summer at 3 tidal levels.

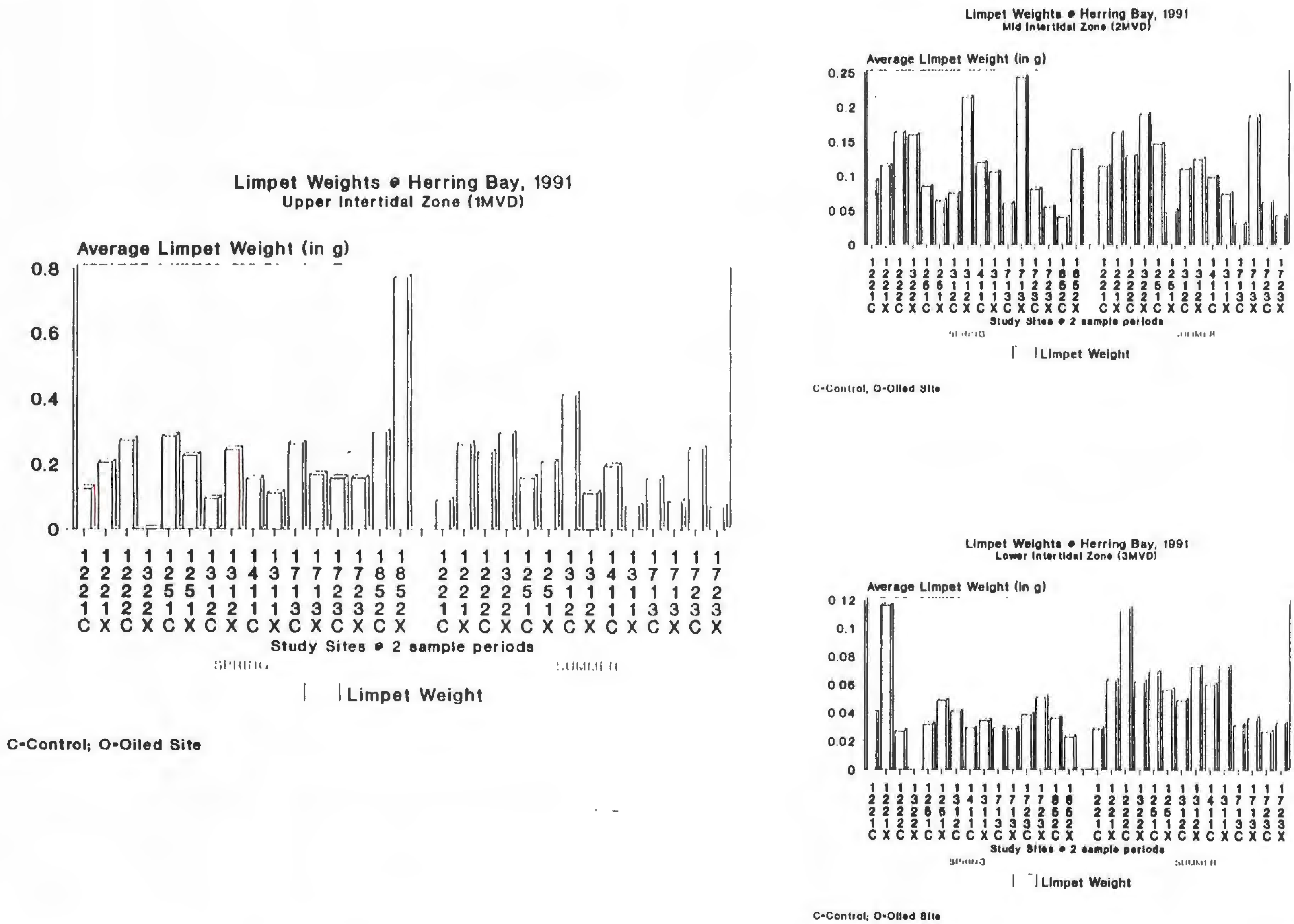
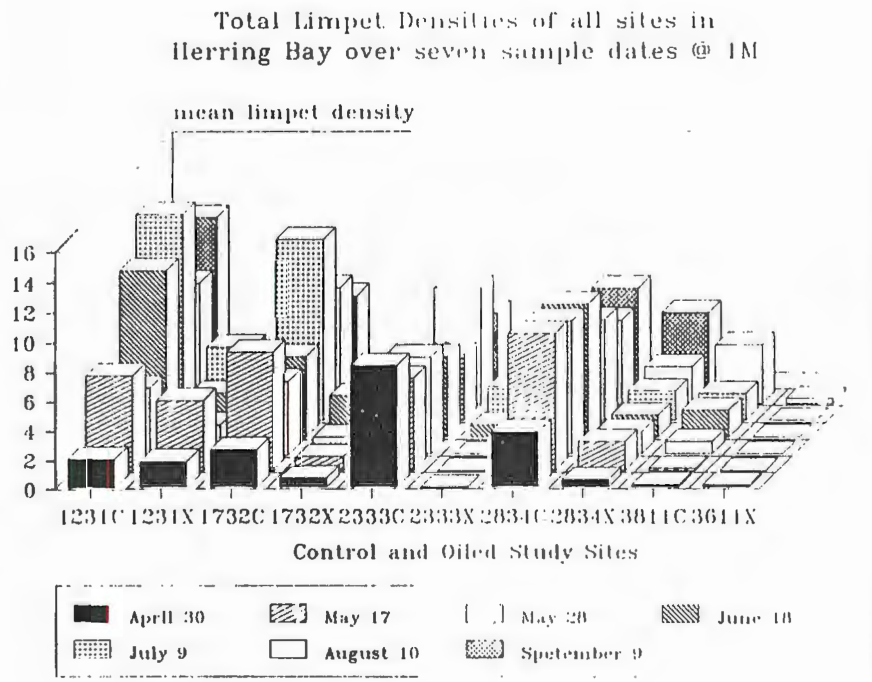
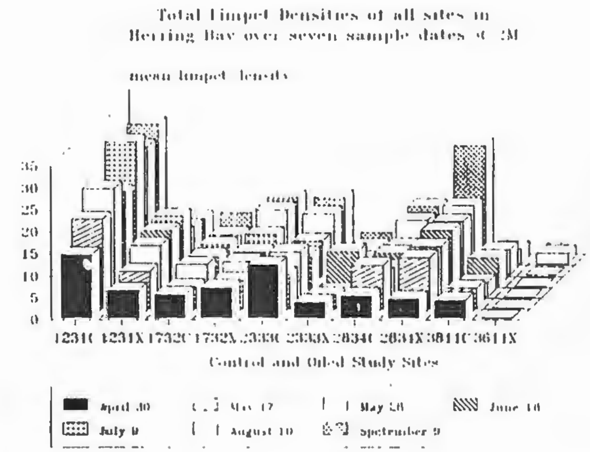


Fig. 4.9. 1991 limpet weights taken from Site Characterization study plots. Samples are from spring and mid-summer at 3 tidal levels.





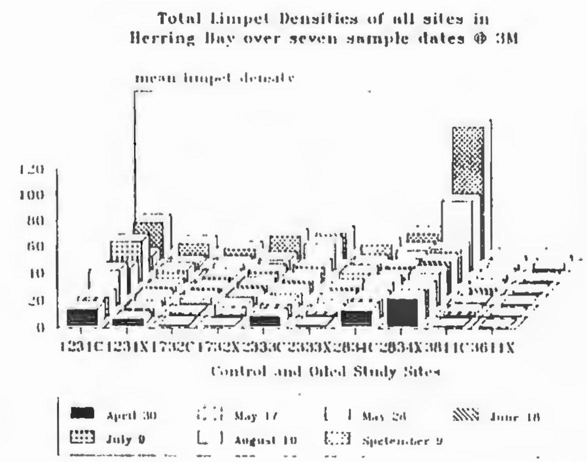


Figure 4.10 Means of total limpets at 3 tidal elevations.
Site numbers with 'C' = Control; 'O' = Oiled.

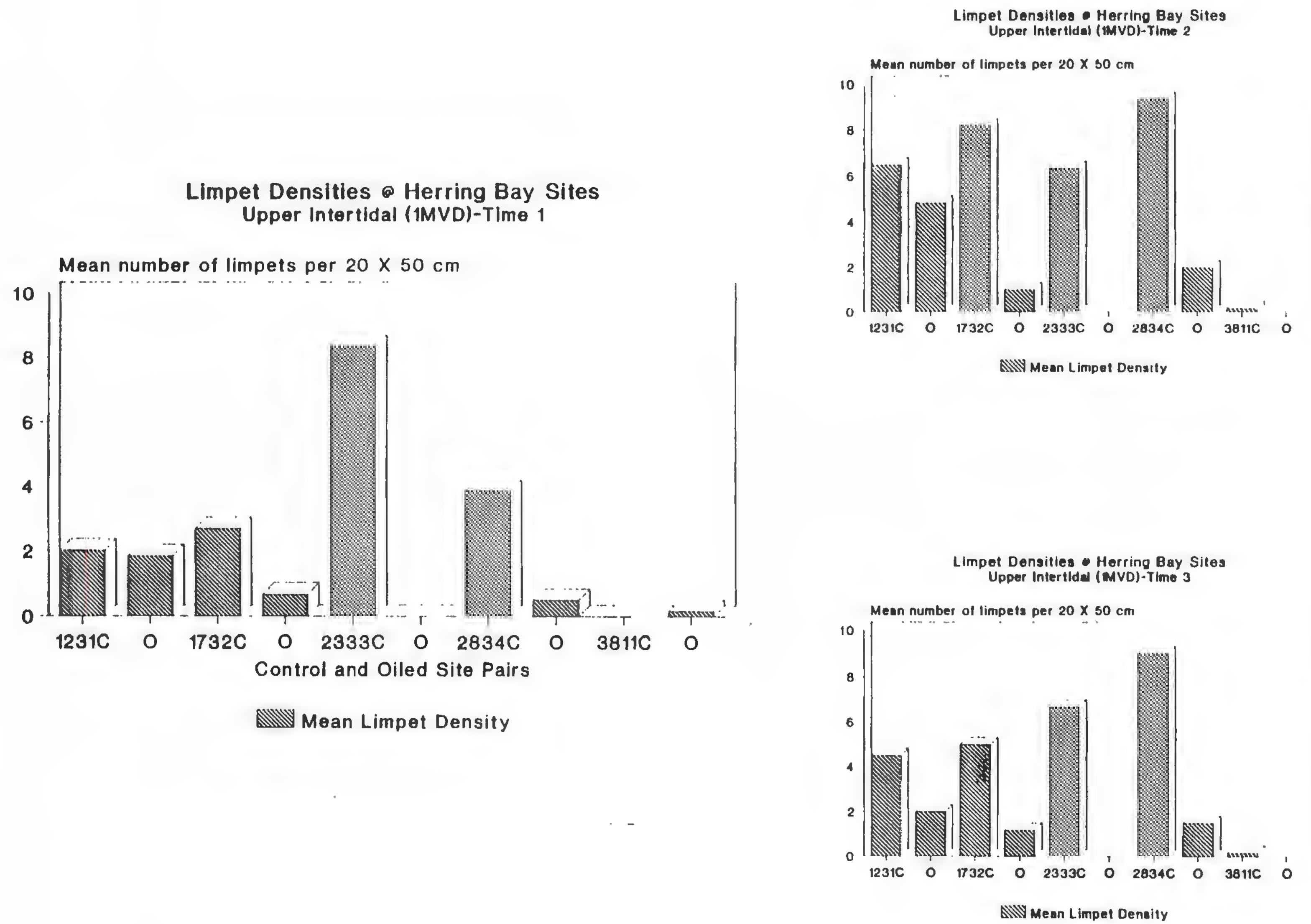


Fig. 4.11.1a. Limpet densities in the upper intertidal zone (1MVD) at five site pairs. Sample dates 1-3.

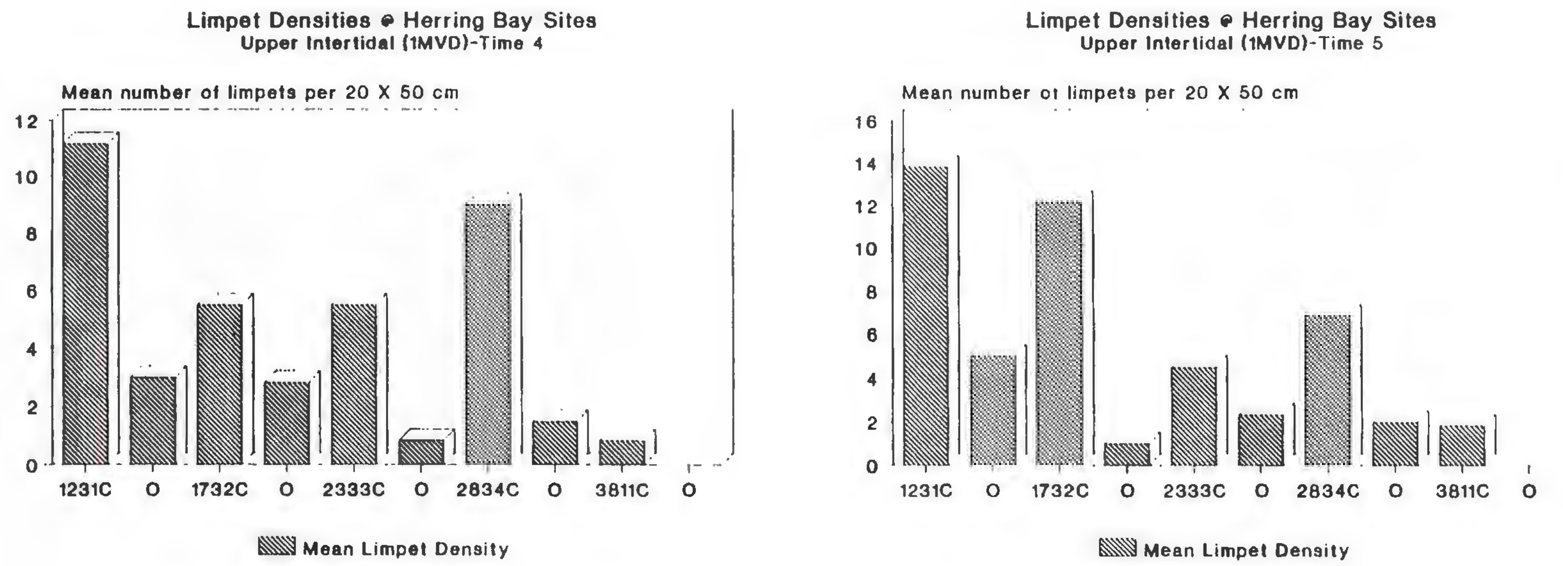


Fig. 4.11.1b. Limpet densities in the upper intertidal zone (1MVD) at five site pairs. Sample dates 4 & 5.

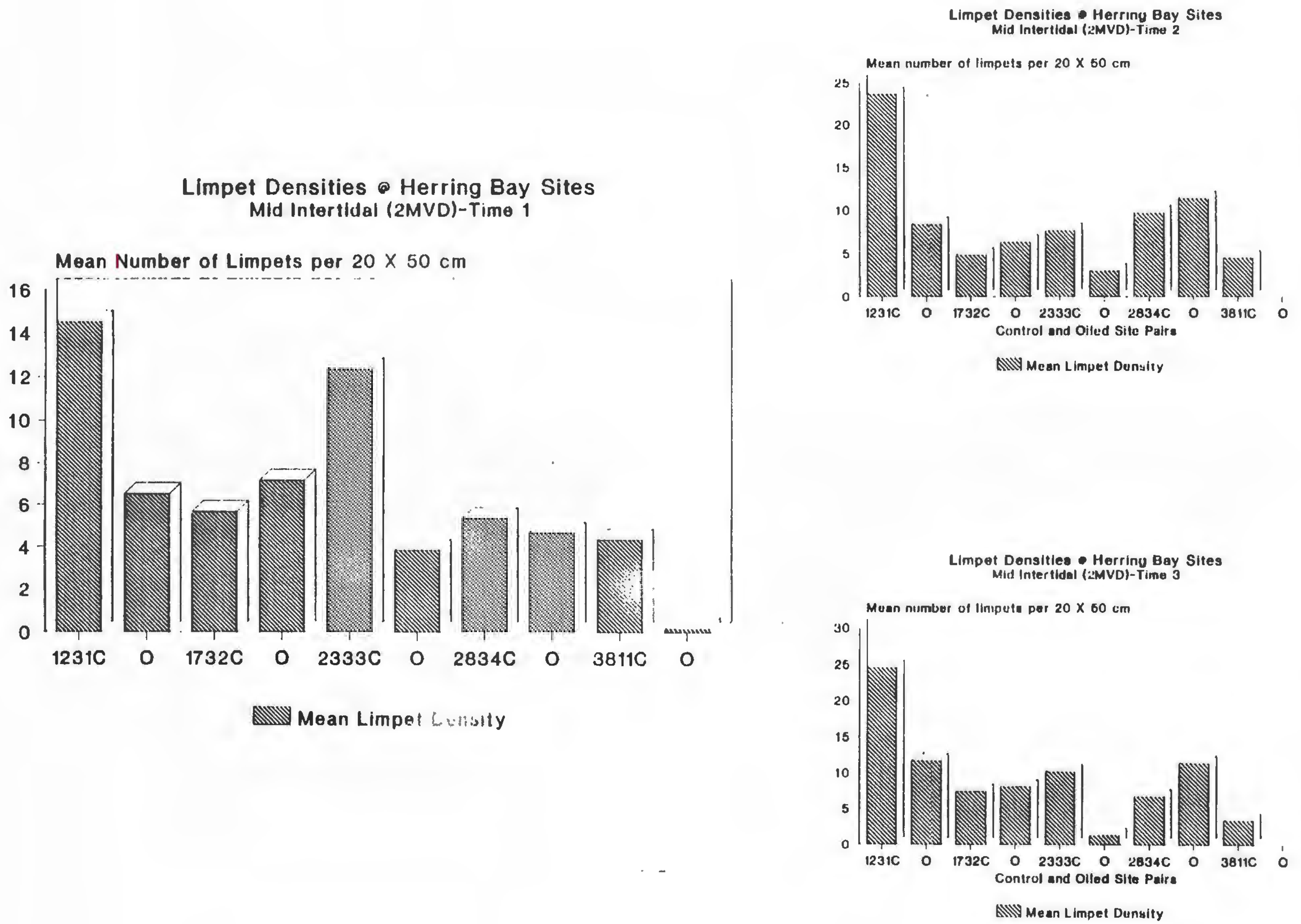


Fig. 4.11.2a. Limpet densities in the mid intertidal zone (2MVD) at five site pairs. Sample dates 1-3.

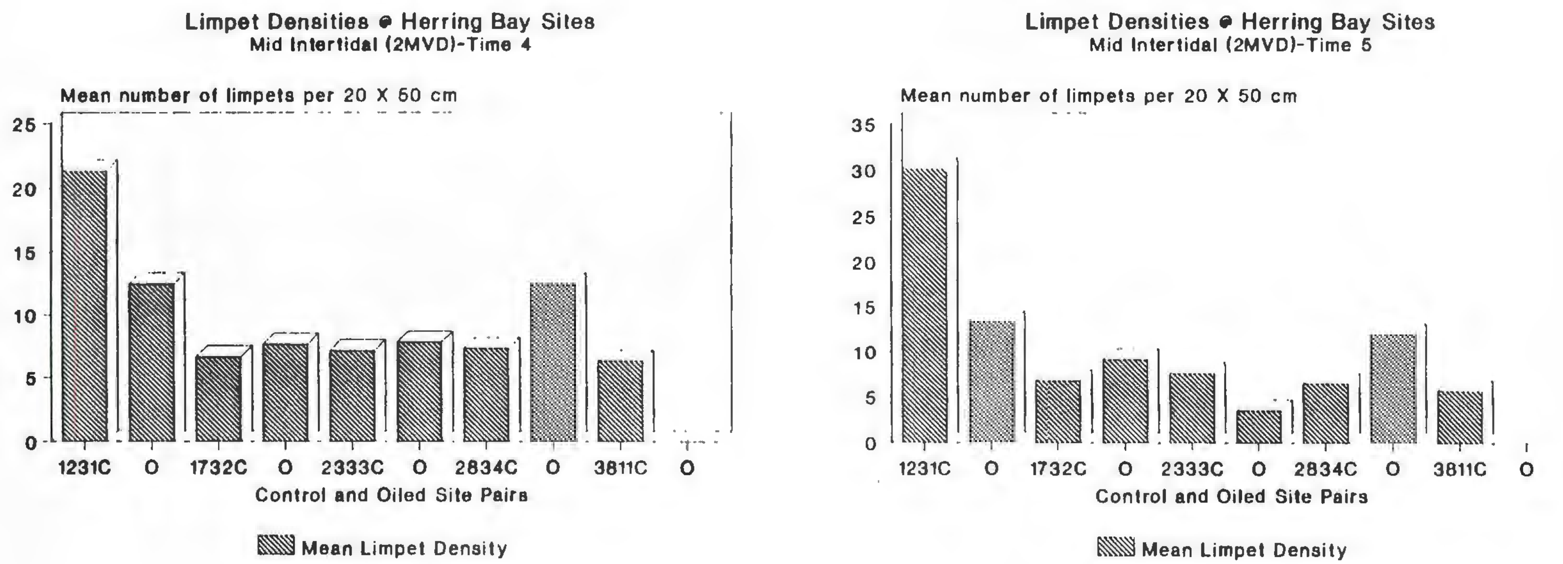


Fig. 4.11.2b. Limpet densities in the mid intertidal zone (2MVD) at five site pairs. Sample dates 4 & 5.

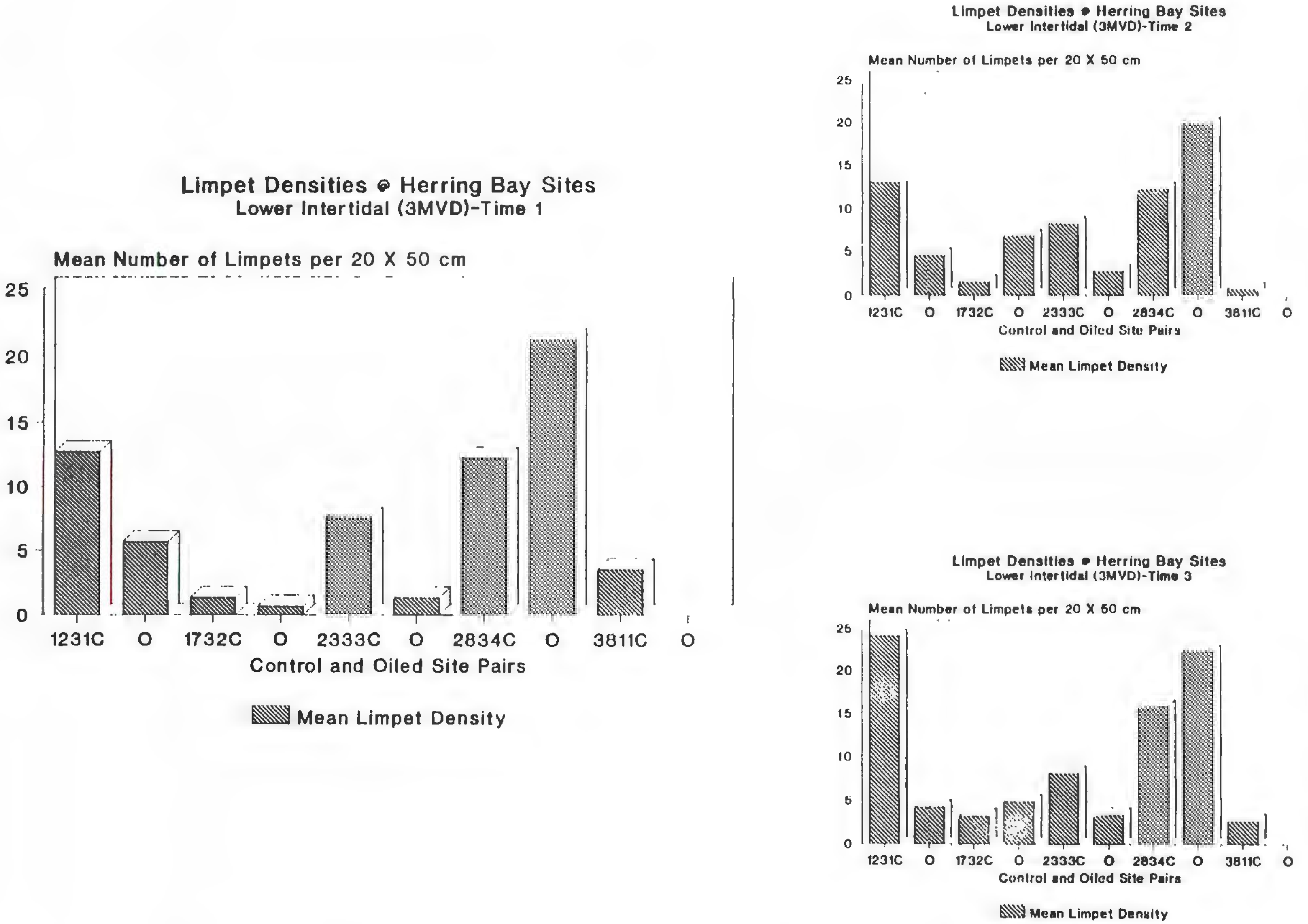
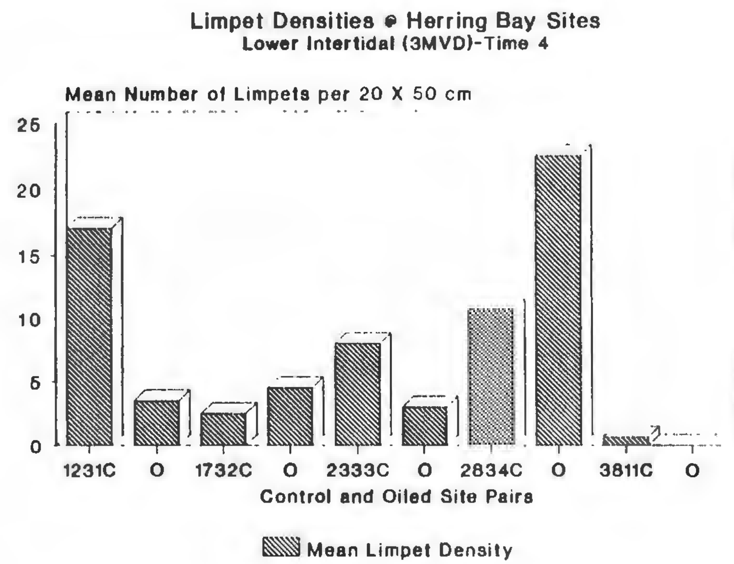


Fig. 4.11.3a. Limpet densities in the lower intertidal zone (3MVD) at five site pairs. Sample dates 1-3.



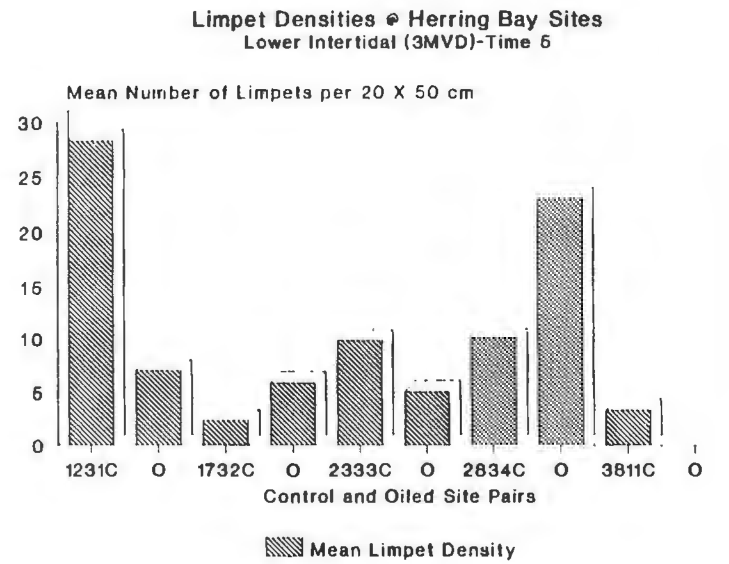


Fig. 4.11.3b. Limpet densities in the lower intertidal zone (3MVD) at five site pairs. Sample dates 4 & 5.

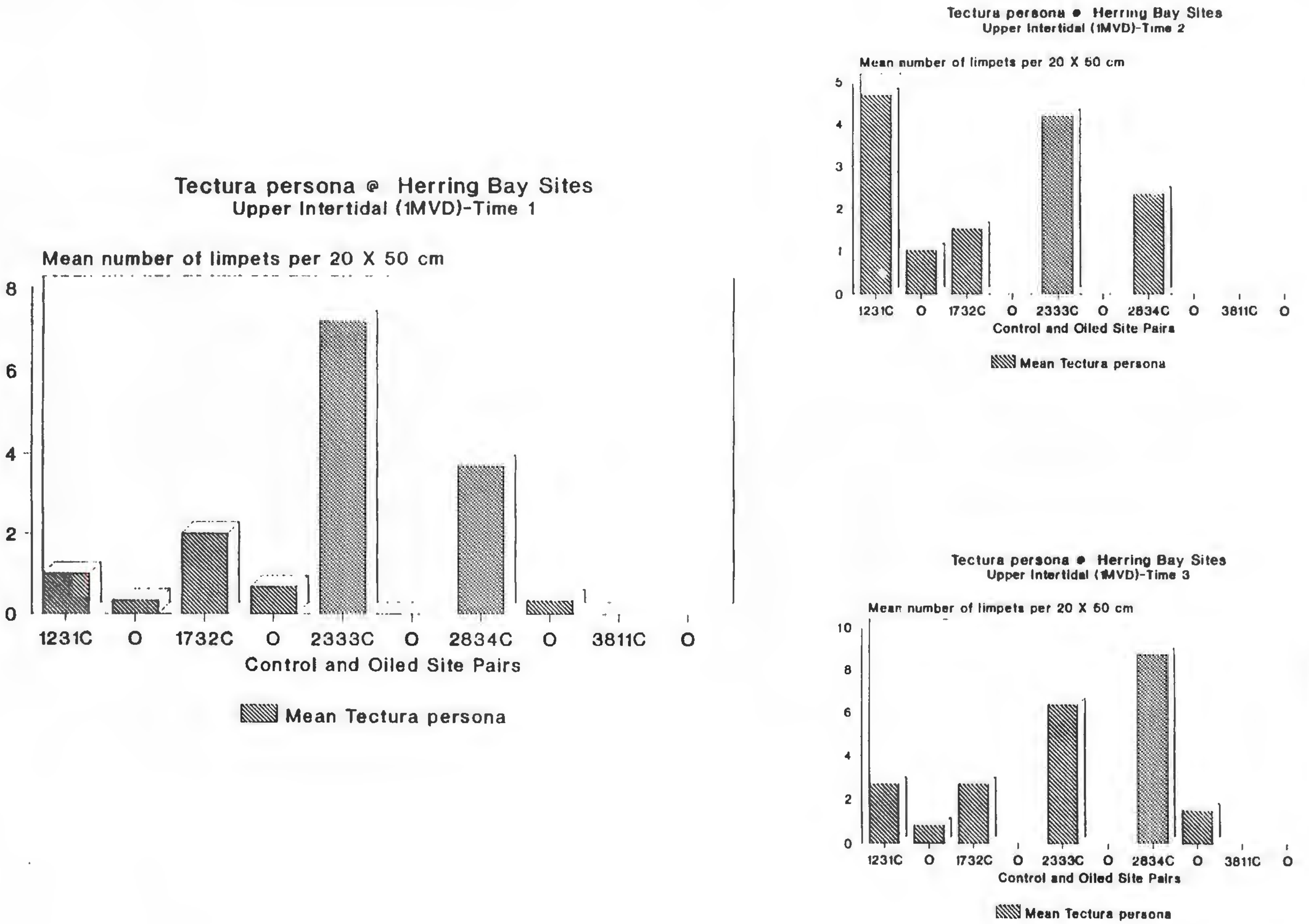
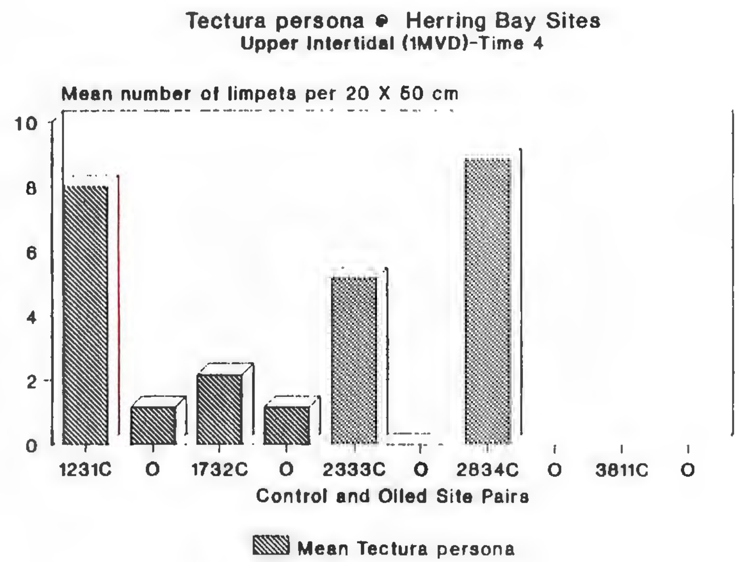


Fig. 4.11.4a. Densities of the limpet, *Tectura persona* in the upper intertidal zone (1MVD) at five site pairs. Sample dates 1-3.



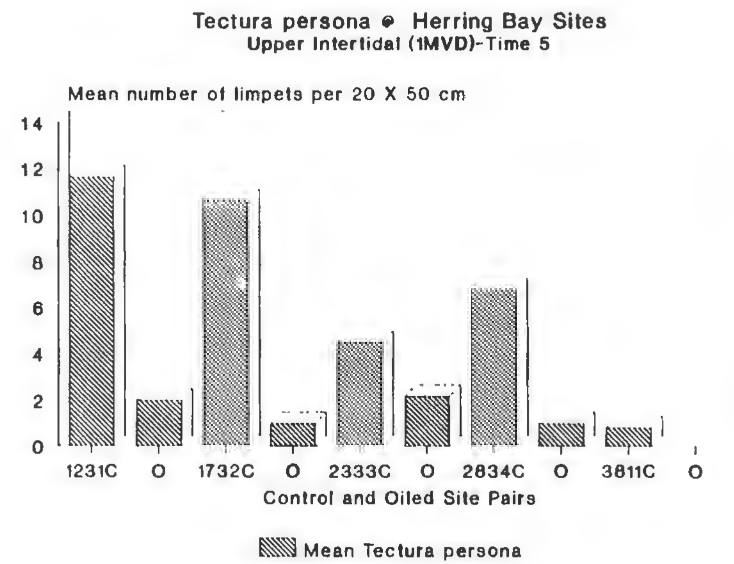
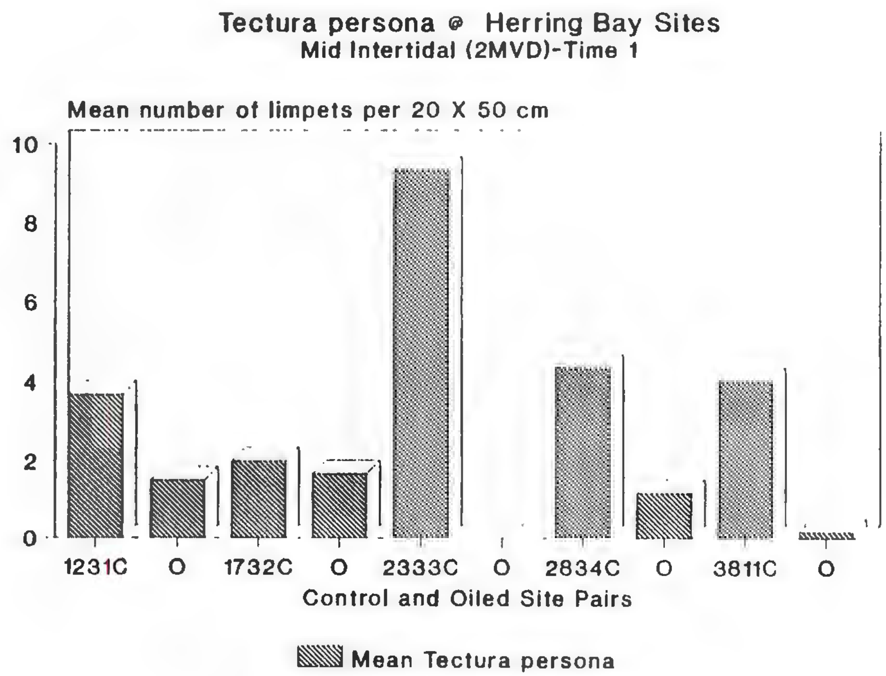
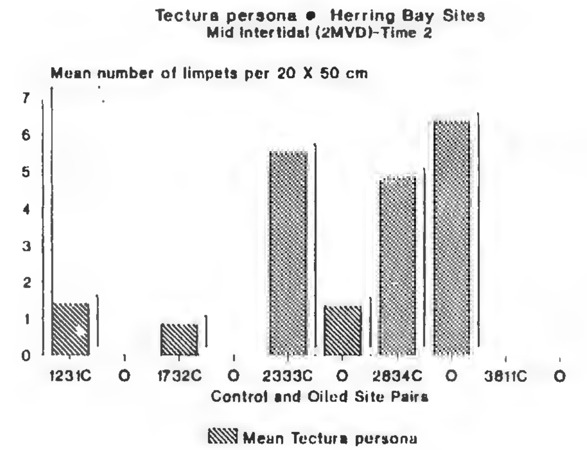


Fig. 4.11.4b. Densities of the limpet, *Tectura persona* in the upper intertidal zone (1MVD) at five site pairs. Sample dates 4 & 5.





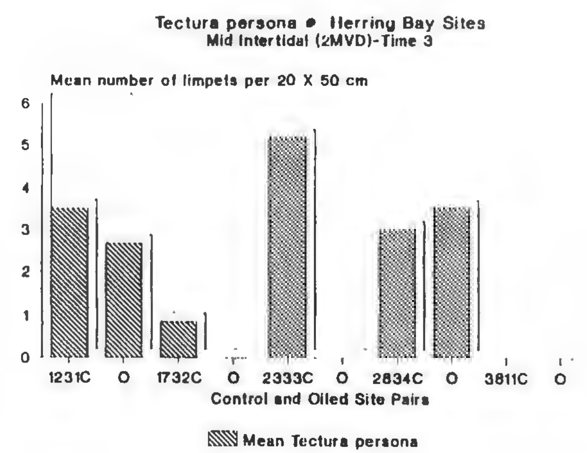
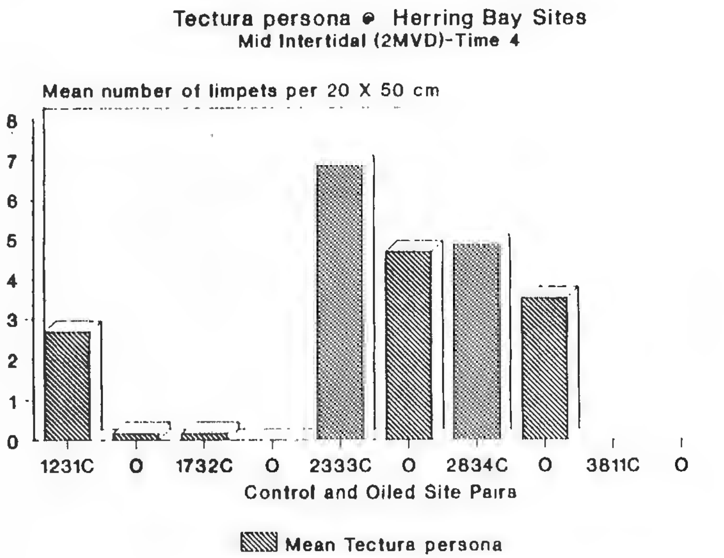


Fig. 4.11.5a. Densities of the limpet, *Tectura persona* in the mid intertidal zone (2MVD) at five site pairs. Sample dates 1-3.



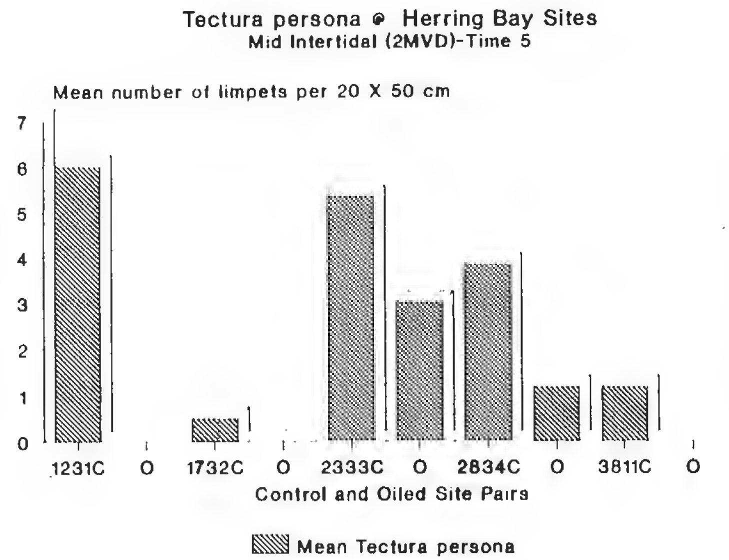
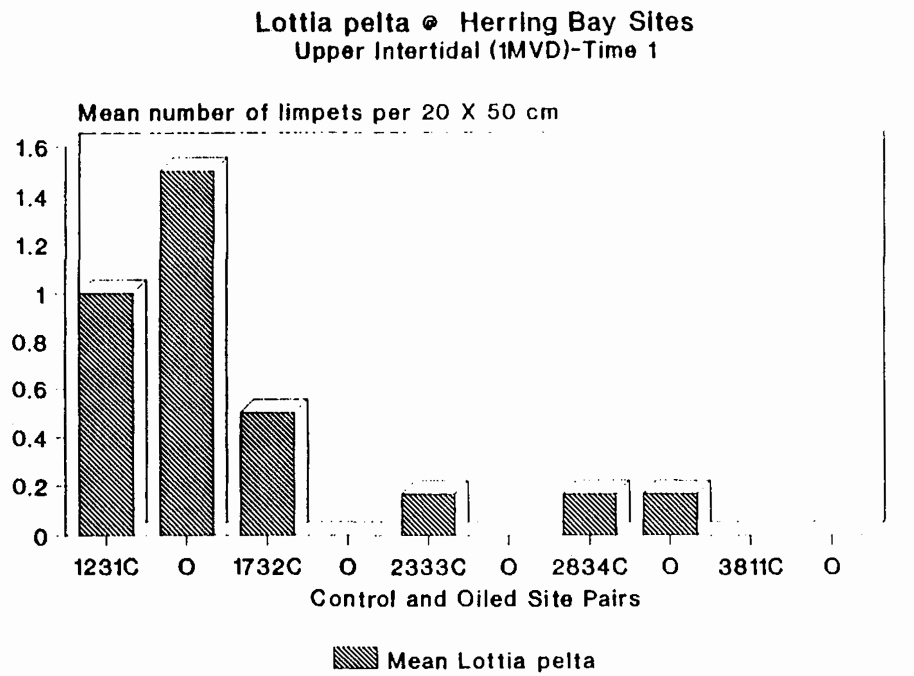
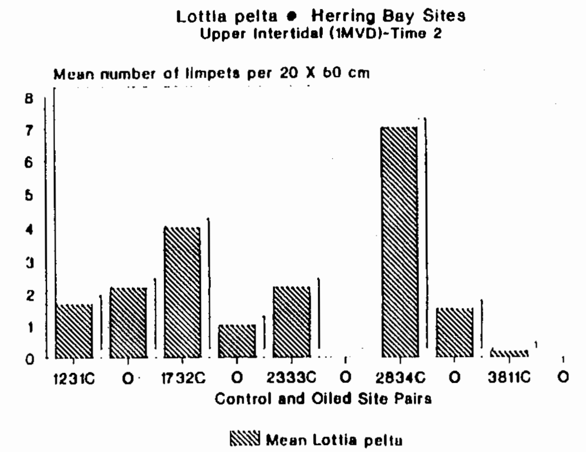


Fig. 4.11.5b. Densities of the limpet, *Tectura persona* in the mid intertidal zone (2MVD) at five site pairs. Sample dates 4 & 5.





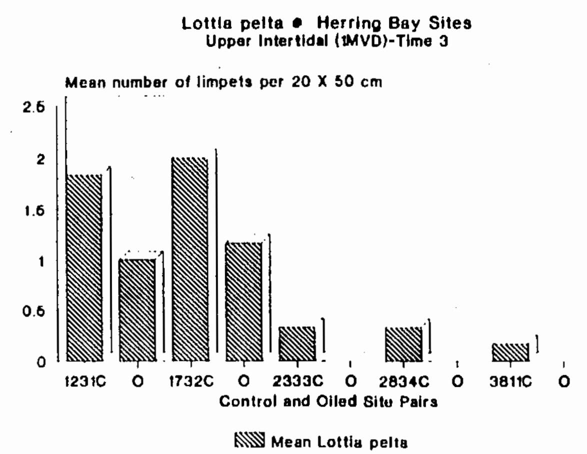


Fig. 4.11.6a. Densities of the limpet, *Lottia pelta,* in the upper intertidal zone (1MVD) at five site pairs. Sample dates 1-3.

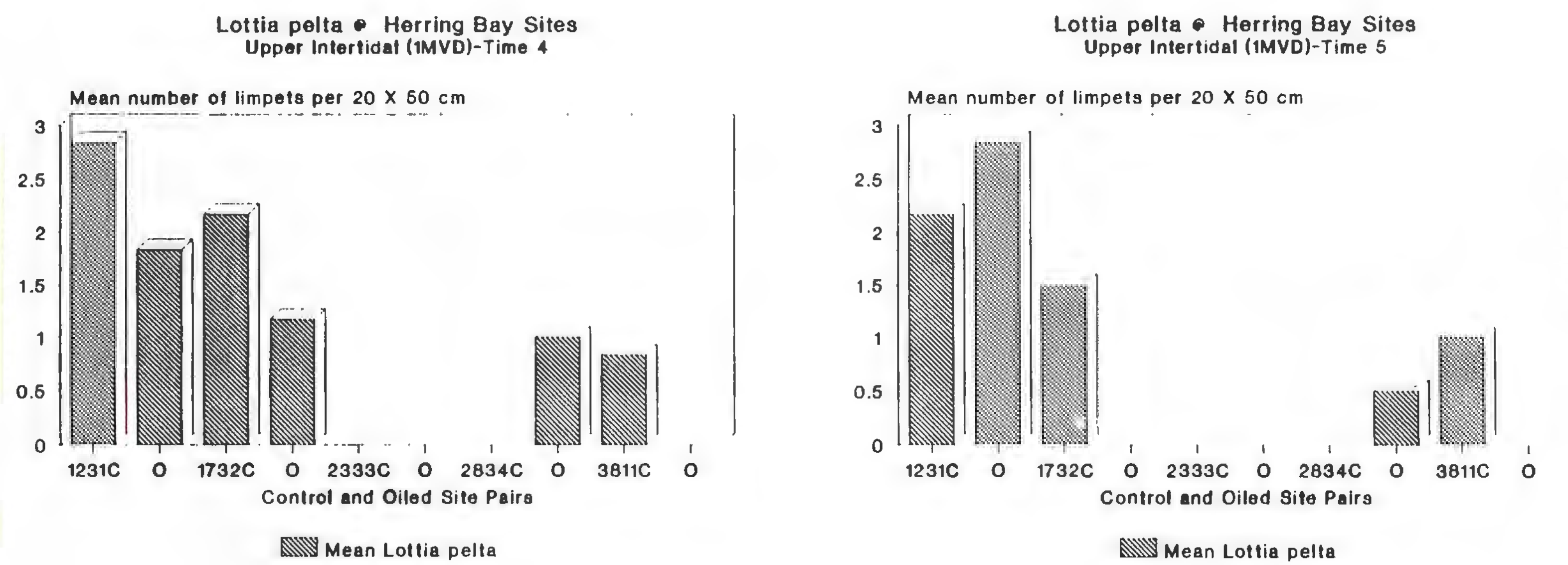


Fig. 4.11.6b. Densities of the limpet, *Lottia pelta,* in the upper intertidal zone (1MVD) at five site pairs. Sample dates 4 & 5.

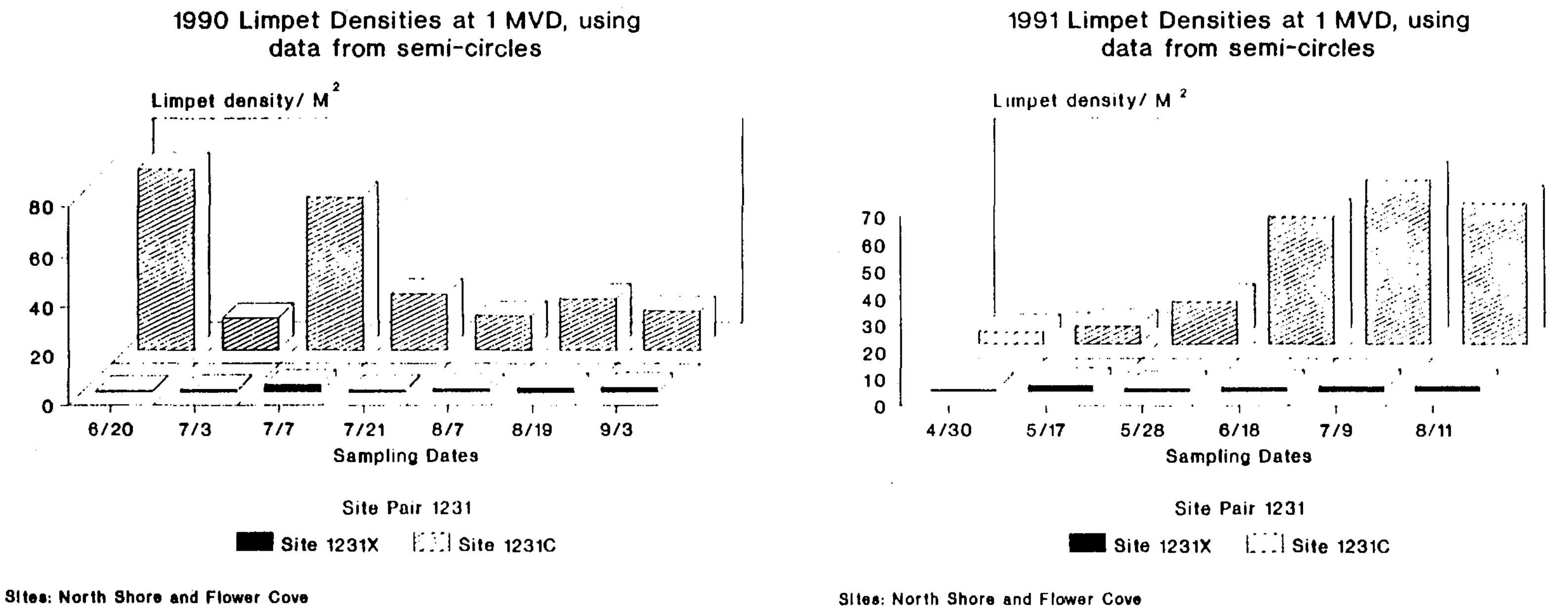
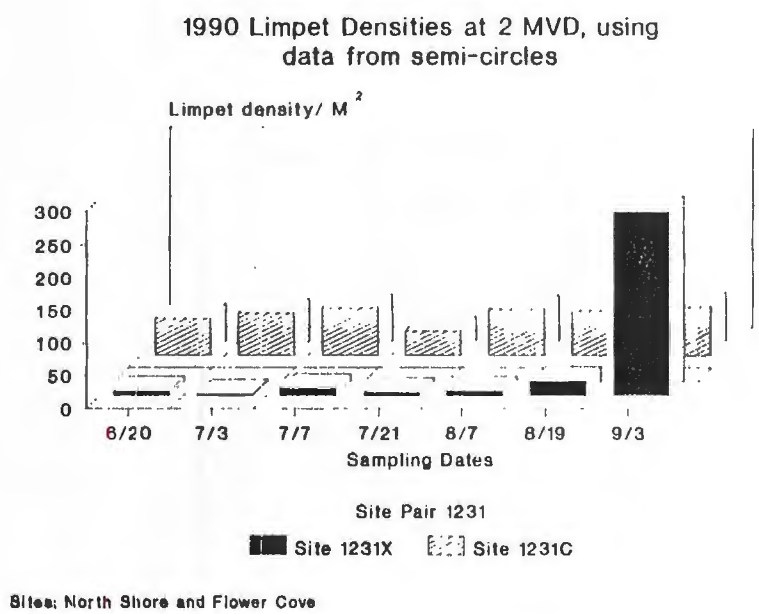


Fig. 4.11.7a. Limpet densities from semicircle estimates at site pair 1231, upper intertidal zone (1MVD).



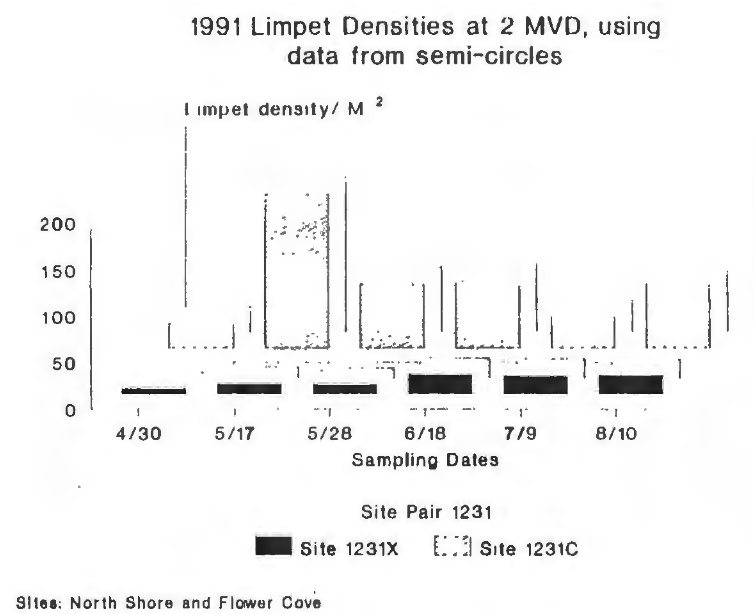
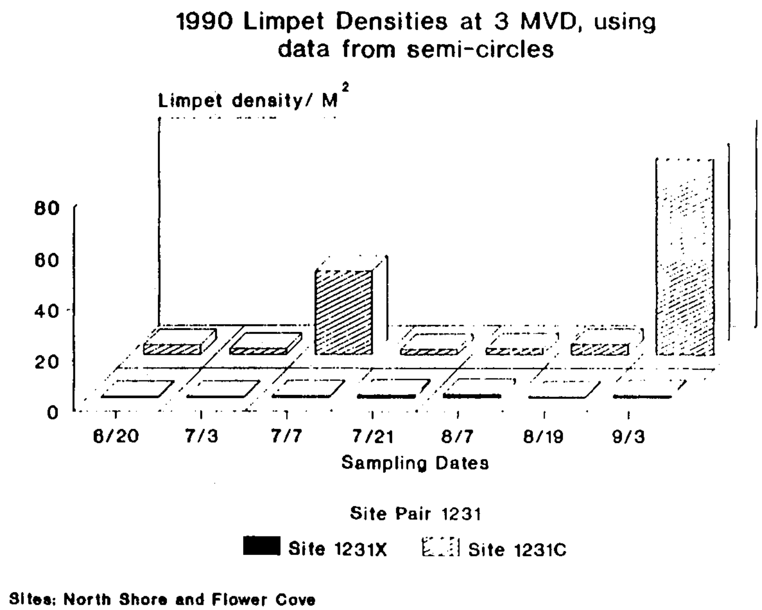


Fig. 4.11.7b. Limpet densities from semicircle estimates at site pair 1231, mid intertidal zone (2MVD).



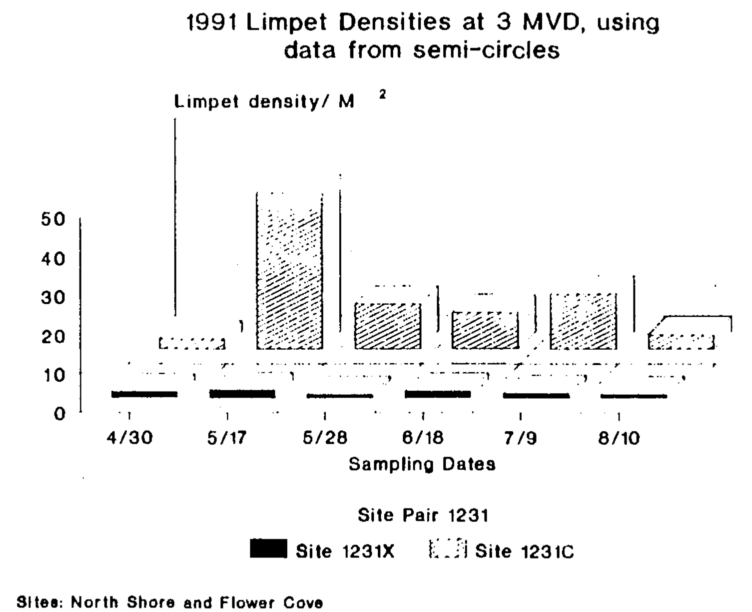
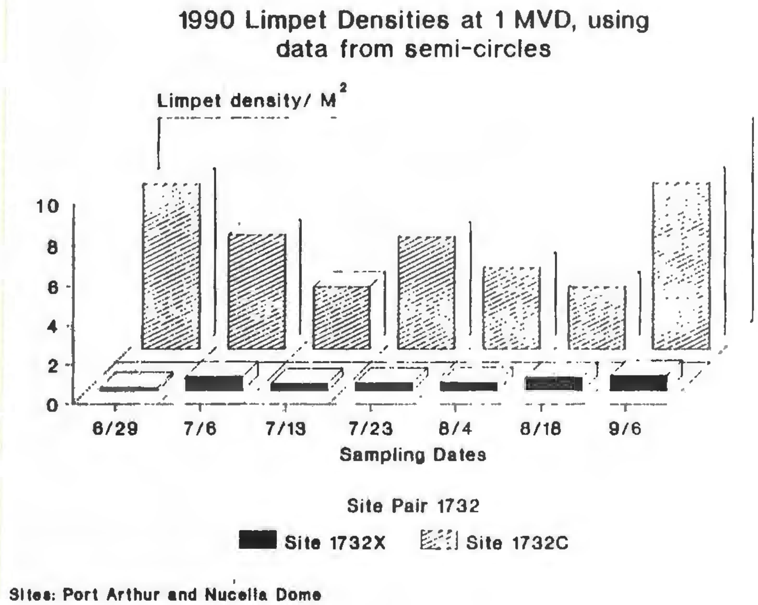


Fig. 4.11.7c. Limpet densities from semicircle estimates at site pair 1231, lower intertidal zone (3MVD).



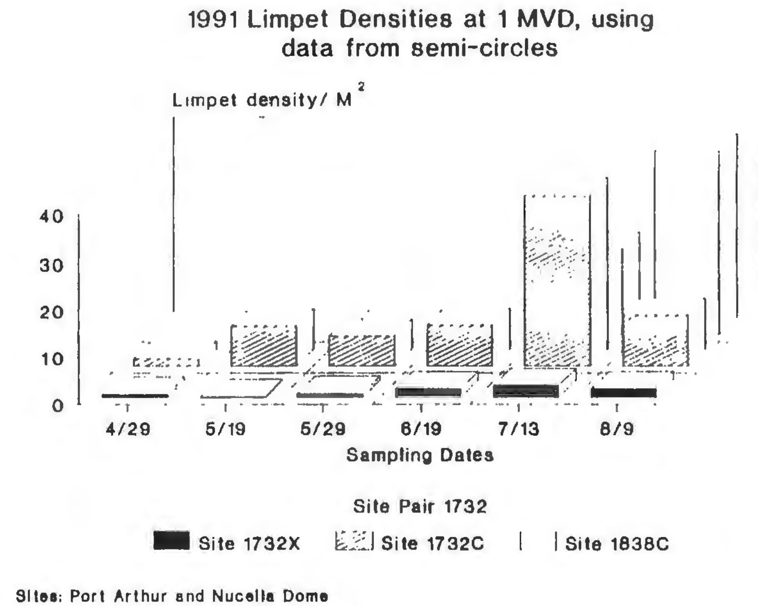
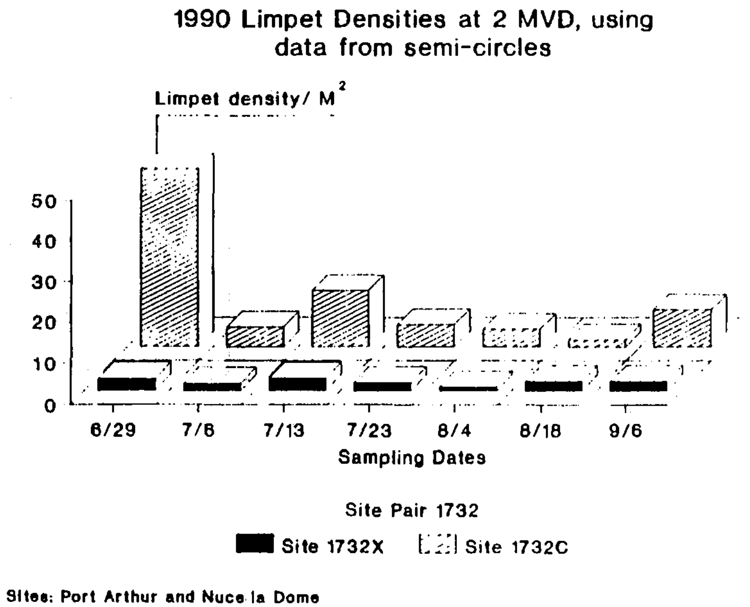


Fig. 4.11.8a. Limpet densities from semicircle estimates at site pair 1732, upper intertidal zone (1MVD). Site 1838C is a second control site, used to compare density estimates to 1732C based on similar location and percent slope.



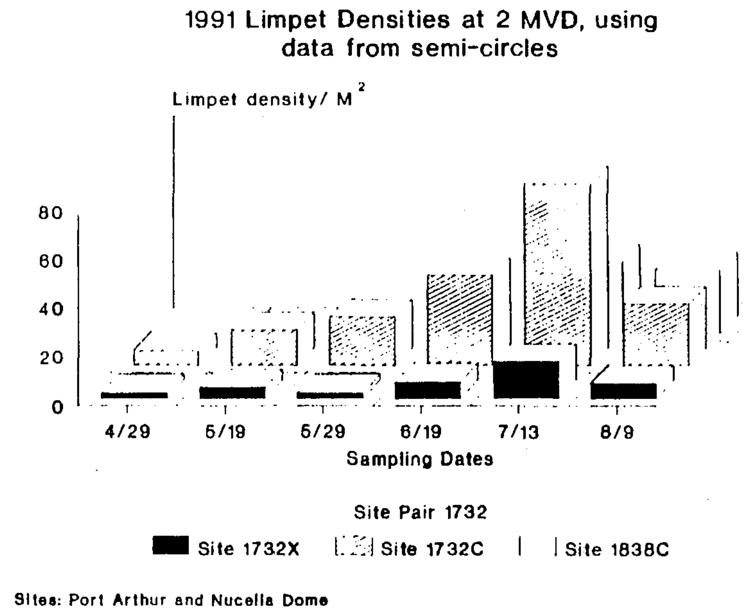
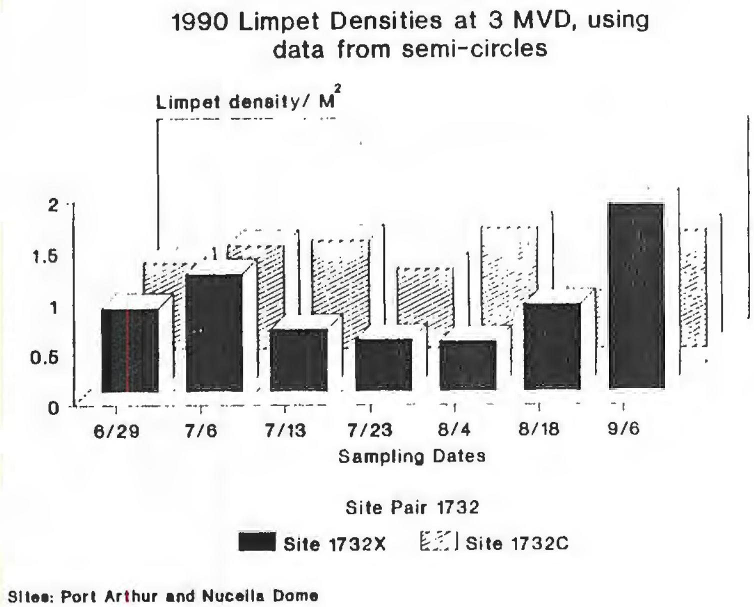


Fig. 4.11.8b. Limpet densities from semicircle estimates at site pair 1732, mid intertidal zone (2MVD). Site 1838C is a second control site, used to compare density estimates to 1732C based on similar location and percent slope.



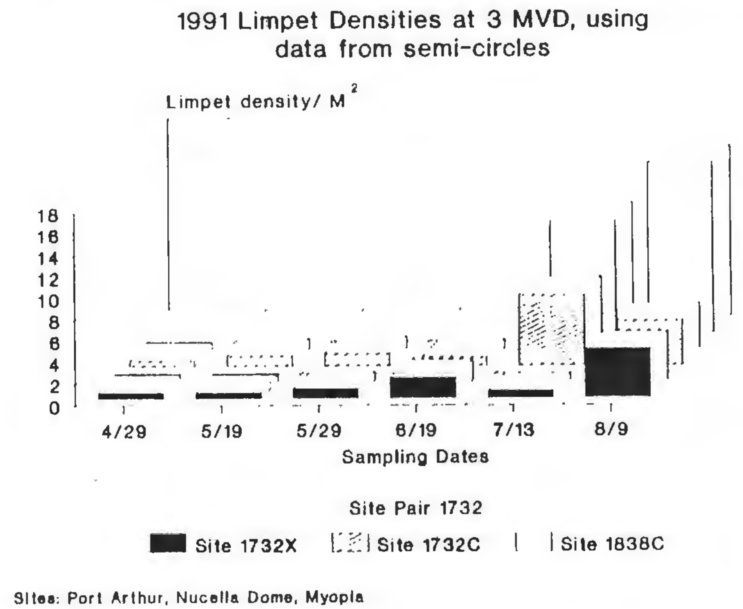
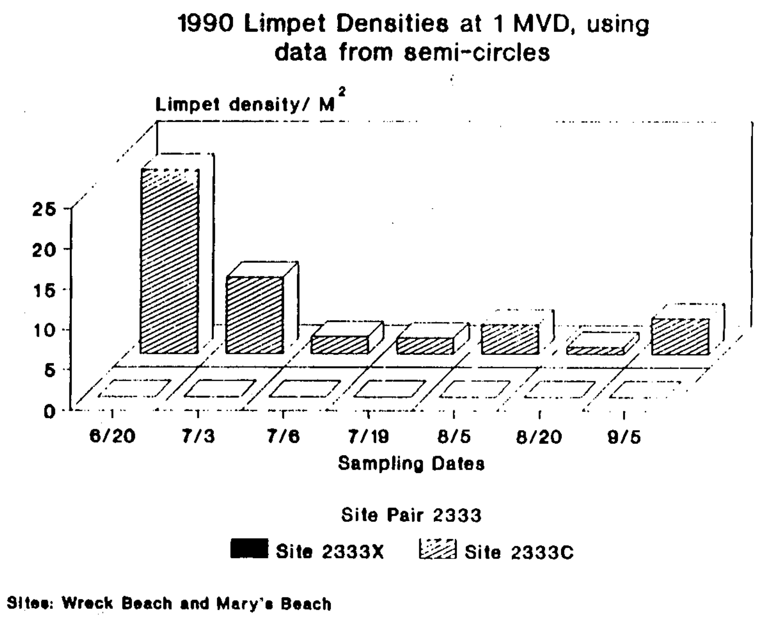


Fig. 4.11.8c. Limpet densities from semicircle estimates at site pair 1732, lower intertidal zone (3MVD). Site 1838C is a second control site, used to compare density estimates to 1732C based on similar location and percent slope.



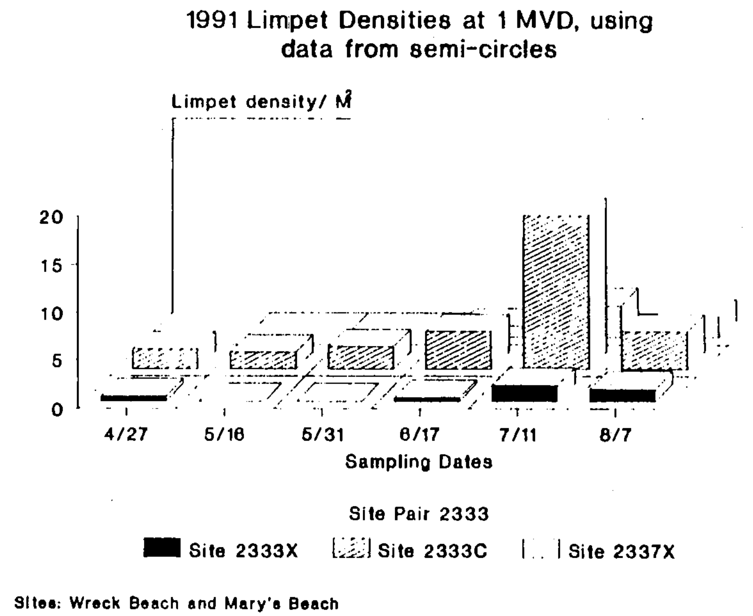
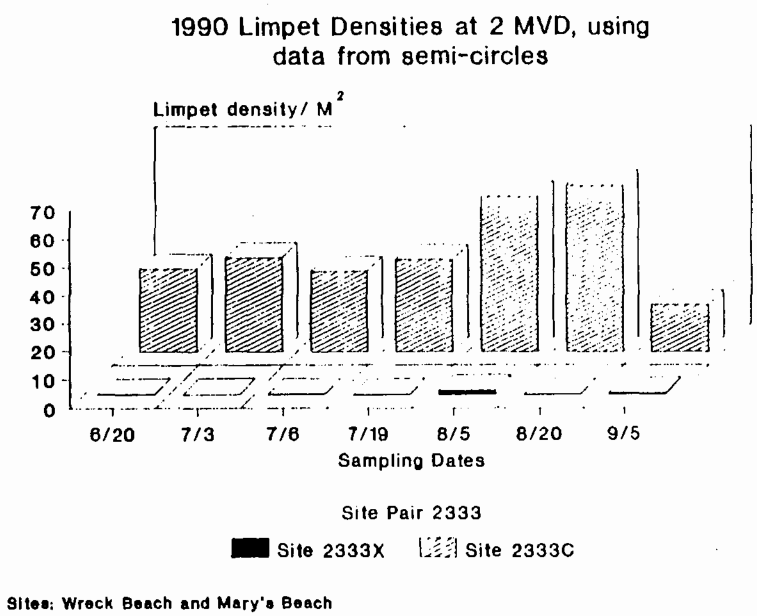


Fig. 4.11.9a. Limpet densities from semicircle estimates at site pair 2333, upper intertidal zone (1MVD). Site 2337X is a second coarse-textured oiled site established in 1991, and is matched to 2333C.



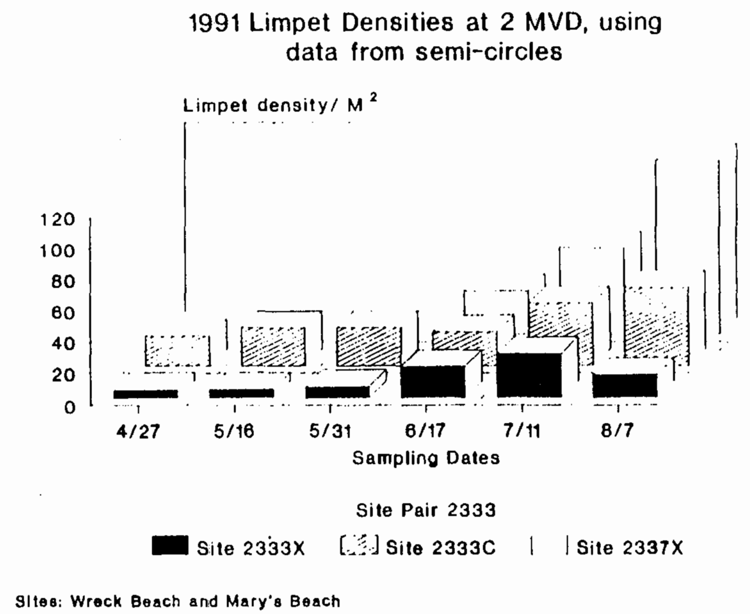
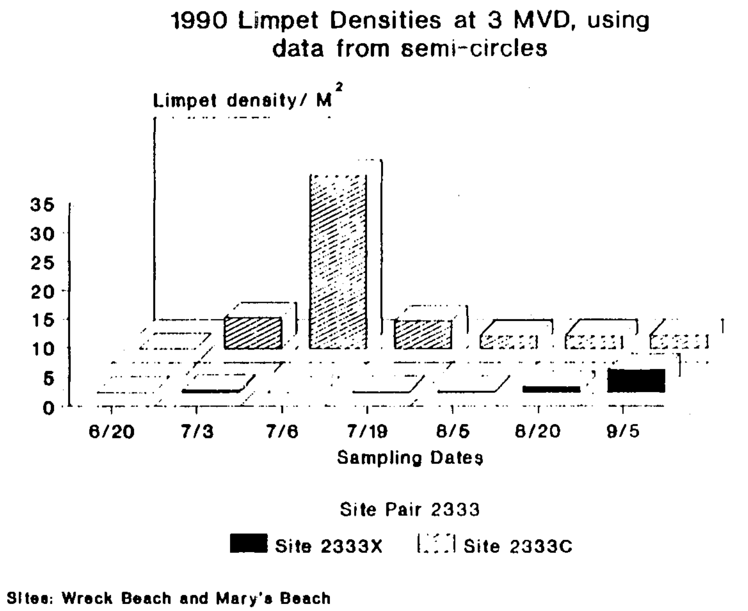


Fig. 4.11.9b. Limpet densities from semicircle estimates at site pair 2333, mid intertidal zone (2MVD). Site 2337X is a second coarse-textured oiled site established in 1991, and is matched to 2333C.



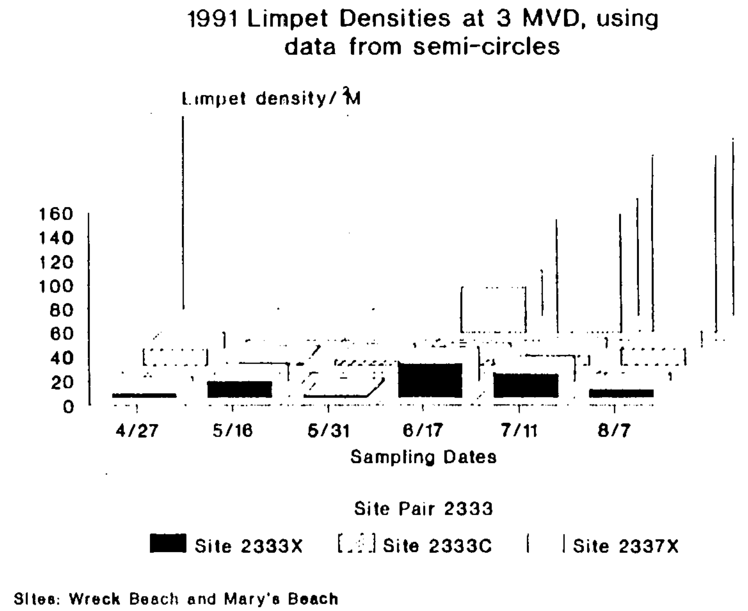
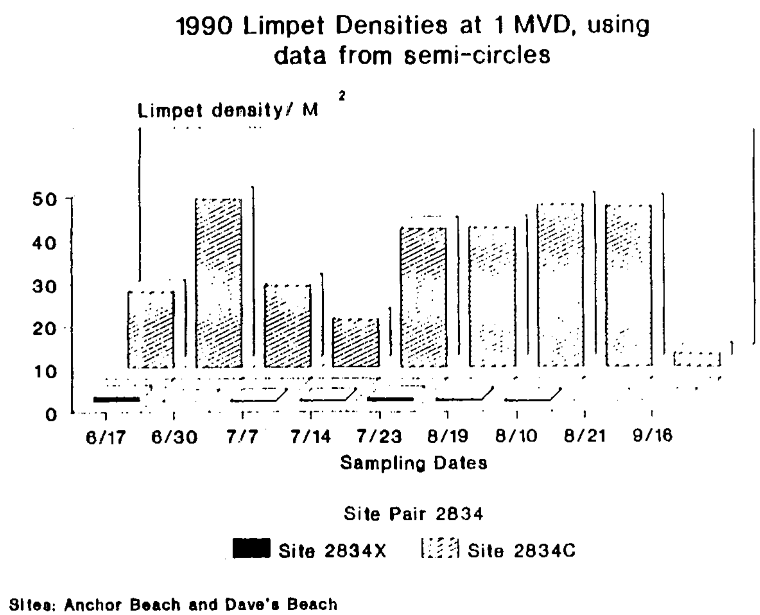


Fig. 4.11.9c. Limpet densities from semicircle estimates at site pair 2333, lower intertidal zone (3MVD). Site 2337X is a second coarse-textured oiled site established in 1991, and is matched to 2333C.



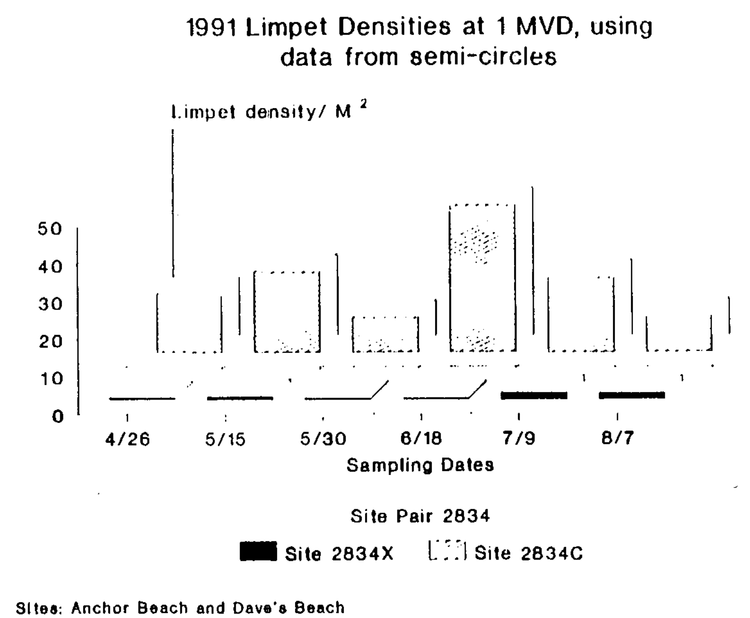
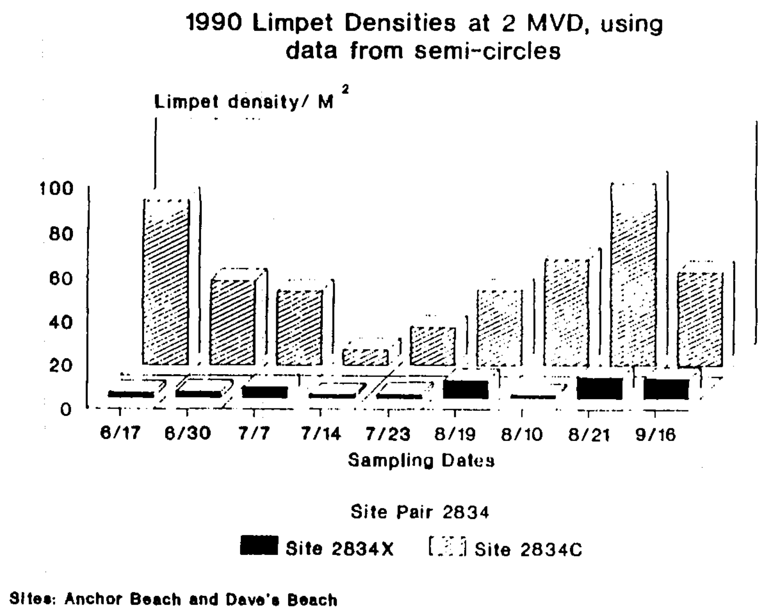


Fig. 4.11.10a. Limpet densities from semicircle estimates at site pair 2834, upper intertidal zone (1MVD).



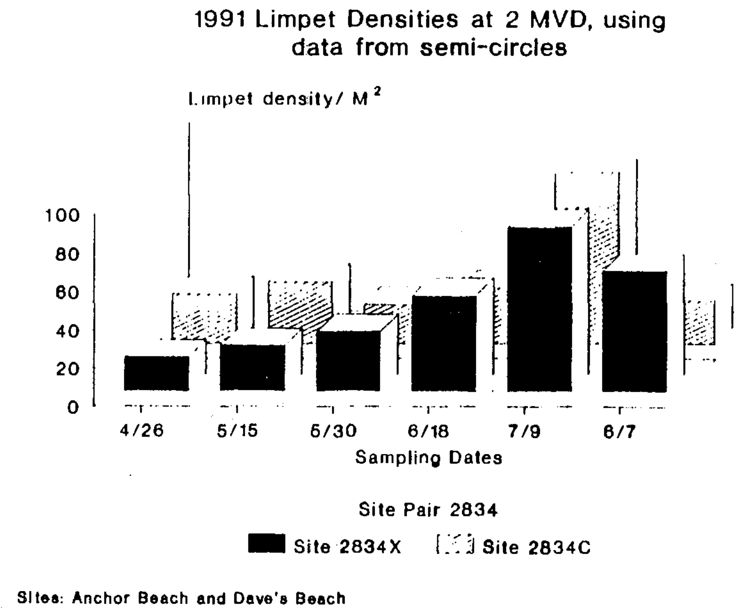
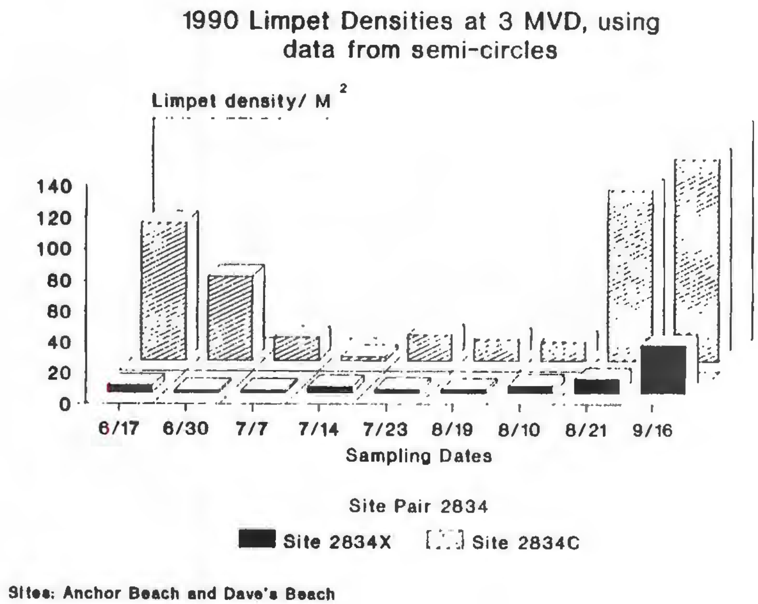


Fig. 4.11.10b. Limpet densities from semicircle estimates at site pair 2834, mid intertidal zone (2MVD).



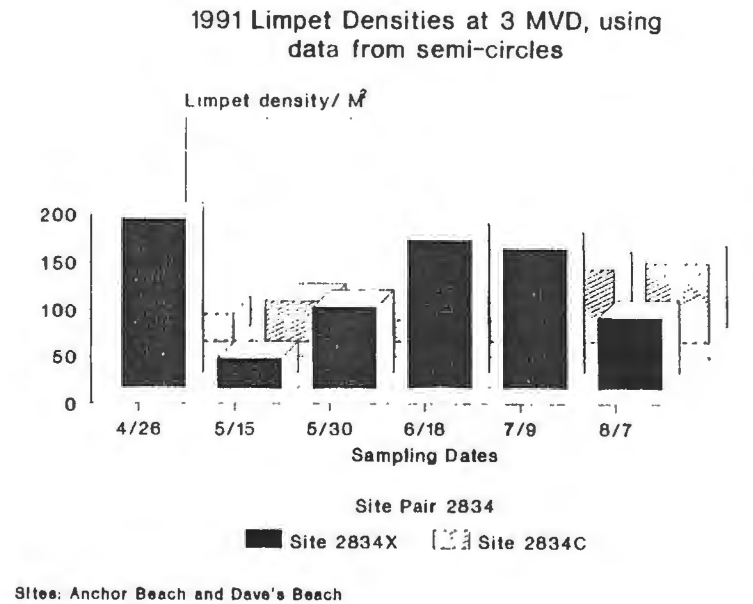
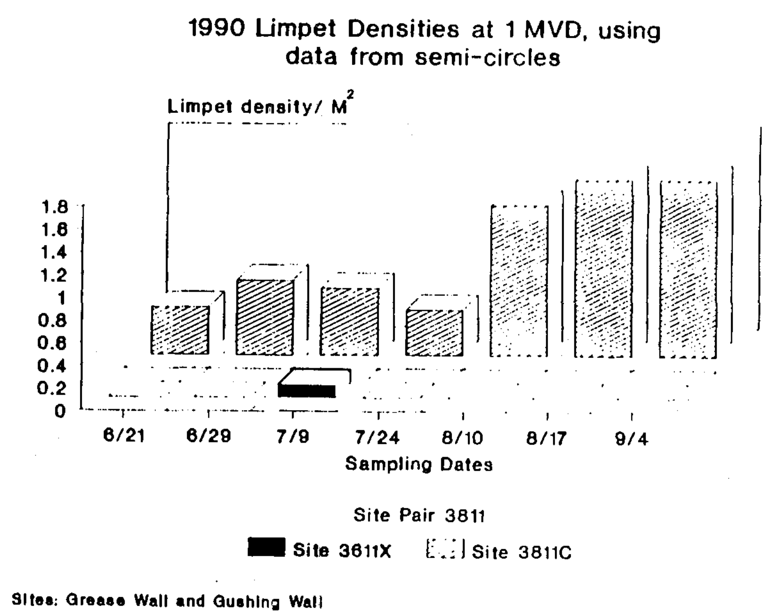


Fig. 4.11.10c. Limpet densities from semicircle estimates at site pair 2834, lower intertidal zone (3MVD).



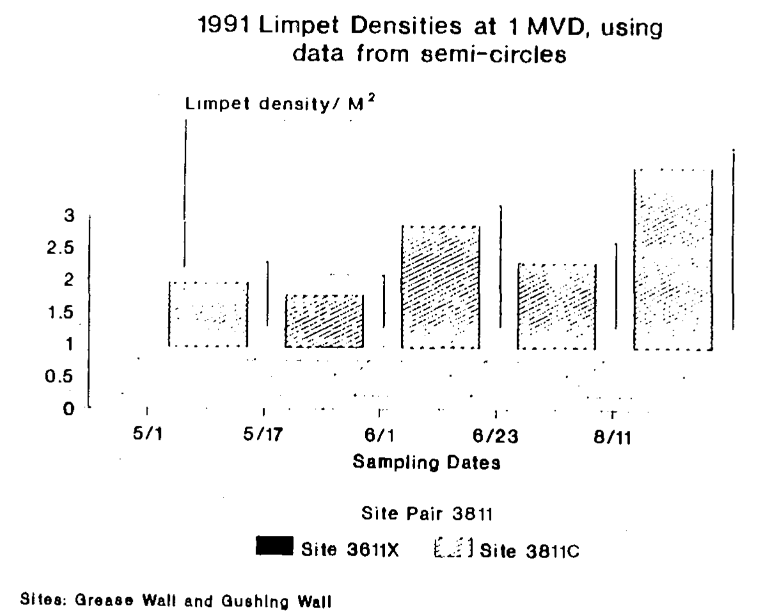
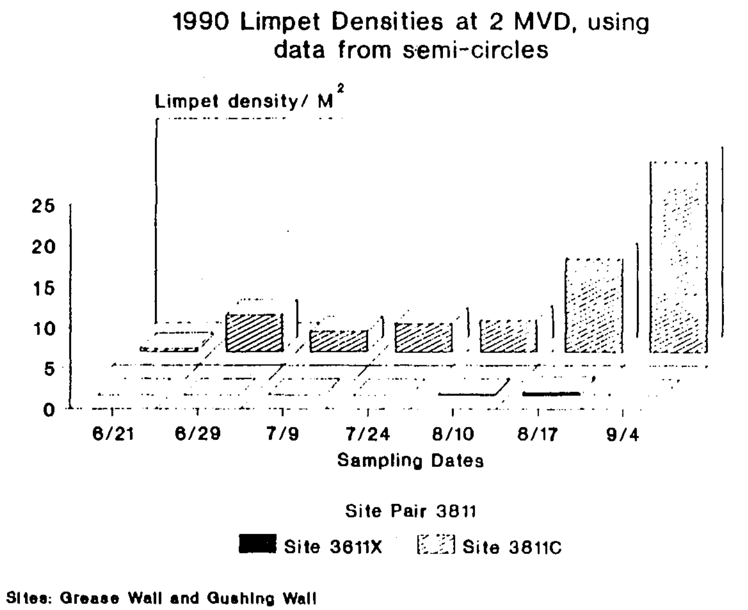


Fig. 4.11.11a. Limpet densities from semicircle estimates at site pair 3811, upper intertidal zone (1MVD).



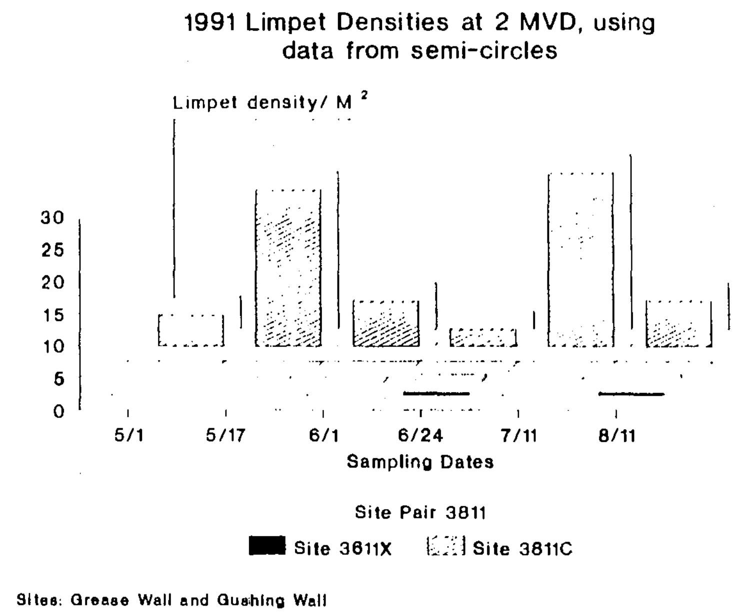
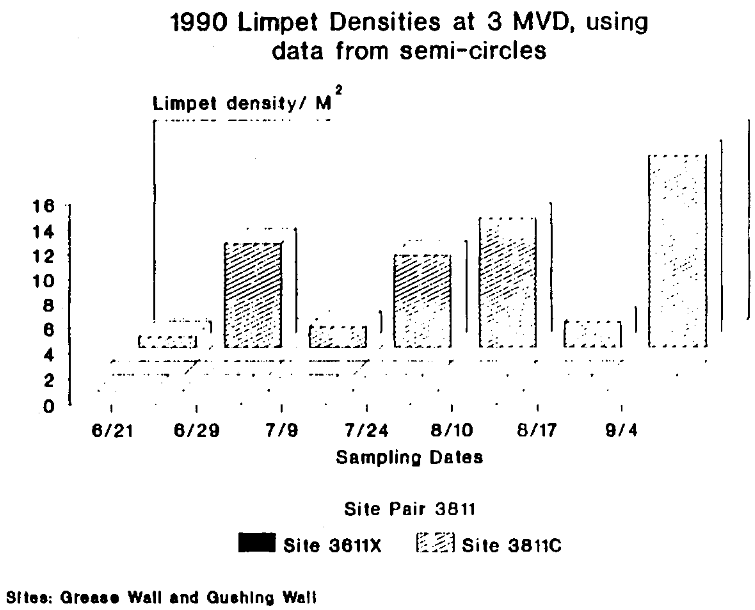


Fig. 4.11.11b. Limpet densities from semicircle estimates at site pair 3811, mid intertidal zone (2MVD).



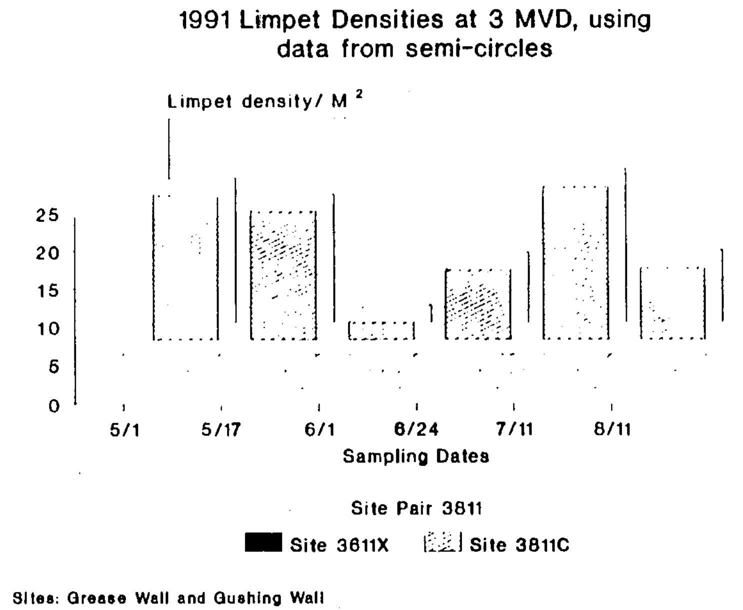


Fig. 4.11.11c. Limpet densities from semicircle estimates at site pair 3811, lower intertidal zone (3MVD).

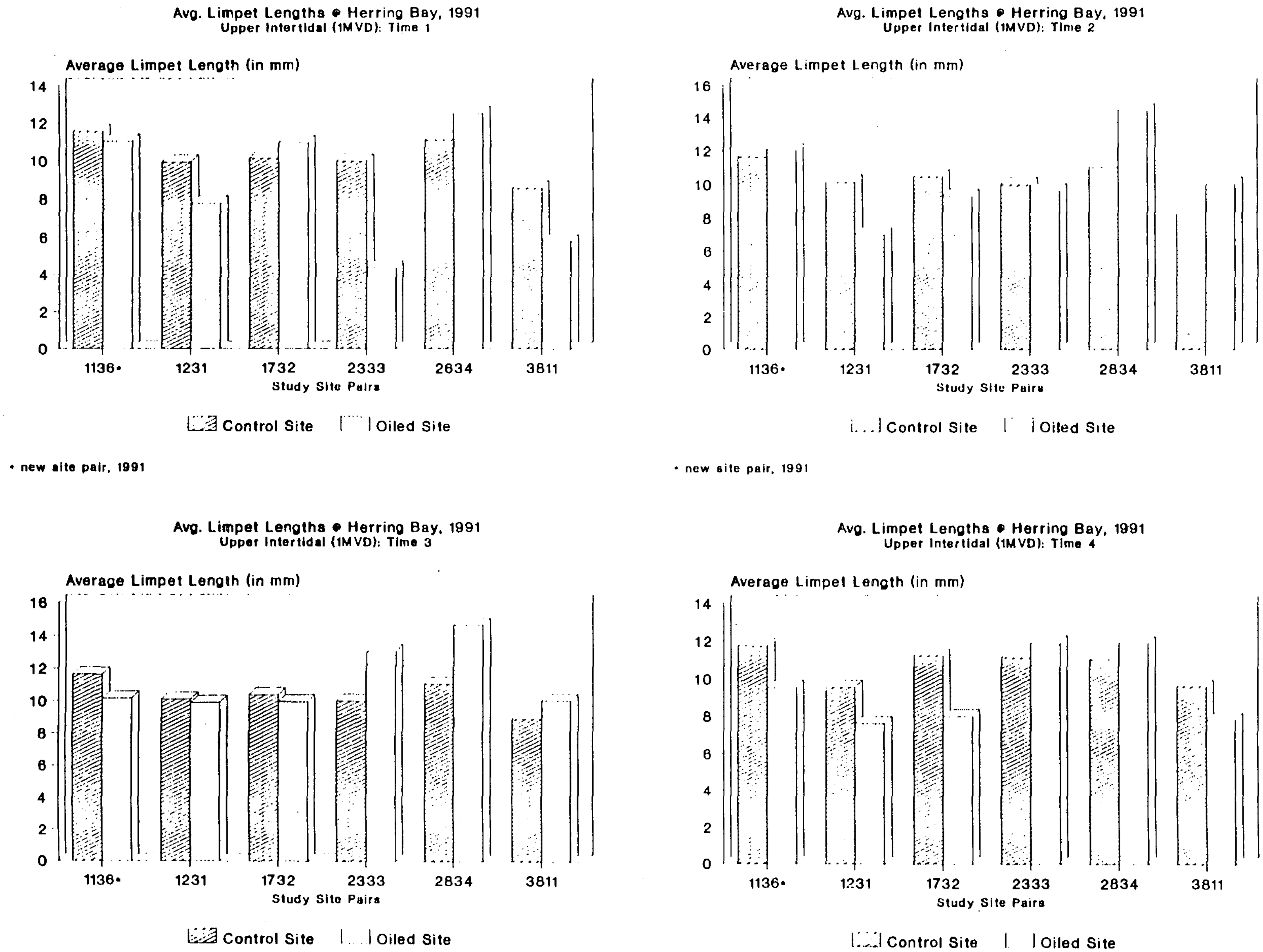
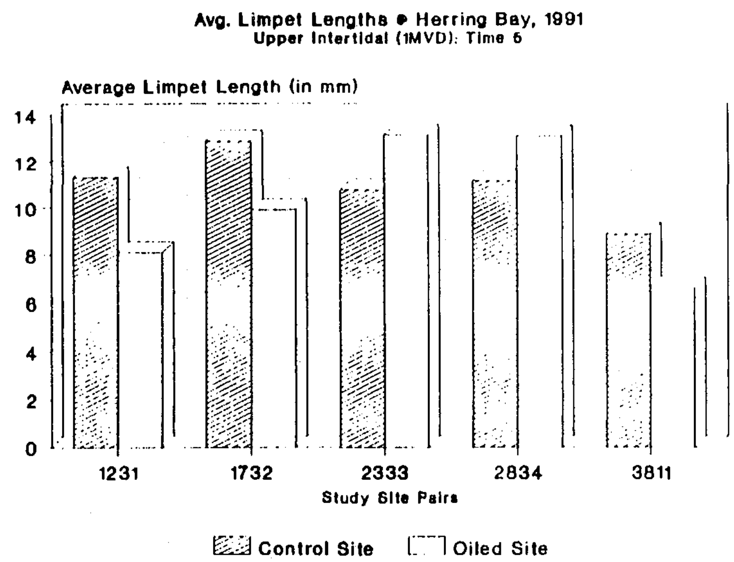
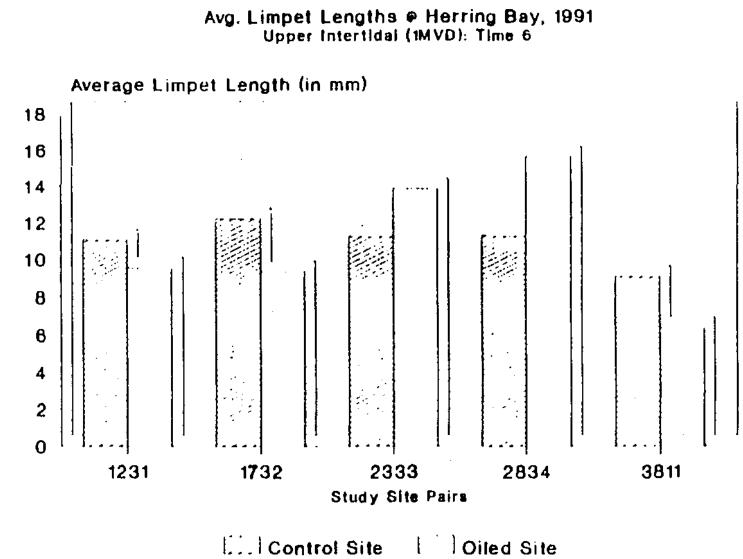


Fig. 4.11.12a. Mean limpet lengths in the upper intertidal zone (1MVD) at all population dynamic study site pairs. Sample dates 1-4 (April-July, 1991).





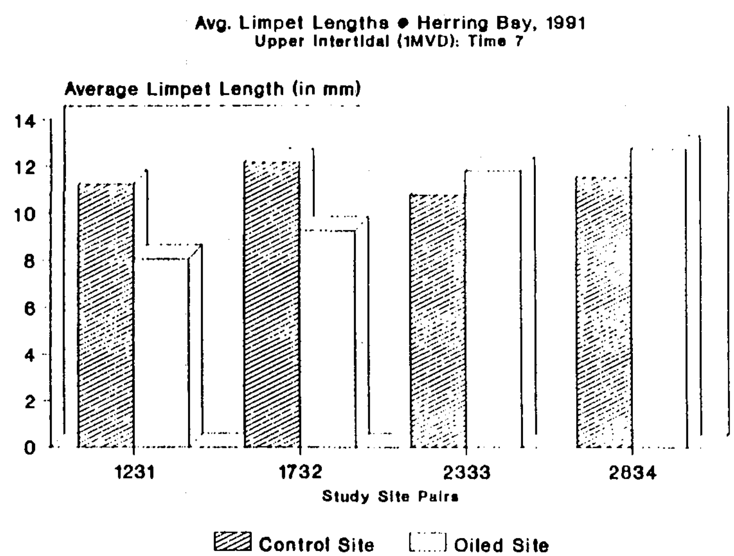


Fig. 4.11.12b. Mean limpet lengths in the upper intertidal zone (1MVD) at all population dynamic study site pairs. Sample dates 5-7 (July-September, 1991).

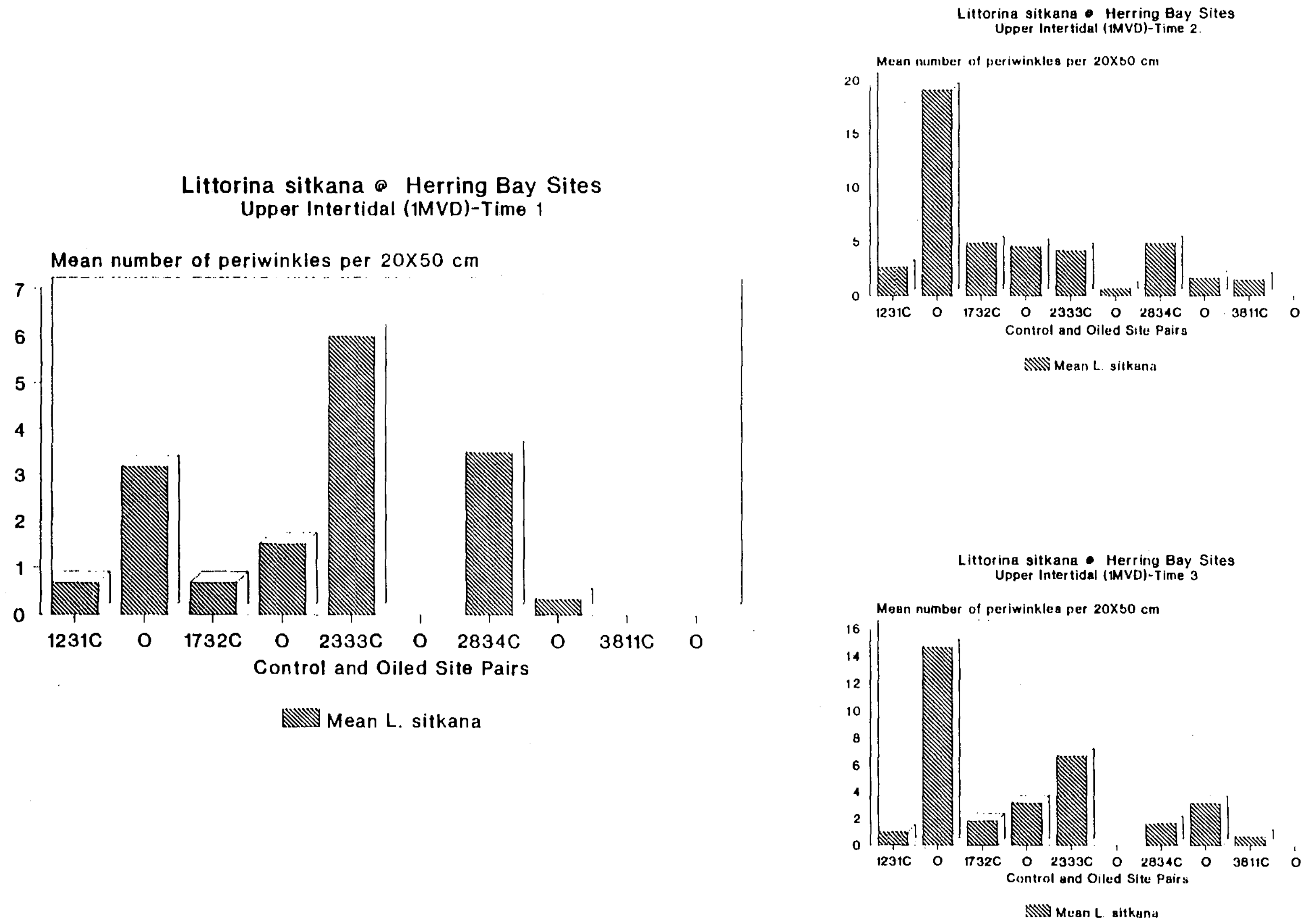


Fig. 4.12.1a: ***Littorina sitkana*** densities in the upper intertidal zone (1MVD) at five site pairs. Sample dates 1-3.

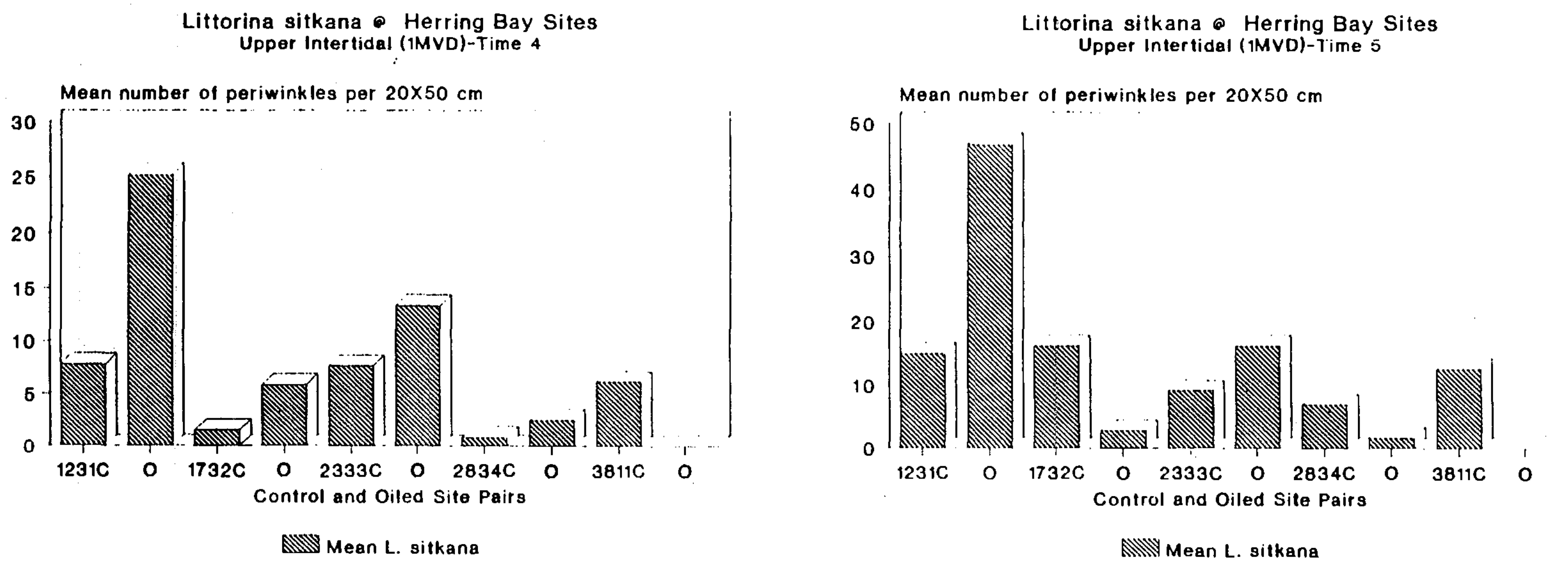


Fig. 4.12.1b. *Littorina sitkana* densities in the upper intertidal zone (1MVD) at five site pairs. Sample dates 4 & 5.

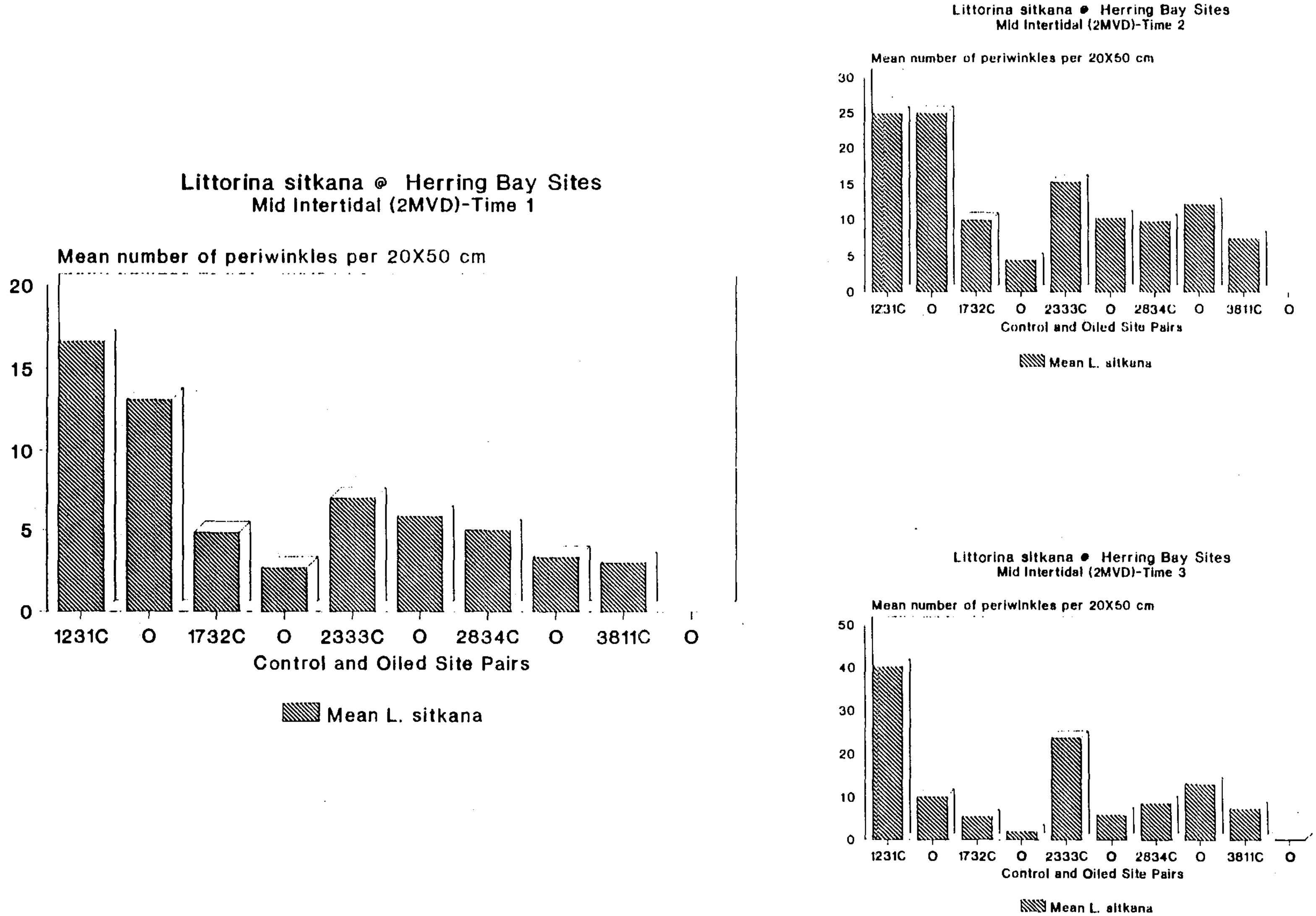
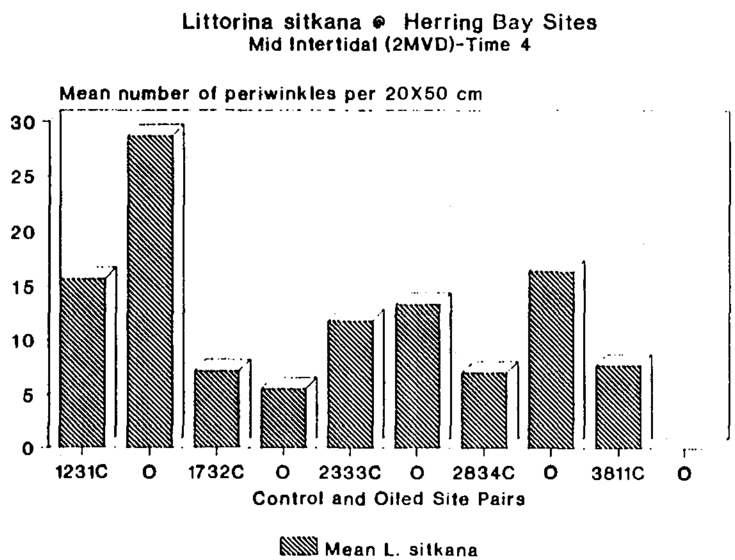


Fig. 4.12.2a. *Littorina sitkana* densities in the mid intertidal zone (2MVD) at five site pairs. Sample dates 1-3.



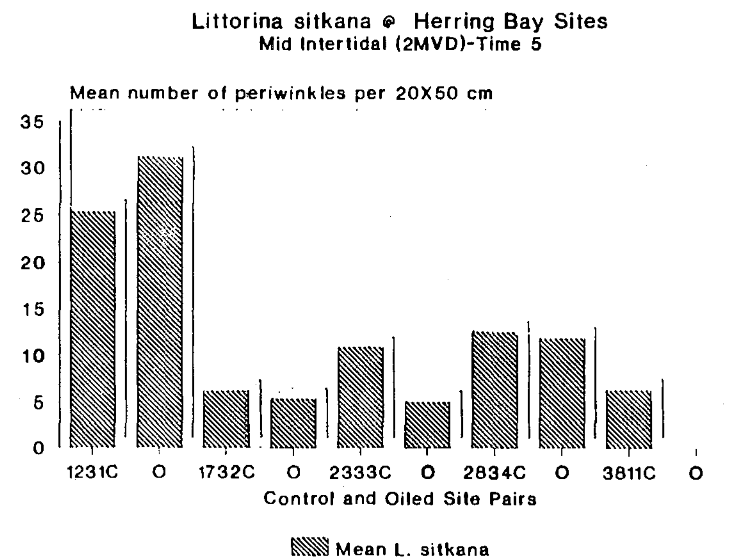


Fig. 4.12.2b. *Littorina sitkana* densities in the mid intertidal zone (2MVD) at five site pairs. Sample dates 4 & 5.

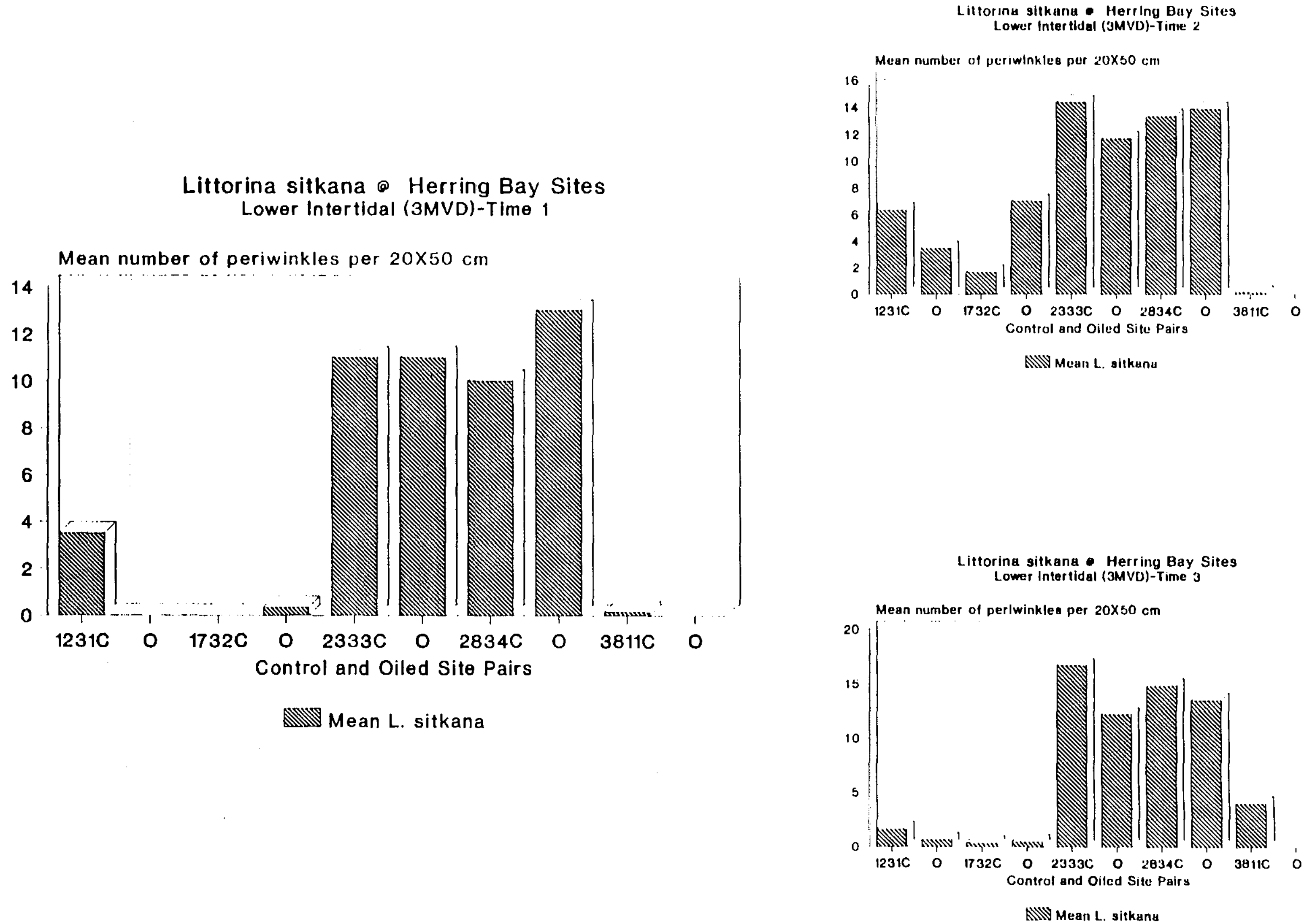
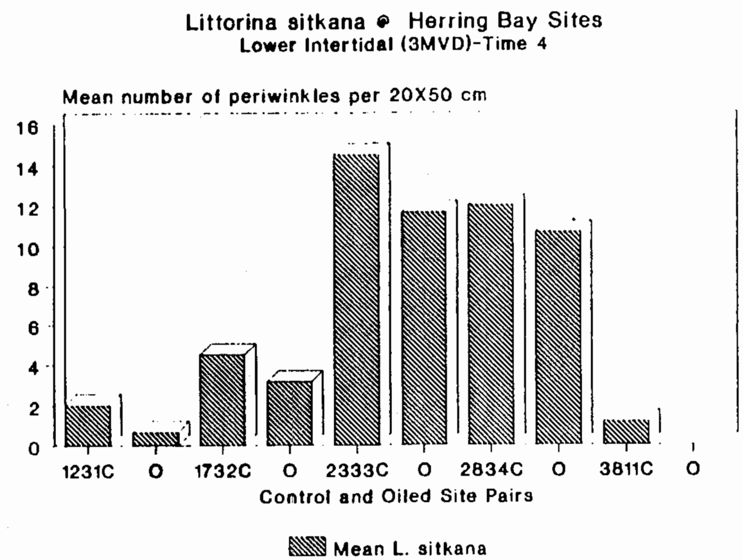


Fig. 4.12.3a. *Littorina sitkana* densities in the lower intertidal zone (3MVD) at five site pairs. Sample dates 1-3.



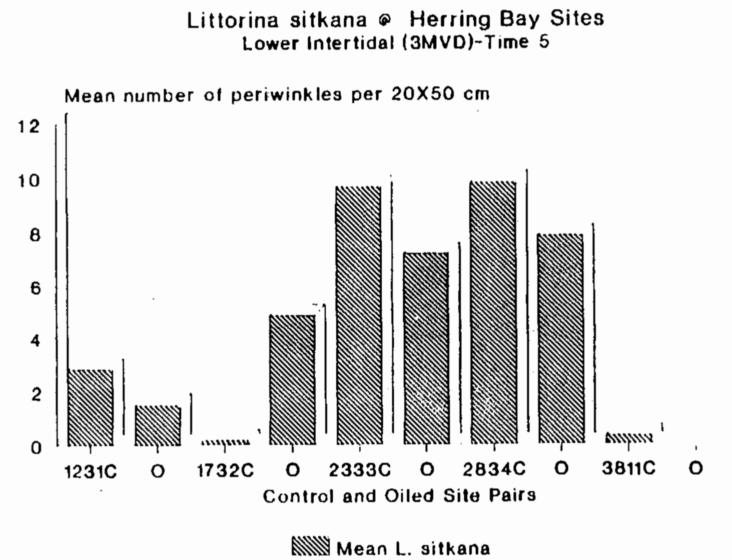
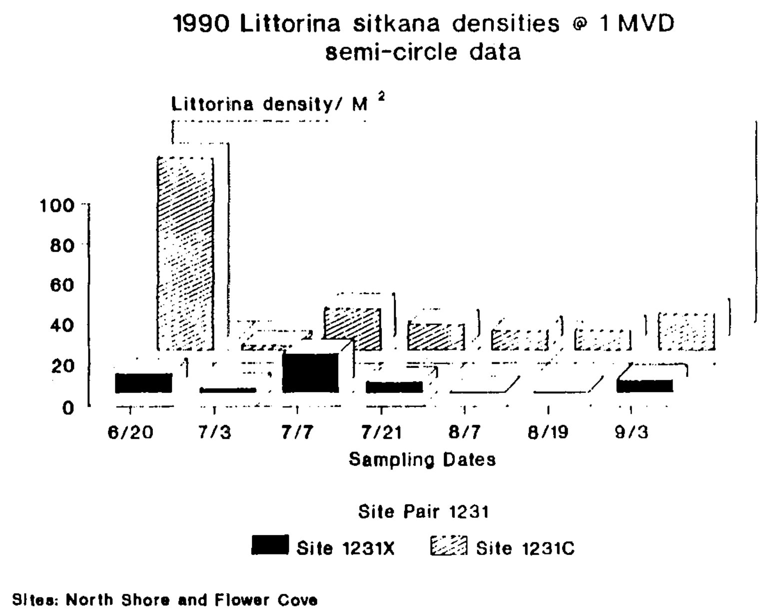


Fig. 4.12.3b. *Littorina sitkana* densities in the lower intertidal zone (3MVD) at five site pairs. Sample dates 4 & 5.



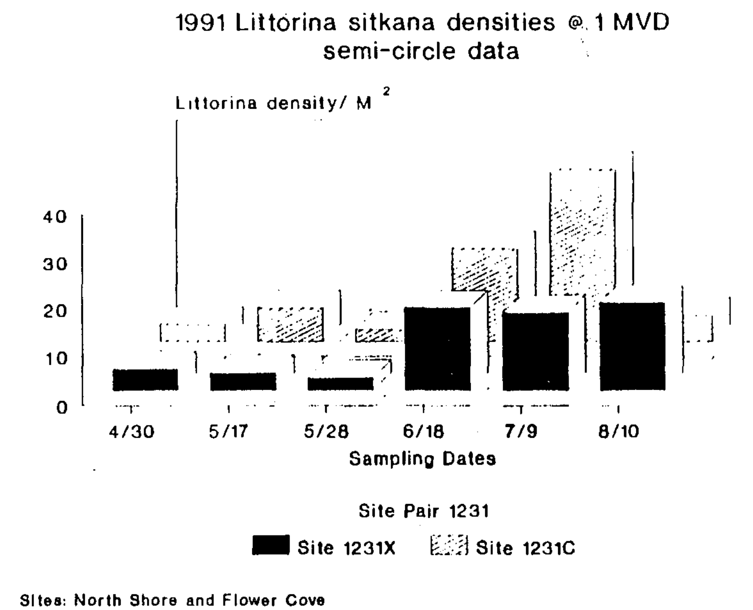
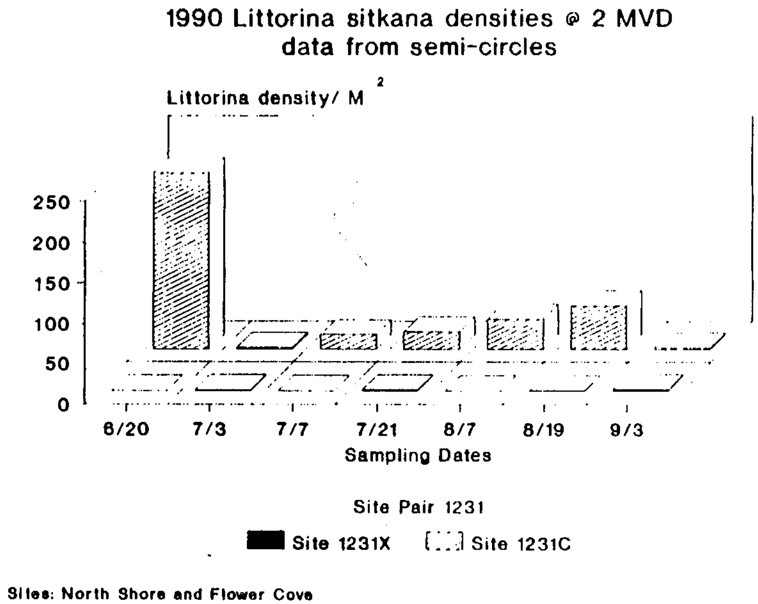


Fig. 4.12.4a. *Littorina sitkana* densities from semicircle estimates at site pair 1231, upper intertidal zone (1MVD).



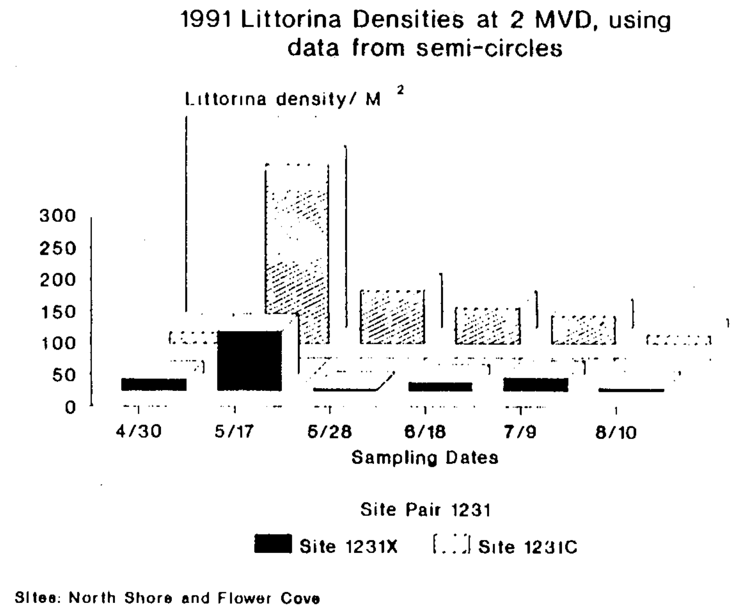
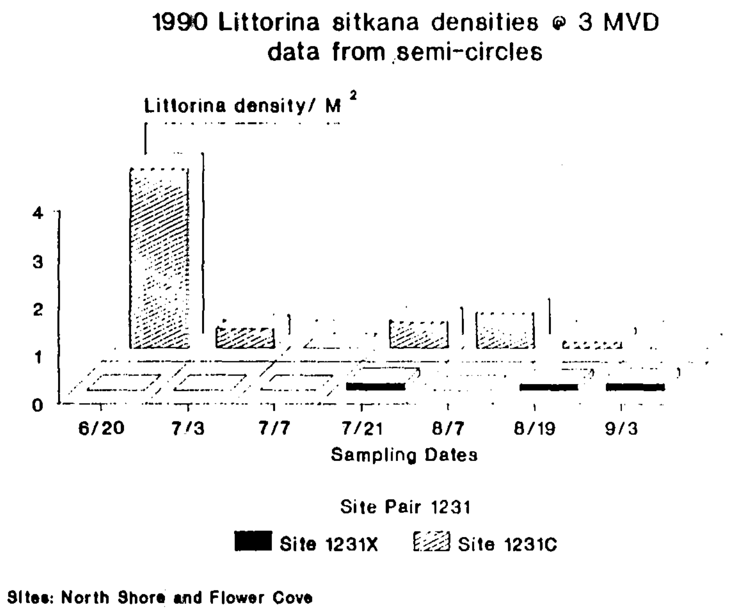


Fig. 4.12.4b. *Littorina sitkana* densities from semicircle estimates at site pair 1231, mid intertidal zone (2MVD).



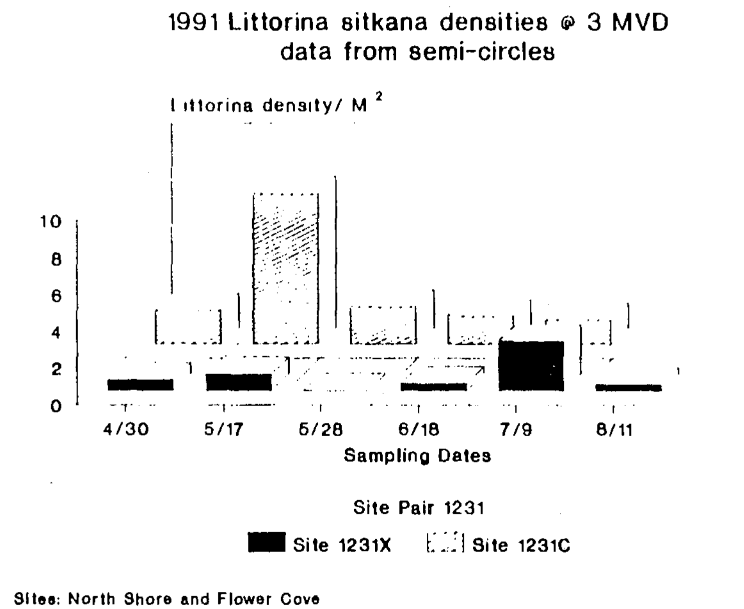
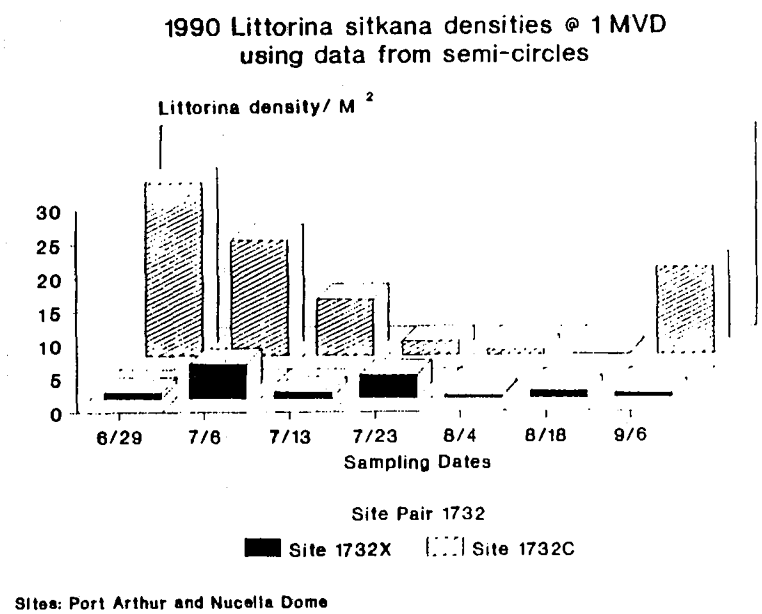


Fig. 4.12.4c. *Littorina sitkana* densities from semicircle estimates at site pair 1231, lower intertidal zone (3MVD).



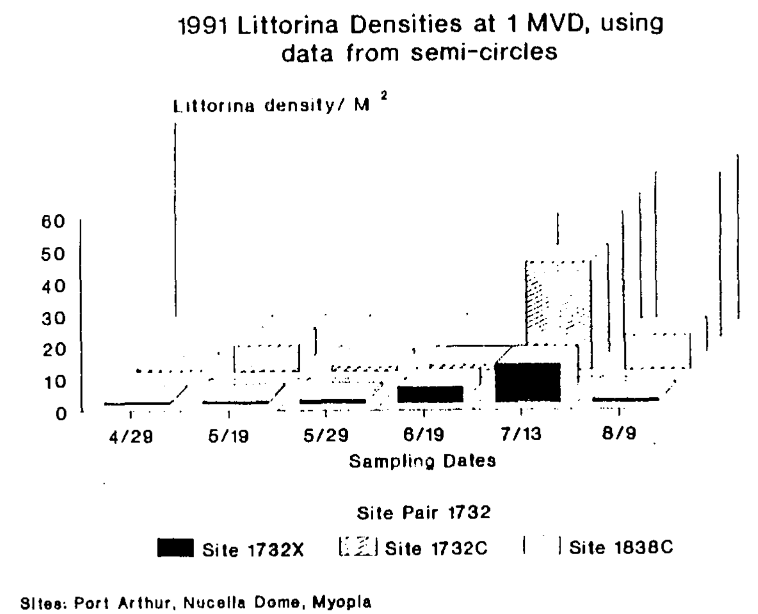


Fig. 4.12.5a. *Littorina sitkana* densities from semicircle estimates at site pair 1732, upper intertidal zone (1MVD). Site 1838C is a second control site, used to compare density estimates to 1732C based on similar location and percent slope.

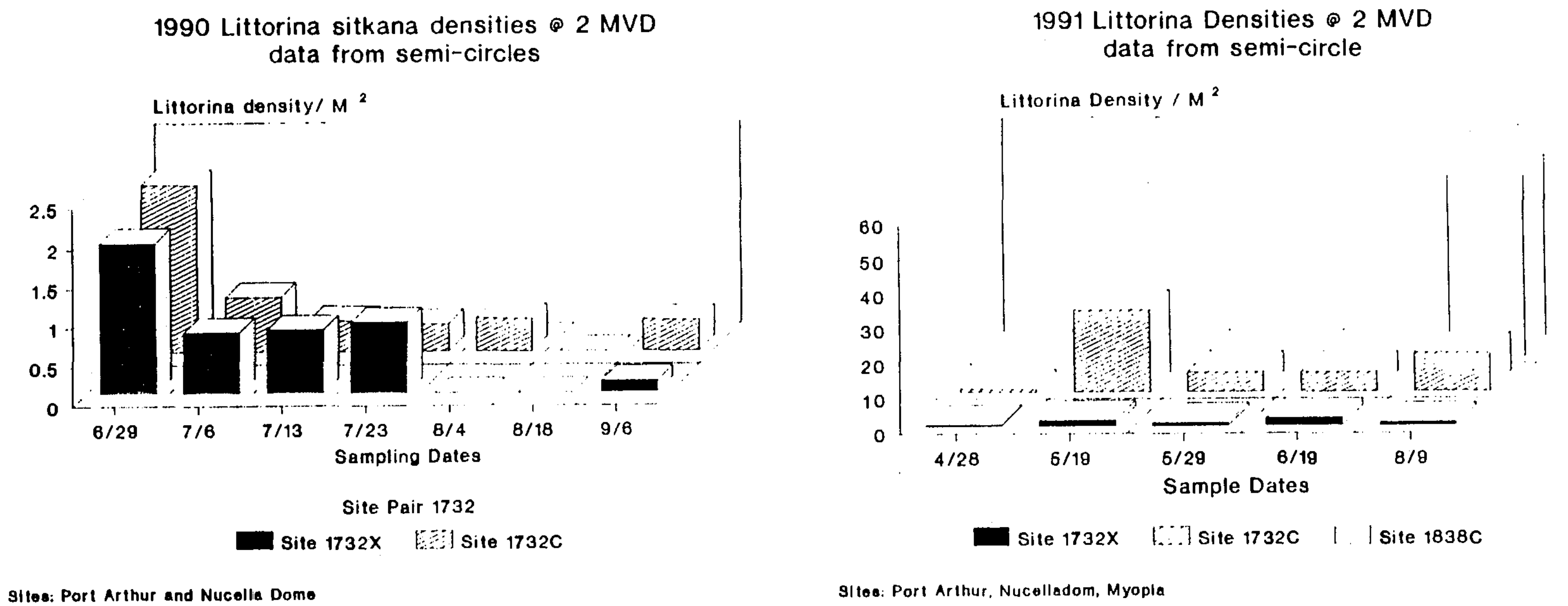
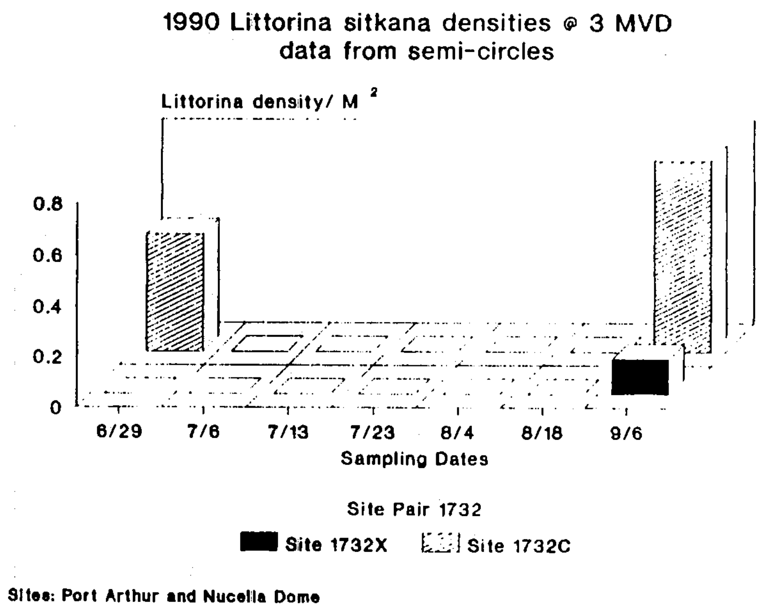


Fig. 4.12.5b. *Littorina sitkana* densities from semicircle estimates at site pair 1732, mid intertidal zone (2MVD). Site 1838C is a second control site, used to compare density estimates to 1732C based on similar location and percent slope.



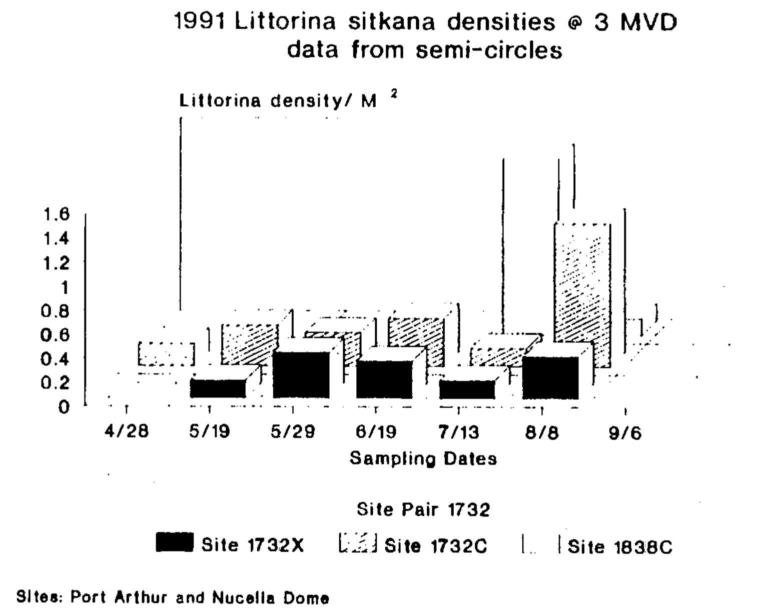
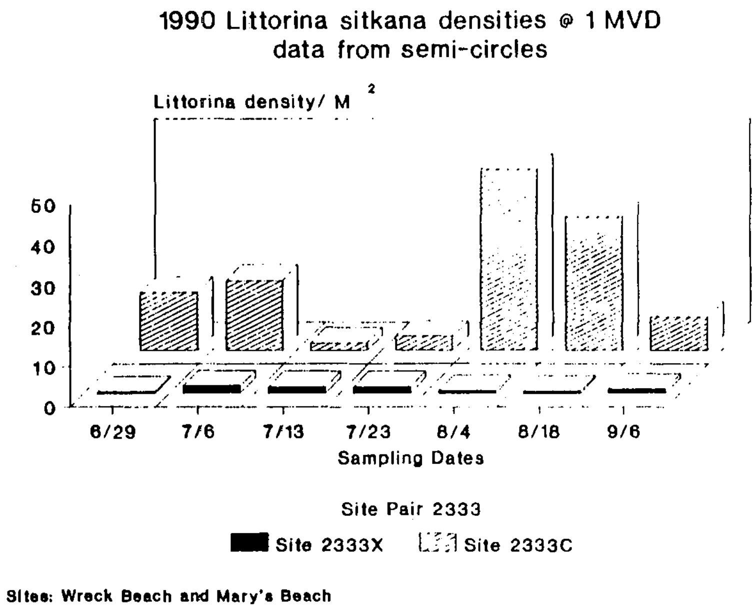


Fig. 4.12.5c. *Littorina sitkana* densities from semicircle estimates at site pair 1732, lower intertidal zone (3MVD). Site 1838C is a second control site, used to compare density estimates to 1732C based on similar location and percent slope.



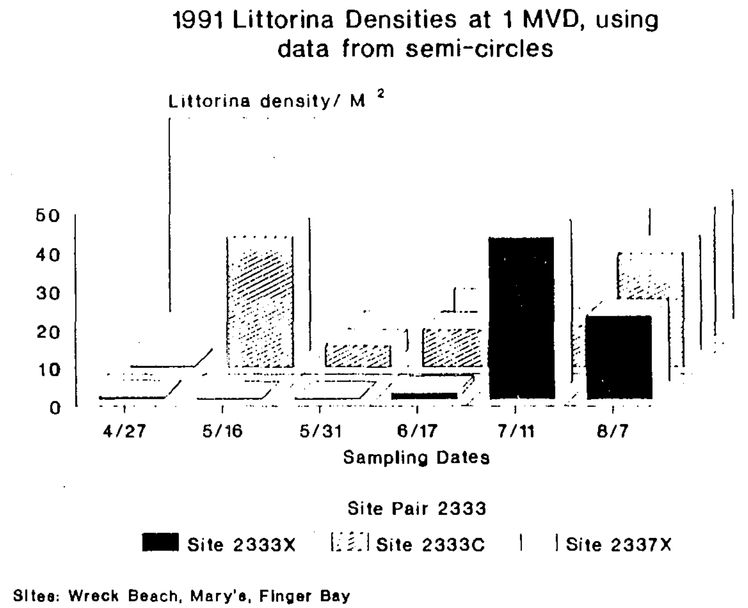


Fig. 4.12.6a. *Littorina sitkana* densities from semicircle estimates at site pair 2333, upper intertidal zone (1MVD). Site 2337X is a second coarse-textured oiled site established in 1991.

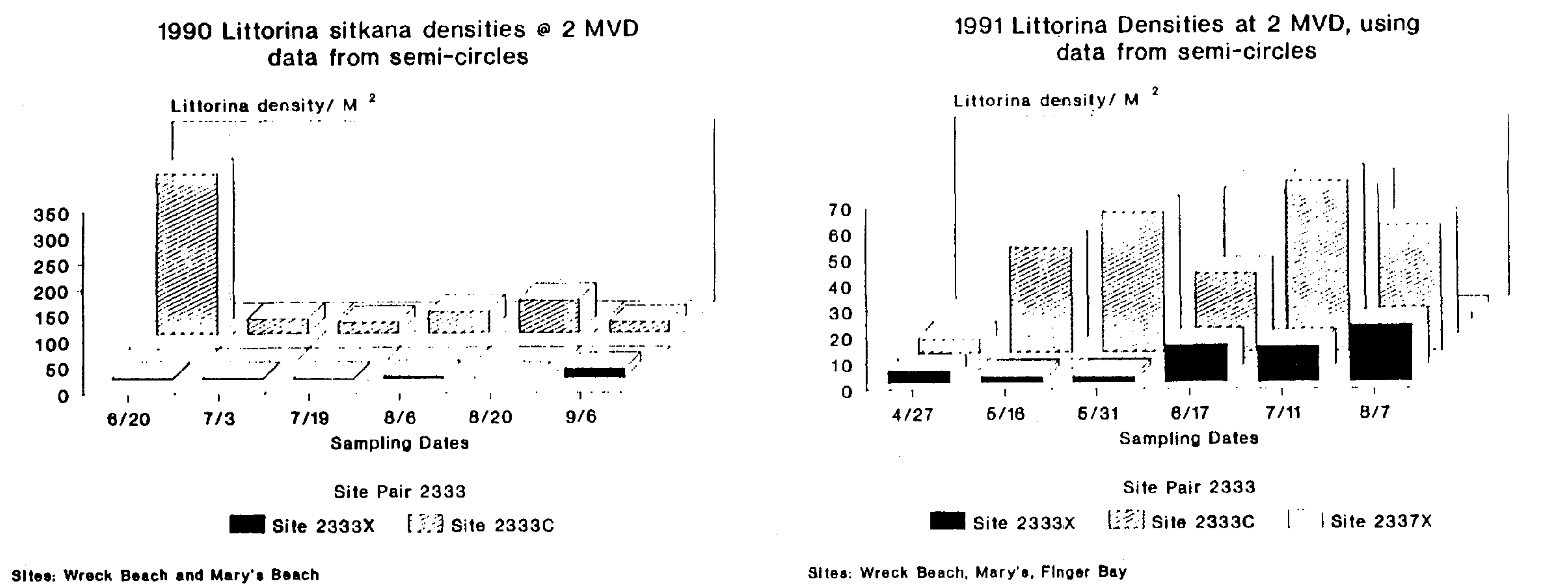
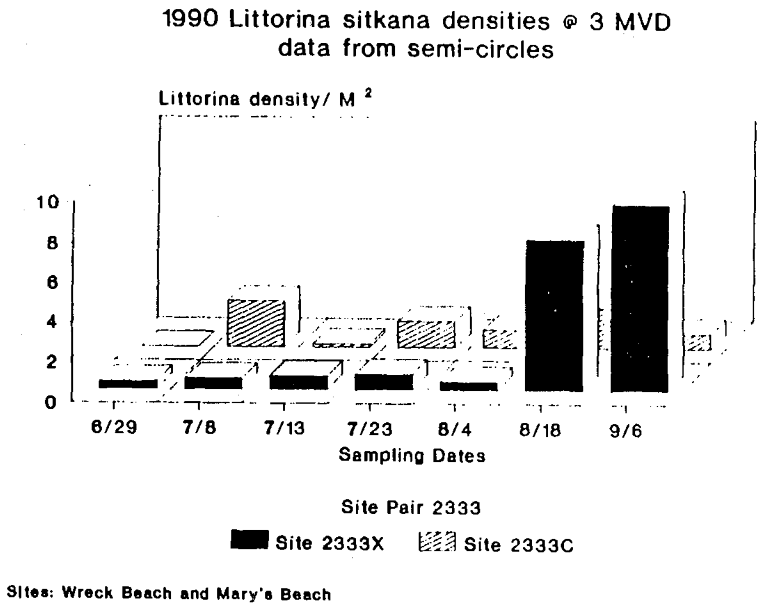


Fig. 4.12.6b. *Littorina sitkana* densities from semicircle estimates at site pair 2333, mid intertidal zone (2MVD). Site 2337X is a second coarse-textured oiled site established in 1991.



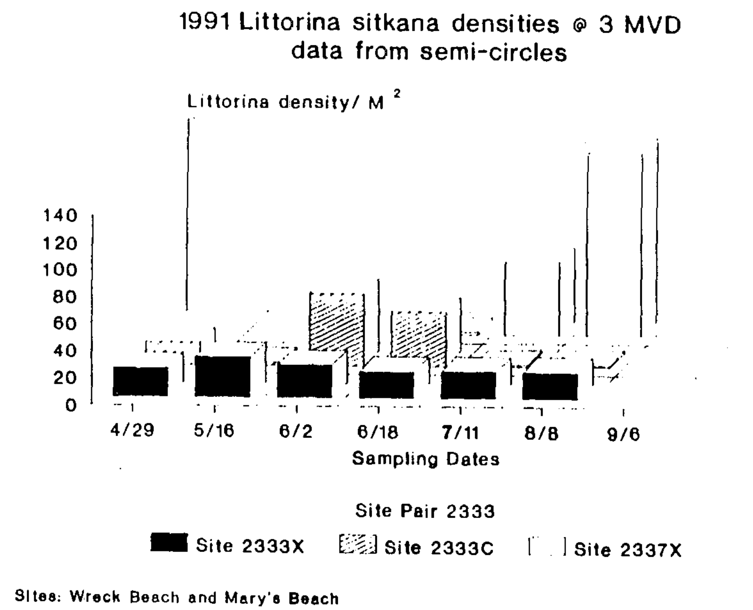
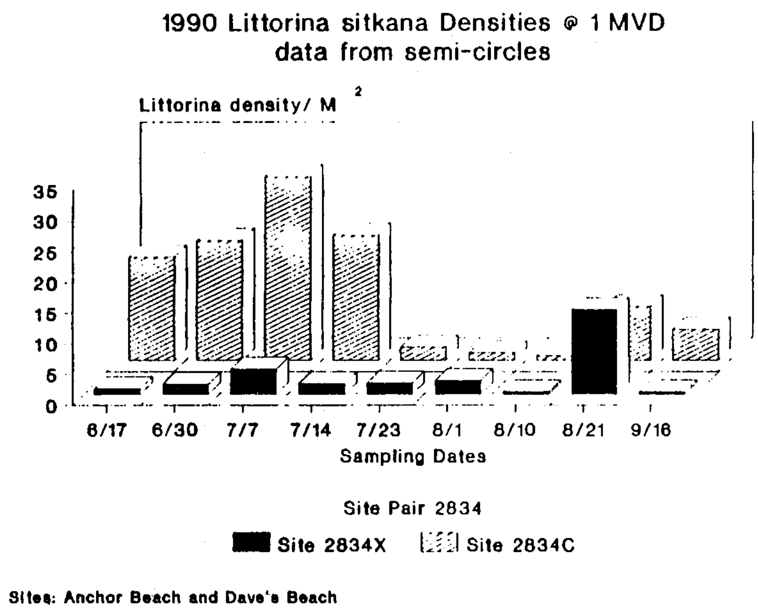


Fig. 4.12.6c. *Littorina sitkana* densities from semicircle estimates at site pair 2333, lower intertidal zone (3MVD). Site 2337X is a second coarse-textured oiled site established in 1991.



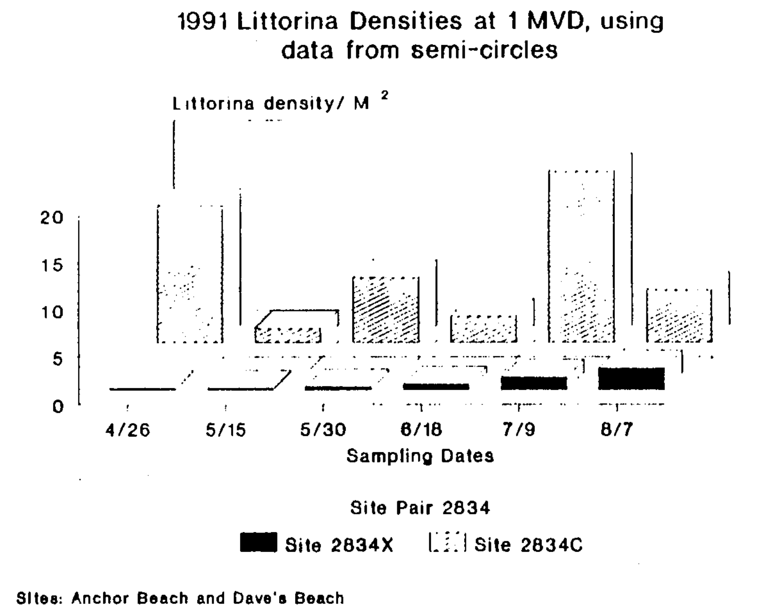
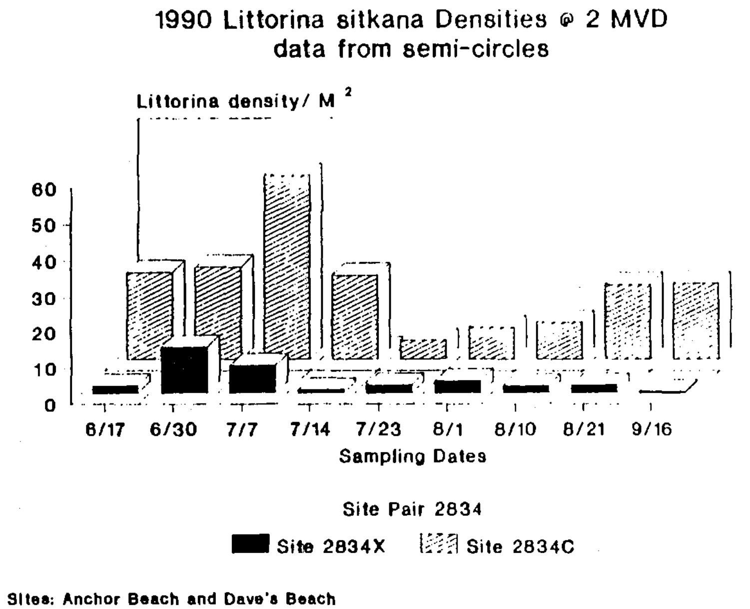


Fig. 4.12.7a. *Littorina sitkana* densities from semicircle estimates at site pair 2834, upper intertidal zone (1MVD).



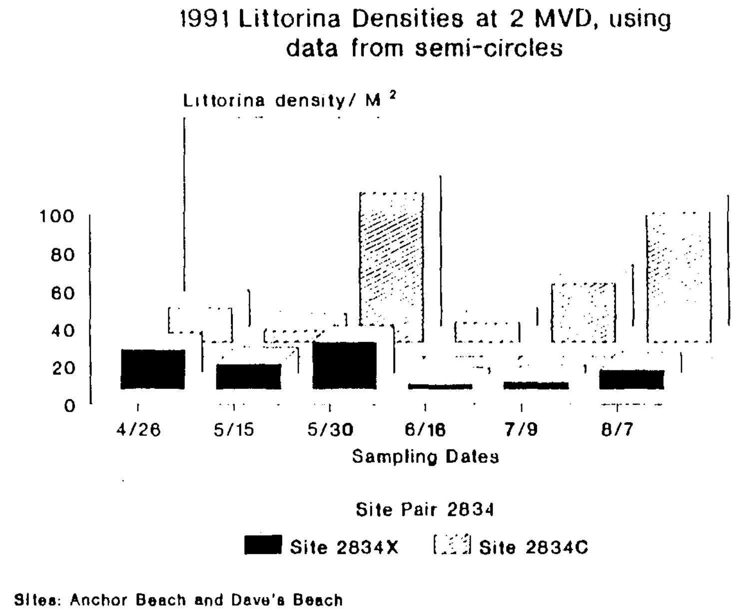
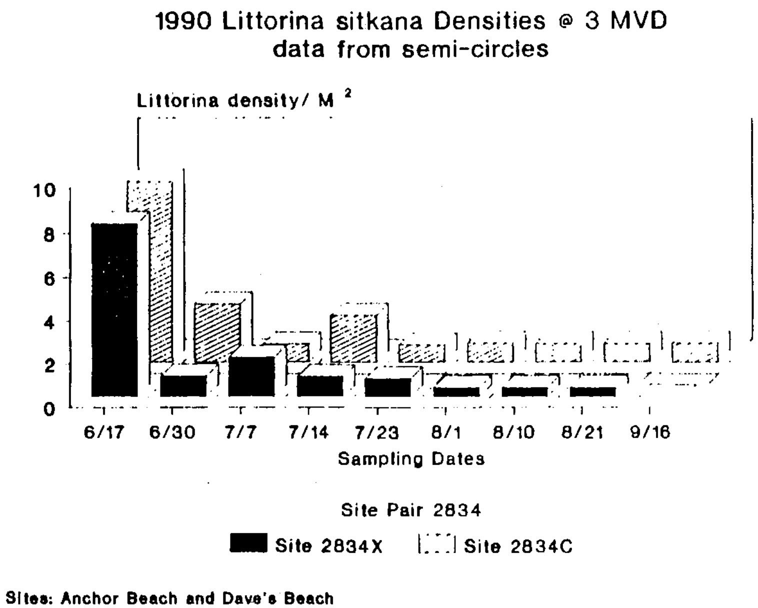


Fig. 4.12.7b. *Littorina sitkana* densities from semicircle estimates at site pair 2834, mid intertidal zone (2MVD).



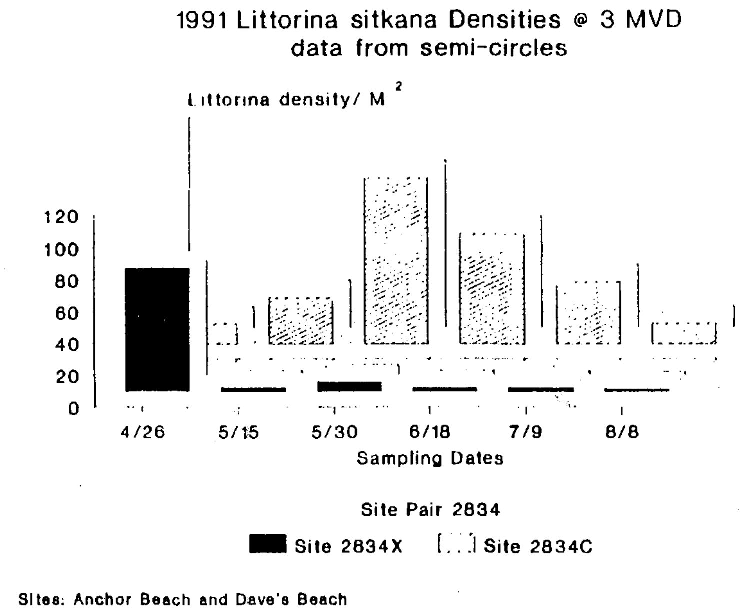
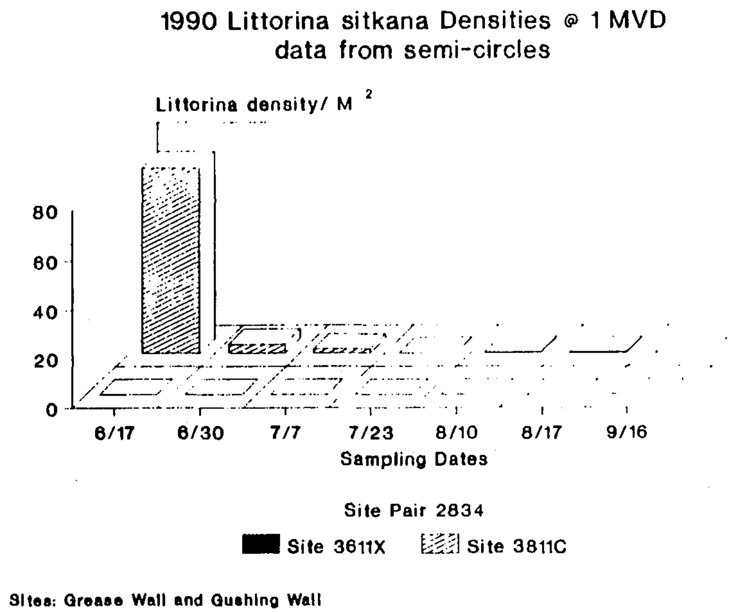


Fig. 4.12.7c. *Littorina sitkana* densities from semicircle estimates at site pair 2834, lower intertidal zone (3MVD).



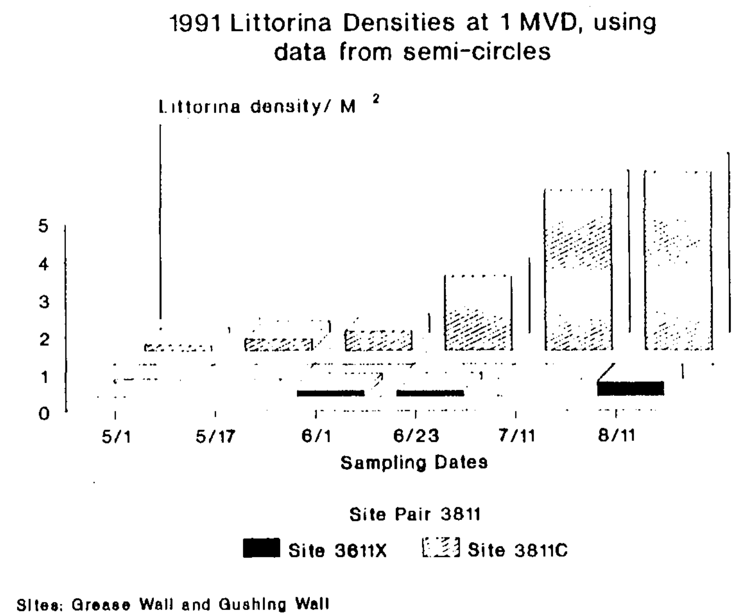
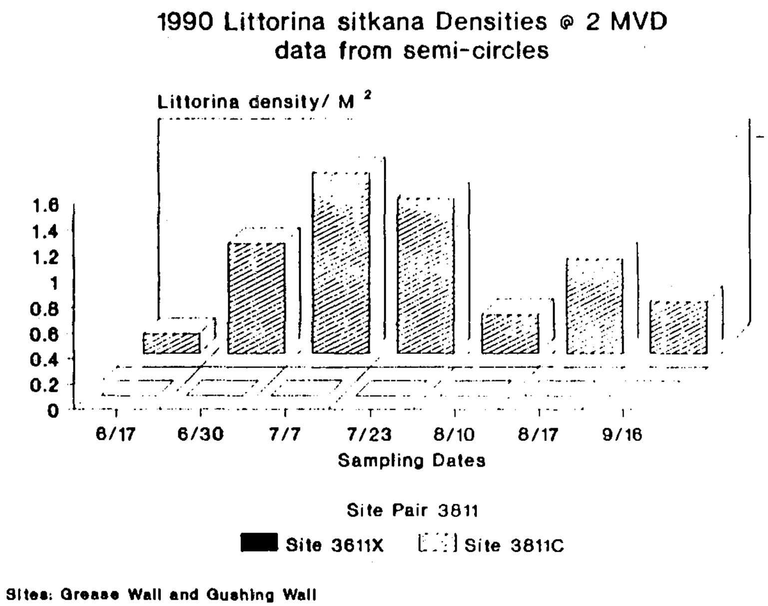


Fig. 4.12.8a. *Littorina sitkana* densities from semicircle estimates at site pair 3811, upper intertidal zone (1MVD).



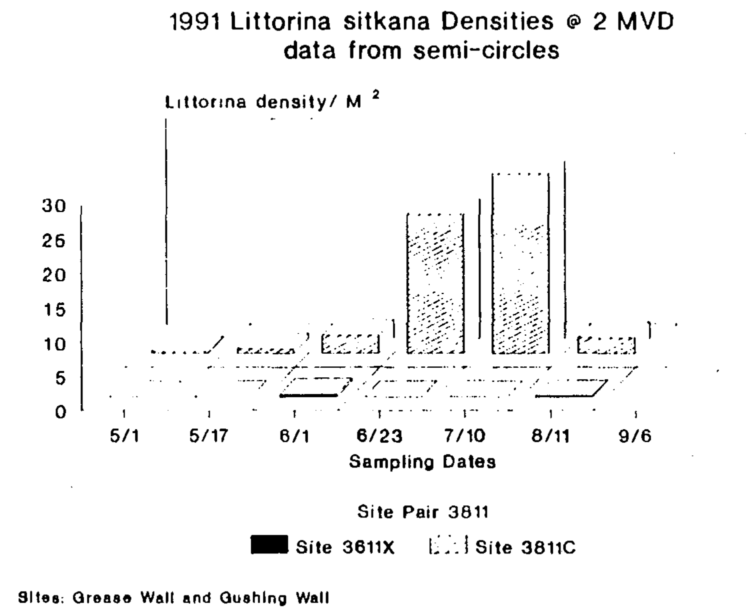
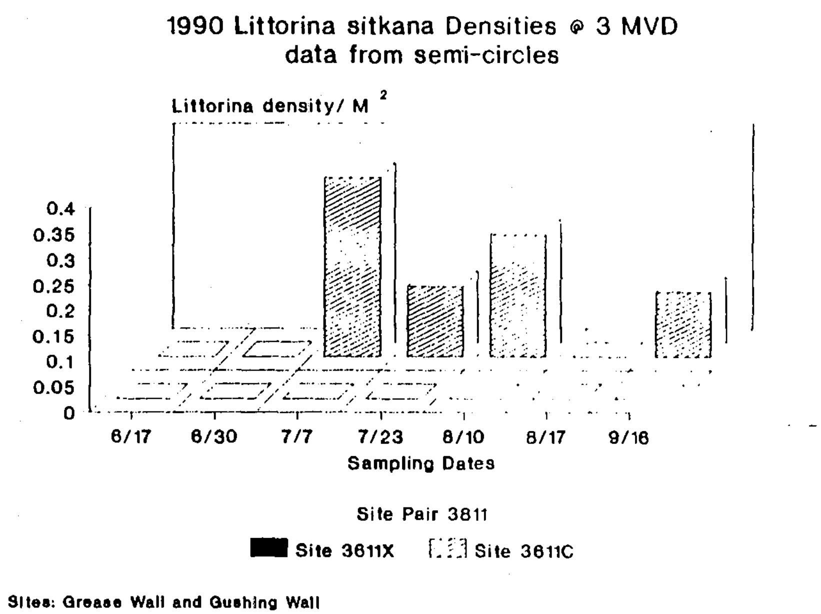


Fig. 4.12.8b. *Littorina sitkana* densities from semicircle estimates at site pair 3811, mid intertidal zone (2MVD).



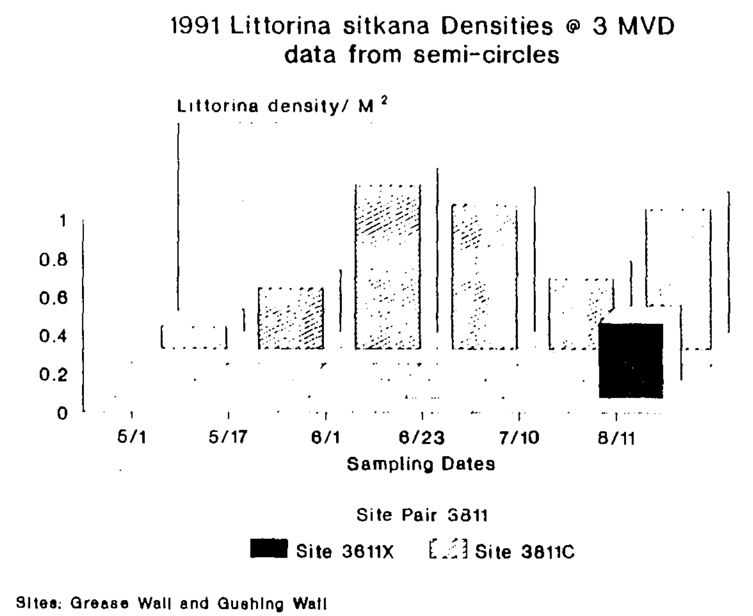


Fig. 4.12.8c. *Littorina sitkana* densities from semicircle estimates at site pair 3811, lower intertidal zone (3MVD).

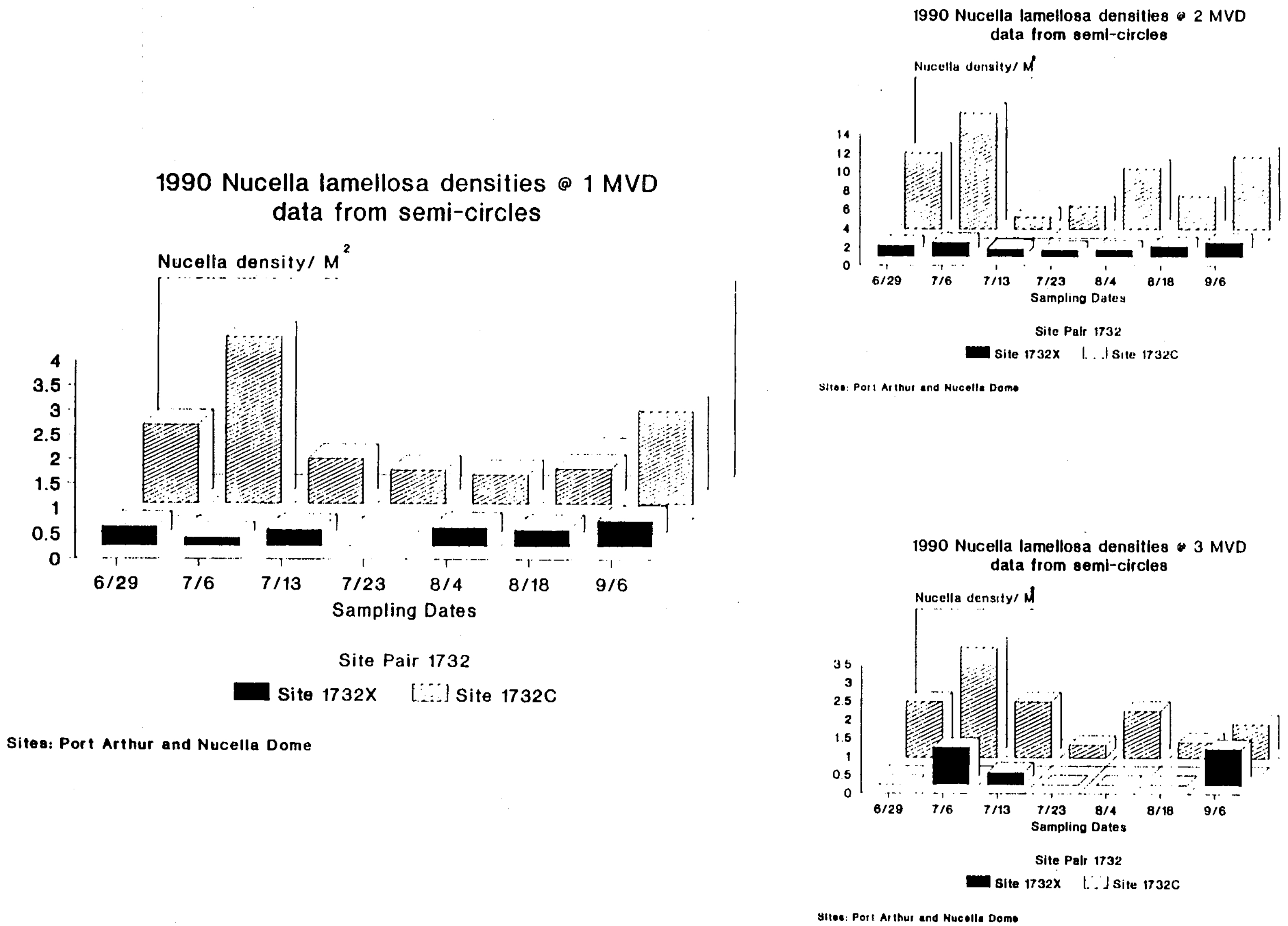
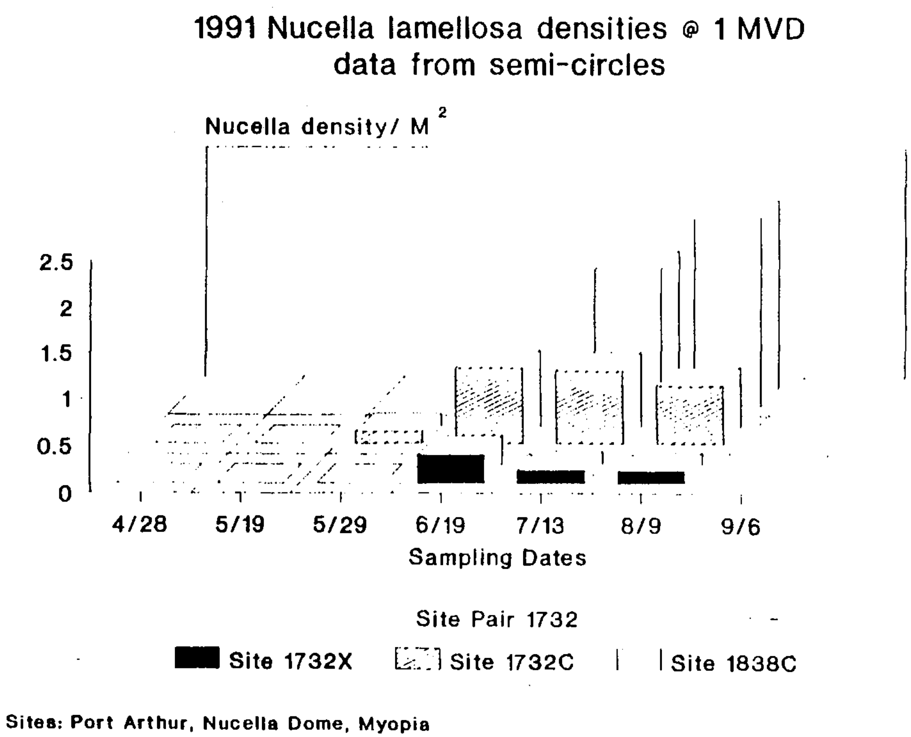
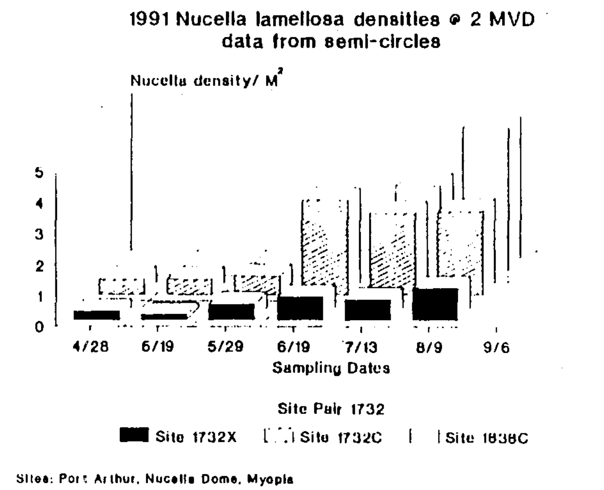


Fig. 4.13.1. 1990 densities of *Nucella lamellosa* at site pair 1732, taken from semicircle density estimates at three tidal levels.





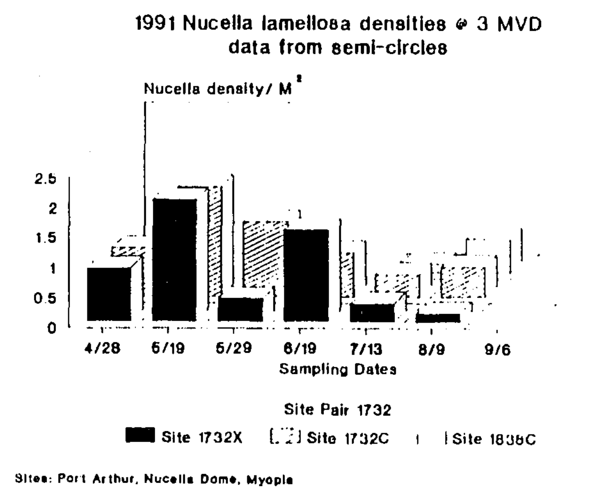


Fig. 4.13.2. 1991 densities of *Nucella lamellosa* at site pair 1732, taken from semicircle density estimates at three tidal levels. Site 1838C serves as a site comparison to 1732C for density estimates based on percent slope of the site.

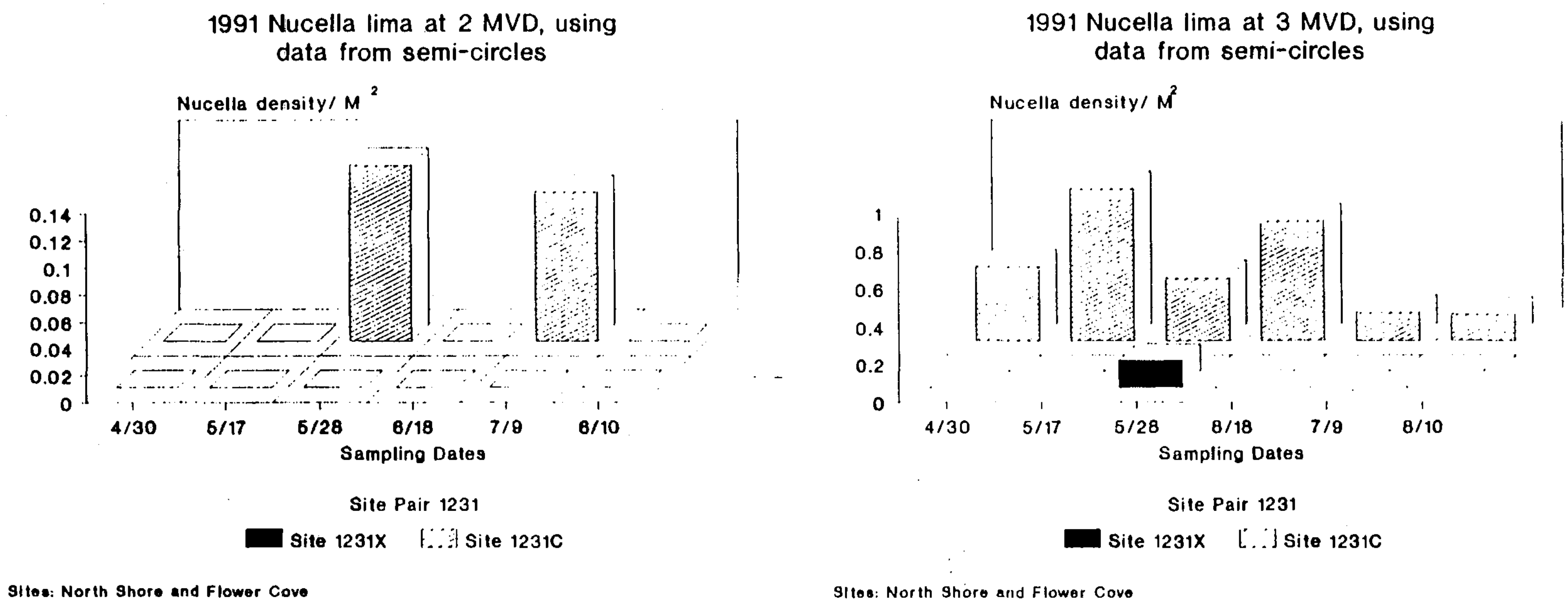
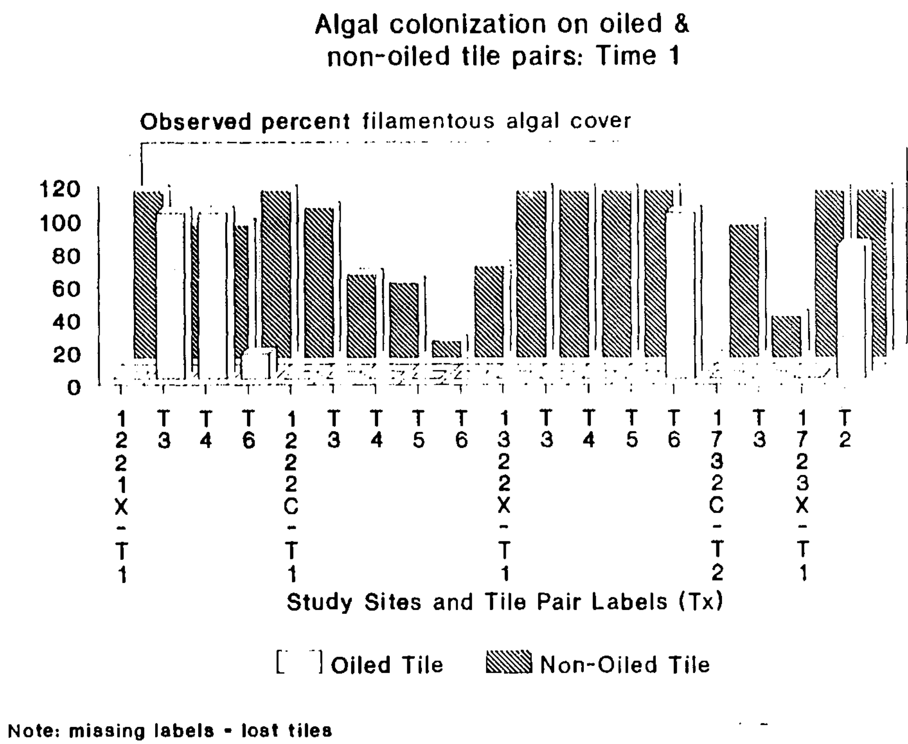
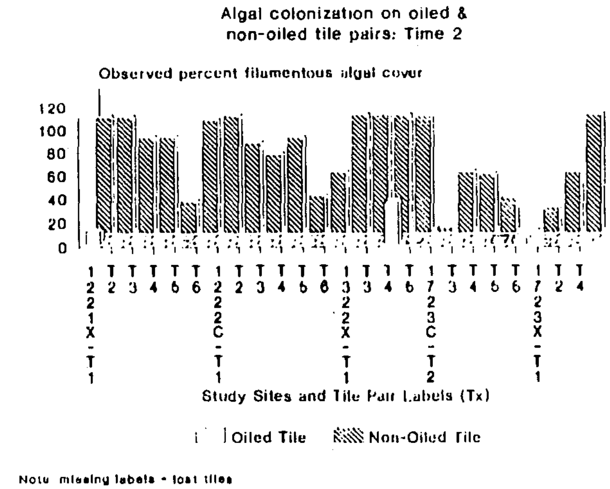


Fig. 4.13.3. 1991 densities of *Nucella lima* at site pair 1231, taken from semicircle density estimates at the second and third tidal level (from mean high high water).





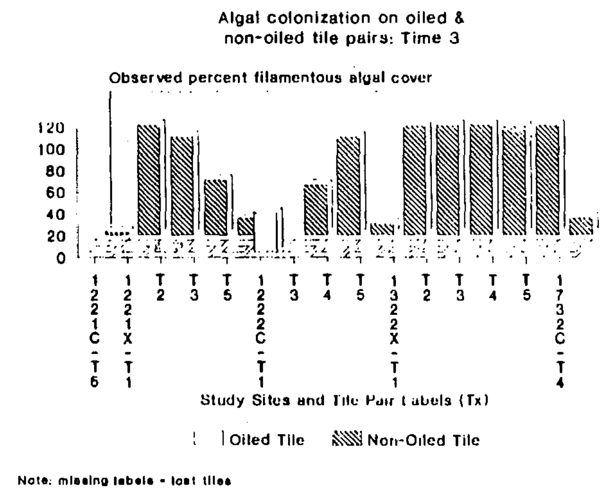


Fig. 4.14. Percent algal cover observed on oiled and non-oiled tiles placed during the summer of 1990 and sampled three times in 1991.

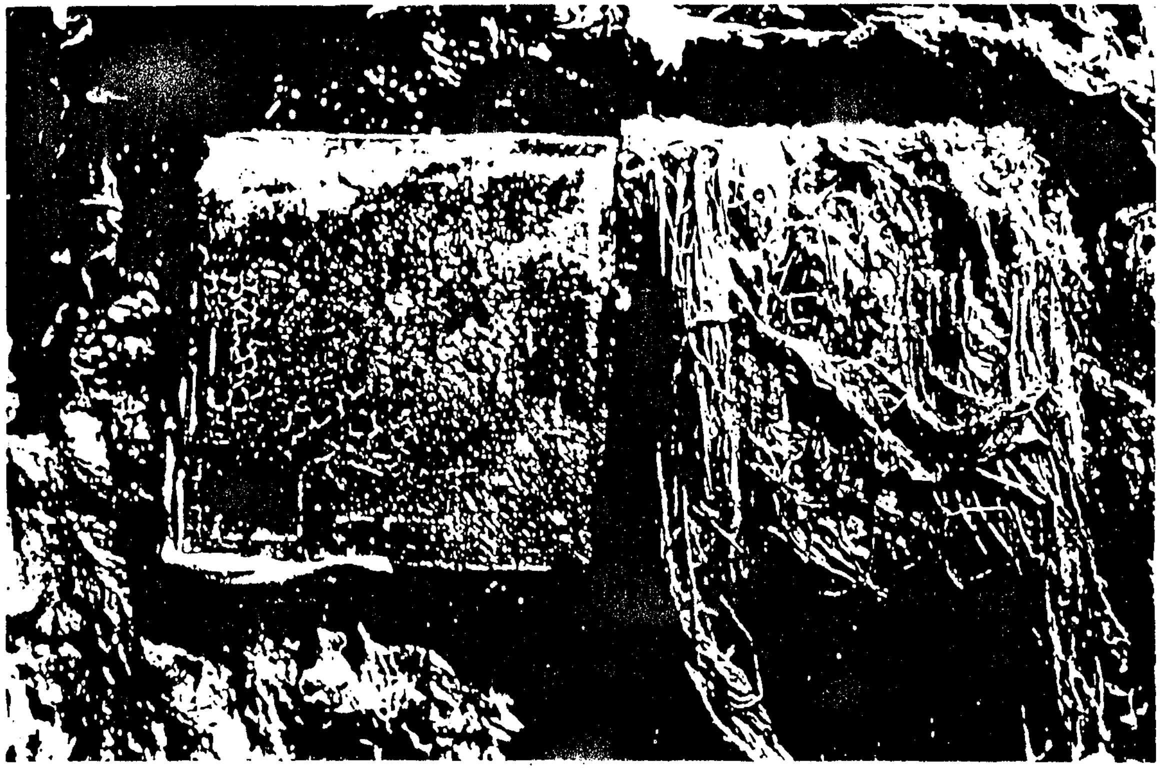
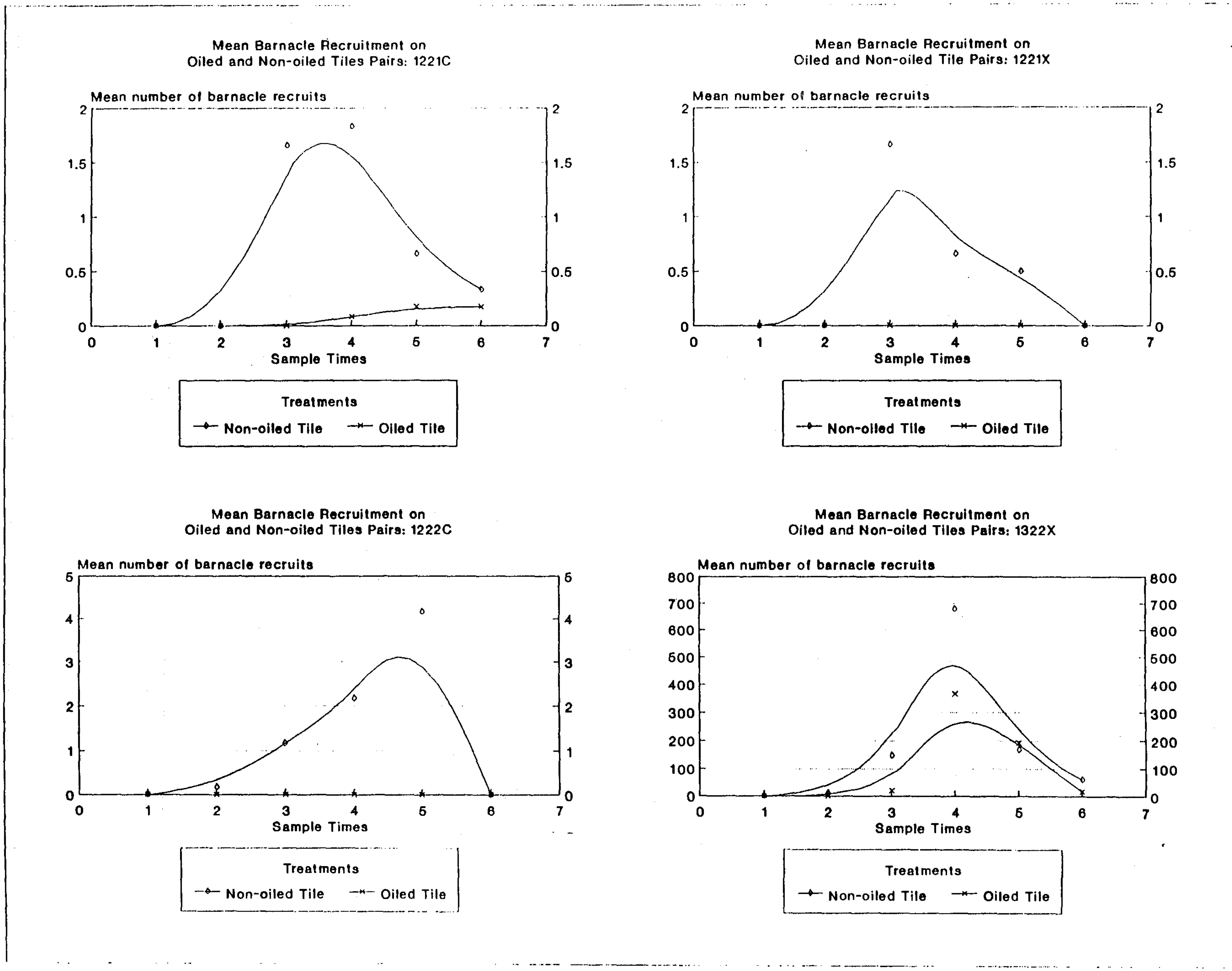
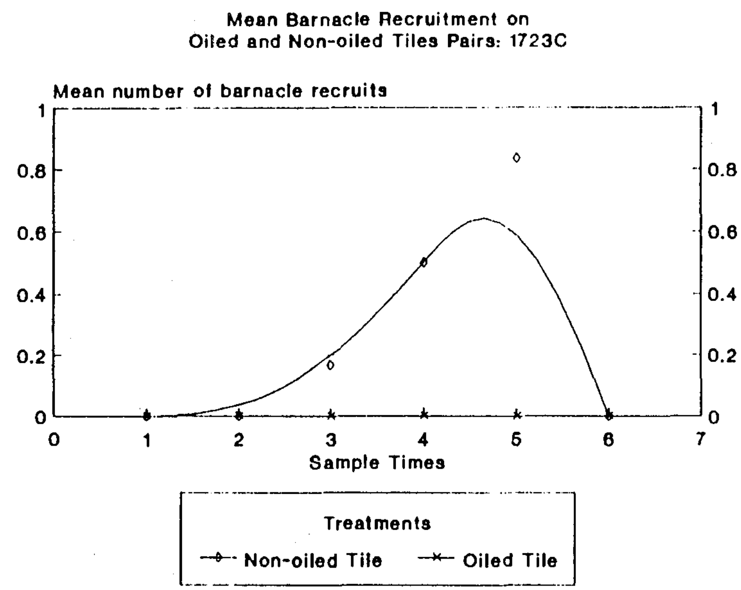


Figure 4.15 Example of algal cover on oiled tile (left) versus a non-oiled tile (right), from 1990 tile pair. Six tile pairs were placed at six different study sites.



ig. 4.16a. Mean number of barnacles observed on oiled a non-oiled tiles placed during the summer of 1990 and samp three imes in 1991. Site pairs 1221 and 1222.



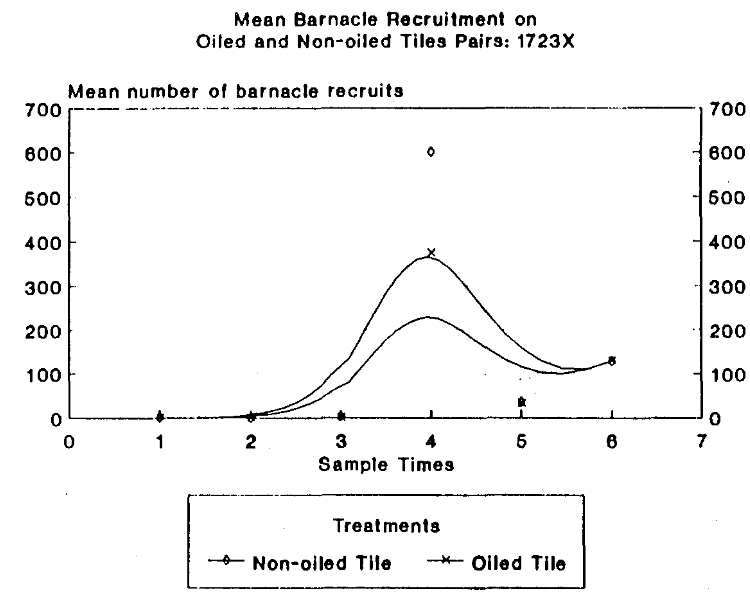


Fig. 4.16b. Mean number of barnacles observed on oiled and non-oiled tiles placed during the summer of 1990 and sampled three times in 1991. Site pair 1723.

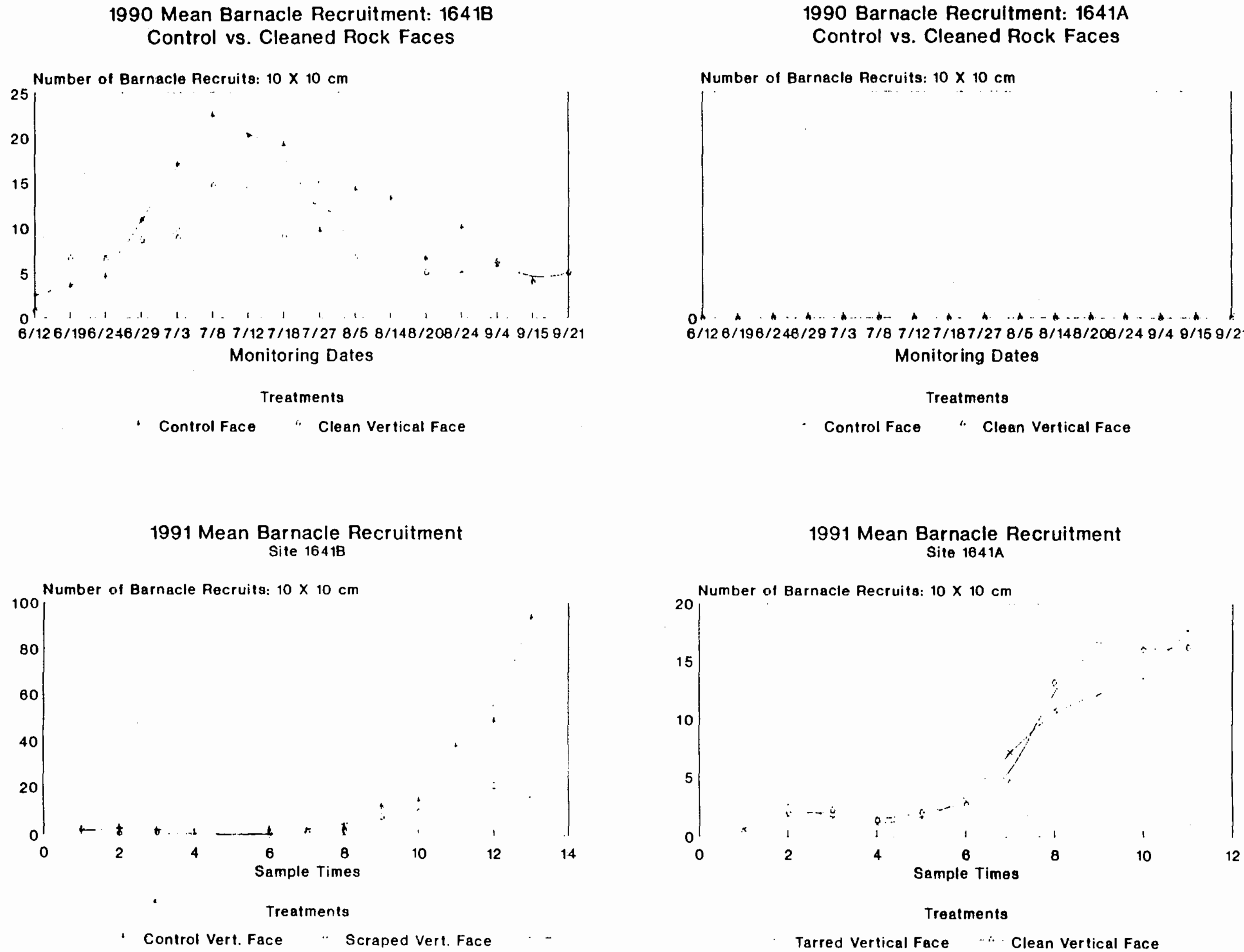
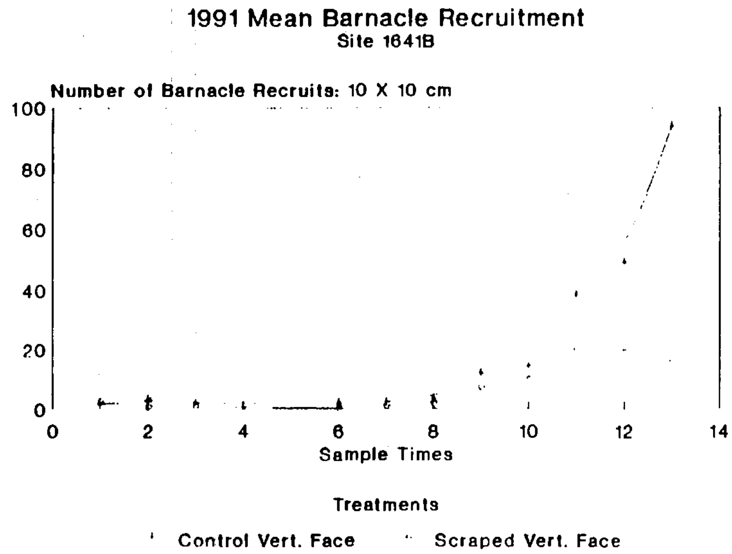
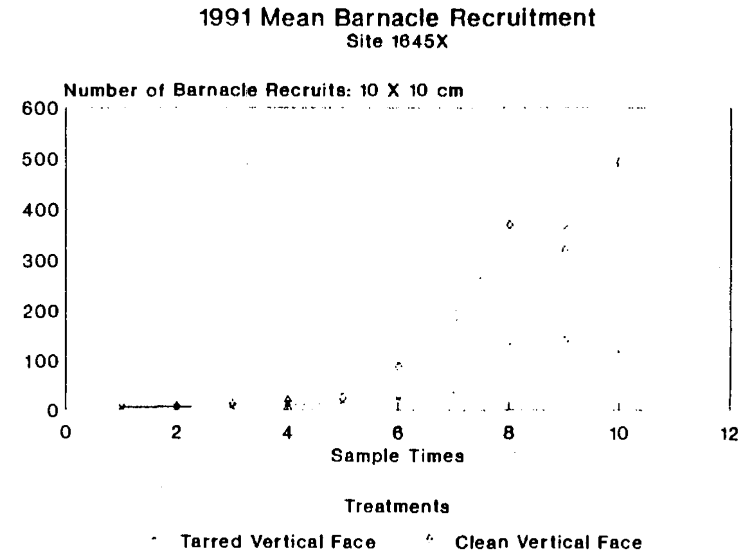


Fig. 4.17.1. 1990 and 1991 mean barnacle recruitment on oiled and cleaned vertical rock faces (10 X 10 cm plots). Site pair 1641. Refer to Table 4.5 for data and test results.





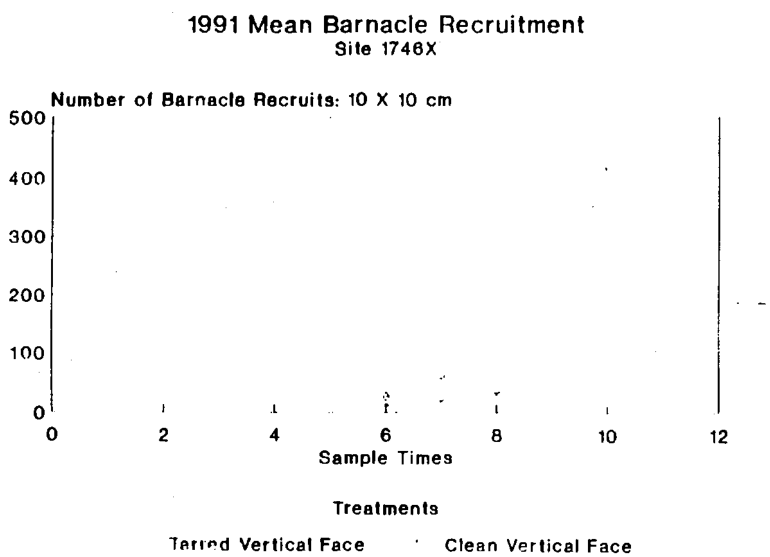


Fig. 4.17.2. 1991 mean barnacle recruitment on oiled and cleaned vertical rock faces (10 X 10 cm plots). Site pair 1641B (control) and pairs 1645X & 1746X (both oiled). Refer to Table 4.5 for data and test results.

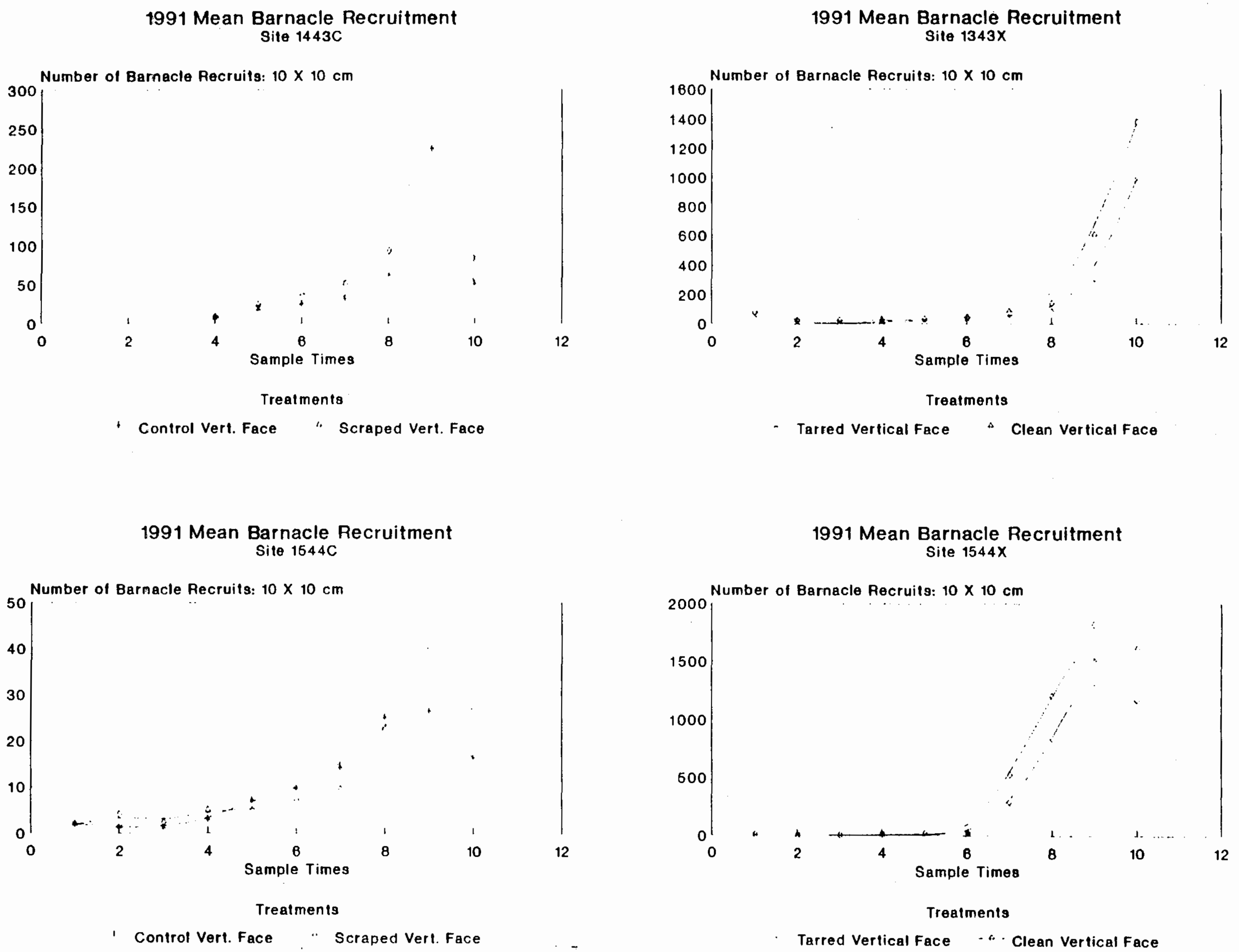


Fig. 4.17.3. 1991 mean barnacle recruitment on oiled and cleaned vertical rock faces (10 X 10 cm plots). Site pairs 1343 & 1544. Refer to Table 4.5 for data and test results.

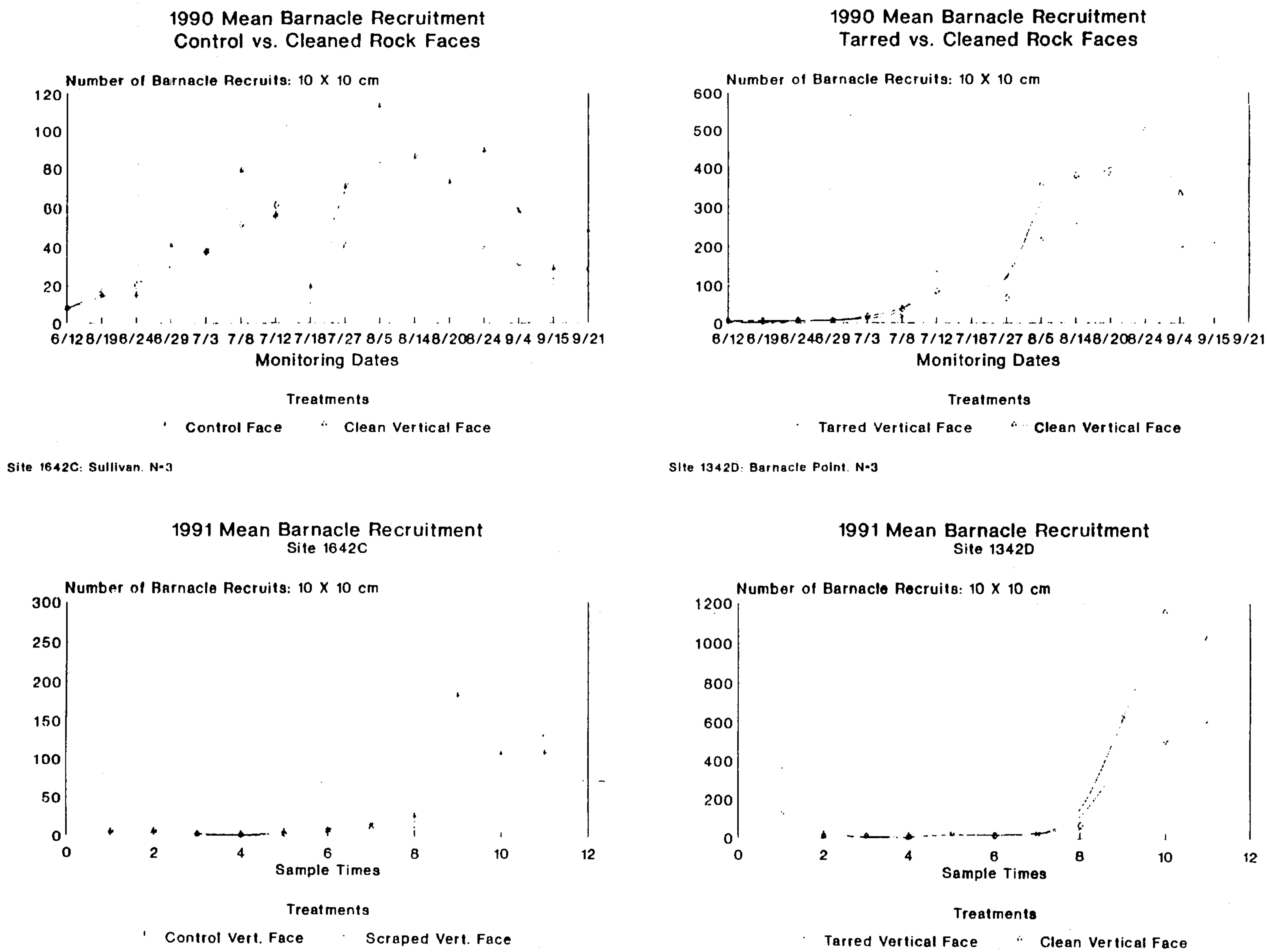
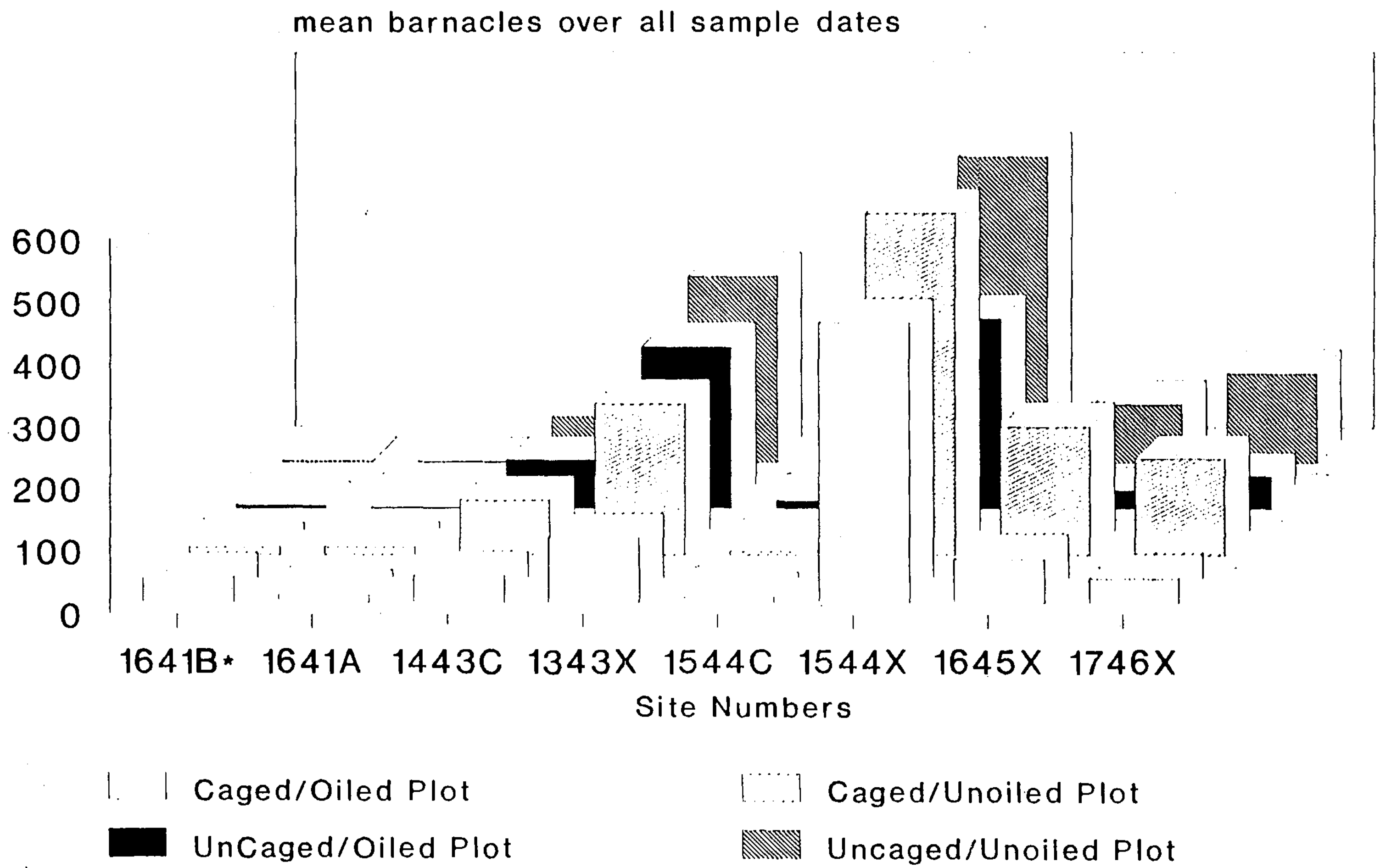


Fig. 4.17.4. 1990 and 1991 mean barnacle recruitment on oiled and cleaned vertical rock faces (10 X 10 cm plots). Site pair 1642. Refer to Table 4.5 for data and test results.

1991 Mean Barnacle Recruitment in Caged vs Uncaged Plots: All Sites



*1641B serves as site control for oiled sites 1645X and 1746X

Fig. 4.17.5. Differences in barnacle recruitment between caged and uncaged plots at all study sites. No significant differences observed [illegible] sites (paired T-test).

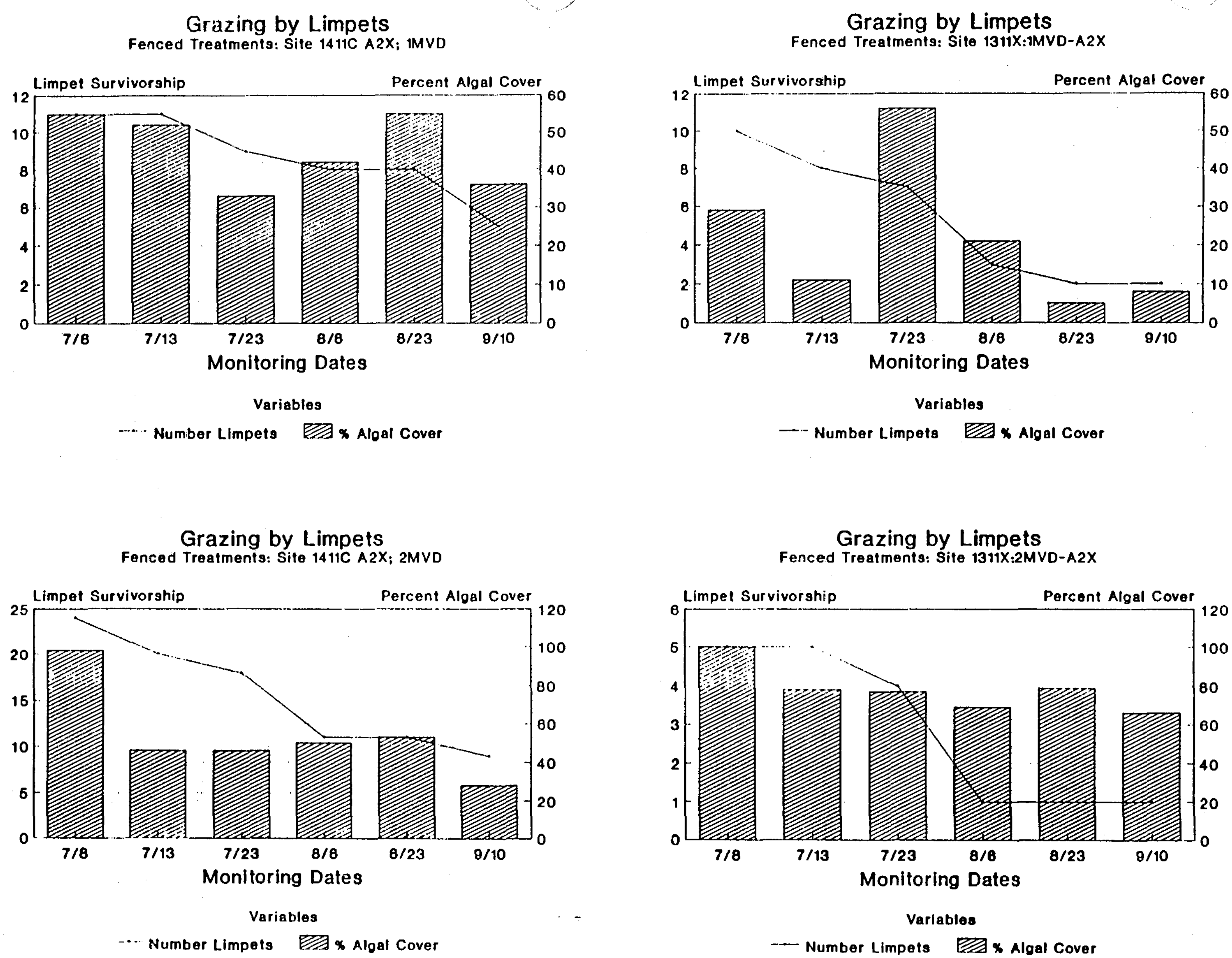


Fig. 4.18.1. Limpet density and percent algal cover in fences at 1 and 2 m elevations of site pair 1411. A2X = fences containing algae with twice the mean density of limpets.

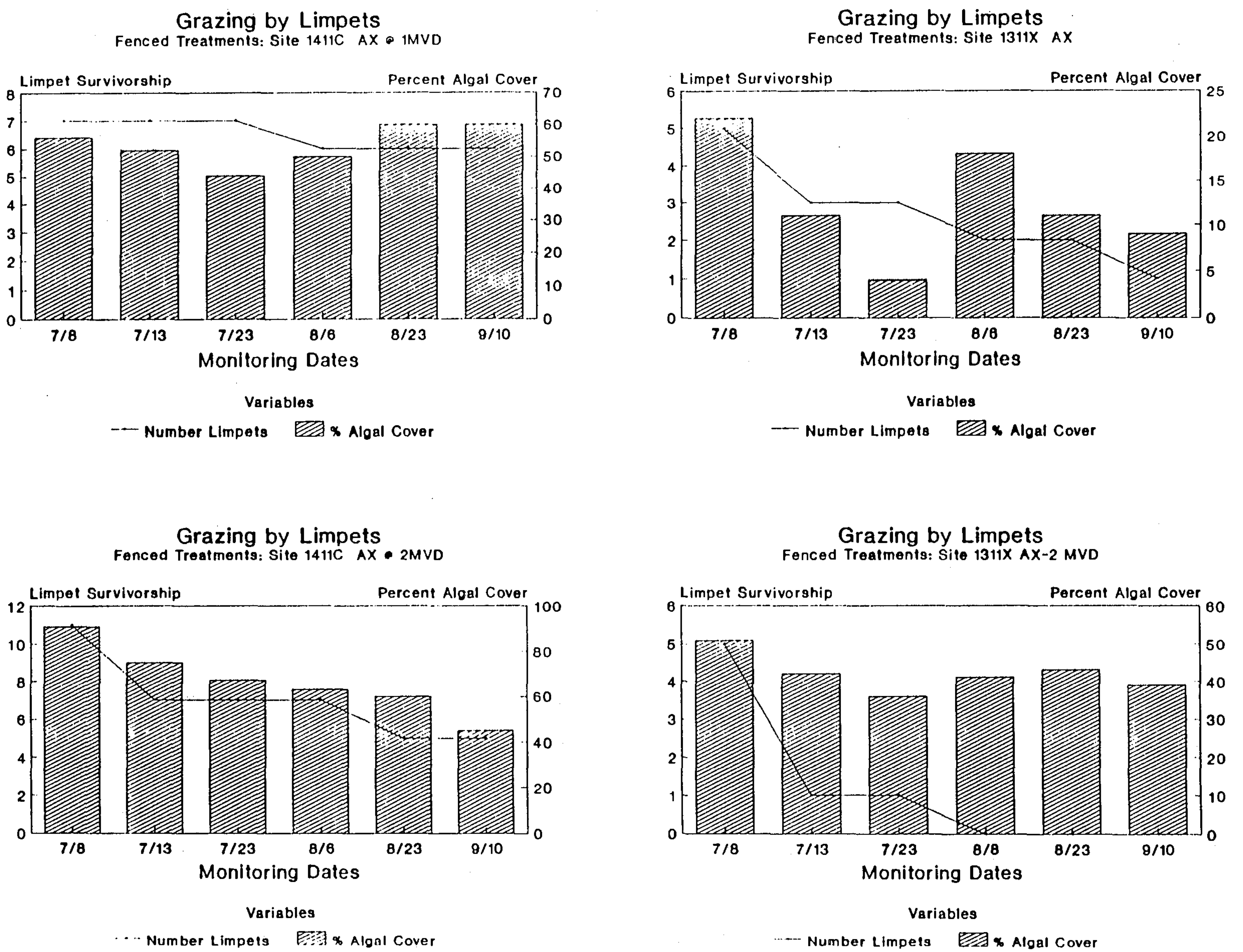


Fig. 4.18.2. Limpet density and percent algal cover in fences at 1 and 2 m elevations of site pair 1411. AX = fences containing algae with the mean density of limpets.

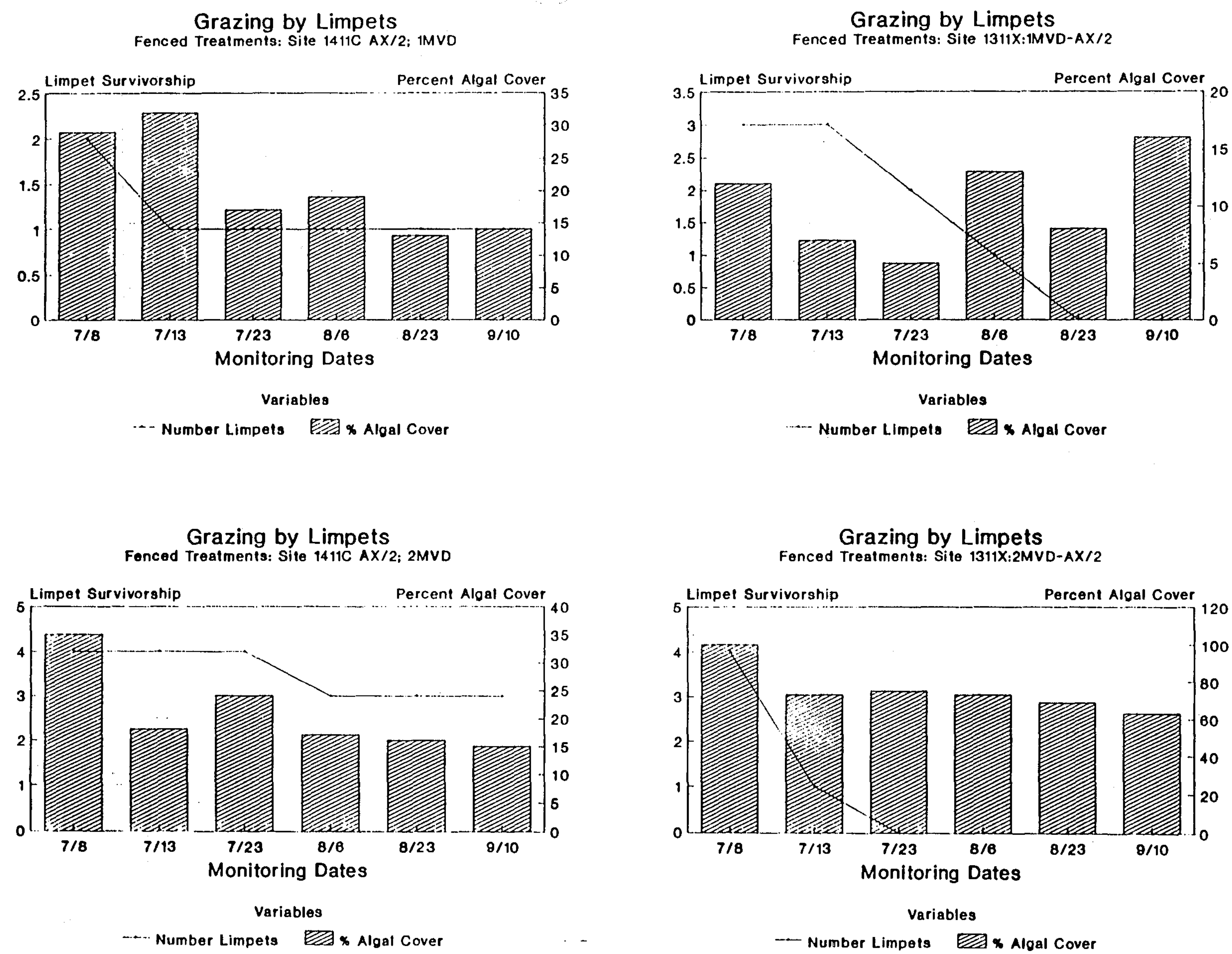


Fig. 4.18.3. Fences containing algae with one-half the mean density of limpets. Site pair 1411.

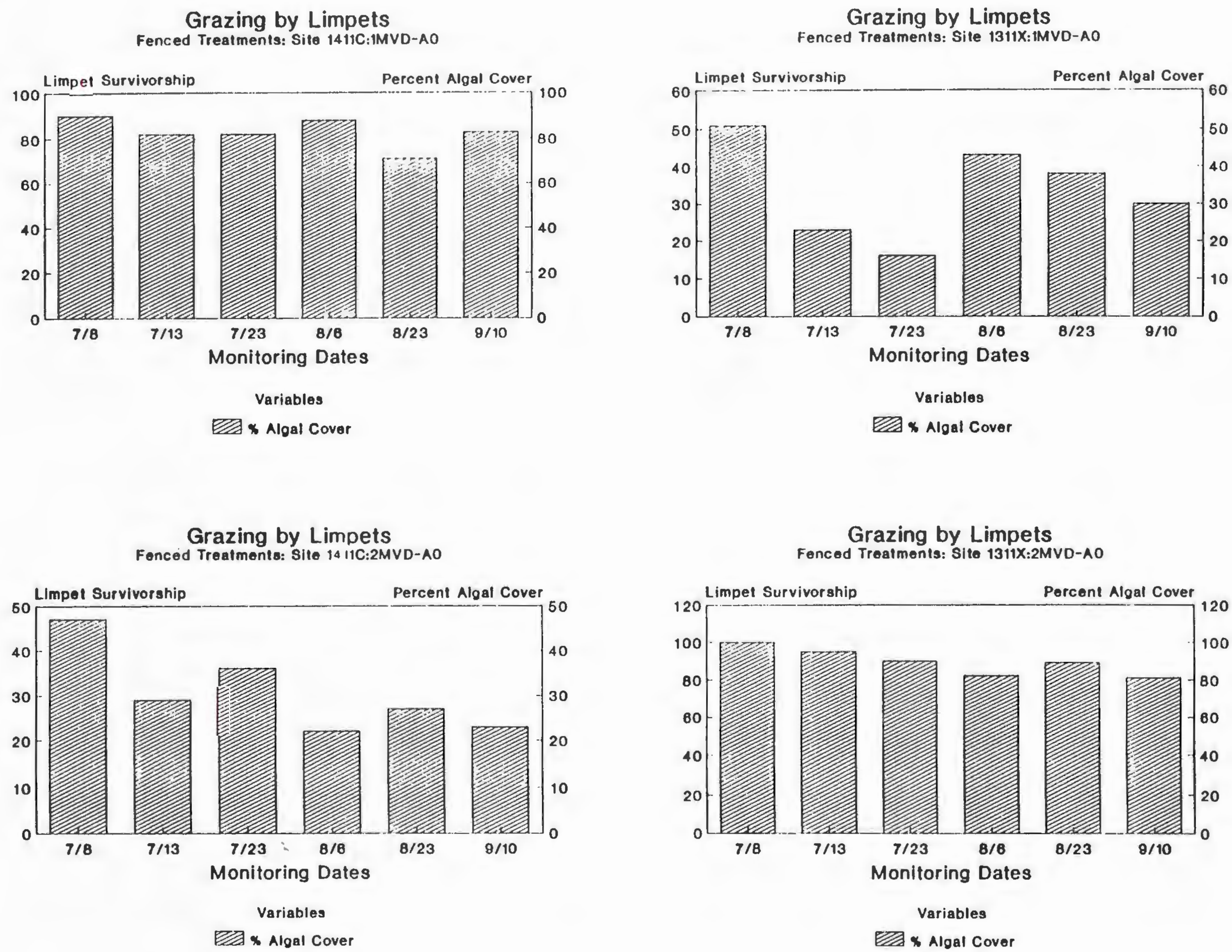


Fig. 4.18.4 Limpet fencing study, site pair 1411. A0 = no limpets in fences with algae retained.

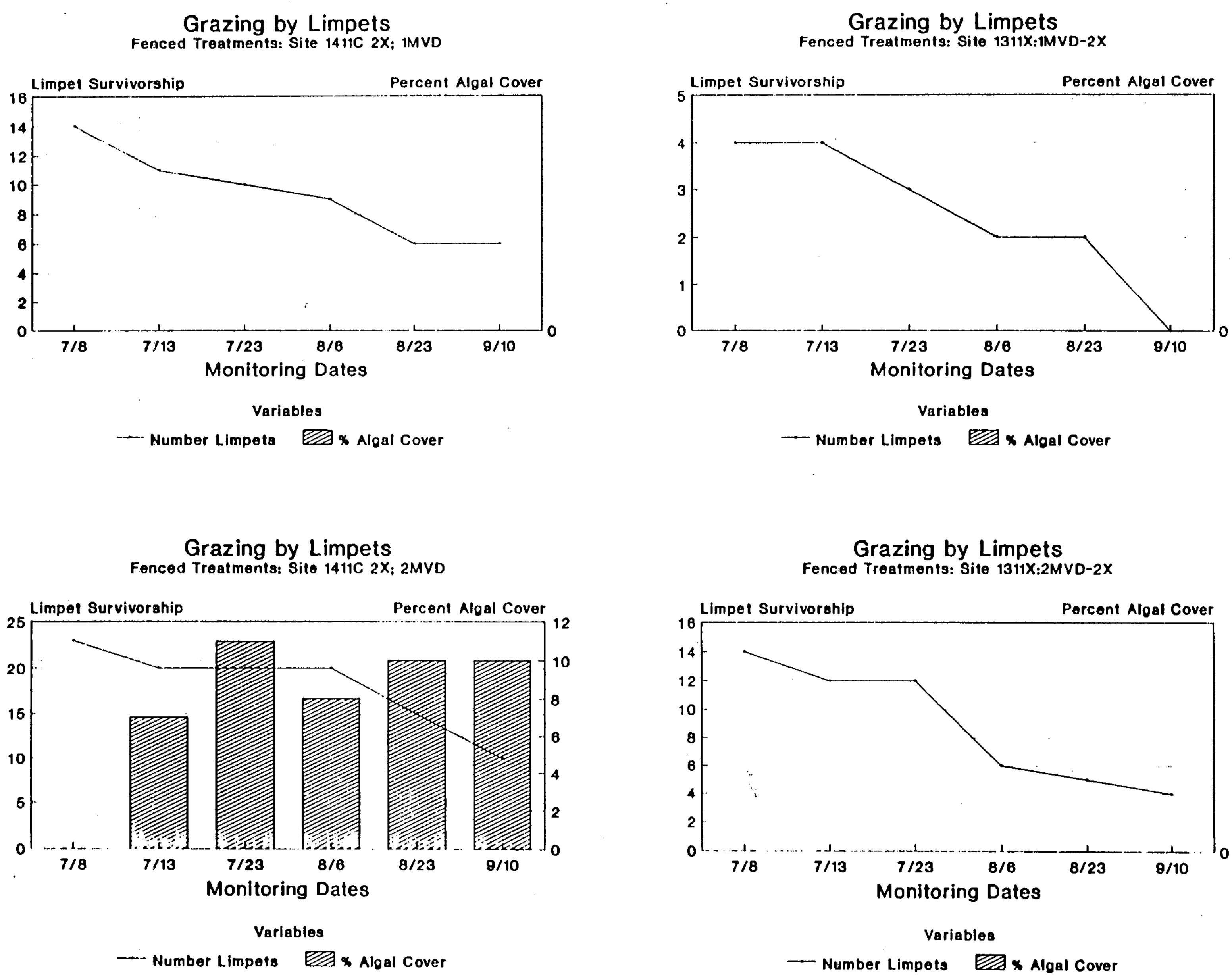


Fig. 4.18.5. Limpet density and percent algal cover in fences at 1 and 2 m elevations of site pair 1411. 2X = fences containing twice the mean density of limpets with algae removed.

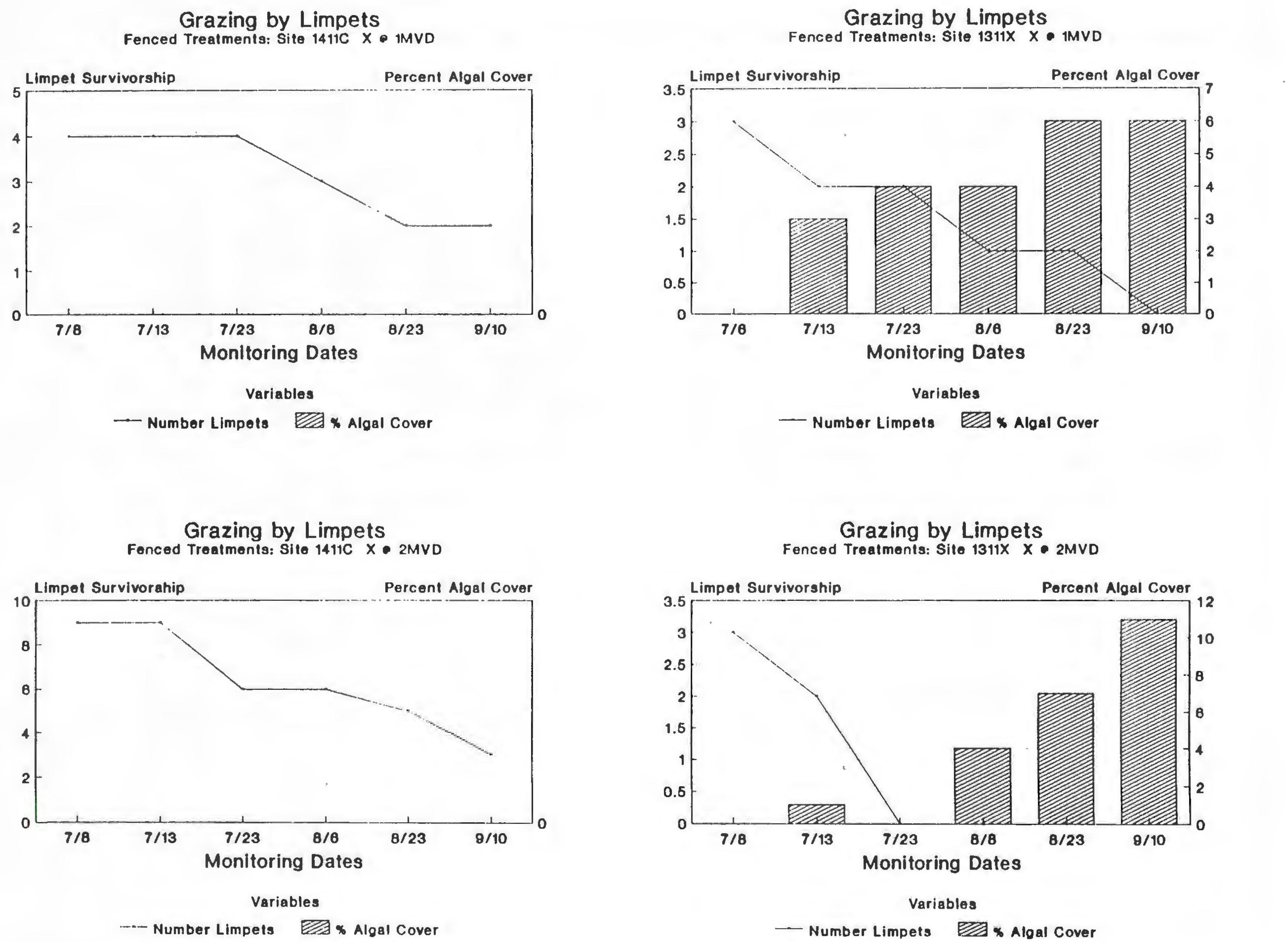


Fig. 4.18.6. Limpet density and percent algal cover in fences at 1 and 2 m elevations of site pair 1411. X = the mean density of limpets with algae removed.

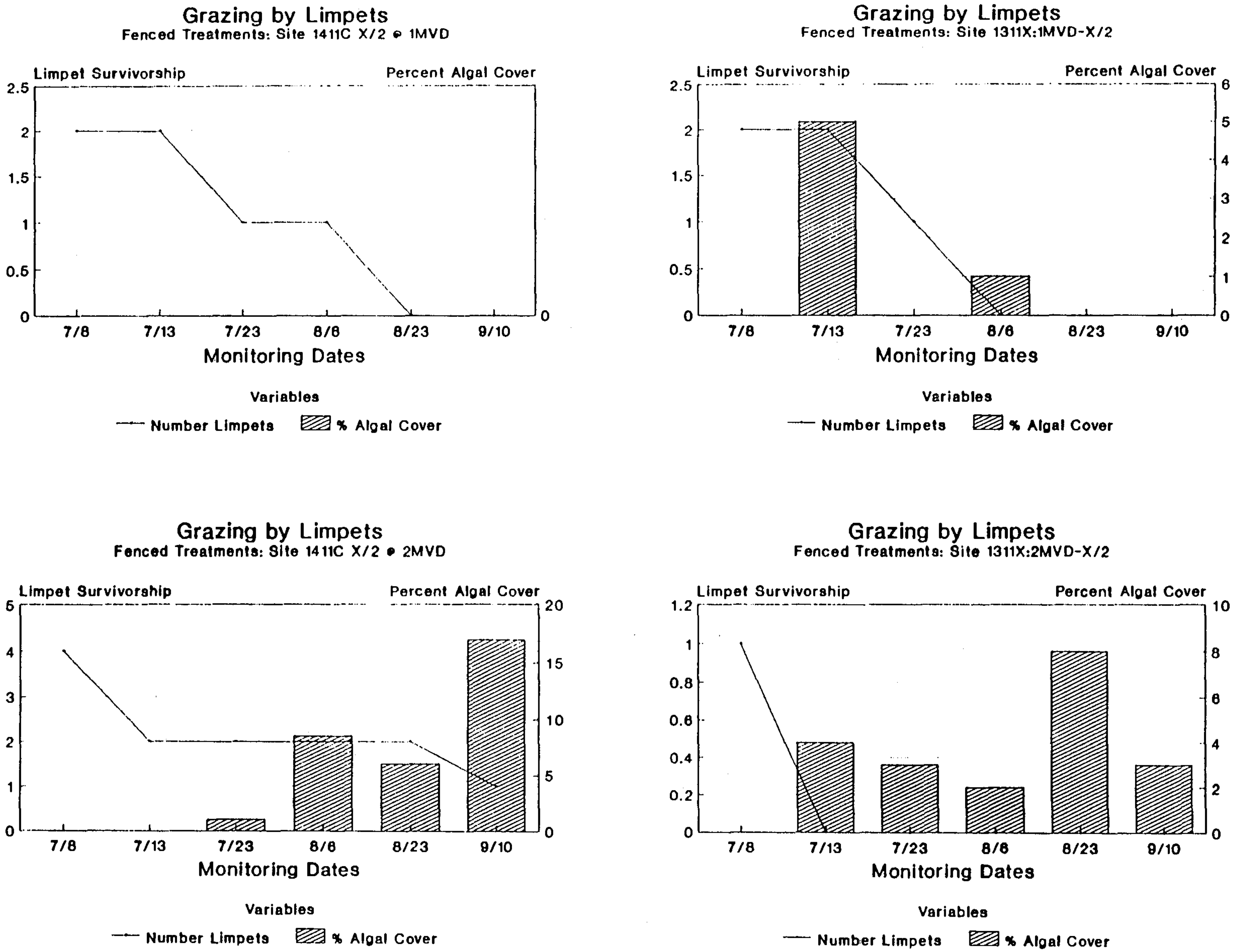


Fig. 4.18.7. Fences containing one-half the mean density of limpets with algae removed. Site pair 1411.

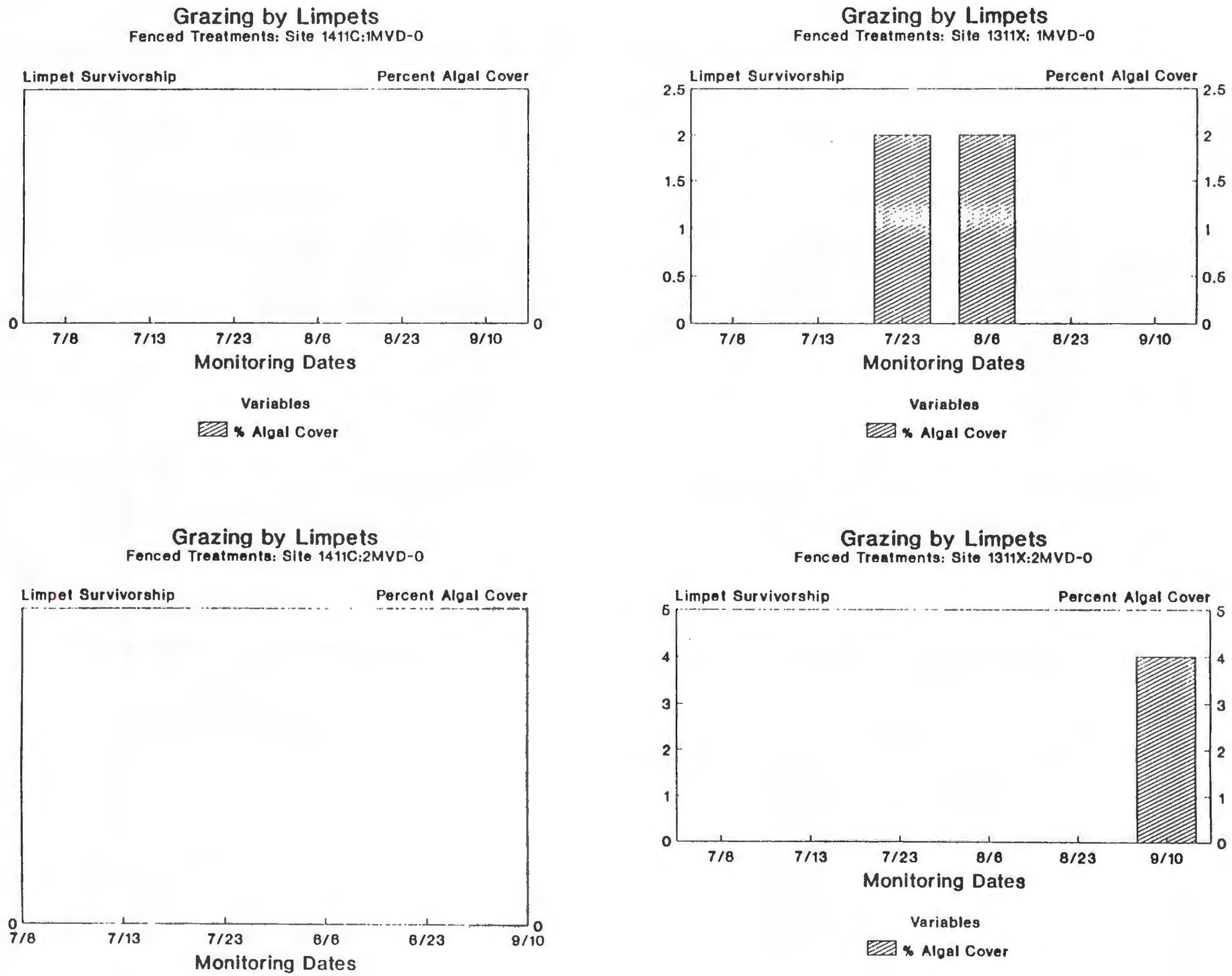


Fig. 4.18.8. Site pair 1411 showing treatment of 0 limpets with algae removed.

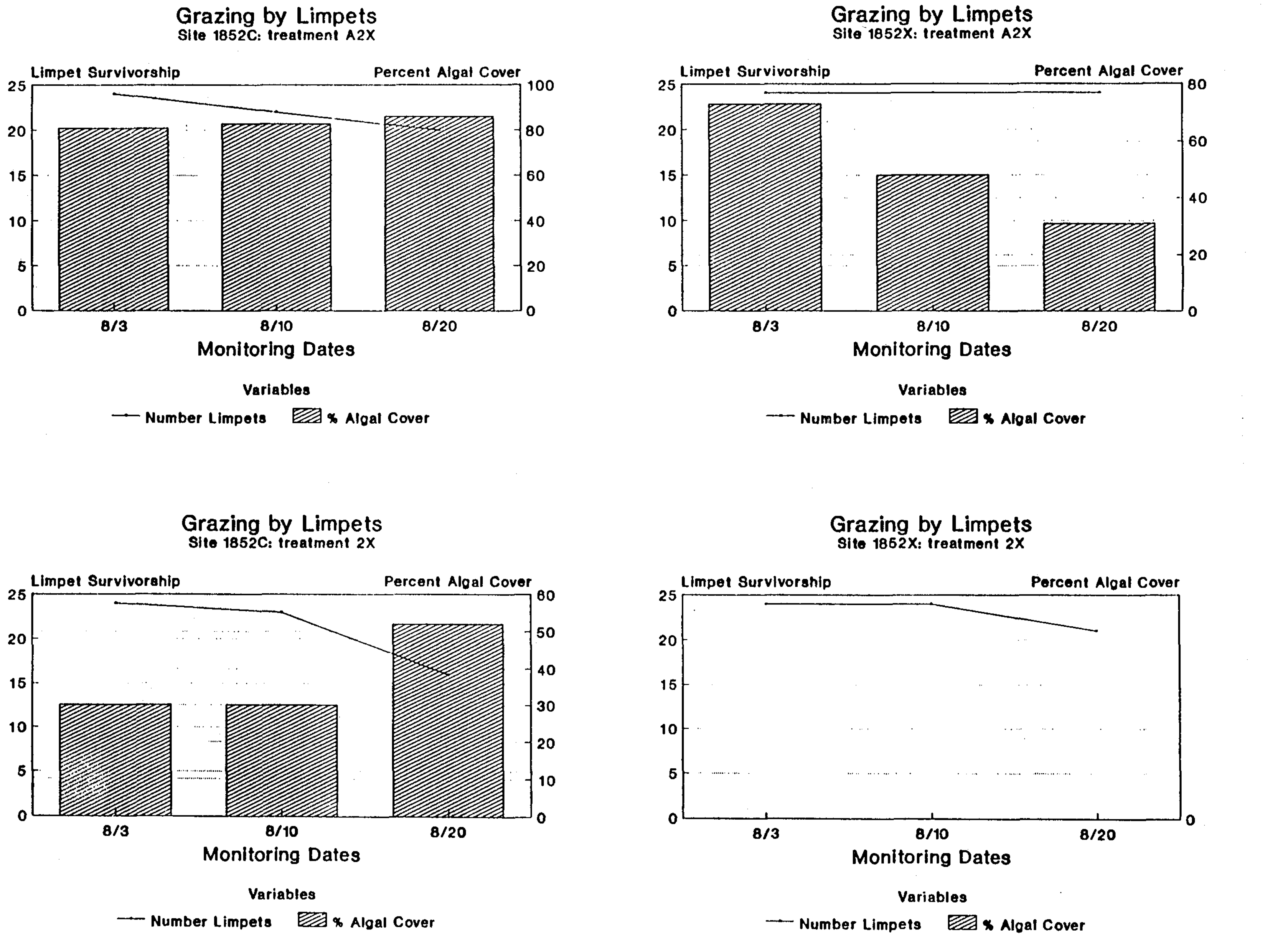
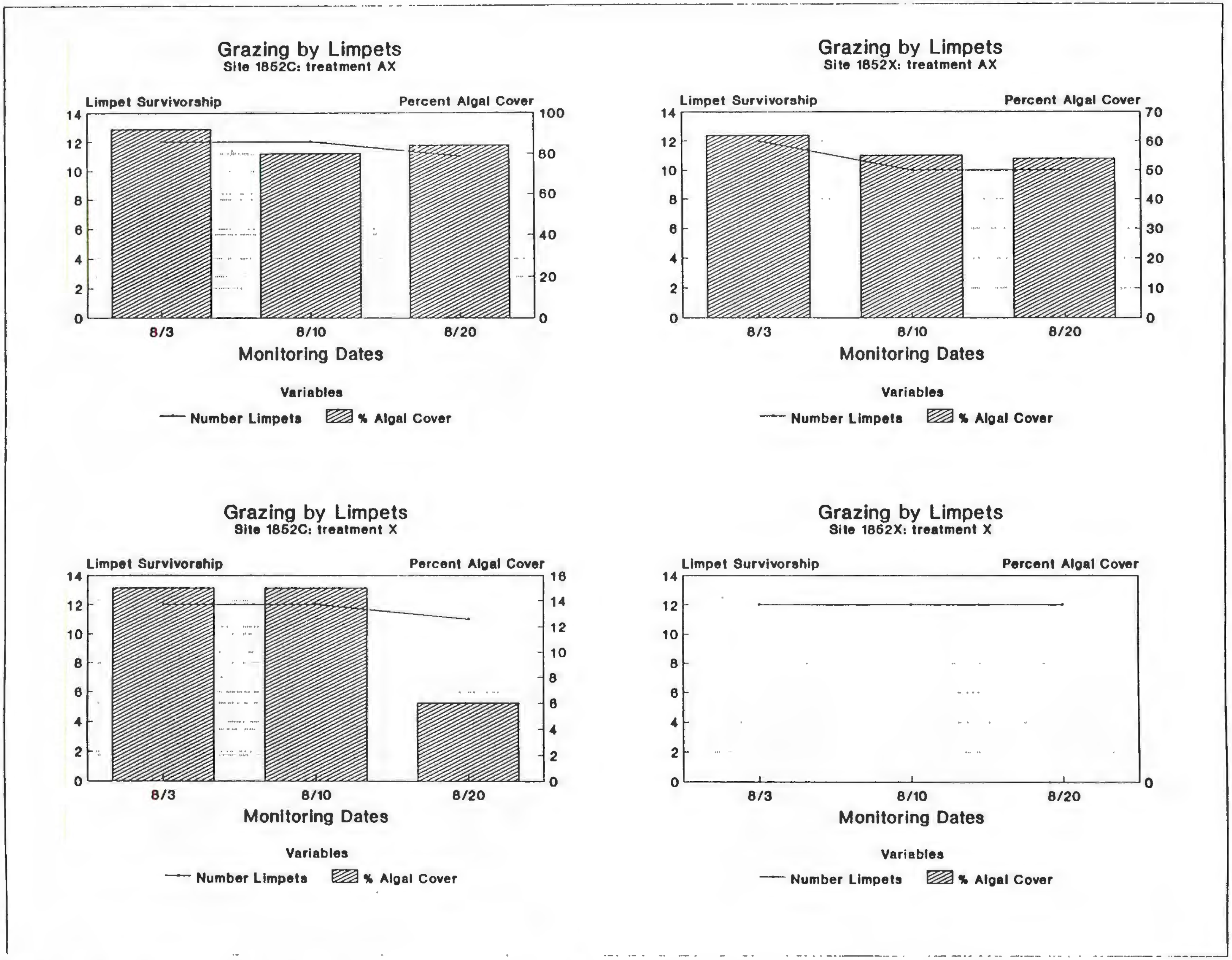


Fig. 4.18.9. Percent algal cover and limpet survivorship of the grazing study, using cages. Site pair 1852. 2 m elevation contour. Treatment 2X = twice the mean density of limpets with ("A") and without algae.



.18.10. Percent algal cover and limpet survivorship of ... zing study, using cages. Site pair 1852. 2 m elevation ... ment AX = the mean density of limpets with ("A") and ... ut algae.

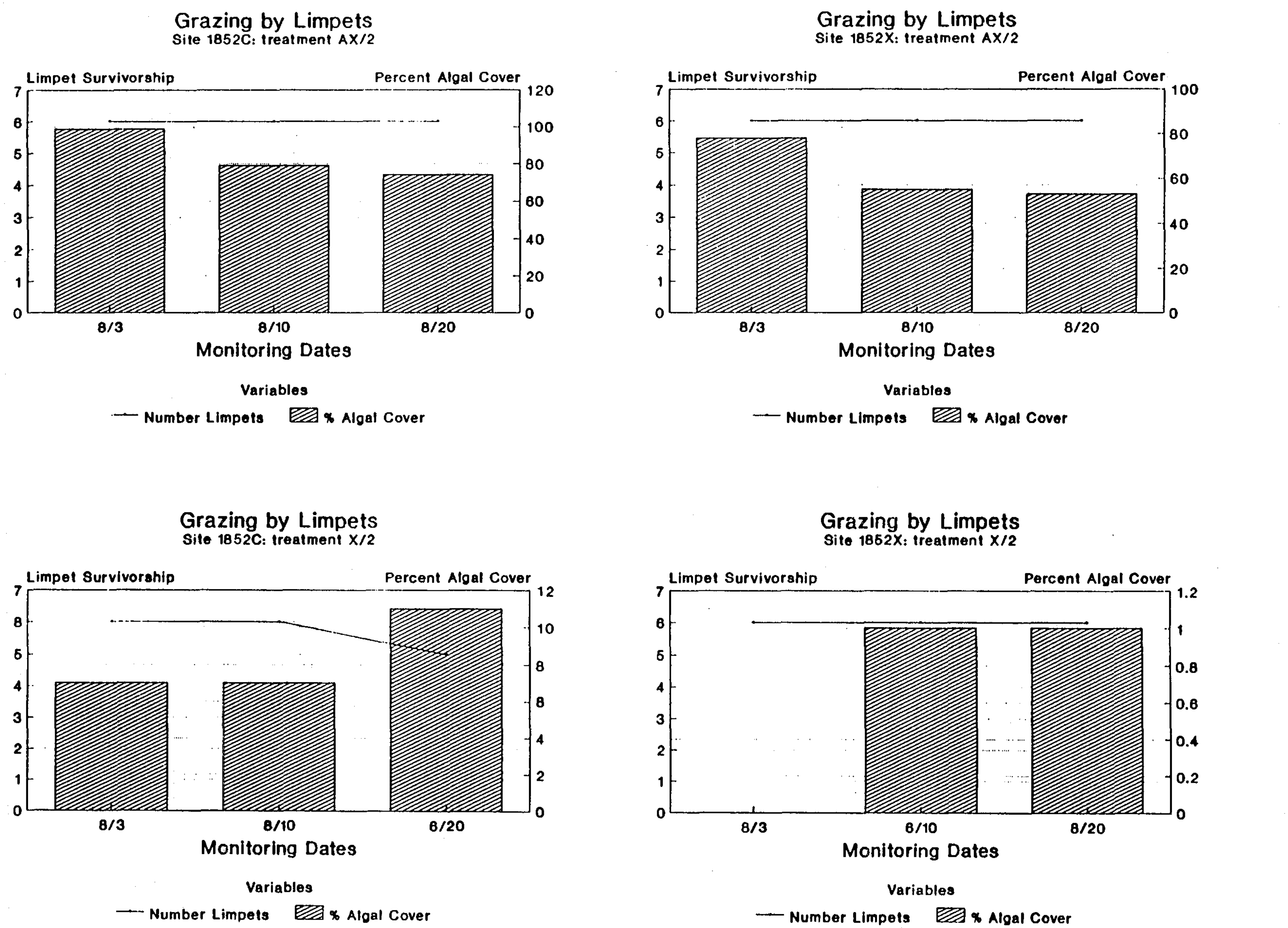
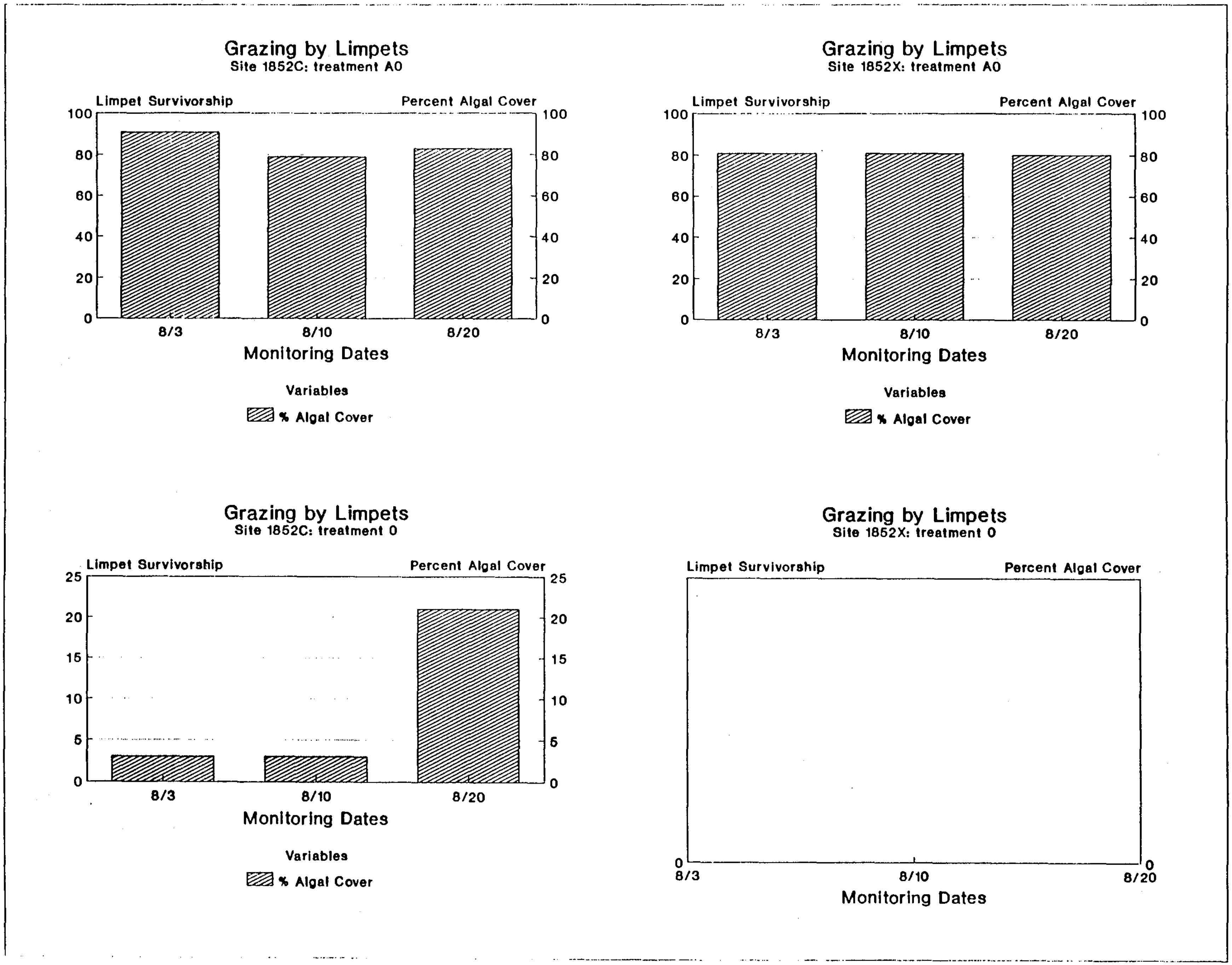


Fig. 4.18.11. Percent algal cover and limpet survivorship of the grazing study, using cages. Site pair 1852. 2 m elevation contour. Treatment ΛX/2 & X/2 = one-half the mean density of limpets with and without algae.



4.18.12. Percent algal cover in limpet caging study limpets placed. Site pair 1852. 2 m elevation contour

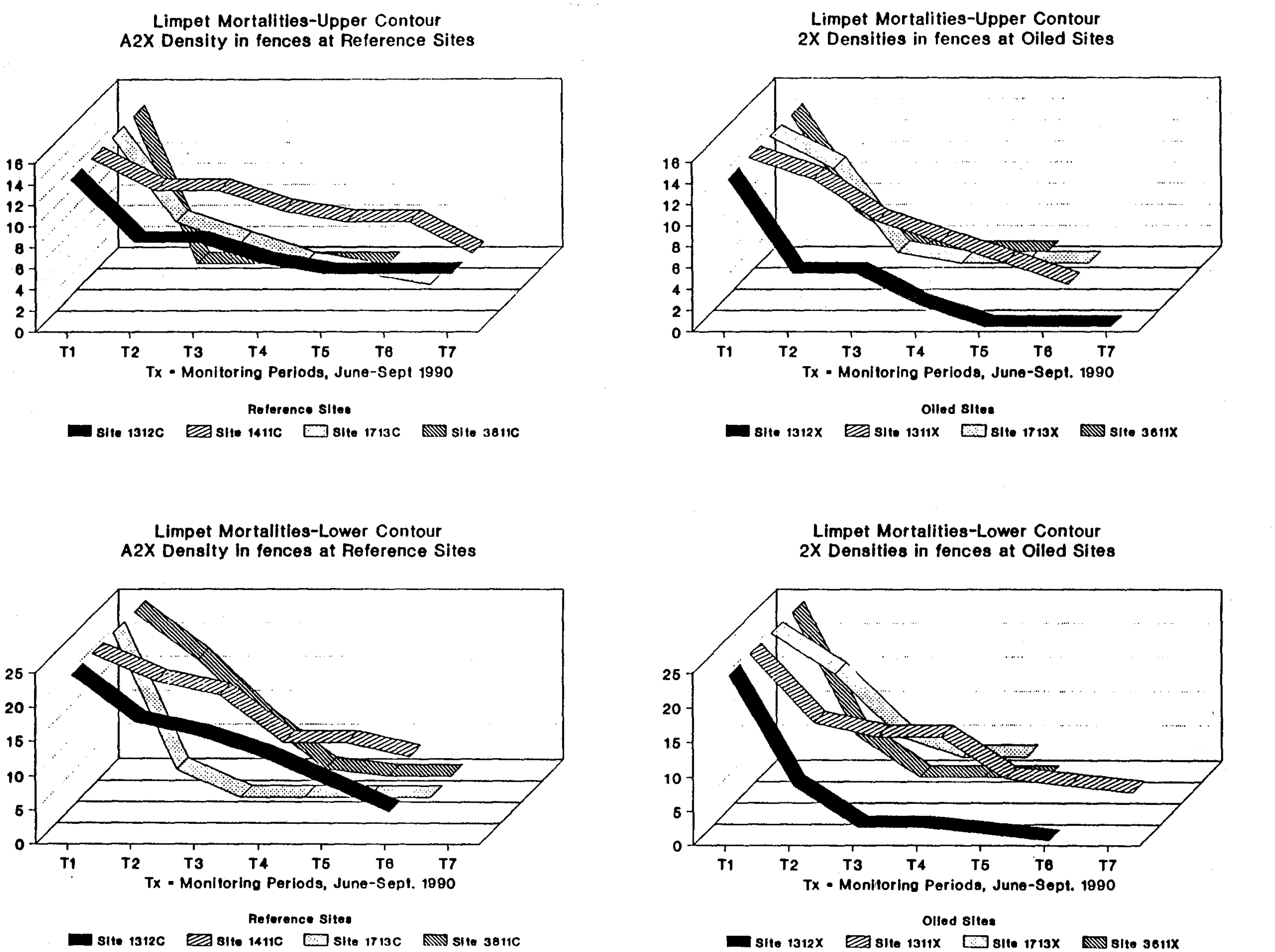
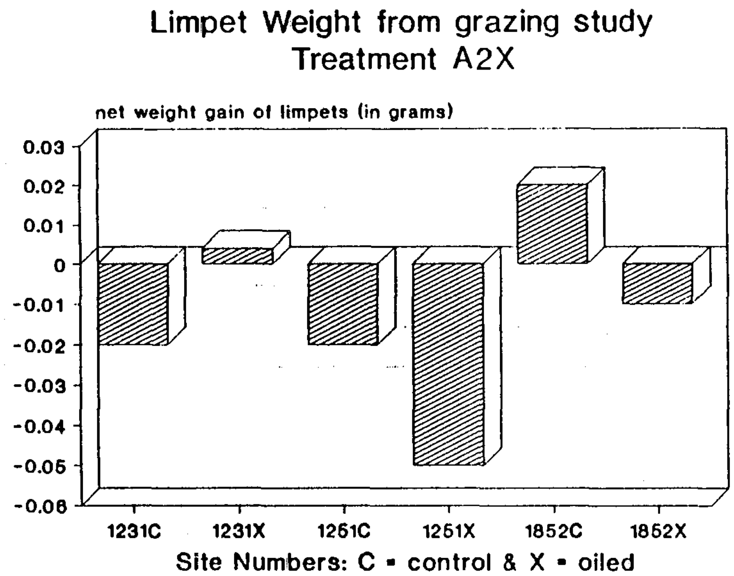
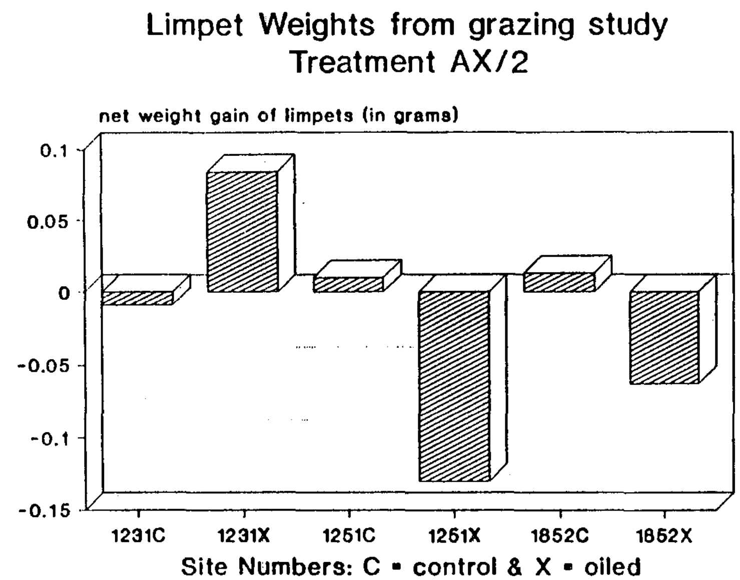


Fig. 4.19. Limpets mortalities of 2X treatments (twice the mean limpet density) in fences with and without algae. Figure shows loss of limpets over time at all control and oiled sites. Data from X and X/2 densities showed similar trends.





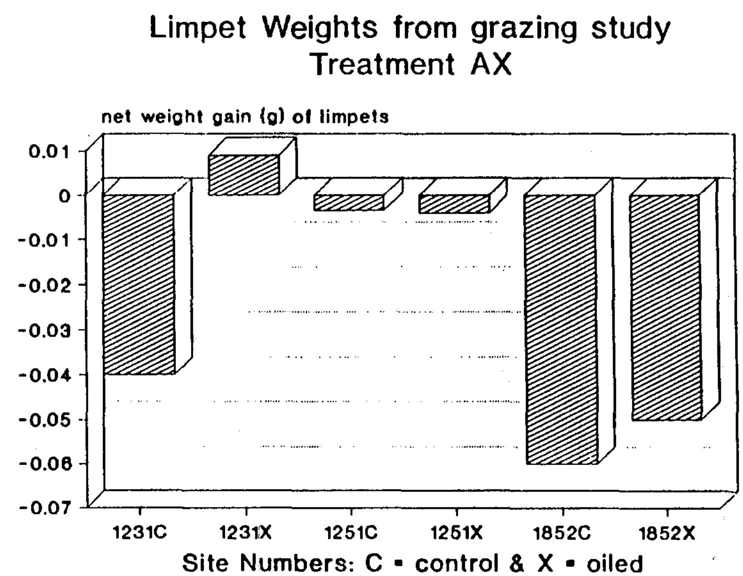
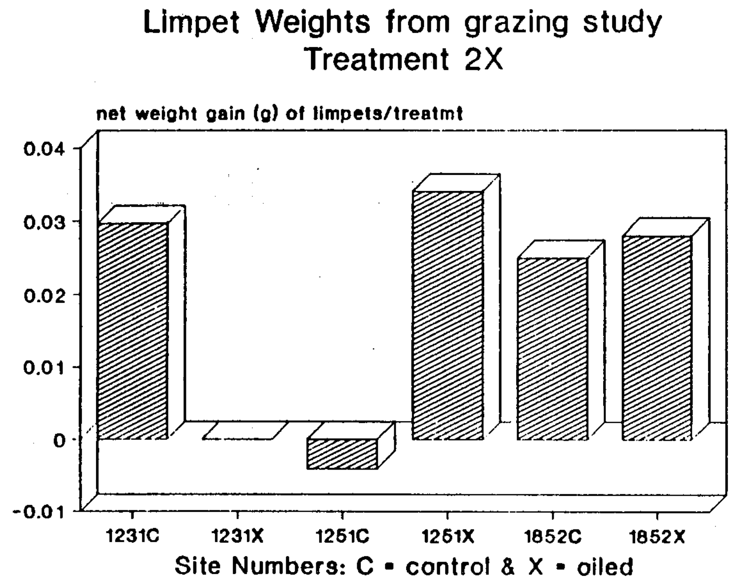
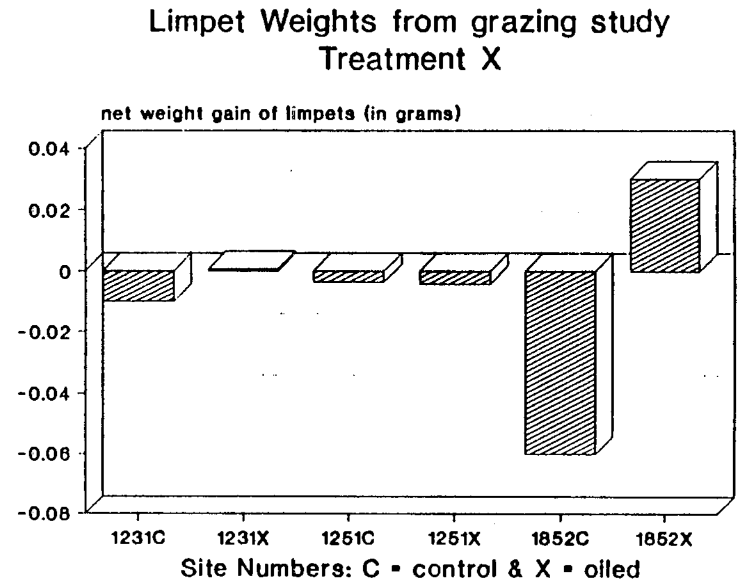


Figure 4.20.1 Net weight gain of limpets surviving after the caging experiment. 3 different density treatments taken from cages with algae present. 2X=twice mean limpet density. X=mean limpet density and X/2=one half mean density.





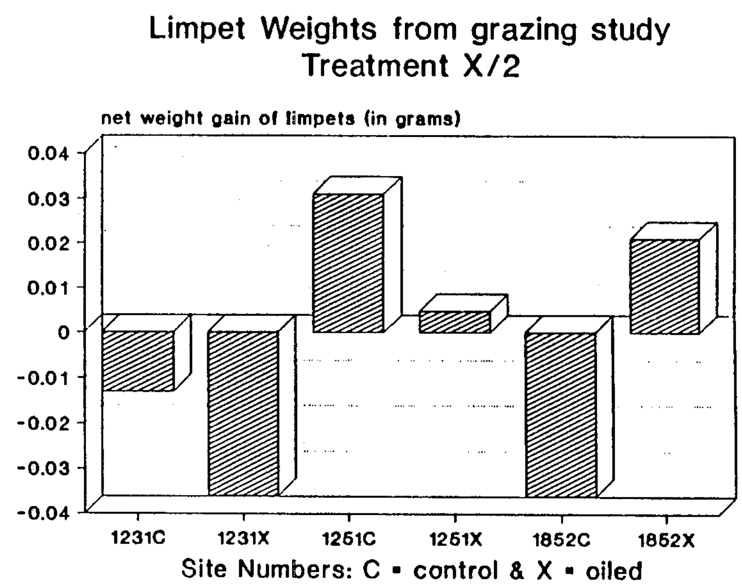
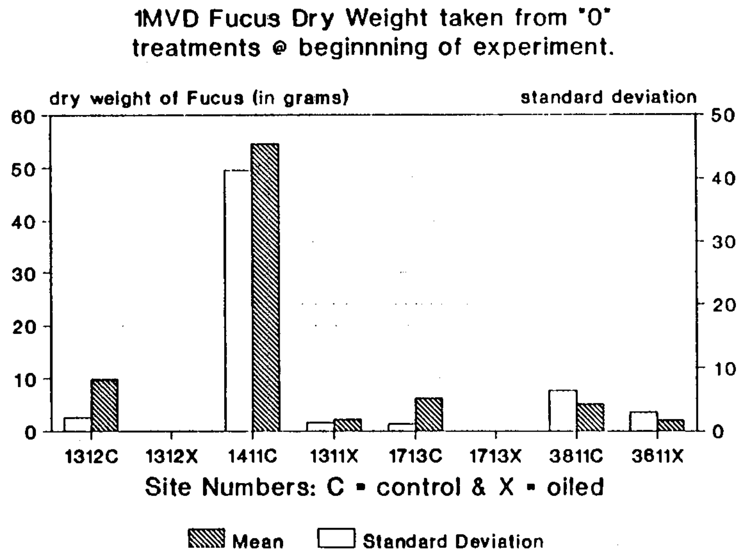
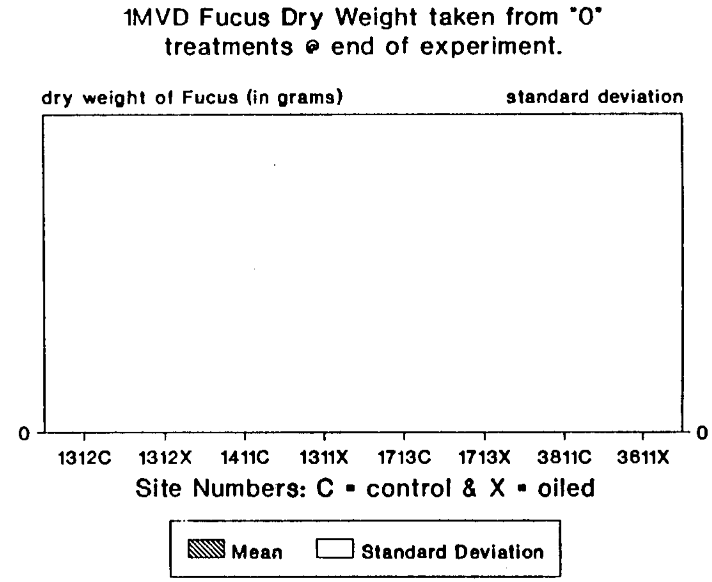


Figure 4.20.2 Net weight gain of limpets surviving the caging experiment.
3 different density treatments taken from cages with algae removed.





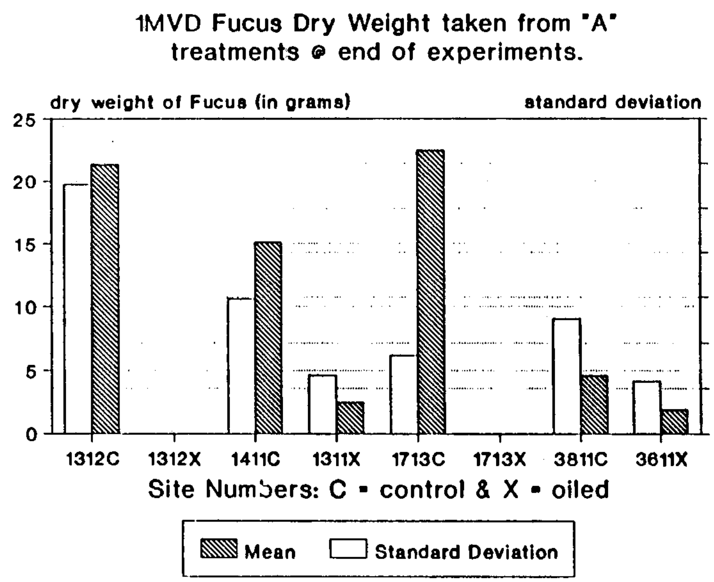
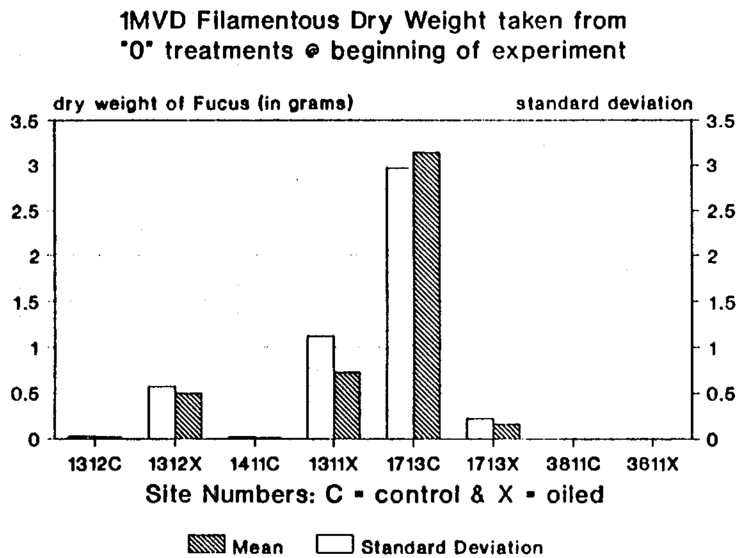
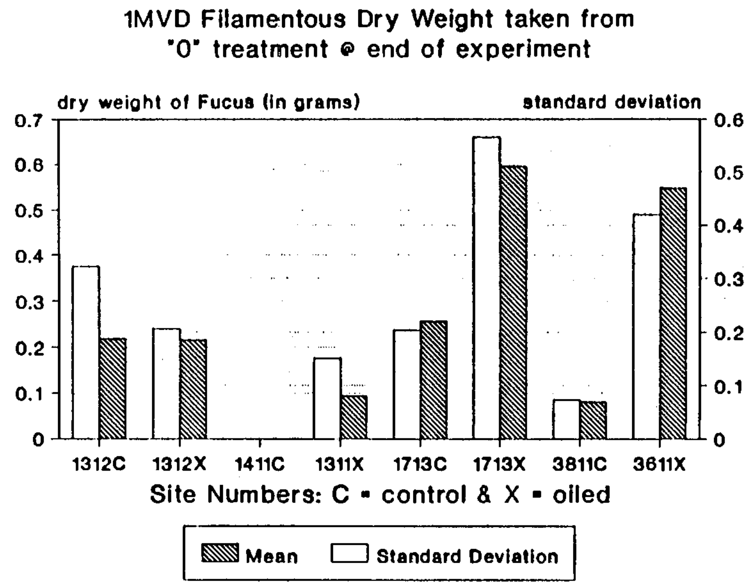


Figure 4.21.1. Mean dry weight of Fucus sp. taken from fences at all sites at 1MVD.





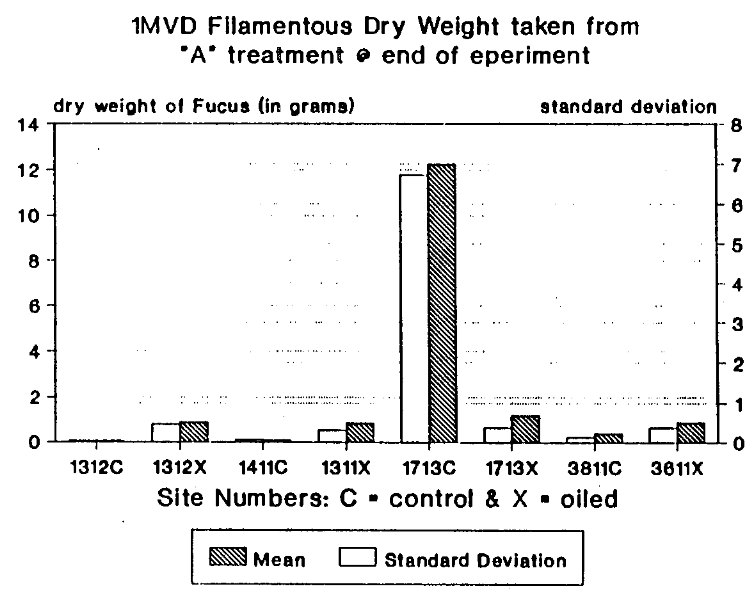
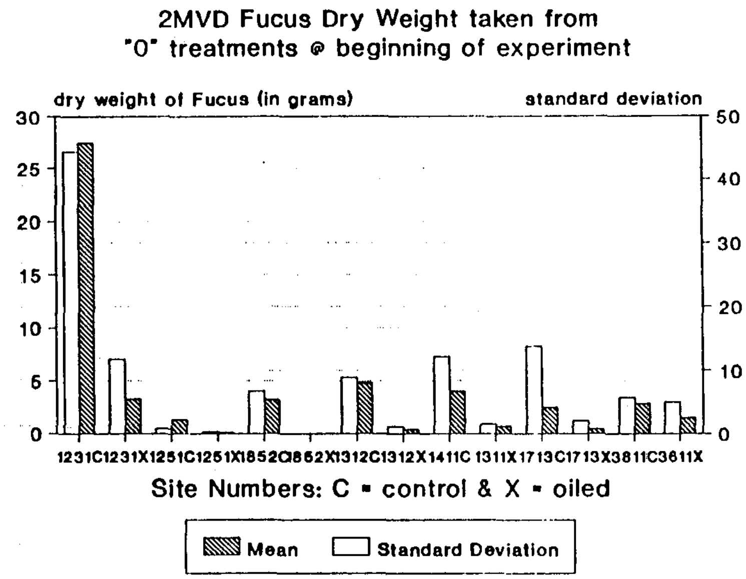
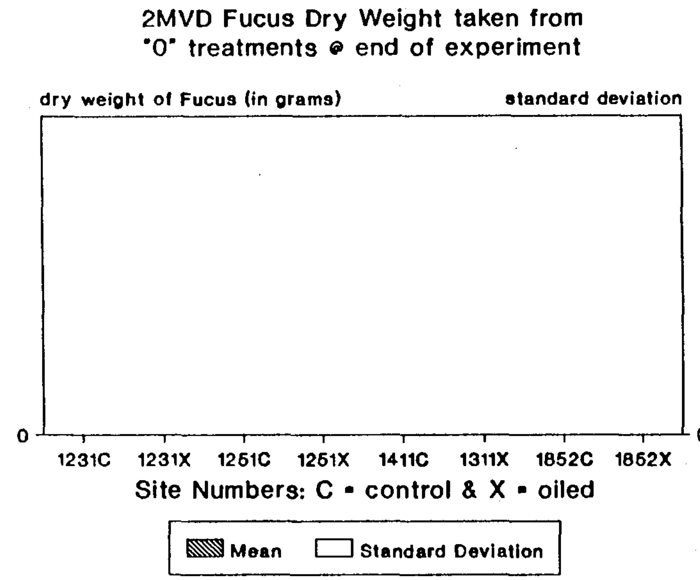


Figure 4.21.2 Mean dry weight of filamentous algae removed from fences before and after experiment.





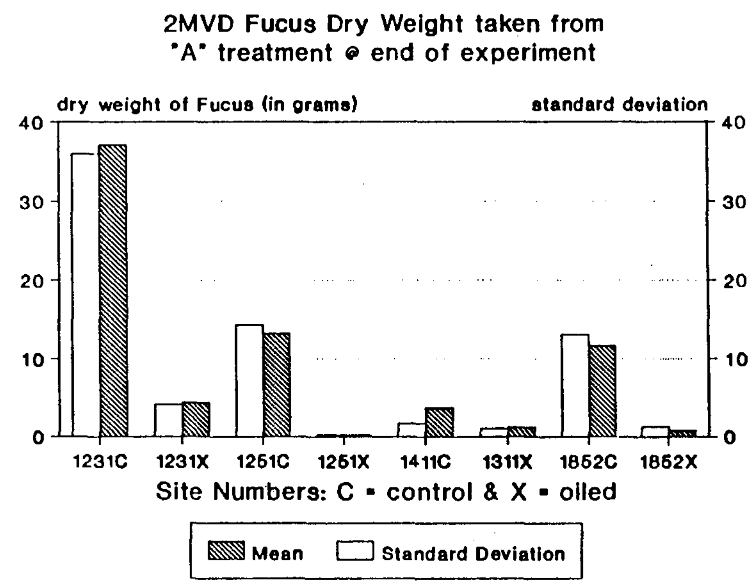
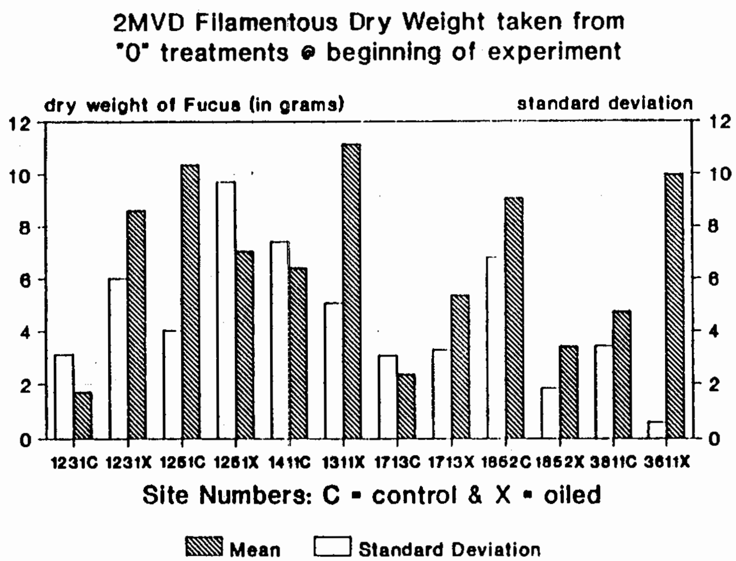
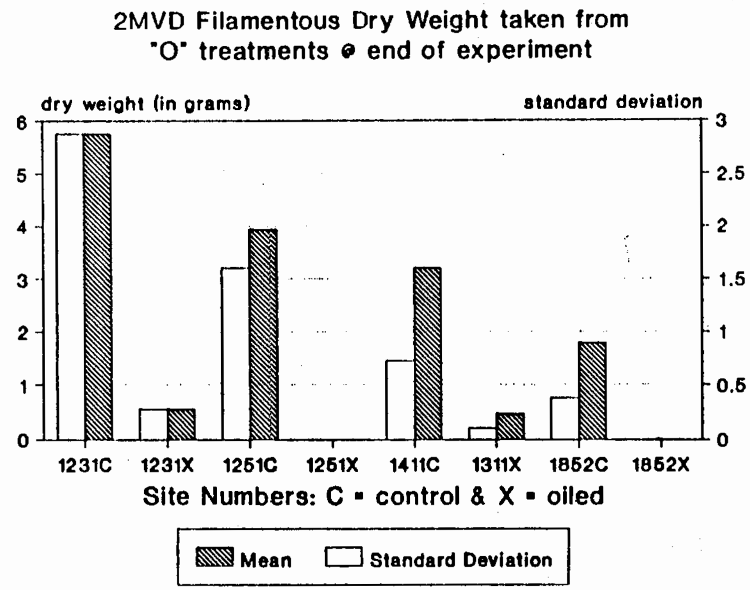


Figure 4.21.3 Mean dry weights of Fucus sp. at lower fence/cage contour before and after experiment.





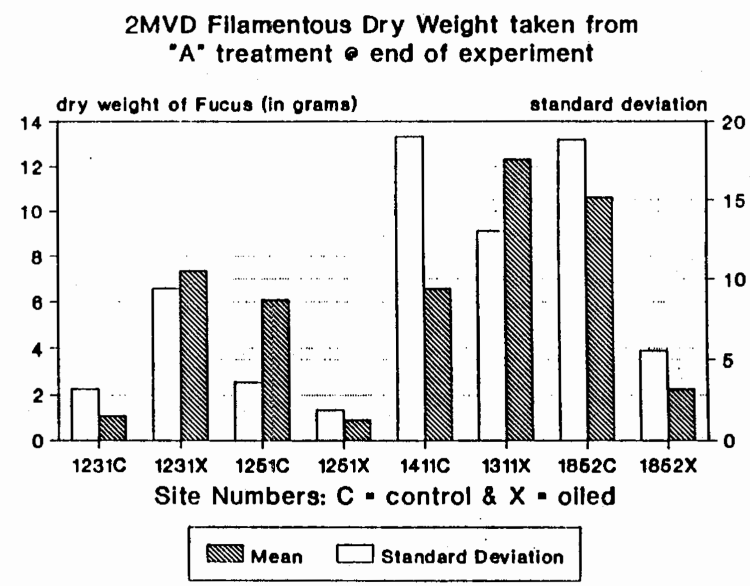


Figure 4.21.4 Mean dry weight of filamentous algae at lower fence/cage contour before and after experiment. Some sites were not sampled for algae at end of experiment.

Table 4.1 Oiled study sites in Herring Bay and most probable shoreline treatment. Treatment status based upon review of ADEC records, interviews and site visits with ADEC staff and shoreline treatment subcontractors working in Herring Bay in 1989.

Site #	Site Name	Segment #	Shoreline Treatment Method
1221X	Barnacle Point	KN145	Hot Water/High Pressure
1231X	North Shore	KN133B	Omni Boom
1251X	Pa-hoi-hoi Partner	KN133B	Omni Boom
1311X	Waikiki	KN133	Omni Boom
1312X	Barnacle Point-East	KN145	Hot Water/High Pressure
1322X	Pa-hoi-hoi Rock	KN133B	Omni Boom
1342D	Barnacle Point-D	KN145	Hot Water/High Pressure
1343X	Jack's	KN145	Hot Water/High Pressure
1361X	Cross Cove	KN133A	Omni Boom
1362X	Split Beach	KN120	Unknown and Undetermined
1544X	Kiska's	KN5011	No Treatment
1641A	Barnacle Point-A	KN145	Hot Water/High Pressure
1645X	Hidden Wall	KN133A	No Treatment
1713X	OTR	KN128	Omni Boom
1723X	Barnacle Point-West	KN145	Hot Water/High Pressure
1732X	Port Arthur	KN133A	No Treatment
1746X	Hazelwood	KN133A	No Treatment
1852X	Blackstone	KN129	Omni Boom
2333X	Wreck Beach	KN131	Omni Boom
2337X	Finger Bay	KN130	Hot Water/Moderate Pressure
2834X	Anchor Beach	KN121	Cold Water High Pressure
3611X	Grease Wall	KN128	Omni Boom*

*only half of this site appears to have received treatment.

Notes: Treatment refers to the most intensive technique used. Other treatment techniques may have also been employed, and bioremediation was added to sites throughout Herring Bay in late August and September, 1989.

Table 4.2. Invertebrates and algae observed at matched site pairs, during Site Characterization Sampling.

SITE 1221C	MAY 14, 1991		
INVERTEBRATES		ALGAE	
Acarida		Cladophora	sericea
Amphipoda	spp	Gumontia	sp.
Balanus	glandula	Enteromorpha	linza
Balanus	crenatus	Fucus	gardneri
Chthalamus	dalli	Gloiopeltis	furcata
Littorina	scutulata	Hildenbrandia	rubra
Littorina	sitkana	Monostroma	undulatum
Unknown limpet	species	Myelophycus	intestinalis
Lottia	pelta	Neorhodomela	aculeata
Modiolus	rectus	Pilayella	washingtoniensis
Mytilus	edulis	Ralfsia	fungiformis
Nucella	lamellosa	Rhodomela	subfusca
Pagurus	sp	Rivularia	atra
Semibalanus	balanoides	Scytosiphon	lomentaria
Tectura	persona	Ulva	fenestrata
Tectura	scutum	Porphyra	spp
		Tar	Spot

SITE 1221X	MAY 14, 1991		
INVETEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Cryptosiphonia	woodii
Balanus	crenatus	Enteromorpha	linza
Bryozoa		Enteromorpha	intestinalis
Chthalamus	dalli	Fucus	gardneri
Littorina	scutulata	Gloiopeltis	furcata
Littorina	sitkana	Halossacion	glandiforme
Lottia	pelta	Hildenbrandia	rubra
Modiolus	rectus	Monostroma	undulatum
Mytilus	edulis	Myelophycus	intestinalis
Pagurus	sp	Neorhodomela	aculeata
Semibalanus	balanoides	Pilayella	washingtoniensis
Spirorbis	sp.	Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Verrucaria	sp.
		Porphyra	spp

* ORA = blue green algal film

SITE 1221C	JULY 23, 1991		
INVERTEBRATES		ALGAE	
Acarida		Cladophora	sericea
Amphipoda	spp	Gumontia	sp.
Balanus	crenatus	Fucus	gardneri
Chthalamus	dalli	Gloiopeltis	furcata
Littorina	scutulata	Hildenbrandia	rubra
Littorina	sitkana	Neorhodomela	aculeata
Lottia	pelta	Pilayella	washingtoniensis
Modiolus	rectus	Ralfsia	fungiformis
Mytilus	edulis	Rhodomela	subfusca
Nucella	lamellosa	Rivularia	atra
Nucella	lima	Verrucaria	sp.
Pagurus	sp		
Semibalanus	balanoides		
Spirorbis	sp		
Tectura	persona		
Tectura	scutum		
Isopoda	spp.		

SITE 1221X	JULY 24, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Acrosiphonia	arcta
Balanus	glandula	Cladophora	sericea
Balanus	crenatus	Cryptosiphonia	woodii
Chthalamus	dalli	Dumontia	contorta
Evasterias	troschelii	Enteromorpha	intestinalis
Littorina	scutulata	Fucus	gardneri
Littorina	sitkana	Gloiopeltis	furcata
Lottia	pelta	Hildenbrandia	rubra
Modiolus	rectus	Monostroma	undulatum
Mytilus	edulis	Myelophycus	intestinalis
Pycnopodia	helianthoides	Neorhodomela	aculeata
Pagurus	sp	Pilayella	washingtoniensis
Semibalanus	balanoides	Ralfsia	fungiformis
Spirorbis	sp	Rhodomela	subfusca
Tectura	persona	Palmaria	callophylloides
Tectura	scutum	Rivularia	atra
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Verrucaria	sp.
		Coralline	ENCRUSTING
		Blue Green algal mat	
		ORA	ORA

* ORA = blue green algal film

SITE 1222C	MAY 21, 1991		
INVERTEBRATES		ALGAE	
Acarida		Cladophora	sericea
Amphipoda	spp	Enteromorpha	linza
Balanus	crenatus	Enteromorpha	intestinalis
Chthalamus	dalli	Fucus	gardneri
Littorina	scutulata	Gloiopeltis	furcata
Littorina	sitkana	Hildenbrandia	rubra
Lottia	pelta	Myelophycus	intestinalis
Modiolus	rectus	Mastocarpus	sp.
Mytilus	edulis	Neorhodomela	aculeata
Semibalanus	balanoides	Pilayella	washingtoniensis
Tectura	persona	Ralfsia	fungiformis
Tectura	scutum	Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Verrucaria	sp.

SITE 1222C	JULY 26, 1991		
INVERTEBRATES		ALGAE	
Balanus	glandula	Cladophora	sericea
Balanus	crenatus	Cryptosiphonia	woodii
Littorina	scutulata	Gumontia	sp.
Littorina	sitkana	Fucus	gardneri
Unknown limpet	species	Gloiopeltis	furcata
Lottia	pelta	Hildenbrandia	rubra
Modiolus	rectus	Licunknownsis	gaylensis
Mytilus	edulis	Myelophycus	intestinalis
Pagurus	sp	Neorhodomela	aculeata
Semibalanus	balanoides	Pilayella	washingtoniensis
Tectura	persona	Rhodomela	subfusca
		Rivularia	atra
		Scytosiphon	lomentaria

SITE 1222C	SEPTEMBER 18, 1991		
INVERTEBRATES		ALGAE	
Katharina	sp	Cladophora	sericea
Ligia	sp	Fucus	gardneri
Littorina	scutulata	Gloiopeltis	furcata
Littorina	sitkana	Hildenbrandia	rubra
Leptasterias	hexactis	Sphacelaria	sp.
Lottia	pelta	Leathesia	difformis
Modiolus	rectus	Mastocarpus	sp.
Mytilus	edulis	Neorhodomela	aculeata
Pagurus	sp	Pilayella	washingtoniensis
Semibalanus	balanoides	Rhodomela	subfusca
Semibalanus	cariosus	Palmaria	callophylloides
Tectura	persona	Rivularia	atra
Tectura	scutum		

* ORA = blue green algal film

SITE 1231C	MAY 28, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Gumontia	sp.
Balanus	crenatus	Enteromorpha	linza
Littorina	scutulata	Enteromorpha	intestinalis
Littorina	sitkana	Fucus	gardneri
Unknown limpet	species	Gloiopeltis	furcata
Lottia	pelta	Hildenbrandia	rubra
Modiolus	rectus	Myelophycus	intestinalis
Mytilus	edulis	Neorhodomela	aculeata
Nucella	lima	Pilayella	washingtoniensis
Pagurus	sp	Ralfsia	fungiformis
Semibalanus	balanoides	Rhodomela	subfusca
Tectura	persona	Palmaria	callophylloides
Oilgochaeta		Rivularia	atra
		Scytosiphon	lomentaria
		Verrucaria	sp.
		Coralline	ARTICULATED

SITE 1231X	MAY 28, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Cryptosiphonia	woodii
Balanus	crenatus	Enteromorpha	linza
Chthalamus	dalli	Enteromorpha	intestinalis
Littorina	scutulata	Fucus	gardneri
Littorina	sitkana	Gloiopeltis	furcata
Unknown limpet	species	Halossacion	glandiforme
Lottia	pelta	Hildenbrandia	rubra
Modiolus	rectus	Sphacelaria	sp.
Mytilus	edulis	Leathesia	difformis
Pagurus	sp	Monostroma	undulatum
Semibalanus	balanoides	Myelophycus	intestinalis
Spirorbis	sp	Neorhodomela	aculeata
Tectura	persona	Pilayella	washingtoniensis
Demospongia		Ptilota	pectinata
		Ralfsia	fungiformis
		Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Verrucaria	sp.
		Coralline	ENCRUSTING
		ORA	ORA

* ORA = blue green algal film

SITE 1251C	MAY 30, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	crenatus	Cryptosiphonia	woodii
Chthalamus	dalli	Devalaria	ramenatcea
Littorina	scutulata	Gumontia	sp.
Littorina	sitkana	Enteromorpha	linza
Unknown limpet	species	Fucus	gardneri
Lottia	pelta	Gloiopeltis	furcata
Modiolus	rectus	Hildenbrandia	rubra
Mytilus	edulis	Myelophycus	intestinalis
Nemertean		Neorhodomela	aculeata
Nucella	lamellosa	Ondonthalia	floccosa
Pagurus	sp	Pilayella	washingtoniensis
Semibalanus	balanoides	Ralfsia	fungiformis
Siphonaria	thersites	Rhodomela	subfusca
Tectura	persona	Rivularia	atra
Isopoda	spp.	Scytosiphon	lomentaria
Idotea	wosnesenskii	Verrucaria	sp.
Platihelminthes		Coralline	ARTICULATED

SITE 1251X	MAY 31, 1991		
INVERTEBRATES		ALGAE	
Acarida		Cladophora	sericea
Amphipoda	spp	Cryptosiphonia	woodii
Balanus	glandula	Gumontia	sp.
Balanus	crenatus	Enteromorpha	linza
Chthalamus	dalli	Enteromorpha	intestinalis
Littorina	scutulata	Fucus	gardneri
Littorina	sitkana	Gloiopeltis	furcata
Lottia	pelta	Halossacion	glandiforme
Modiolus	rectus	Hildenbrandia	rubra
Mytilus	edulis	Sphacelaria	sp.
Pagurus	sp	Leathesia	difformis
Semibalanus	balanoides	Monostroma	undulatum
Spirorbis	sp	Myelophycus	intestinalis
Tectura	persona	Neorhodomela	aculeata
Tectura	scutum	Pilayella	washingtoniensis
Isopoda	spp.	Polysiphonia	senticulosa
		Ralfsia	fungiformis
		Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Verrucaria	sp.
		Coralline	ENCRUSTING
		ORA	ORA

* ORA = blue green algal film

SITE 1251C	JULY 28, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Acrosiphonia	arcta
Balanus	crenatus	Cladophora	sericea
Littorina	scutulata	Cryptosiphonia	woodii
Littorina	sitkana	Dumontia	contorta
Unknown limpet	species	Gumontia	sp.
Lottia	pelta	Fucus	gardneri
Lottia	borealis	Gloiopeltis	furcata
Modiolus	rectus	Hildenbrandia	rubra
Mytilus	edulis	Myelophycus	intestinalis
Nemertean		Neorhodomela	aculeata
Nucella	lima	Pilayella	washingtoniensis
Pagurus	sp	Ralfsia	fungiformis
Semibalanus	balanoides	Rhodomela	subfusca
Spirorbis	sp	Palmaria	callophylloides
Tectura	persona	Rivularia	atra
Tectura	scutum	Scytosiphon	lomentaria
		Ulothrix	implexa
		Verrucaria	sp.

SITE 1251X	JULY 27, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Acrosiphonia	arcta
Balanus	glandula	Cladophora	sericea
Balanus	crenatus	Cryptosiphonia	woodii
Chthalamus	dalli	Dumontia	contorta
Littorina	scutulata	Enteromorpha	linza
Littorina	sitkana	Enteromorpha	intestinalis
Lottia	pelta	Fucus	gardneri
Modiolus	rectus	Halossacion	glandiforme
Mytilus	edulis	Hildenbrandia	rubra
Nemertean		Sphacelaria	sp.
Pagurus	sp	Myelophycus	intestinalis
Semibalanus	balanoides	Neorhodomela	aculeata
Spirorbis	sp	Pilayella	washingtoniensis
Tectura	scutum	Ralfsia	fungiformis
		Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Verrucaria	

* ORA = blue green algal film

SITE 1251C	SEPTEMBER 17, 1990		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Littorina	scutulata	Cryptosiphonia	woodii
Littorina	sitkana	Fucus	gardneri
Lottia	pelta	Gloiopeltis	furcata
Modiolus	rectus	Hildenbrandia	rubra
Mytilus	edulis	Sphacelaria	sp.
Pagurus	sp	Leathesia	difformis
Semibalanus	balanoides	Mastocarpus	sp.
Semibalanus	cariosus	Neorhodomela	aculeata
Spirorbis	sp	Pilayella	washingtoniensis
Tectura	persona	Rhodomela	subfusca
Tectura	scutum	Palmaria	callophylloides
		Rivularia	atra

SITE 1251X	SEPTEMBER 9, 1990		
INVERTEBRATES		ALGAE	
Evasterias	troschelii		
Littorina	scutulata	Cladophora	sericea
Littorina	sitkana	Enteromorpha	intestinalis
Lottia	pelta	Fucus	gardneri
Modiolus	rectus	Hildenbrandia	rubra
Mytilus	edulis	Myelophycus	intestinalis
Pagurus	sp	Mastocarpus	sp.
Semibalanus	balanoides	Pilayella	washingtoniensis
		Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Coralline	ARTICULATED
		Coralline	ENCRUSTING

* ORA = blue green algal film

SITE 1311X	SEPTEMBER 8, 1990		
INVERTEBRATES		ALGAE	
Evasterias	trascheli1	Cladophora	sericea
Littorina	scutulata	Cryptosiphonia	woodii
Littorina	sitkana	Enteromorpha	intestinalis
Lottia	pelta	Fucus	gardneri
Modiolus	rectus	Hildenbrandia	rubra
Mytilus	edulis	Mastocarpus	sp
Nucella	lamellosa	Pilayella	washingtoniensis
Pycnopodia	helianthoides	Rhodomela	subjusca
Pagurus	sp	Palmaria	callophylloides
Searlesia	dira	Rivularia	atra
Semibalanus	balanoides	Coralline	Articllated
Semibalanus	cariosus	Coralline	ENCRUSTING
Spirorbis	sp		
Tectura	persona		

SITE 1311X	MAY 11, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Enteromorpha	linza
Balanus	crenatus	Enteromorpha	intestinalis
Chthalamus	dalli	Fucus	gardneri
Littorina	scutulata	Halossacion	glandiforme
Littorina	sitkana	Hildenbrandia	rubra
Unknown limpet	species	Licunknownsis	gaylensis
Lottia	pelta	Monostroma	undulatum
Modiolus	rectus	Myelophycus	intestinalis
Mytilus	edulis	Neorhodomela	aculeata
Nucella	lamellosa	Ondonthalia	floccosa
Pagurus	sp	Pilayella	washingtoniensis
Searlesia	dira	Polysiphonia	senticulosa
Semibalanus	balanoides	Ptilota	pectinata
Semibalanus	cariosus	Rhodomela	subfusca
Spirorbis	sp	Palmaria	callophylloides
Tectura	persona	Rivularia	atra
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Verrucaria	sp.
		Coralline	ARTICULATED
		Coralline	ENCRUSTING
		Blue Green algal mat	

SITE 1311X	JULY 25, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Acrosiphonia	arcta
Balanus	glandula	Cladophora	sericea
Balanus	crenatus	Cryptosiphonia	woodii
Bryozoa		Devalaria	ramenatcea
Chthalamus	dalli	Dumontia	contorta
Dermasterias	imbricata	Gumontia	sp.
Littorina	scutulata	Enteromorpha	intestinalis
Littorina	sitkana	Fucus	gardneri
Lottia	pelta	Halossacion	glandiforme
Modiolus	rectus	Hildenbrandia	rubra
Mytilus	edulis	Sphacelaria	sp.
Nucella	lamellosa	Monostroma	undulatum
Pycnopodia	helianthoides	Myelophycus	intestinalis
Pagurus	sp	Neorhodomela	aculeata
Searlesia	dira	Pilayella	washingtoniensis
Semibalanus	balanoides	Polysiphonia	senticulosa
Spirorbis	sp	Ralfsia	fungiformis
		Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Ulothrix	implexa
		Ulva	fenestrata
		Verrucaria	sp.
		Coralline	ARTICULATED
		Coralline	ENCRUSTING

* ORA = blue green algal film

SITE 1312C	SEPTEMBER 7, 1990		
INVERTEBRATES		ALGAE	
Littorina	scutulata	Cladophora	sericea
Littorina	sitkana	Cryptosiphonia	woodii
Lottia	pelta	Fucus	gardneri
Modiolus	rectus	Gloiopeltis	furcata
Mytilus	edulis	Hildenbrandia	rubra
Nucella	lamellosa	Leathesia	difformis
Nucella	lima	Rhodomela	subfusca
Pagurus	sp	Rivularia	atra
Semibalanus	balanoides	Coralline	ENCRUSTING
Semibalanus	cariosus		
Tectura	persona		
Tectura	scutum		

SITE 1312X	SEPTEMBER 8, 1990		
INVERTEBRATES		ALGAE	
Littorina	scutulata	Enteromorpha	intestinalis
Littorina	sitkana	Fucus	gardneri
Lottia	pelta	Pilayella	washingtoniensis
Modiolus	rectus	Rhodomela	subfusca
Mytilus	edulis	Rivularia	atra
Pagurus	sp	ORA	ORA
Semibalanus	balanoides		
Tectura	persona		
Tectura	scutum		

* ORA = blue green algal film

SITE 1312X	JULY 8, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	crenatus	Cryptosiphonia	woodii
Littorina	scutulata	Gumontia	sp.
Littorina	sitkana	Fucus	gardneri
Unknown limpet	species	Gloiopeltis	furcata
Lottia	pelta	Hildenbrandia	rubra
Lottia	borealis	Leathesia	difformis
Modiolus	rectus	Myelophycus	intestinalis
Mytilus	edulis	Neorhodomela	aculeata
Nucella	lima	Pilayella	washingtoniensis
Pagurus	sp	Ralfsia	fungiformis
Semibalanus	balanoides	Rhodomela	subfusca
Spirorbis	sp	Rivularia	atra
Tectura	persona	Scytosiphon	lomentaria
Tectura	scutum	Verrucaria	sp.
Isopoda	spp.		
Idotea	wosnesenskii		
Demospongia			

SITE 1312X	JULY 27, 1991		
INVERTEBRATES		ALGAE	
Anthopleura	artemisia	Cladophora	sericea
Balanus	crenatus	Cryptosiphonia	woodii
Bryozoa		Devalaria	ramenatcea
Chthalamus	dalli	Gumontia	sp.
Littorina	scutulata	Enteromorpha	linza
Littorina	sitkana	Enteromorpha	intestinalis
Unknown limpet	species	Fucus	gardneri
Lottia	pelta	Gloiopeltis	furcata
Modiolus	rectus	Halossacion	glandiforme
Mytilus	edulis	Hildenbrandia	rubra
Pagurus	sp	Sphacelaria	sp.
Semibalanus	balanoides	Monostroma	undulatum
Spirorbis	sp	Myelophycus	intestinalis
Tectura	persona	Neorhodomela	aculeata
Tectura	scutum	Pilayella	washingtoniensis
		Ralfsia	fungiformis
		Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Verrucaria	sp.
		Coralline	ARTICULATED
		Coralline	ENCRUSTING
		ORA	ORA

SITE 1312X	SEPTEMBER 8, 1991		
INVERTEBRATES		ALGAE	
Littorina	scutulata	Cladophora	sericea
Littorina	sitkana	Enteromorpha	intestinalis
Lottia	pelta	Fucus	gardneri
Semibalanus	balanoides	Hildenbrandia	rubra
Semibalanus	cariosus	Sphacelaria	sp.
Spirorbis	sp	Mastocarpus	sp.
Tectura	persona	Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Coralline	ARTICULATED
		Coralline	ENCRUSTING

* ORA = blue green algal film

SITE 1312C	MAY 12, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Enteromorpha	linza
Balanus	crenatus	Fucus	gardneri
Chthalamus	dalli	Gloiopeltis	furcata
Littorina	scutulata	Hildenbrandia	rubra
Littorina	sitkana	Monostroma	undulatum
Unknown limpet	species	Myelophycus	intestinalis
Lottia	pelta	Mastocarpus	sp.
Modiolus	rectus	Neorhodomela	aculeata
Mytilus	edulis	Pilayella	washingtoniensis
Nucella	lima	Rhodomela	subfusca
Pagurus	sp	Rivularia	atra
Semibalanus	balanoides	Scytosiphon	lomentaria
Semibalanus	cariosus	Ulva	fenestrata
Tectura	persona	Verrucaria	sp.
Isopoda	spp.	Coralline	ARTICULATED

SITE 1312X	MAY 13, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Cryptosiphonia	woodii
Balanus	crenatus	Enteromorpha	linza
Bryozoa		Enteromorpha	intestinalis
Chthalamus	dalli	Fucus	gardneri
Littorina	scutulata	Gloiopeltis	furcata
Littorina	sitkana	Halossacion	glandiforme
Unknown limpet	species	Hildenbrandia	rubra
Lottia	pelta	Myelophycus	undulatum
Modiolus	rectus	Mastocarpus	intestinalis
Mytilus	edulis	Neorhodomela	aculeata
Nucella	lima	Pilayella	floccosa
Pagurus	sp	Pilayella	washingtoniensis
Semibalanus	balanoides	Ptilota	pectinata
Spirorbis	sp	Ralfsia	fungiformis
Tectura	persona	Rhodomela	subfusca
Tectura	scutum	Palmaria	callophylloides
Oilgochaeta		Rivularia	atra
Isopoda	spp.	Scytosiphon	lomentaria
		Ulva	fenestrata
		Coralline	ARTICULATED
		Porphyra	spp
		ORA	ORA

* ORA = blue green algal film

SITE 1322X	MAY 21, 1991		
INVERTEBRATES		ALGAE	
Acarida		Cladophora	sericea
Anthopleura	artemisia	Cryptosiphonia	woodii
Amphipoda	spp	Enteromorpha	linza
Balanus	glandula	Enteromorpha	intestinalis
Balanus	crenatus	Fucus	gardneri
Bryozoa		Gloiopeltis	furcata
Chthalamus	dalli	Halossacion	glandiforme
Littorina	scutulata	Hildenbrandia	rubra
Littorina	sitkana	Rivularia	atra
Unknown limpet	species	Coralline	ARTICULATED
Lottia	pelta	Coralline	ENCRUSTING
Modiolus	rectus		
Mytilus	edulis		
Nemertean			
Pagurus	sp		
Semibalanus	balanoides		
Spirorbis	sp		
Tectura	persona		

SITE 1322X	JULY 25, 1991		
INVERTEBRATES		ALGAE	
Anthopleura	artemisia	Cladophora	sericea
Amphipoda	spp	Cryptosiphonia	woodii
Balanus	glandula	Enteromorpha	linza
Balanus	crenatus	Enteromorpha	intestinalis
Chthalamus	dalli	Fucus	gardneri
Littorina	scutulata	Gloiopeltis	furcata
Littorina	sitkana	Halossacion	glandiforme
Unknown limpet	species	Hildenbrandia	rubra
Lottia	pelta	Myelophycus	intestinalis
Modiolus	rectus	Neorhodomela	aculeata
Mytilus	edulis	Pilayella	washingtoniensis
Pagurus	sp	Polysiphonia	senticulosa
Semibalanus	balanoides	Ralfsia	fungiformis
Spirorbis	sp	Rhodomela	subfusca
Tectura	persona	Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Verrucaria	sp.

* ORA = blue green algal film

SITE 1411C		SEPTEMBER 7, 1990	
INVERTEBRATES		ALGAE	
Ligia	sp	Cladophora	sericea
Littorina	scutulata	Cryptosiphonia	woodii
Littorina	sitkana	Fucus	gardneri
Lottia	pelta	Hildenbrandia	rubra
Modiolus	rectus	Mastocarpus	sp.
Mytilus	edulis	Pilayella	washingtoniensis
Pagurus	sp	Rhodomela	subfusca
Semibalanus	balanoides	Palmaria	callophylloides
Semibalanus	cariosus	Rivularia	atra
Tectura	persona	Coralline	ARTICULATED
Tectura	scutum		

SITE 1411C		MAY 11, 1991	
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Ligia	sp	Enteromorpha	linza
Littorina	scutulata	Enteromorpha	intestinalis
Littorina	sitkana	Fucus	gardneri
Unknown limpet	species	Gloiopeltis	furcata
Lottia	pelta	Halossacion	glandiforme
Mytilus	edulis	Hildenbrandia	rubra
Nucella	lima	Myelophycus	intestinalis
Pagurus	sp	Neorhodomela	aculeata
Semibalanus	balanoides	Ondonthalia	floccosa
Semibalanus	cariosus	Rhodomela	subfusca
Tectura	persona	Rivularia	atra
Oilgochaeta		Scytosiphon	lomentaria
		Coralline	ARTICULATED
		Blue Green algal mat	

SITE 1411C		JULY 26, 1991	
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Cryptosiphonia	woodii
Balanus	crenatus	Dumontia	contorta
Chthalamus	dalli	Gumontia	sp.
Littorina	scutulata	Fucus	gardneri
Littorina	sitkana	Gloiopeltis	furcata
Unknown limpet	species	Hildenbrandia	rubra
Lottia	pelta	Sphacelaria	sp.
Lottia	borealis	Myelophycus	intestinalis
Modiolus	rectus	Neorhodomela	aculeata
Mytilus	edulis	Pilayella	washingtoniensis
Pagurus	sp	Ralfsia	fungiformis
Semibalanus	balanoides	Rhodomela	subfusca
Spirorbis	sp	Rivularia	atra
Tectura	persona	Scytosiphon	lomentaria
Tectura	scutum	Ulothrix	implexa
Isopoda	spp.	Verrucaria	sp.
		Coralline	ARTICULATED
		Coralline	ENCRUSTING

* ORA = blue green algal film

SITE 1713C	JUNE 3, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Cryptosiphonia	woodii
Balanus	crenatus	Devalaria	ramenatcea
Bryozoa		Gumontia	sp.
Chthalamus	dalli	Enteromorpha	linza
Littorina	scutulata	Enteromorpha	intestinalis
Littorina	sitkana	Fucus	gardneri
Lottia	pelta	Gloiopeltis	furcata
Modiolus	rectus	Hildenbrandia	rubra
Mytilus	edulis	Sphacelaria	sp.
Nucella	lamellosa	Myelophycus	intestinalis
Pagurus	sp	Neorhodomela	aculeata
Semibalanus	balanoides	Pilayella	washingtoniensis
Siphonaria	thersites	Ralfsia	fungiformis
Spirorbis	sp	Rhodomela	subfusca
Tectura	persona	Palmaria	callophylloides
Tectura	scutum	Rivularia	atra
Isopoda	spp.	Scytosiphon	lomentaria

SITE 1713X	JUNE 2, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Cryptosiphonia	woodii
Balanus	crenatus	Devalaria	ramenatcea
Bryozoa		Enteromorpha	intestinalis
Chthalamus	dalli	Enteromorpha	clathrata
Littorina	scutulata	Fucus	gardneri
Littorina	sitkana	Gloiopeltis	furcata
Unknown limpet	species	Hildenbrandia	rubra
Lottia	pelta	Monostroma	undulatum
Modiolus	rectus	Myelophycus	intestinalis
Mytilus	edulis	Neorhodomela	aculeata
Nucella	lamellosa	Pilayella	washingtoniensis
Pagurus	sp	Polysiphonia	senticulosa
Semibalanus	balanoides	Ralfsia	fungiformis
Spirorbis	sp	Rhodomela	subfusca
Tectura	persona	Palmaria	callophylloides
Tectura	scutum	Rivularia	atra
Idotea	wosnesenskii	Scytosiphon	lomentaria
Demospongia		Ulva	fenestrata
		Verrucaria	sp.
		Coralline	ENCRUSTING
		Blue Green algal mat	
		Porphyra	spp

* ORA = blue green algal film

SITE 1713C	JULY 30, 1991		
INVERTEBRATES		ALGAE	
Acarida		Cladophora	sericea
Balanus	glandula	Cryptosiphonia	woodii
Balanus	crenatus	Devalaria	ramenatcea
Bryozoa		Gumontia	sp.
Chthalamus	dalli	Enteromorpha	intestinalis
Littorina	scutulata	Fucus	gardneri
Littorina	sitkana	Gloiopeltis	furcata
Unknown limpet	species	Halossacion	glandiforme
Lottia	pelta	Hildenbrandia	rubra
Modiolus	rectus	Sphacelaria	sp.
Mytilus	edulis	Licunknownsis	gaylensis
Nucella	lamellosa	Neorhodomela	aculeata
Pagurus	sp	Pilayella	washingtoniensis
Semibalanus	balanoides	Rhodomela	subfusca
Spirorbis	sp	Palmaria	callophylloides
Tectura	persona	Rivularia	atra
Tectura	scutum	Verrucaria	sp.
		Coralline	ENCRUSTING

SITE 1713X	JULY 30, 1991		
INVERTEBRATES		ALGAE	
Balanus	crenatus	Cladophora	sericea
Bryozoa		Cryptosiphonia	woodii
Chthalamus	dalli	Devalaria	ramenatcea
Littorina	scutulata	Gumontia	sp.
Littorina	sitkana	Enteromorpha	intestinalis
Unknown limpet	species	Fucus	gardneri
Lottia	pelta	Gloiopeltis	furcata
Modiolus	rectus	Halossacion	glandiforme
Mytilus	edulis	Hildenbrandia	rubra
Pagurus	sp	Sphacelaria	sp.
Semibalanus	balanoides	Monostroma	undulatum
Tectura	persona	Myelophycus	intestinalis
Tectura	scutum	Neorhodomela	aculeata
		Pilayella	washingtoniensis
		Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Verrucaria	sp.
		Coralline	ENCRUSTING

* ORA = blue green algal film

SITE 1723C	SEPTEMBER 6, 1990		
INVERTEBRATES		ALGAE	
Ligia	sp	Cladophora	sericea
Littorina	scutulata	Cryptosiphonia	woodii
Littorina	sitkana	Fucus	gardneri
Lottia	pelta	Gloiopeltis	furcata
Modiolus	rectus	Leathesia	difformis
Mytilus	edulis	Pilayella	washingtoniensis
Nucella	lima	Rhodomela	subfusca
Pagurus	sp	Rivularia	atra
Semibalanus	balanoides		
Semibalanus	cariosus		
Tectura	persona		
Tectura	scutum		

SITE 1723X	SEPTEMBER 5, 1990		
INVERTEBRATES		ALGAE	
Anthopleura	artemisia	Cladophora	sericea
Balanus	glandula	Cryptosiphonia	woodii
Eualis	biunguis	Fucus	gardneri
Ligia	sp	Gloiopeltis	furcata
Littorina	scutulata	Halosaccion	glandiforme
Littorina	sitkana	Hildenbrandia	rubra
Lottia	pelta	Leathesia	difformis
Modiolus	rectus	Mastocarpus	sp.
Mytilus	edulis	Neorhodomela	aculeata
Pycnopodia	helianthoides	Pilayella	washingtoniensis
Pagurus	sp	Phycodrys	rigii
Polychaete	sp	Ptilota	pectinata
Semibalanus	balanoides	Ralfsia	fungiformis
Semibalanus	cariosus	Rhodomela	subfusca
Spirorbis	sp	Palmaria	callophylloides
Tectura	persona	Rivularia	atra
Tectura	scutum	Coralline	ARTICULATED
		Coralline	ENCRUSTING

* ORA = blue green algal film

SITE 1723C	MAY 12, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Enteromorpha	gardneri
Balanus	crenatus	Fucus	furcata
Littorina	scutulata	Gloiopeltis	rubra
Littorina	sitkana	Hildenbrandia	intestinalis
Unknown limpet	species	Myelophycus	aculeata
Lottia	pelta	Neorhodomela	washingtoniensis
Modiolus	rectus	Pilayella	subfusca
Mytilus	edulis	Rhodomela	atra
Nucella	lima	Rivularia	lomentaria
Pagurus	sp	Scytosiphon	sp.
Searlesia	dira	Verrucaria	
Semibalanus	balanoides		
Tectura	persona		
Tectura	scutum		
Isopoda	spp.		

SITE 1723X	MAY 13, 1991		
INVERTEBRATES		ALGAE	
Anthopleura	artemisia	Cladophora	sericea
Amphipoda	spp	Cryptosiphonia	woodii
Balanus	glandula	Constantinea	simplex
Balanus	crenatus	Enteromorpha	linza
Bryozoa		Enteromorpha	intestinalis
Chthalamus	dalli	Fucus	gardneri
Littorina	scutulata	Gloiopeltis	furcata
Littorina	sitkana	Halossacion	glandiforme
Unknown limpet	species	Hildenbrandia	rubra
Lottia	pelta	Leathesia	difformis
Modiolus	rectus	Monostroma	undulatum
Mytilus	edulis	Myelophycus	intestinalis
Pagurus	sp	Neorhodomela	aculeata
Semibalanus	balanoides	Ondonthalia	floccosa
Semibalanus	cariosus	Pilayella	washingtoniensis
Spirorbis	sp	Polysiphonia	senticulosa
Tectura	persona	Ralfsia	fungiformis
		Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Verrucaria	sp.
		Coralline	ARTICULATED
		Coralline	ENCRUSTING
		ORA	ORA

* ORA = blue green algal film

SITE 1723C	JULY 29, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	crenatus	Cryptosiphonia	woodii
Littorina	scutulata	Gumontia	sp.
Littorina	sitkana	Fucus	gardneri
Unknown limpet	species	Gloiopeltis	furcata
Lottia	pelta	Hildenbrandia	rubra
Lottia	borealis	Leathesia	difformis
Modiolus	rectus	Myelophycus	intestinalis
Mytilus	edulis	Neorhodomela	aculeata
Nemertean		Pilayella	washingtoniensis
Nucella	lima	Ralfsia	fungiformis
Pagurus	sp	Rhodomela	subfusca
Semibalanus	balanoides	Rivularia	atra
Tectura	persona	Scytosiphon	lomentaria
Tectura	scutum	Verrucaria	sp.
Isopoda	spp.		

SITE 1723X	JULY 29, 1991		
INVERTEBRATES		ALGAE	
Anthopleura	artemisia	Cladophora	sericea
Balanus	glandula	Cryptosiphonia	woodii
Balanus	crenatus	Devalaria	ramenatcea
Bryozoa		Dumontia	contorta
Chthalamus	dalli	Gumontia	sp.
Evasterias	troschelii	Enteromorpha	intestinalis
Littorina	scutulata	Fucus	gardneri
Littorina	sitkana	Gloiopeltis	furcata
Leptasterias	hexactis	Halossacion	glandiforme
Unknown limpet	species	Hildenbrandia	rubra
Lottia	pelta	Leathesia	difformis
Lottia	borealis	Monostroma	undulatum
Modiolus	rectus	Myelophycus	intestinalis
Mytilus	edulis	Neorhodomela	aculeata
Pagurus	sp	Pilayella	washingtoniensis
Semibalanus	balanoides	Ptilota	pectinata
Spirorbis	sp	Ralfsia	fungiformis
Tectura	persona	Rhodomela	subfusca
Tectura	scutum	Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Verrucaria	sp.
		Coralline	ARTICULATED
		Coralline	ENCRUSTING

* ORA = blue green algal film

SITE 1732C	MAY 29, 1991		
INVERTEBRATES		ALGAE	
Balanus	crenatus	Cladophora	sericea
Chthalamus	dalli	Cryptosiphonia	woodii
Littorina	scutulata	Enteromorpha	linza
Littorina	sitkana	Enteromorpha	intestinalis
Unknown limpet	species	Fucus	gardneri
Lottia	pelta	Hildenbrandia	rubra
Mytilus	edulis	Monostroma	undulatum
Nucella	lamellosa	Myelophycus	intestinalis
Semibalanus	balanoides	Neorhodomela	aculeata
Spirorbis	sp	Pilayella	washingtoniensis
Tectura	persona	Polysiphonia	senticulosa
		Rhodomela	subfusca
		Palmaria	callophylloides
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Coralline	ENCRUSTING

SITE 1732X	MAY 29, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Cryptosiphonia	woodii
Balanus	crenatus	Devalaria	ramenatcea
Bryozoa		Gumontia	sp.
Chthalamus	dalli	Enteromorpha	linza
Dermasterias	imbricata	Enteromorpha	intestinalis
Littorina	scutulata	Fucus	gardneri
Littorina	sitkana	Gloiopeltis	furcata
Unknown limpet	species	Halossacion	glandiforme
Lottia	pelta	Hildenbrandia	rubra
Modiolus	rectus	Sphacelaria	sp.
Mytilus	edulis	Leathesia	difformis
Nucella	lamellosa	Monostroma	undulatum
Pagurus	sp	Myelophycus	intestinalis
Semibalanus	balanoides	Mastocarpus	sp.
Siphonaria	thersites	Neorhodomela	aculeata
Spirorbis	sp	Pilayella	washingtoniensis
Tectura	persona	Polysiphonia	senticulosa
		Ptilota	pectinata
		Ralfsia	fungiformis
		Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Verrucaria	sp.
		Coralline	ARTICULATED
		Coralline	ENCRUSTING
		Porphyra	spp

* ORA = blue green algal film

SITE 1852C	SEPTEMBER 18, 1990		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Cryptosiphonia	woodii
Ligia	sp	Fucus	gardneri
Littorina	scutulata	Gloiopeltis	furcata
Littorina	sitkana	Halossacion	glandiforme
Lottia	pelta	Hildenbrandia	rubra
Modiolus	rectus	Sphacelaria	sp.
Mytilus	edulis	Leathesia	difformis
Pagurus	sp	Licunknownsis	gaylensis
Semibalanus	balanoides	Mastocarpus	sp.
Tectura	persona	Pilayella	washingtoniensis
		Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Coralline	ARTICULATED

SITE 1852X	SEPTEMBER 19, 1990		
INVERTEBRATES		ALGAE	
Littorina	scutulata	Cladophora	sericea
Littorina	sitkana	Enteromorpha	intestinalis
Lottia	pelta	Fucus	gardneri
Modiolus	rectus	Hildenbrandia	rubra
Mytilus	edulis	Pilayella	washingtoniensis
Semibalanus	balanoides	Polysiphonia	senticulosa
		Rhodomela	subfusca

* ORA = blue green algal film

SITE 1852C	JUNE 1, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	glandula	Cryptosiphonia	woodii
Balanus	crenatus	Devalaria	ramenatcea
Chthalamus	dalli	Gumontia	sp.
Littorina	scutulata	Enteromorpha	linza
Littorina	sitkana	Enteromorpha	intestinalis
Lottia	pelta	Fucus	gardneri
Modiolus	rectus	Gloiopeltis	furcata
Mytilus	edulis	Hildenbrandia	rubra
Nemertean		Sphacelaria	sp.
Pagurus	sp	Monostroma	undulatum
Semibalanus	balanoides	Myelophycus	intestinalis
Spirorbis	sp	Neorhodomela	aculeata
Tectura	persona	Ondonthalia	floccosa
Oilgochaeta		Pilayella	washingtoniensis
Isopoda	spp.	Polysiphonia	senticulosa
Platihelminthes		Ralfsia	fungiformis
		Rhodomela	subfusca
		Palmaria	callophylloides
		Rivularia	atra
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Coralline	ARTICULATED
		Coralline	ENCRUSTING

SITE 1852X	JUNE 2, 1991		
INVERTEBRATES		ALGAE	
Amphipoda	spp	Cladophora	sericea
Balanus	crenatus	Devalaria	ramenatcea
Chthalamus	dalli	Enteromorpha	linza
Littorina	scutulata	Enteromorpha	intestinalis
Littorina	sitkana	Enteromorpha	clathrata
Lottia	pelta	Fucus	gardneri
Mytilus	edulis	Halossacion	glandiforme
Nemertean		Hildenbrandia	rubra
Pagurus	sp	Sphacelaria	sp.
Semibalanus	balanoides	Monostroma	undulatum
Siphonaria	thersites	Myelophycus	intestinalis
Tectura	persona	Neorhodomela	aculeata
Tectura	scutum	Ondonthalia	floccosa
Isopoda	spp.	Pilayella	washingtoniensis
Idotea	wosnesenskii	Polysiphonia	senticulosa
		Ralfsia	fungiformis
		Rhodomela	subfusca
		Rivularia	atra
		Scytosiphon	lomentaria
		Ulva	fenestrata
		Verrucaria	sp.
		Blue Green algal mat	
		Porphyra	spp
		ORA	ORA

* ORA = blue green algal film

Table 4.3. Means and probabilities from repeated measures analysis at five population dynamic study sites. "MVD" refers to the meter of vertical drop below MHHW.

Site Pair	Control mean over all sample dates	Oiled mean over all sample dates	Reapeated Measures Probablities SITE	DATE	DATE*SITE
1MVD					
1231	8.21	2.97	0.0383	0.0013	0.0274
1732	6.78	1.26	0.0452	0.0661	0.0556
2333	6.3	0.95	0.0183	0.3126	0.0027
2834	7.19	2.14	0.0352	0.0123	0.0192
3811	1.166	0.0833	***	***	***
2MVD					
1231	23.78	9.8	0.0033	0.0069	0.2054
1732	6.71	9	0.5094	0.256	0.847
2333	9.85	4	0.002	0.2306	0.0516
2834	7.97	12.76	0.073	0.0003	0.0654
3811	4.58	0.416	***	***	***
3MVD					
1231	18.64	5.42	0.338	0.1252	0.4457
1732	2.8	6.3	0.2521	0.0343	0.3682
2333	11.09	4.04	0.0412	0.0254	0.5091
2834	13.09	37.19	0.005	0.03	0.0559
3811	2.41	0	***	***	***

Table 4.4. Means and probabilities from Paired T-tests on oiled and nonoiled tile pairs placed in 1991.

Site Number	Date	Barnacle Recruits Unoiled	Barnacle Recruits Oiled	Probability Paired T-test	Fucus Recruits Unoiled	Fucus Recruits Oiled	Probability Paired T-test
1221C	1	0	0	1			
1221C	2	0	0	1			
1221C	3	1.666667	0	0.1051			
1221C	4	1.833333	0	0.0896			
1221C	5	0.666667	0	0.1747			
1221C	6	0.333333	0	0.1747	1	0	0.2031
1221X	1	0	0	1			
1221X	2	0	0	1			
1221X	3	0.166667	0	0.3632			
1221X	4	0.666667	0	0.1747			
1221X	5	0.5	0	0.2031	2.66667	0	0.2648
1221X	6	0	0	1	15.6667	0	0.156
1222C	1	0	0	1			
1222C	2	0.166667	0	0.3632			
1222C	3	1.666667	0	0.0925			
1222C	4	2.166667	0	0.1006	0.3333	0.1667	0.6952
1222C	5	4.166667	0	0.195			
1222C	6	0	0	2			
1322X	1	0	0	1			
1322X	2	12.33333	0	0.1536			
1322X	3	148	20.5	0.238			
1322X	4	681.3333	367	0.0408			
1322X	5	168	192	0.7579			
1322X	6	62	16.6667	0.1213	4.5	0	0.1366
1723C	1	0	0	1			
1723C	2	0	0	1			
1723C	3	0.166667	0	0.3632			
1723C	4	0.5	0	0.0756			
1723C	5	0.833333	0	0.3632			
1723C	6	0	0	1	44.3333	0	0.1006
1723X	1	0	0	1			
1723X	2	0.166667	0	0.3632			
1723X	3	3.666667	0.83333	0.3686			
1723X	4	600.8333	373.833	0.2135			
1723X	5	35.83333	33	0.7665	0.33333	0	0.3632
1723X	6	127.6667	130.333	0.9332	10.5	0	0.1644

Table 4.5. Mean barnacle recruitment on oiled and scraped vertical rock faces (10 X 10 cm plots).

Site	Date	Barnacle Recruits Oiled	Nonoiled	Probabilities Paired T-test	Site	Date	Barnacles Oiled	Nonoiled	Probabilities Paired T-test
1443C	**				1343X	1	6.17	22.83	0.0060
	**					2	6.67	21.83	0.0096
	**					3	10.67	24.67	0.0904
	4	6.50	8.00	0.5177		4	20.00	31.17	0.1600
	5	18.33	24.00	0.5308		5	27.83	43.33	0.0201
	6	25.17	37.17	0.1927		6	44.50	80.67	0.0170
	7	32.00	50.17	0.1830		7	99.67	138.17	0.3594
	8	62.50	92.67	0.2426		8	292.83	604.00	0.0112
	9	224.33	274.33	0.5303		9	982.50	1374.83	0.0713
	10	51.67	81.17	0.1619		10	323.17	368.33	0.3520
1544C	1	2.00	1.75	0.8240	1544X	1	0.50	1.75	0.1942
	2	1.25	4.00	0.0892		2	0.50	1.75	0.1337
	3	1.25	2.25	0.1817		3	0.75	2.50	0.2933
	4	3.00	5.00	0.3318		4	9.50	7.75	0.5849
	5	7.25	5.00	0.2779		5	9.00	12.00	0.6564
	6	9.75	7.25	0.1552		6	11.25	18.25	0.4192
	7	14.25	9.50	0.3508		7	26.75	5235.00	0.3022
	8	25.25	22.50	0.6118		8	812.50	15.00	0.3053
	9	26.50	40.00	0.5224		9	151.75	1825.00	0.3014
	10	16.50	26.75	0.4914		10	1142.00	1605	0.0561
1641B	1	1.60	2.20	0.6827	1641A	1	0.60	0.40	0.7040
	2	3.17	0.67	0.0067		2	2.67	2.00	0.6554
	3	1.80	1.00	0.0993		3	1.50	2.17	0.5946
	6	2.17	0.17	0.0028		4	1.00	1.33	0.7711
	7	2.33	1.17	0.0583		5	1.52	2.00	0.7131
	8	3.50	1.50	0.0409		6	3.00	2.67	0.8053
	9	12.33	7.50	0.2200		7	7.17	4.50	0.4826
	10	14.50	9.50	0.2128		8	10.83	13.17	0.5943
	11	38.33	20.17	0.0575		9	12.17	16.67	0.4679
	12	48.83	21.00	0.1108		10	13.50	16.00	0.7832
	13	93.83	16.00	0.1615		11	17.67	16.17	0.7602
1642C	1	4.00	5.00	0.7295	1342D	1	136.33	372.67	0.1033
	2	4.33	5.67	0.7618		2	7.67	7.00	0.8534
	3	3.33	1.33	-		3	8.33	7.00	0.7618
	4	1.00	1.33	0.8399		4	4.67	5.67	0.7745
	5	5.00	2.00	0.2863		5	21.33	22.67	0.8845
	6	8.67	5.00	0.0927		6	22.33	16.00	0.2874
	7	15.33	9.67	0.0848		7	22.67	24.33	0.8003
	8	26.33	15.33	0.0865		8	52.00	68.00	0.2007
	9	183.00	282.00	0.4028		9	450.33	619.33	0.0096
	10	108.33	156.00	0.2181		10	493.33	1152.67	0.0052
	11	109.33	130.33	0.3543		11	606.67	1018.67	0.1024
1645X*	1	4.17	7.00	0.3807	1746X*	6	12	25.83	0.4686
	2	5.17	7.17	0.5402		7	18.67	62.67	0.2628
	3	5.33	11.00	0.3795		8	30.33	75.83	0.2491
	4	9.33	18.33	0.3333		9	54.67	166	0.0702
	5	14.17	23.67	0.4360		10	110.33	419.5	0.0932
	6	22.00	87.33	0.1003					
	7	35.67	179.67	0.0924					
	8	131.33	367.50	0.0480					
	9	146.17	317.00	0.2030					
	10	116.33	490.83	0.0041					

** This site not sampled on the first 3 dates.

* These sites matched to control site 1641B.

11. Pre-Spill and Post-Spil Concentrations of Hydrocarbons in Sediments and Mussels at Intertidal Sites in Prince William Sound

1991
#11

PRE-SPILL AND POST-SPILL CONCENTRATIONS OF HYDROCARBONS IN SEDIMENTS AND MUSSELS AT INTERTIDAL SITES WITHIN PRINCE WILLIAM SOUND AND THE GULF OF ALASKA.

Coastal Habitat Intertidal Number 1B
and Recovery Monitoring Study Number 11

STATUS REPORT - 1991

Malin M. Babcock and John F. Karinen

NOAA: National Marine Fisheries Service
Auke Bay Laboratory
11305 Glacier Highway
Juneau, Alaska 99801-8626

LIST OF TABLE AND FIGURES

Table 1. Sediment hydrocarbon data from Prince William Sound sites, 1989-1990. Means and standard error of total aromatic hydrocarbons, selected aromatic groups, and phytane are given in ng/g dry weight. N = number of samples analyzed.

Table 2. Mussel (*Mytilus trossulus*) hydrocarbon data from Prince William Sound sites, 1989-1990. Total aromatic hydrocarbons, sums of selected aromatic groups, and phytane are presented as ng/g dry weight and all are single samples (n = 1).

Figure 1. Coastal Habitat 1B sampling sites in Prince William Sound.

Figure 2. Sums of selected aromatic hydrocarbons in sediments from 6 sites in Prince William Sound, comparing values from 1977-1980 with spring and summer, 1989. n = sample size; vertical bars = standard error.

Figure 3. Total aromatic hydrocarbons in sediments from Prince William Sound, 1989 and 1990, after the *EXXON VALDEZ* oil spill. Refer to Table 1 for sample size and standard error values. *, see text.

Figure 4. Means of aromatic hydrocarbon groups and phytane in sediments from Elrington Isl., Sleepy Bay and Bay of Isles, 1989 and 1990. Concentrations in ng/g dry weight. See Table 1 for sample sizes and standard errors.

Figure 5. Means of aromatic hydrocarbon groups and phytane in sediments from sites in Prince William Sound, 1989 and 1990. Concentrations in ng/g dry weight. See Table 1 for further details.

Figure 6. Mean aromatic hydrocarbon groups and phytane in sediments from Rocky Bay and Constantine Harbor, 1989 and 1990. These sites have high vessel usage. Values in ng/g dry weight.

Figure 7. Total aromatic hydrocarbons, selected aromatic hydrocarbon groups and phytane in mussels and sediments from Sleepy Bay, April and June, 1990. Concentrations in ng/g dry weight. See Tables 1 and 2 for sample size and standard error.

Figure 8. Aromatic hydrocarbon groups and phytane in mussels and sediments from 4 sites in Prince William Sound, March 1989 and April 1990. See Tables 1 and 2 for sample size and standard error.

EXECUTIVE SUMMARY

On 26 March 1989, we began resampling 10 historically established intertidal hydrocarbon baseline sites in Prince William Sound (PWS) in response to the *Exxon Valdez* oil spill. We also established 10 additional sites along the spill trajectory before oiling, and sampled after oiling to measure the increase of hydrocarbon levels in sediments and mussels resulting from the spill.

Concentrations of total polynuclear aromatic hydrocarbons (PAH) in fine sediments collected from sites just before or at the time of the *Exxon Valdez* oil spill were measured for 6 sites established for an historical baseline in 1977-81. Four sites (Bligh Island, Naked Island, Siwash Bay and Olsen Bay) had aromatic hydrocarbon levels at or only slightly elevated over the historical levels for the period March 1989 to August 1990 (<100 ng/g dry wt.). Rocky Bay and Constantine Harbor, both of which are subjected to high vessel usage, showed continued elevated total aromatic hydrocarbons (~300 and ~600 ng/g dry wt.) not different from historical levels.

Sleepy Bay, a heavily oiled site, had PAH concentrations in sediments nearly 100 times historical levels (established for other sites in the Sound) in May 1989 (939 ng/g dry weight). Sediment PAHs had declined to 160 - 170 ng/g dry weight in April 1990 and remained stable through August 1990. Two oiled sites, Bay of Isles, and Elrington Island) showed increases (2-3 fold) of aromatic hydrocarbons in sediments in 1989, decreases in Aug 1989, and further increases in April 1990. By Aug 1990 PAH sediment concentrations at Elrington Island had decreased to values similar to unoiled sites, but Bay of Isles sediments remain slightly elevated over unoiled sites.

Examination of the relative proportions of aromatic hydrocarbon groups in intertidal sediments at the 10 sites indicates that the *Exxon Valdez* oil spill contributed hydrocarbons to the Sleepy Bay, Bay of Isles, and Elrington Island sites, and masked any other input sources at Sleepy Bay. At sites with less accumulated oil; sources of hydrocarbons in addition to the spill were probably combustion products, spilled fuels, or some other anthropogenic source.

Sleepy Bay mussels showed extremely high concentrations of PAHs in 1990 samples (2056 and 4550 ng/g dry weight). Mussels from Naked Island, Bligh Island, Barnes Cove and Siwash Bay showed intermediate PAH levels (200 to 520 ng/g dry weight in March 1989. There were no detectable aromatic hydrocarbons in mussels samples 1977-1980. The limited data available precludes reliable interpretation.

INTRODUCTION

Damage assessment of the oil spill in Prince William Sound (PWS) requires information on hydrocarbon contamination levels in water, sediment and biota prior to the spill (baseline) and at various times after the spill occurred to determine the potential impact and duration of impact. Hydrocarbon baseline information is available for several sites in PWS prior to oil transport and for the first four years of oil shipment. A baseline for hydrocarbon levels in mussels, sediment, water, and fish had been established at 10 sites from 1977 to 1980. Six additional sites were established in the path of the spill in 1989. Almost all sites are located on low energy, low gradient beaches, often associated with eel grass. All sites have adjacent bands of mussels (Mytilus trossulus).

The first sampling trip (April 1991) was funding under NRDA Coastal Habitat Study 1B and the second trip (August) under Restoration/Monitoring Study 11.

OBJECTIVES

A. To sample and estimate hydrocarbon concentrations in mussels and sediments from 16 sites within Prince William Sound to document occurrence, persistence and recovery from petroleum hydrocarbon contamination.

B. To test the hypothesis that petroleum hydrocarbon concentration in sediments and mussels is the same for the historical baseline, the pre-spill and post-spill period.

C. To document changes in abundance intertidal epifauna and test the hypothesis that no differences occur at oiled and unoiled sites.

Note: While these objectives are restated, they remain the same as in the Detailed Study Plan for 1991.

METHODS

Ten intertidal sites in PWS were sampled for sediments, mussels, water, and fish annually from 1977 to 1981 to establish a baseline against which future changes in hydrocarbon concentrations could be measured. These sites were resampled in March 1989 immediately before several of them were impacted by the *Exxon Valdez* oil spill (EVOS), and additional sites were established to cover areas in the projected path of the oil spill. Sediment and mussel samples were taken. Photo documentation was added for mussel at each site. Sites were resampled post spill in April, May, June and August 1989, in April, June and August in 1990, and in April and August 1991. Details of methodology are described in the study plan dated 27 September 1989. PWS sites are shown on Figure 1.

All hydrocarbon data still needs to be tested with principal component analyses to verify source as *Exxon Valdez* crude oil.

RESULTS

Site Locations

The locations of the 16 sites sampled in 1989, 1990, and 1991 are shown in Figure 1. Locations of all sites in Prince William Sound and the Kenai Peninsula (sampled in 1989 and 1990 only) are provided in Table 1 of the 1990 annual report.

Collections 1989 and 1990

Intertidal samples were collected on five trips to Prince William Sound and the Kenai Peninsula in 1989. A total of 386 samples were collected.

Three trips to Prince William Sound and two trips to the Kenai Peninsula were made in the summer of 1990 to collect intertidal samples. A total of 285 samples were collected.

Collections 1991

Two trips to Prince William Sound were made in 1991 to collect intertidal sediments and mussels; (1) April 13-20 and (2) August 6-14. A total of 254 samples were collected. Funding for the April trip was under NRDA and for the August under the Restoration and Recovery Monitoring phase. During the August trip several additional sites were surveyed for mussels on or near heavily oiled substrates (buried oil in gravel, cobble, sand). One site (Sleepy Bay) was sampled in early September while one of the PI's was diving for NRDA Study S1. We were unable to sample this site during the regular August trip because of weather.

Analysis of 1989 and 1990 Sediment and Mussel Samples

We compare the aromatic hydrocarbon concentrations of sediments from 6 sites in Prince William Sound for the period March through June 1989 with the average total aromatic hydrocarbons found in sediment at these same sites for the period 1977-1980 (Figure 2). This comparison was made by summing 23 aromatic hydrocarbon analytes common to both sets of data.

Mean total aromatic hydrocarbons, means of selected aromatic hydrocarbon groups and phytane are given for 10 sites in Prince William Sound for samples collected in 1989 and 1990 (Table 1; Figures 3 - 6). Aromatic hydrocarbons and phytanes in mussels are also presented (Table 2; Figures 7 and 8).

With the exception of the hydrocarbon data used for Figure 2, all data presented is based on available information in the NRDA Database prior to resubmission of data by the Auke Bay Laboratory (this occurred 5 November 1991). Patterns and interpretations of concentrations for most analytes should remain the same, but these recent data recalculations may result in lower values for naphthalenes, and, subsequently, for total aromatic hydrocarbons.

Baseline levels in sediments and mussels. Historical baseline levels (1977 - 1980) of polynuclear aromatic hydrocarbons (PAH) in sediments from six sites in Prince William Sound indicate low levels at Bligh Island, Naked Island, Olsen Bay and Siwash Bay (all <25 ng/g dry weight) and somewhat higher concentrations in sediments from Rocky Bay and Constantine Harbor (between 150 and 210 ng/g dry weight) (Figure 2). The latter two sites have had continual high vessel usage and the Rocky Bay site is, additionally, subjected to occasional intense pressure for commercial herring harvest.

Measurements of PAHs in sediments from Bligh Island and Naked Island taken in March - June 1989 show no increase in total PAH levels. PAH concentrations in 1989 at Olsen Bay (May 89) and Siwash Bay (Mar 89) do show increases over historical baseline levels although are still under 40 ng/g dry weight. The higher levels at Olsen Bay in May 89 may be due to increased vessel usage as a result of the *Exxon Valdez* oil spill on 25 Mar 89. This cannot be the case for the elevated levels found Mar 89 in Siwash Bay. We know of no cause for this finding. PAH concentrations at Siwash Bay do show a decrease to 23 ng/g dry weight in April 1990 and remained stable for June and August 1990.

Sediments, 1989 - 1990. Sleepy Bay sediments showed concentrations of PAHs of 930 ng/g dry weight - almost 100 time the historical levels at other PWS sites and at unoiled sites in 1989 and 1990 (Figure 3). Sleepy Bay sediments petroleum hydrocarbons levels decreased to 164 ng/g dry weight in April 1990 and remained stable through June and August 1990 - still elevated over unoiled sites by about 10 times. Two other sites (Bay of Isles and Elrington Island) with obvious oiling and/or tar contamination showed elevated sediment aromatic hydrocarbons levels in May 89. In contrast to Sleepy Bay, these levels were between 100 and 200 ng/g dry weight. PAHs in sediments at Elrington Island and Bay of Isles decreased to levels not different from unoiled sites in August but then, in April 1990, increases to levels greater than shown for May 1989. PAH sediment levels at these sites had returned to <100 ng/g dry weight by June 1990 (Figure 3).

Some sites showed apparent peak levels in sediments in the springs of 1989 and 1990 with lower levels in late summer of each year (Figure 3). The significance of these changes at Bay of Isles and Elrington Island is unknown but may reflect deposition due to winter storm activity, at least for the spring, 1990 samples.

Total polynuclear aromatic hydrocarbon (PAH) concentrations in sediments at 5 sites within Prince William Sound along the spill path, prior to impact of the spill, were similar to the low-level historical concentrations at control and low impacted sites (<100 ng/g dry wt.) (Table 1; Figure 3). Naked Island sediments showed a slight increase in PAH concentrations in June 1989 but returned to levels identical to those at Olsen Bay, Siwash Bay and Bligh Island by April 1990. From March 1989 to August 1990 concentrations of PAHs remained low at three of the sites (Olsen Bay, Siwash Bay, and Bligh Island) but were elevated at Barnes Cove (Figure 3) (Note - the high value for Barnes Cove, May 1989, indicated by the asterisk in Figure 3, is not included in the mean value. PAH composition for all three replicates indicate a combustion source for these samples), in May 1989. The slight elevation in PAHs shown for Siwash Bay is discussed above under the section on historical baseline levels.

Means of selected groups of PAHs and phytane in sediments are plotted by month and year at ten sites (Figures 4, 5, and 6). The relative concentrations of phenanthrenes, dibenzothiophene, fluorenes, chrysenes, and phytane in Prudhoe Bay crude oil (PBCO) are shown in each Figure, upper left. The only site which shows a pattern similar pattern to PBCO is Sleepy Bay in May and August 1989. All other sites show patterns with either components missing, modified, or added indicating weathering or that there may be other sources for these groups; i.e. combustion products of forest fires or fuels, small spills, etc. Phytane, a component of crude oil, is missing from sediments at most sites save Sleepy Bay, Bay of Isles, and Elrington Island (Figure 4). All three of these sites had visible oil pollution. The other sites had no visible oil.

Concentrations of mean aromatic hydrocarbon groups and phytane at Rocky Bay and Constantine are shown in Figure 6. Patterns differ from those shown for Prudhoe Bay crude oil. There is proportionally lower dibenzothiophenes and slightly higher levels of fluorenes and chrysenes. There is no detectible phytane at these sites for any of the sampling periods. The patterns of PAH groups in sediments differed among the group of sites from the eastern part of PWS versus Rocky Bay and Constantine Harbor both of which have high vessel usage. The eastern sites (Bligh Island, Olsen Bay and Naked Island) had a relatively higher proportion of chrysene than did Rocky Bay or Constantine Harbor (see Table 1; Figures 4 and 6). Chrysene was the major polyaromatic compound (43%) in benthic sediments at a site nearest the ballast diffuser in Port Valdez (Karinen 1988). Fluorenes were proportionately higher in Rocky Bay and Constantine Harbor indicative of a different source for hydrocarbons there.

<u>Mussel hydrocarbon concentrations</u>. Only limited hydrocarbon data is available in the NRDA database for mussels (Table 2; Figures 7 and 8).

Mussels from the heavily oiled site at Sleepy Bay in April and June 1990 had a pattern of PAHs quite similar to Prudhoe Bay crude oil with the exception that the proportion of naphthalene was much less than in PBCO (~9100 ng/g) and chrysene appears to persist in higher proportions than found in PBCO. Low levels of naphthalene compared to Prudhoe Bay crude oil (see Figure 6) is to be expected as naphthalenes should have been lost from the oil by the time it reached Sleepy Bay through evaporation and adsorption to particulate matter in the water column. Total PAHs were very high in April 1990 (4550 ng/g dry wt.) but declined to about half that level by June 1990 (2056 ng/g dry wt.). Concentration in sediments remained at the same level over this period (about 160 ng/g dry wt.).

Total aromatic hydrocarbons and naphthalene were 3-10 times more abundant in mussel tissue in March 1989 than in sediments at Naked and Bligh Islands and at Barnes Cove and Siwash Bay (Tables 1 and 2; Figure 8). Total aromatic hydrocarbons in mussels were highest at Naked and Bligh Islands (519 and 300 ng/g dry wt.) and about the same at Barnes Cove and Siwash Bay (~200 ng/g dry wt.). Naphthalene, an extremely volatile aromatic component, comprised at least 68% of the total aromatics founds in mussels at all 4 sites. Naphthalene levels may be modified after examination of data following resubmission. If elevated levels persist, after recalulation, the source of these hydrocarbons is very likely the EVOS which indicates a very rapid spreading of hydrocarbons throughout PWS in the early days following the spill. Other sources might have been the intense vehicular activity following the grounding of the *Exxon Valdez*. Aromatic hydrocarbons were virtually absent from mussel tissues collected in 1977-80 at three of these sites (Barnes Cove was not sampled during this period).

Total aromatic hydrocarbons in mussels in April 1990 declined at all four sites to 100-150 ng/g dry wt. Concentrations were about 1/4 to 2/3 the 1989 levels and did not decline proportionately at all sites. Levels at Naked and Bligh Island sites showed the greatest decline. Phytane was absent from mussel tissue at all sites in March 1989 but was present at all four sites in April 1990. No phytane was present in the sediments at these four sites in either 1989 or 1990.

All data still needs to be tested with principal component analyses to identify and verify sources of hydrocarbons. Data also needs to be recalucated following the recent resubmission of all hydrocarbon data from the Auke Bay Laboratory.

Photographic Quadrats

Mussel transect quadrat photos were analyzed for the occurrence of epifauna for May and August 1989. Most of this work occurred in 1990; data for 2 sites was remeasured and analyzed this current year. Sites analyzed were Barnes Cove, Bay of Isles, Bligh Island, Elrington Island, Naked Island and Olsen Bay. Data from Barnes Cove has been rejected because of the extremely heavy cover of *Fucus* which obscured epifauna - making accurate analyses impossible.

Dominant epifauna at all sites for both time periods was *Mytilus trossulus* and *Semibalanus balanoides*. Of lesser occurrence were *Nucella lima* and *Littorina sitkana*. Counts of live mussels in May 1898 ranged from an average 1.6 (1.6 standard deviation; n=8) individuals per quadrat at Bligh Island to 20.5 (8.1 sd; n=8) at Elrington Island. In August 1989, live mussels ranged from an average 0.88 (1.4 standard deviation; n=8) individuals per quadrat at Bligh Island to 19.9 (8.2 sd; n=7) at Elrington Island. There were no significant differences ($p<0.05$; ANOVA, Tukey comparison) between the May and August time periods at any of the sites analyzed.

Elrington Island was the only site that showed significant differences in the presence of dead (generally gaping) mussels between May and August (0.5 $\pm$0.8 sd individuals per quadrat vs 4.4 $\pm$3.2 sd; $p<0.05$). However, this significance disappears when dead mussels are considered as a percentage of live mussels (15.0% $\pm$7% vs 24% $\pm$5%; $p<0.05$) for May and August 1989.

There were no significant differences between the May and August time periods at any of the sites analyzed in the densities of barnacles, the other dominant species.

STATUS OF INJURY ASSESSMENT

Progress in meeting Objectives A and B is still hampered by on going analyses and delays in hydrocarbon data being incorporated into the NRDA database. For the sediments that are in the NRDA datase, fully 1 of 3 replicates for each of all sites for each time period, April 1990 and June 1990 (40+ individual samples) are compromised by being part of TAMU-GERG analytical catalogs. This, of course, reduces the power of ANOVA, subsequent multiple comparisons and any interpretations of the statistics. None of this data is used in the foregoing data interpretation.

Other statistical tests, specifically principal component tests, are just being started on various data sets. Recalculated hydrocarbon data has just (6 November 1991) been resubmitted by the Auke Bay Laboratory and, except for limited comparison on 23 analytes common to both the historical measurements and 1989 measurements, this data may result is differing interpretations for naphthalenes and total aromatic hydrocarbons. This uncertainty of data in the NRDA database has also precluded any analyses of alkane data for both sediments and mussels. Hydrocarbon data for 2 sites (Perry Island and Crab Bay) in Prince William Sound and the 4 Kenai Peninsula sites (Quicksand Cove, Petrof Point, Verdant Cove and Harris Bay) is simply not available yet.

Analytical data is available for only 25 mussel samples (out of a total of over 250 samples). All represent n = 1, making statistical interpretation impossible in this report.

For Objective C, the transect photos, data has been completed for 1989 on 6 sites for May and August 1989. Variability in densities of mussels and barnacles from quadrat to quadrat, site to site, and time period to time period probably will mask any differences between oiled and non-oiled sites. Only limited hydrocarbon data for these sites are available to date to provide background for the tests.

The main thrust of this coastal habitat study is to provide linkage to other NRDA and Restoration/Monitoring studies through documentation of the presence and persistence of petroleum hydrocarbons in the intertidal areas. The Principal Investigators participated in an informal survey/study to examine contaminated mussel beds, summer 1991 in Prince William Sound, and the real concern was that continued recontamination of mussels by *Exxon Valdez* crude oil trapped underneath densely packed mussel beds was affecting physiological and/or reproductive parameters in harlequin ducks, oystercatchers, and juvenile sea otters.

Except for the U.S. Forest Service NRDA Study Coastal Habitats 1A, existing NTDA/Restoration/Recovery Studies have mainly used mussels, per se, as chemical surrogates indicating levels of petroleum contamination. Little attention has been paid to biological aspects of hydrocarbon exposure to mussels or to bioaccumulation through the food chain. We will attempt to address some of these issues in our 1992 proposal.

LITERATURE CITED

Karinen, John F., L. Scott Ramos, Patty G. Prohaska, William D. MacLeod, Jr. In Preparation. Hydrocarbon Distribution in the Marine Environment of Port Valdez and Prince William Sound, Alaska.

Table 1. Sediment hydrocabon data from Prince William Sound sites, 1989-1990. Means and standard error of total aromatic hydrocarbons, selected aromatic groups, and phytane are given in ng/g dry weight. N = number of samples analyzed.

SITE/ DATECOL	N	T AROMATICS Mean	se	PHENAN-THRENES Mean	se	DIBENZO-THIOPHENES Mean	se	FLUORENES Mean	se	CHRYSENES Mean	se	PHYTANE Mean	se
Barnes Cove													
Mar-89	6	69.7	5.8	10.7	1.6	1.2	0.1	2.8	0.6	3.1	0.9	0.0	0.0
Apr-89	3	150.0	12.6	21.4	14.0	3.6	1.4	3.2	0.7	10.4	4.3	0.0	0.0
May-89	2	274.6	0.3	48.8	0.2	10.8	3.7	12.1	0.9	30.6	7.9	0.0	0.0
May-89	1	949.2		134.7		37.4		17.4		110.0		0.0	
Aug-89	3	162.6	27.7	20.7	3.0	3.7	0.4	3.6	0.4	9.3	1.3	0.0	0.0
Apr-90	2	156.0	20.6	17.8	3.6	5.1	0.8	7.4	1.0	3.6	0.0	0.0	0.0
Bay of Isles													
Mar-89	3	70.4	20.9	2.7	0.7	0.3	0.2	0.3	0.2	2.6	1.3	0.0	0.0
Apr-89	2	34.1	13.0	3.2	3.2	1.1	0.8	0.0	0.0	1.2	0.8	0.0	0.0
May-89	3	188.4	77.3	59.2	30.6	31.2	12.6	11.0	6.0	11.1	4.6	13.2	8.0
Aug-89	3	60.4	14.0	10.3	4.9	3.1	2.2	1.1	0.0	6.4	1.6	1.9	1.9
Apr-90	2	216.2	20.5	73.9	3.3	36.3	1.7	14.0	1.6	25.4	4.4	12.4	11.1
Jun-90	2	95.6	14.3	30.2	6.3	17.8	6.4	8.1	1.9	10.7	1.8	0.0	0.0
Aug-90	1	59.1		15.1		6.7		0.7		8.9		21.9	
Bligh Island													
Mar-89	1	23.5		3.6		0.2		1.3		1.9		0.0	
May-89	3	38.0	17.1	9.2	4.1	2.4	1.9	1.9	0.5	4.9	2.7	0.0	0.0
Aug-89	3	48.3	14.1	8.3	4.8	0.7	0.2	1.2	0.6	4.1	1.5	0.0	0.0
Apr-90	2	33.6	13.2	2.8	1.0	0.2	0.1	2.7	1.7	0.6	0.6	0.0	0.0
Aug-90	2	17.8	0.4	3.1	0.2	0.7	0.1	1.4	0.4	2.3	0.4	3.8	1.3
Constantine Harbor													
Mar-89	3	633.8	27.8	211.6	11.2	24.2	1.9	46.5	0.9	47.6	2.1	0.0	0.0
May-89	1	562.5		195.7		19.6		45.4		43.5		0.0	
Aug-89	2	588.6	34.2	203.9	2.2	23.4	3.6	50.2	3.6	48.6	5.2	0.0	0.0
Apr-90	1	663.6		202.0		33.8		75.6		59.3		0.0	
Jun-90	2	653.0	74.7	199.5	14.6	27.7	4.9	91.9	23.1	44.4	7.8	0.0	0.0
Elrington Island													
May-89	3	125.5	35.6	50.4	13.8	27.6	9.6	12.3	4.7	12.0	2.1	9.1	5.5
Aug-89	3	35.5	19.1	13.0	7.6	2.8	0.8	1.0	0.5	6.0	3.4	0.0	0.0
Apr-90	2	162.9	85.6	27.2	9.7	28.3	11.5	53.1	33.4	20.7	20.2	0.0	0.0
Jun-90	2	11.4	10.3	2.8	2.8	0.9	0.8	2.1	2.1	1.4	1.4	0.6	0.6
Aug-90	3	10.7	2.1	1.3	0.6	0.6	0.2	0.9	0.1	1.9	0.2	10.4	3.3
Naked Island													
Mar-89	2	45.9	13.4	8.4	5.1	1.8	1.1	1.5	0.6	8.4	7.3	0.0	0.0
Apr-89	3	70.1	41.0	15.6	12.9	2.1	1.5	3.7	3.7	3.2	0.8	0.0	0.0
May-89	2	61.9	22.6	17.1	10.7	4.0	0.5	1.2	0.6	8.5	3.8	0.0	0.0
Jun-89	1	108.7		31.8		11.0		4.2		12.0		0.2	
Aug-89	2	76.3	10.2	18.3	6.0	2.5	0.3	5.2	1.2	8.6	3.4	0.0	0.0
Apr-90	1	31.2		7.3		1.2		3.4		1.8		0.0	
Olsen Bay													
Apr-89	3	27.9	2.7	1.0	0.4	0.2	0.2	1.1	0.2	1.7	0.2	0.0	0.0
May-89	3	59.6	18.1	12.0	5.4	0.9	0.5	4.5	1.9	6.3	3.0	0.0	0.0
Aug-89	3	26.7	4.5	6.9	2.0	0.4	0.0	2.0	0.4	1.7	0.9	1.8	1.1
Apr-90	2	19.2	1.8	4.0	0.7	0.4	0.0	1.4	0.4	0.1	0.1	0.0	0.0
Jun-90	1	18.0		5.4		0.0		0.3		0.0		1.2	
Aug-90	3	21.8	7.6	3.3	0.9	0.3	0.3	4.9	4.1	1.2	0.3	1.5	0.8
Rocky Bay													
Mar-89	3	329.3	50.2	94.8	12.3	6.4	0.8	33.7	7.2	16.0	1.6	0.0	0.0
May-89	3	292.9	38.0	94.9	11.7	8.2	2.2	36.2	5.3	20.6	4.9	0.0	0.0
Aug-89	3	273.7	26.0	93.0	8.5	3.8	1.6	31.2	5.8	18.6	1.7	0.0	0.0
Apr-90	3	317.7	13.8	93.0	4.4	9.5	1.3	56.5	7.4	15.4	0.7	0.0	0.0
Siwash Bay													
Mar-89	3	85.3	15.7	16.8	8.8	1.5	0.7	4.3	1.3	6.5	3.3	0.0	0.0
May-89	3	10.6	1.5	0.0	0.0	0.2	0.2	0.3	0.2	0.0	0.0	0.0	0.0
Aug-89	3	53.1	12.2	10.5	5.1	0.6	0.6	3.1	1.5	4.5	2.1	0.0	0.0
Apr-90	2	22.6	10.8	4.3	1.0	1.8	1.1	1.1	0.2	0.7	0.4	0.6	0.5
Jun-90	2	35.9	2.2	3.5	3.2	0.7	0.5	6.1	5.3	0.3	0.3	2.0	2.0
Aug-90	3	13.6	3.3	2.3	0.3	0.1	0.1	0.7	0.2	0.8	0.3	5.0	0.5
Sleepy Bay													
May-89	3	930.0	404.2	356.0	139.2	175.5	66.4	78.8	40.1	54.9	17.1	141.3	57.4
Aug-89	2	715.6	63.9	306.9	41.1	193.4	16.9	55.7	18.9	91.7	10.3	268.2	30.2
Apr-90	2	164.3	25.3	56.8	11.2	26.0	9.1	7.5	2.7	33.7	0.8	25.4	5.1
Jun-90	2	159.1	12.9	39.2	0.8	28.4	3.9	17.0	10.7	34.9	4.1	36.1	6.3
Aug-90	3	170.0	43.0	50.6	16.8	38.6	11.7	8.8	3.2	42.3	8.9	47.1	5.9

Table 2. Mussel (*Mytilus trossulus*) hydrocarbon data from Prince William Sound sites, 1989-1990. Total aromatic hydrocarbons, sums of selected aromatic groups, and phytane are presented as ng/g dry weight and all are single samples (N = 1).

SITE	DATE	T AROMATICS	PHENANTHRENES	DIBENZOTHIOPHENES	FLUORENES	CHRYSENES	PHYTANE
Barnes Cove	Mar-89	206.5	12.9	0.0	23.9	0.0	0.0
	Apr-90	106.1	15.2	2.7	3.1	4.4	138.0
	Jun-90	98.0	8.8	3.2	1.3	0.9	21.8
Bligh Isl.	Mar-89	299.5	25.6	0.1	24.2	5.4	0.0
	Apr-90	106.6	12.7	1.8	2.1	1.2	42.5
	Jun-90	138.3	19.3	1.9	4.3	3.4	21.3
Bay 'Isles	Apr-90	379.8	258.5	3.8	2.8	20.4	250.2
	Jun-90	622.6	302.0	116.1	92.9	16.9	183.8
Constantine Harbor	Apr-90	150.4	11.6	3.9	6.5	2.4	168.4
	Jun-90	99.6	11.4	1.6	3.4	1.8	13.1
Elrington Island	Apr-90	174.6	12.9	2.9	3.6	19.3	156.4
	Jun-90	137.8	16.3	2.2	2.1	10.6	206.9
Naked Isl.	Mar-89	519.4	23.4	0.3	26.8	14.8	0.0
	Apr-90	138.0	12.1	1.5	5.9	7.7	42.4
	Jun-90	78.4	8.7	0.8	1.9	1.1	6.0
Olsen Bay	Apr-90	95.0	11.1	1.6	2.6	1.4	0.0
	Jun-90	95.5	11.7	0.9	1.6	1.2	47.5
Rocky Bay	Mar-89	800.2	32.1	2.3	27.7	0.1	0.0
	Apr-90	181.8	21.4	2.3	5.3	4.1	38.8
	Jun-90	37.8	4.6	0.7	1.1	1.1	35.4
Siwash Bay	Mar-89	225.4	32.7	0.0	31.1	0.1	0.0
	Apr-90	151.1	9.4	0.9	3.8	4.8	99.6
	Jun-90	77.5	9.0	0.8	1.1	0.3	7.8
Sleepy Bay	Apr-90	4549.4	1857.9	1119.8	388.7	690.0	652.7
	Jun-90	2055.8	788.5	360.4	242.2	383.3	418.4

igure 1. Coastal Habitat 1B sampling sites in Prince William Sound. ▲ = historical sites ■ = established in 1989.

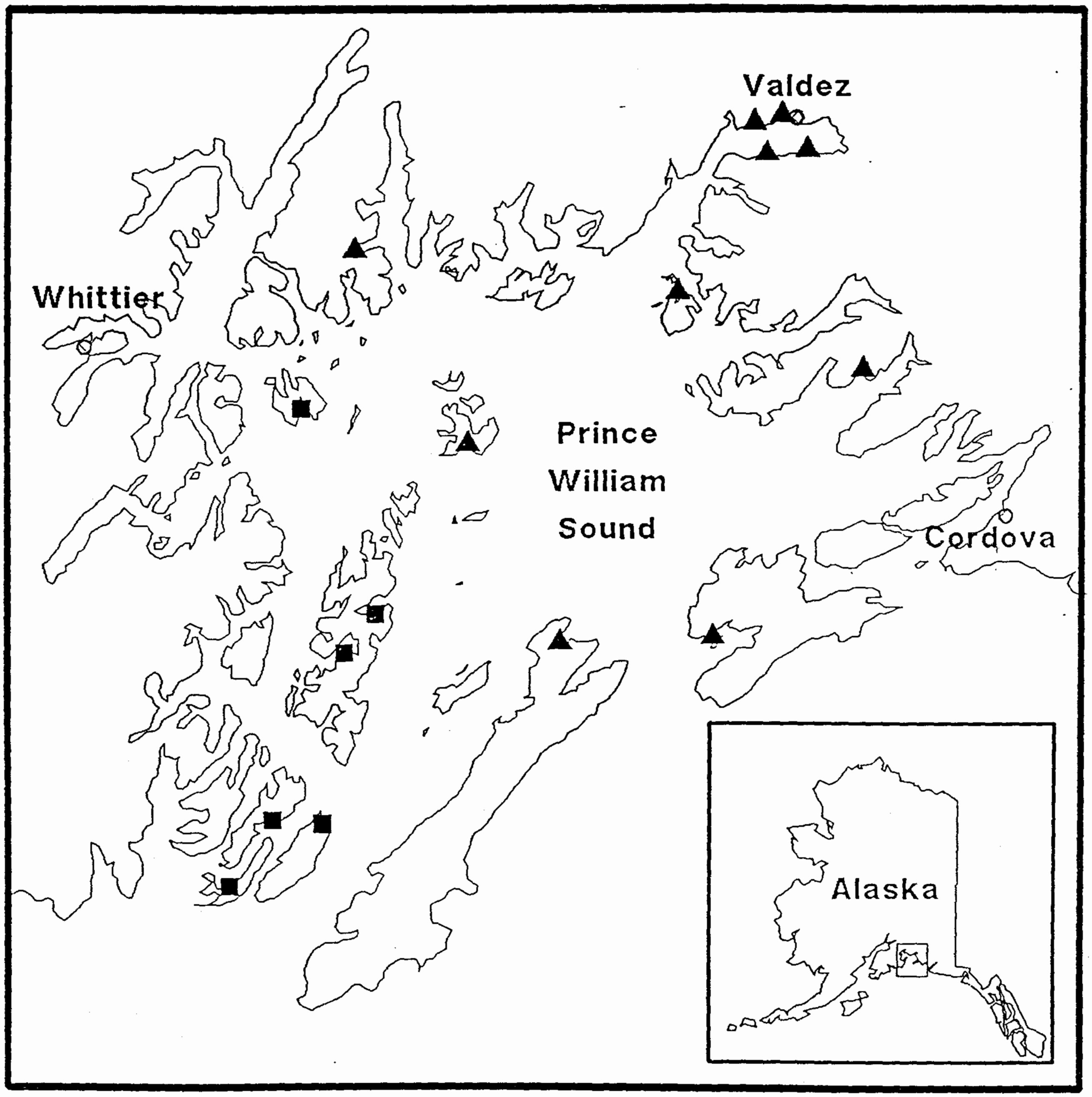


Figure 2. Sums of selected aromatic hydrocarbons in sediments from 6 sites in Prince William Sound, comparing values from 1977–1980 with spring and summer, 1989. n = sample size; vertical bars = standard error.

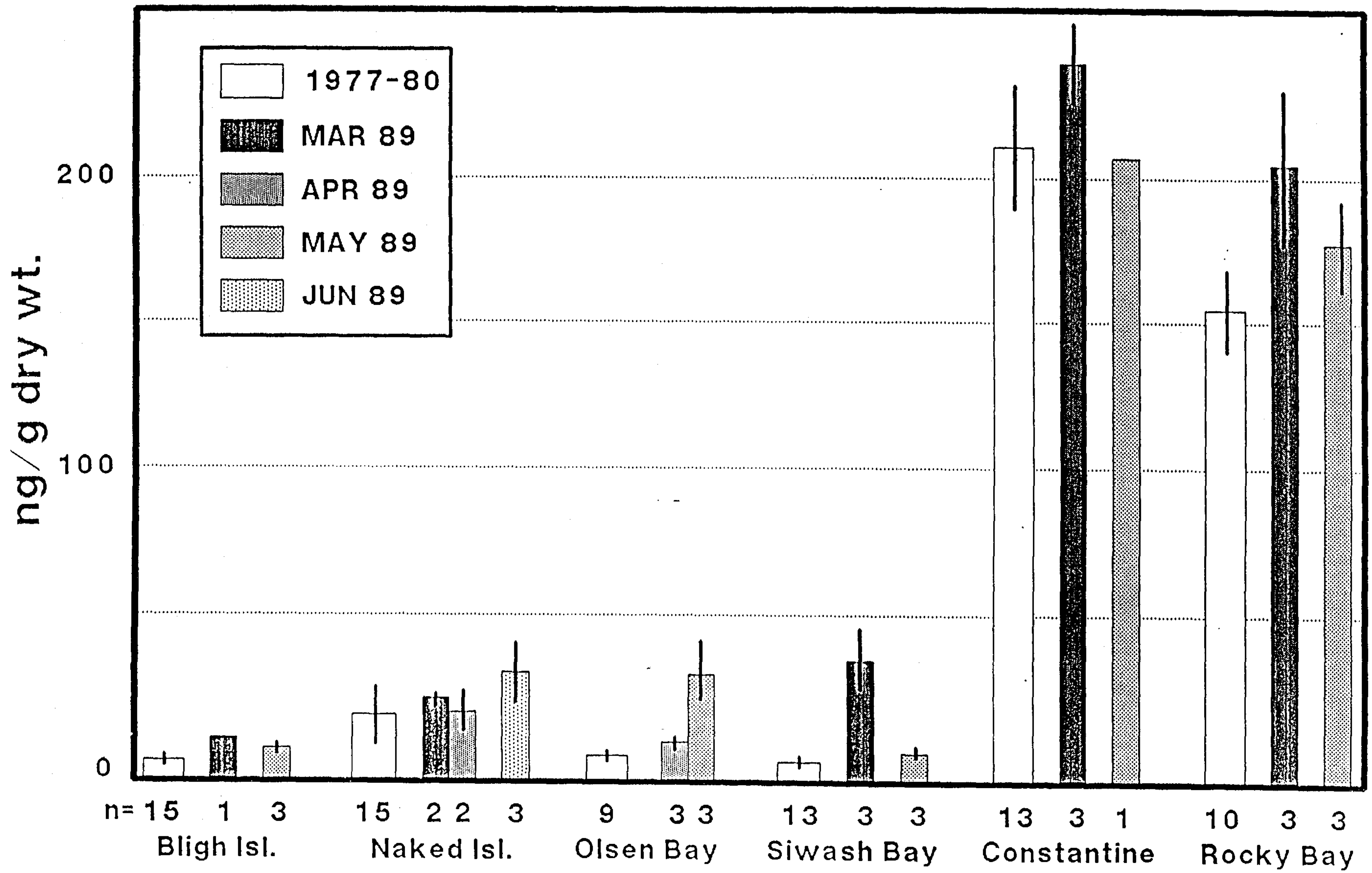


Figure 3. Total aromatic hydrocarbons in sediments from Prince William Sound, 1989 and 1990, after the EXXON VALDEZ oil spill. See Table 1 for sample sizes and standard errors. *, see text.

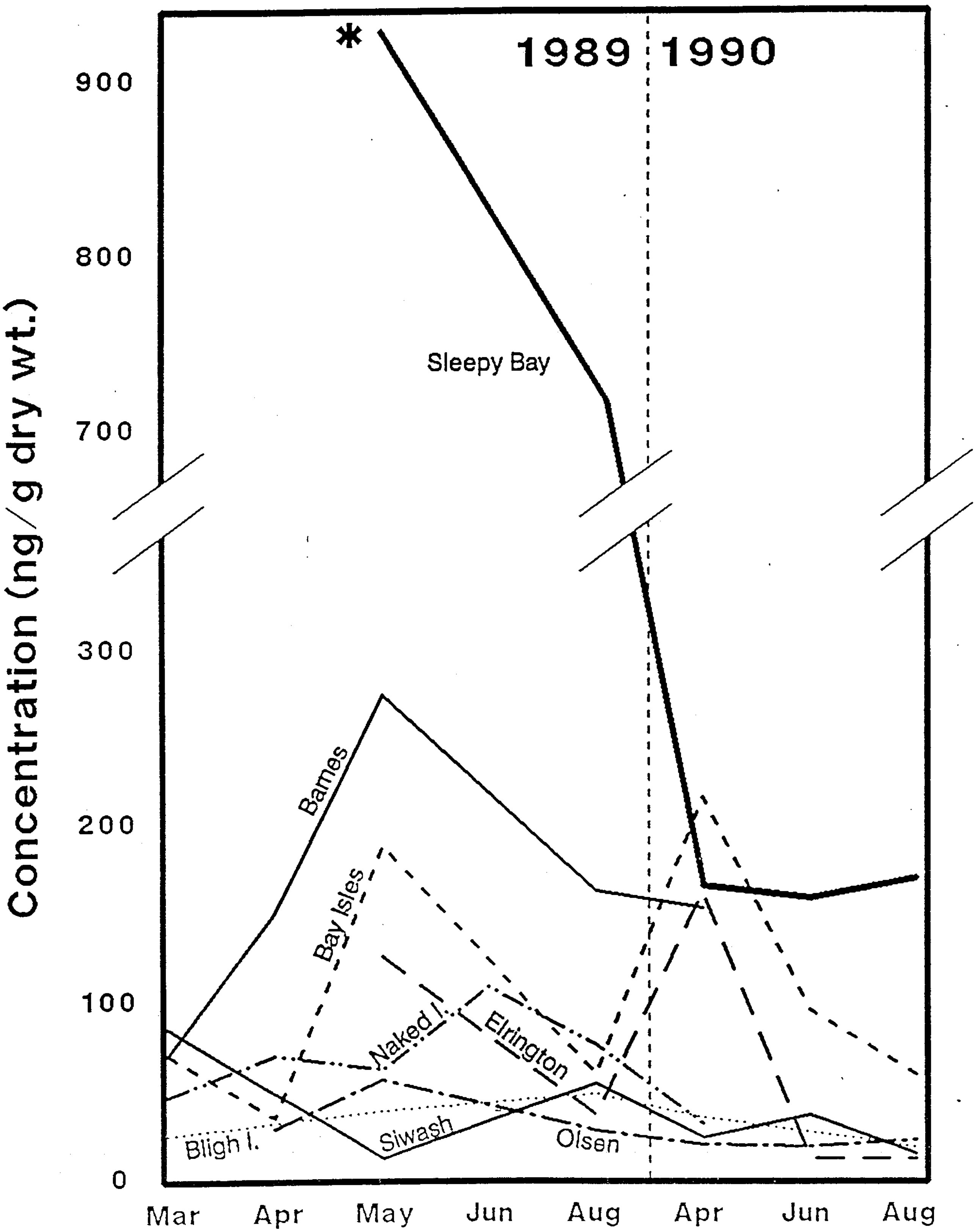


Figure 4. Means of aromatic hydrocarbon groups and phytane in sediments from Elrington Island, Sleepy Bay and Bay of Isles, 1989 and 1990. Concentrations in ng/g dry weight. See Table 1 for sample sizes and standard errors.

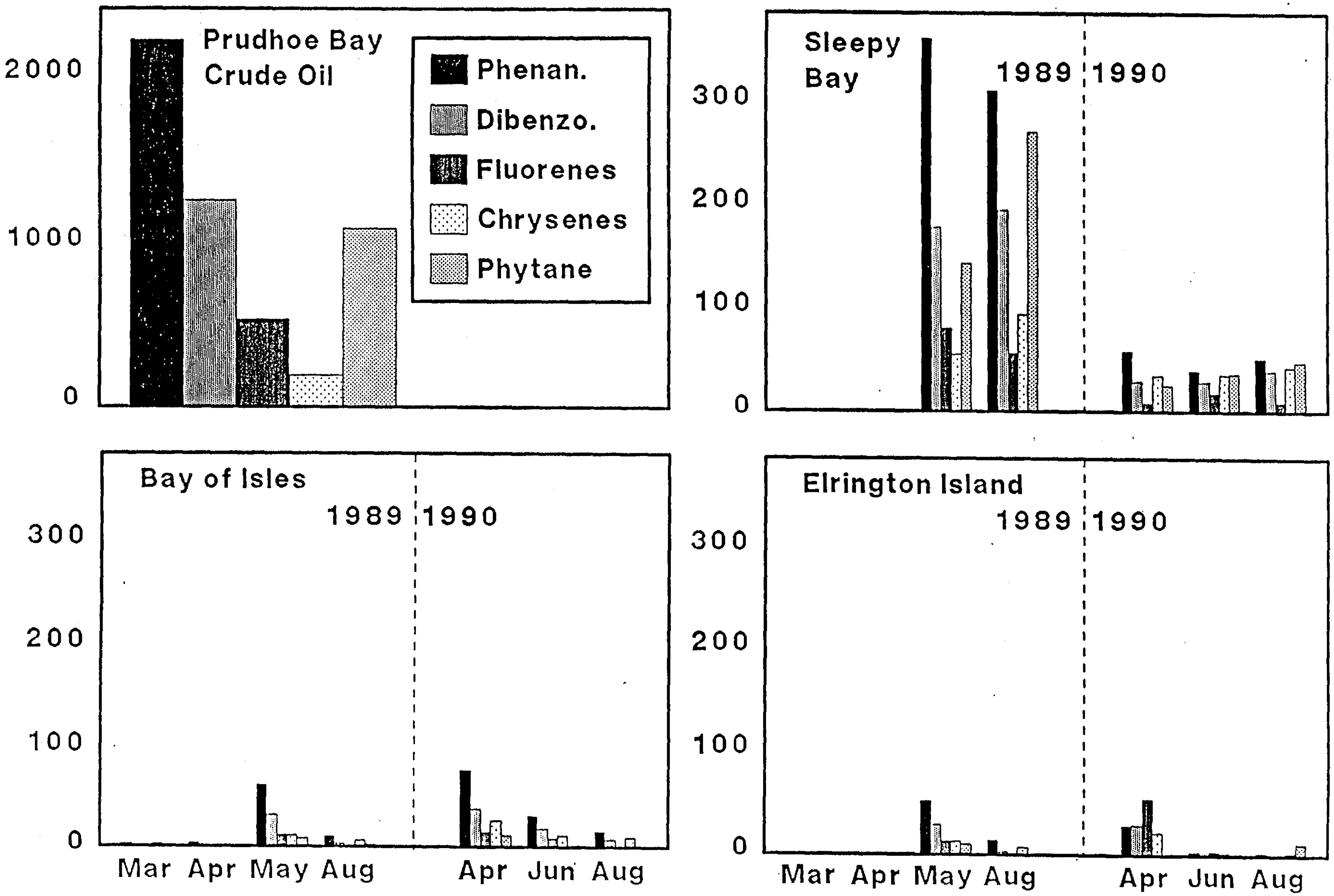


Figure 5. Means of aromatic hydrocarbon groups and phytane in sediments from sites in Prince William Sound, 1989 and 1990. Concentraions in ng/g dry weight. See Table 1 for further details.

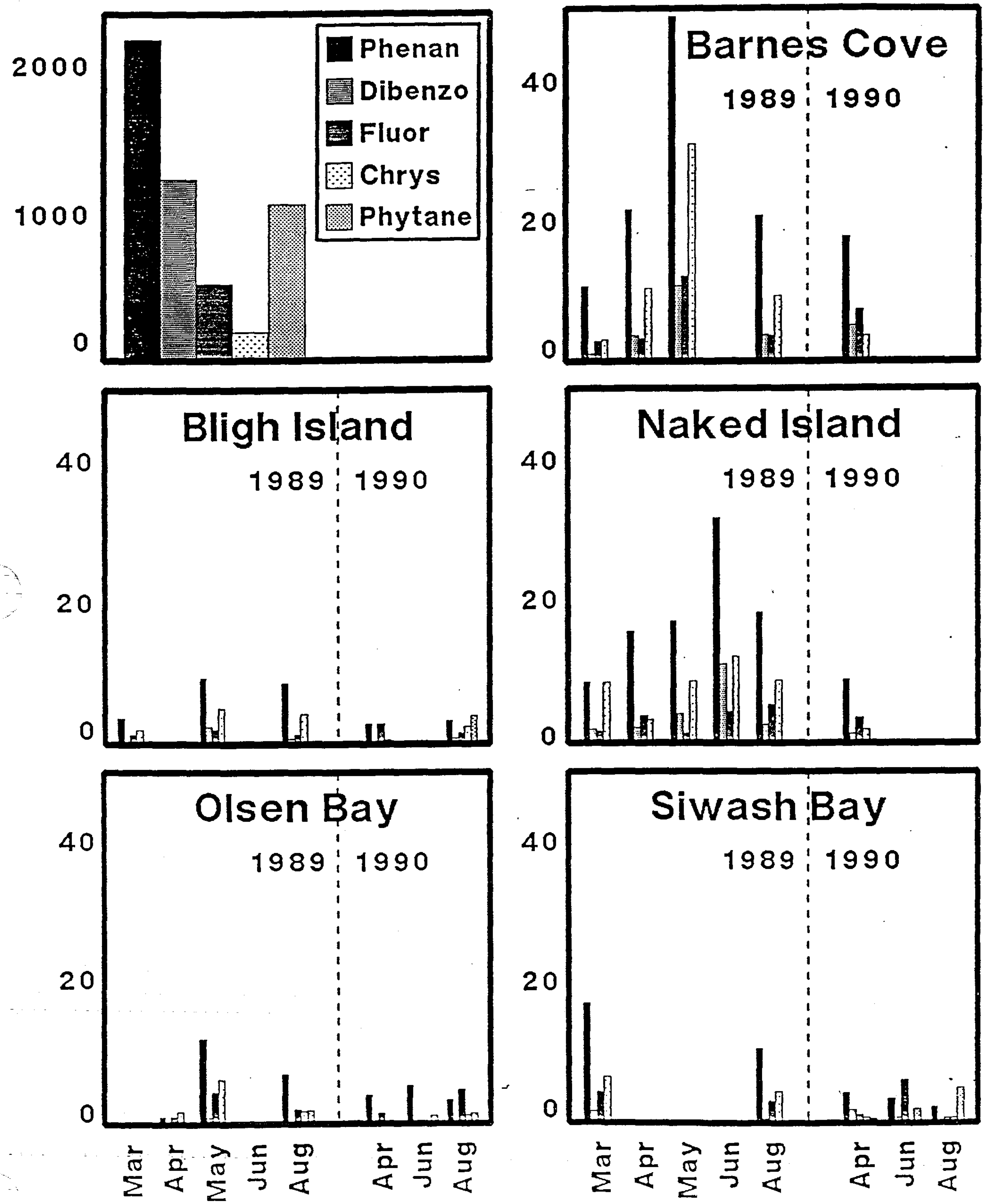


Figure 6. Mean aromatic hydrocarbon groups and phytane in sediments from Rocky Bay and Constantine Harbor, 1989 and 1990. These sites have high vessel usage. Values in ng/g dry weight.

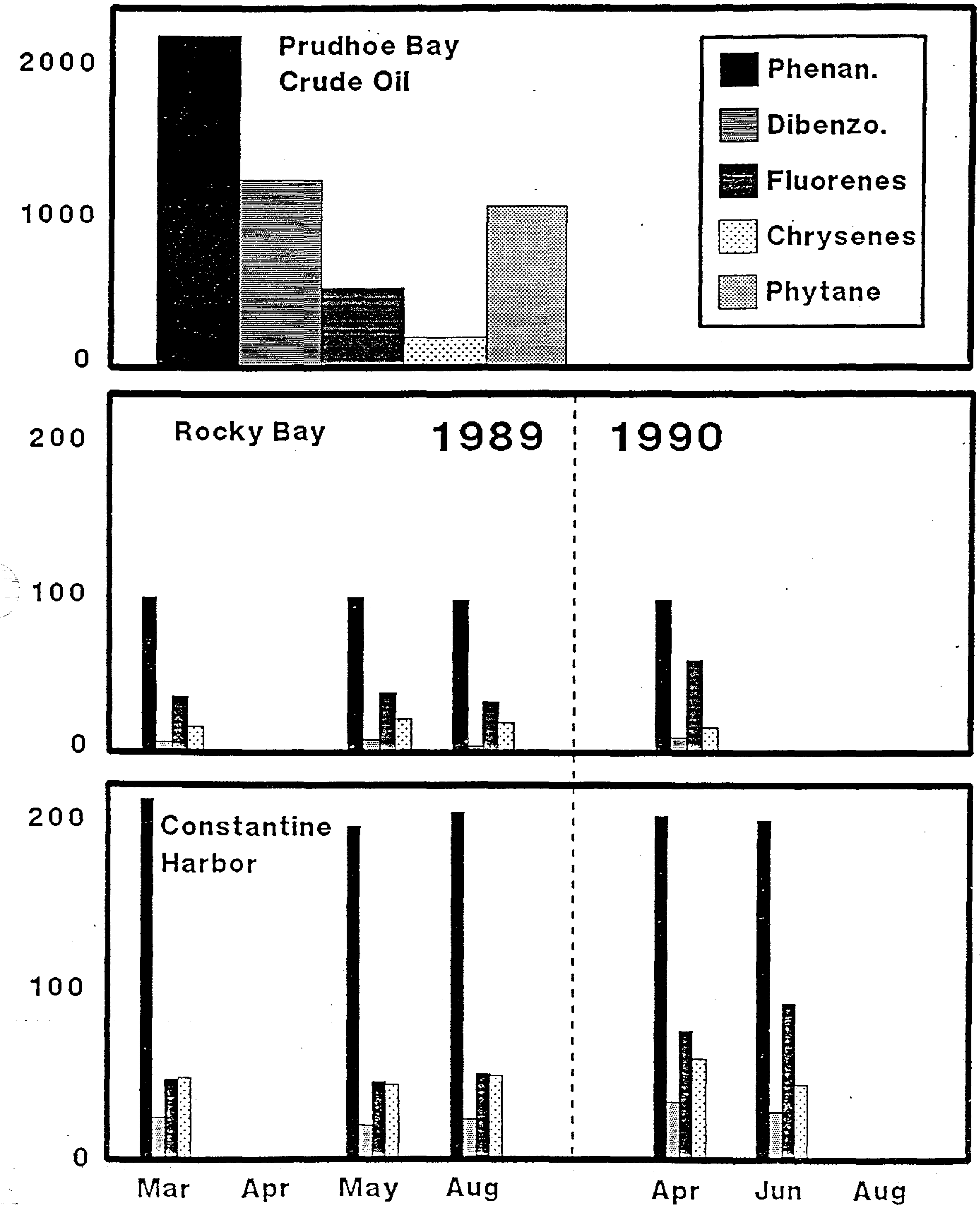


Figure 7. Mean aromatic hydrocarbons groups and phytane in mussels and sediments from Sleepy Bay, April and June, 1990. See Tables 1 and 2 for sample sizes and standard error.

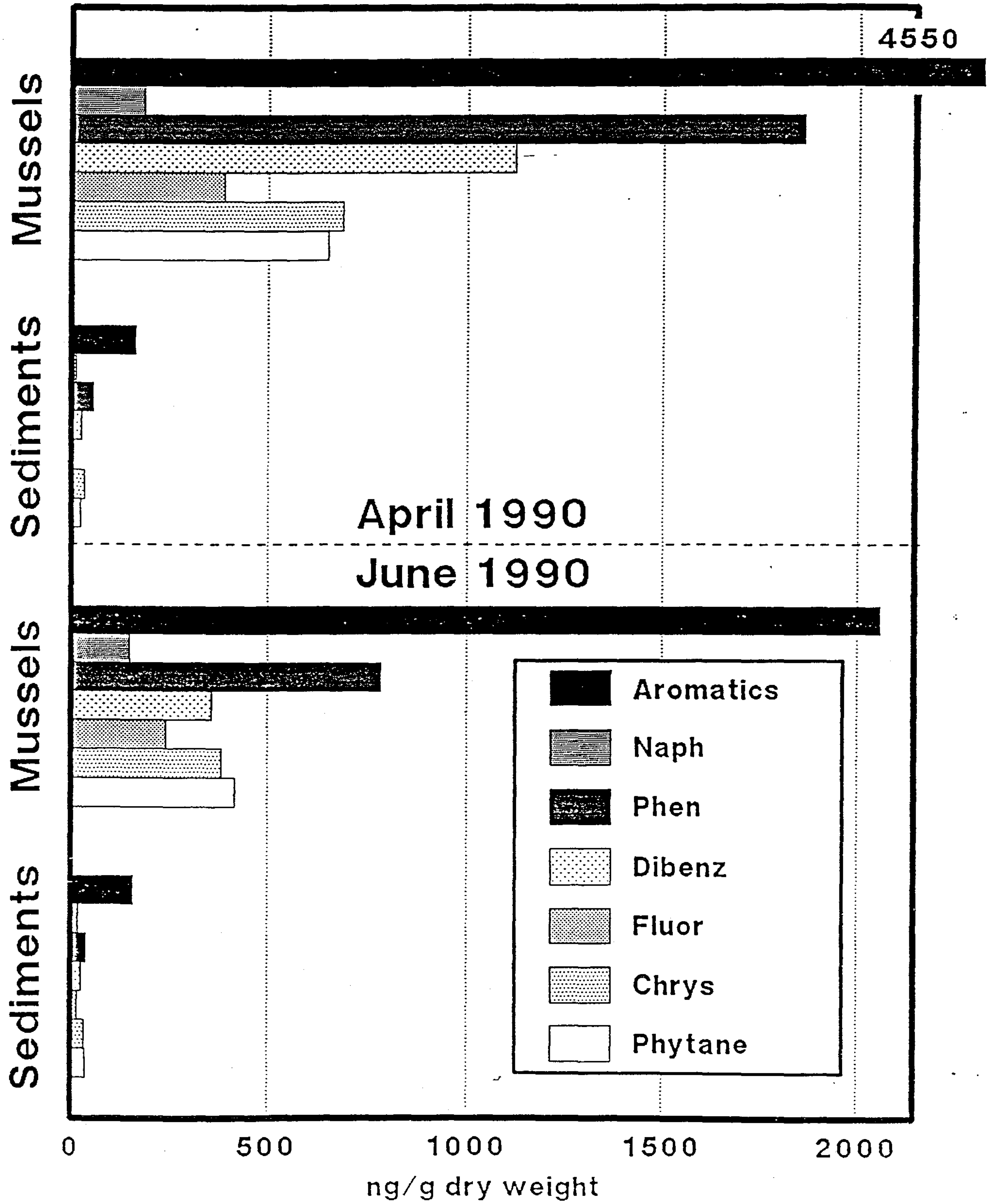
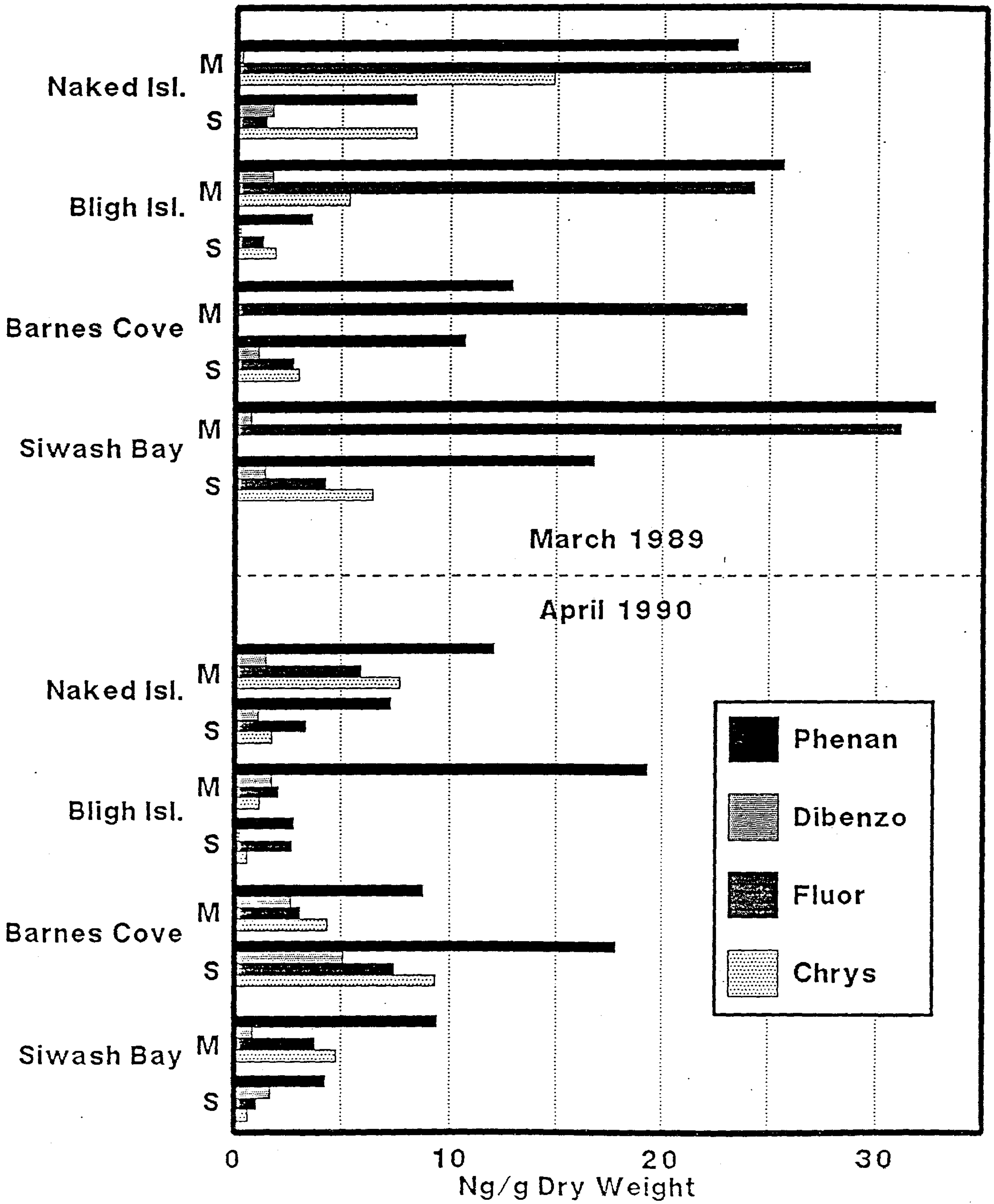


Figure 8. Aromatic hydrocarbon groups in mussels and sediments from four sites in Prince William Sound, March 1989 and April 1990. See Tables 1 and 2 for sample size and standard error.



12. Survey of Injured Tidal Marshes in Prince William Sound and the Gulf of Alaska

#12

Survey of Injured Tidal Marshes in the Gulf of Alaska and Prince William Sound: Preliminary Report

by

James G. Wyant (Research Scientist)

ManTech Environmental Technology Inc.
USEPA Environmental Research Laboratory
200 SW 35th Street, Corvallis, OR 97333

November 18, 1991

Submitted to:

Mostafa Shirazi (Project Officer)

U.S. Environmental Protection Agency
Environmental Research Laboratory
200 SW 35th Street, Corvallis, OR 97333

SUMMARY

The primary objective of this study was to assess the relative abundance of tidal marsh habitat within the area impacted by the *Exxon Valdez* oil spill that occurred in March 1989. The study was conducted in two stages. The first stage consisted of searching existing databases for possible tidal marsh locations in the oil spill affected area. This search consisted of an analysis of a database that had been established by the state of Alaska in conjunction with the oil spill response effort. A preliminary list of potentially injured tidal marsh sites was compiled from these searches. The second stage consisted of field visits by EPA Region 10 and Environmental Research Laboratory-Corvallis(ERL-C) scientists to assess natural recovery and potential need for restoration at potentially affected tidal marsh sites. The study plan called for quantitative assessments and advisement of work if expert opinion indicated a need for restoration intervention. However, except for a single case (Bay of Isles), natural recovery of all oiled marshes that were visited or observed on overflights was deemed sufficient and no restoration was warranted. Because the Bay of Isles site was small (approximately 800 m^2), relative to the area of salt marsh habitat in or adjacent to the oil impact area, no additional restoration activities are recommended for oil impacts on tidal marshes resulting from the *Exxon Valdez* oil spill of 1989.

INTRODUCTION

In March 1989 the *Exxon Valdez* ran aground on Bligh Reef in Prince William Sound, spilling approximately 11 million gallons of Prudhoe Bay Crude Oil into the water and impacting over one thousand miles of coastal resources in the Prince William Sound (PWS) and the Gulf of Alaska (GOA). The *Exxon Valdez* oil spill (EVOS) affected the region's environment, including floral and faunal populations, recreational, educational, and aesthetic attributes.

A restoration planning process was initiated in late 1989 to begin addressing ways to help restore resources impacted by the EVOS. A restoration planning progress report, prepared by the interagency Restoration Planning Work Group (RPWG) was released in August 1990. This report defines restoration as "actions undertaken to return an injured resource to its baseline condition, as measured in terms of the injured resource's physical, chemical, or biological properties or the services it previously provided." (RPWG, 1990a, 1990b).

The coastal areas in the PWS and the GOA consist of varied rocky shores, with many small inlets and coves that shelter tidal marshes. Tidal marshes have been classified as the most sensitive shore-type to oil pollution (Ganning et al., 1984). It has been estimated that 2-20 years are required for tidal marshes to recover naturally (Cairns and Buikema, 1984; RPWG, 1990a, 1990b). Oil is rapidly buried in marshes because they are low energy systems, and degradation is limited under the anaerobic conditions found in these environments (Cairns and Buikema, 1984).

Tidal marshes represent a relatively small percentage of the coastline affected by EVOS, however, they are important components of the coastal ecosystem. Tidal marshes are mostly herbaceous, and may serve to stabilize shorelines, serve as feeding and resting areas for birds, and possibly as alternative food sources for grazing mammals (Seneca et al., 1982). However, with two exceptions (Tonsina Bay and Bay of Isles) preliminary surveys suggested that most marshes known to be affected by EVOS received only minor or patchy insult as a result of either initial oiling and/or clean-up efforts.

On the other hand, because tidal marshes are critically important wildlife habitats and because they are not spatially extensive or particularly notable to an untrained observer, the possibility that important impacts to salt marsh habitats had been overlooked was considered an important item to rectify. If tidal marshes had been significantly impacted by EVOS, restoration efforts would then be justified. However, if only a small impact could be identified, the economic cost and logistic effort needed to rectify minor (relative to the total marsh habitat in the vicinity) impacts might outweigh the benefit of marsh restoration.

METHODS and PRELIMINARY RESULTS

The first stage consisted of searching existing databases for possible tidal marsh locations in the oil spill affected area. This search consisted of an analysis of a data base that had been established by the state of Alaska in conjunction with the oil spill response effort. This data base included information gathered over approximately a two year period (Spring 1989 to Spring 1991, inclusive). The data sets that were assessed were gathered by: (1) Alaska Department of Fish and Game, (2) Alaska Department of Environmental Conservation, and (3) the National Park Service. Data types included location data, shoreline type, sediment type and mix (percentage), beach energy, environmental sensitivity rating and a keyword search (lagoon, marsh, bog).

The data sets were assembled in a relational database using Rbase for DOS version 3.1a and a query was run using SQL concepts of "views" and projected tables (Slocomb 1991). A preliminary list of 21 potentially injured tidal marsh site was compiled from these searches.

The second stage consisted of field visits by EPA Region 10 and ERL-C scientists in August 1991 to assess natural recovery and potential need for restoration at potentially affected tidal marsh sites. Logistic consideration prevented landing at each of the 21 potential marsh site, though overflights of 18 sites occurred and landings were made at 9 sites with a repeat landing at the Bay of Isles site.

Three categories of data were assessed at each field site actually visited: (1) estimation of aboveground plant cover and apparent vegetation vigor (using visual symptoms), (2) sediment coring for presence/absence of rhizomes and roots, and (3) paced or measured area of estimated extent of marsh habitat prior to the oil spill.

Site assessment required individual tidal marsh site evaluation in the field which assesses the need for site restoration based on the following criteria:

- Extent of living/dead vegetation biomass - Evaluating vegetation belowground in the absence of aboveground cover was especially important, because rhizomes present in the substrate indicate the prespill areal extent of a marsh.

- Apparent cover - This criterion provided information on the extent of the visibly impacted area. If approximately 20% of the original marsh area exhibited greater than reduction in vegetative cover, the marsh was considered for restoration. In addition, if the impacted area was greater than 10 m^2, site restoration is also considered. This accounts for situations in which a small percentage of a large marsh is injured, but the total area affected is rather large. These two criteria were considered the minimum size criteria for restoration activities, but are only guidelines. The final decision for restoring a site depended on best professional judgement in the field. Information generated under this criterion will serve as the "injured baseline" from which restoration success (assessed through vegetative cover) will be measured.

- Vigor - This criterion evaluates visible stress on the ecosystem independent of apparent cover, through judgement of plant health (i.e. brown dying plants versus green healthy plants). Therefore, even if there is a large percent of vegetative cover in an impacted tidal marsh, if a large quantity of it is of low vigor (brown and dying), then the marsh would qualify for restoration. The actual trigger for restoration requires low "vigor" on greater than 20% of the original marsh area.

At each site care was taken not to injure sites with equipment or foot traffic. Observations involving biomass, fringe impacts, percent cover, vigor and natural recovery (e.g. recolonization by vegetation and marine invertebrates) were made relying on the experience and professional judgement of three ERL-C and one EPA-HQ scientist. Substrate sampling to determine the presence or absence of residual roots and rhizomes was accomplished through use of 4 cm diameter soil core samplers. The presence of partially decomposed root masses and visual assessment of buried oil were taken as indicators of the areal extent of the marsh and potential for restoration without further remediation, respectively. Gravel and rocky substrates were manually overturned to examine the extent of subsurface oil. Tape measured or paced estimates the estimated area impacted were used to determine if area was greater than the minimum area (10 m^2) deemed reasonable for restoration. Photographs were made at each site. If a marsh did not exhibit visible impact from oil (reduced cover or vigor) or if a marsh did not fall within minimum area guidelines, no restoration actions were recommended. Only a single tidal marsh (Bay of Isles, Figure 1) evidenced oil-related impacts, poor natural recovery and areal extent greater than 10 m^2. The estimated area of impact was approximately 800 m^2.

Figure 1. Oiled Tidal Marsh at Bay of Isles.

DISCUSSION

According to Gundlach and Hayes' proposed environmental classification, tidal marshes have been classified as the most sensitive shore type to oil pollution (Ganning et al., 1984). It has been estimated that 2-20 years are required for tidal marshes to recover naturally (Cairns and Buikema, 1984; RPWG, 1990). Other estimates have been less conservative, and have suggested up to 10 years or more for recovery (Baker et al., 1990a, 1990b). The slow rates of natural recovery may prompt efforts to hasten the rate of natural recovery through restoration efforts. However, there are several trade-off that should be considered.

First, Refined oils are generally more toxic than crude oils, and weathered crude is less toxic than fresh crude because many of the toxic components evaporate. Tidal marsh plants can be affected by oil through physical smothering and absorption of toxic oil fractions (Getter et al., 1984, DeLaune et al. 1984, Ziemam et al. 1984). However, the oil deposited into PWS and GOA coastal ecosystems was weathered crude and we found no evidence of continued toxicity in tidal marshes.

Oil is rapidly buried in marshes because they are low energy systems, and degradation is limited under the anaerobic conditions found in these environments (Cairns and Buikema, 1984). Oil may persist in tidal marsh sediments in Prince William Sound for many years. For example, in the West Falmouth oil spill of 1969, it took four years for alkanes to disappear from the sediment, and after eight years heavy aromatics and naphthenes were still present. Recovery was not complete after eight years (Burns and Teal, 1979). Historical attempts to clean oil from marshes have shown that clean-up methods which disturb the soil or hydrology of the marsh may have long-term effects equal to or more severe than direct oiling (Cairns and Buikema, 1984; Baker et al., 1990a, 1990b). This is because clean-up may remove the living organisms and alter the habitat. At the same time, removal of oil from marshes through natural processes is slow because marshes are sedimentary, anaerobic habitats with minimal flushing. We anticipated little potential for restoration success at the Bay of Isles site without further remediation of oil contained in the marsh substrate.

Recovery processes can begin in the presence of residual oil (Dicks 1975, Baker et al., 1990). Even high levels of weathered crude in the substrate may not prevent revegetation (Getter et al., 1984). Natural marsh recovery begins when oil toxicity is reduced to a point that can be tolerated by recolonizers (Baker et al., 1990). Full tidal marsh recovery hinges on reduction in oil toxicity or availability; availability of propagules; stability of sediments; and biotic interactions (Getter et al., 1984). In PWS, Baker et al., 1990, saw new plant growth in marsh sediments with visible oil residues. In an *Amoco Cadiz* marsh study, Puccinellia planted on freshly oiled sites were still alive after one year (Seneca et al., 1982). In a study of oil pollution in a New England salt marsh, Burns and Teal (1979) discovered that areas with more than 1 to 2 mg oil/g sediment did not contain living plants. They also observed higher plant regrowth between 1973 and 1975, in conjunction with a decrease in aromatic hydrocarbons in surface sediments, although regrowth was very uneven over the oiled marsh. Petroleum hydrocarbons can accumulate in animals as well as sediment, but according to Baker et al. (1990) animals quickly cleanse themselves. Burns and Teal (1979) also did not find any evidence of food chain magnification within aquatic marsh organisms.

Some researchers, such as Dr. John Teal, advocate natural recovery of ecosystems, based on the principle that nature is better able to restore itself than man (RPWG, 1990). Regarding the *Exxon Valdez* oil spill, Dr. Teal expressed concern that technological solutions may have adverse effects on Prince William Sound (RPWG, 1990). Dr. Teal cited marshes that had recovered naturally from the West Falmouth oil spill as an example. These marshes began to return after three years and recovery continued, even though oil was still in the mud 20 years later (RPWG, 1990). Other researchers suggest that both natural recovery and active restoration may be appropriate, but are situation dependent (Broome et al. 1986, Broome 1989, Getter et al., 1984).

RECOMMENDATION

Restoration activities in heavily oiled marshes may be expected to require both substantial effort and extended time periods. The presence of oil in high concentrations at a site may complicate restoration efforts, and vegetation regrowth in these areas may occur slowly.

Except for a single case (Bay of Isles), natural recovery of all oiled marshes that were visited or observed on overflights was deemed sufficient and no restoration was warranted. Because the Bay of Isles site was small (approximately 800 m^2) relative to the area of salt marsh habitat in or adjacent to the oil impact area (for example, consider the Copper River Delta), no additional restoration activities are recommended for tidal marsh impacts from the *Exxon Valdez* oil spill of 1989.

The proximity of the Copper River delta, an extensive and critical tidal marsh habitat area, to the Prince William Sound shipping lanes suggests that future oil spills may potentially impact tidal marsh habitats. Furthermore, Title VII, Oil Pollution Research and Development Program, of the Oil Pollution Act of 1990, (P.L. 101-380) specifically notes the importance of "research and development of methods to restore and rehabilitate natural resources damaged by oil discharges ... and the preparation of scientific monitoring and evaluation plans" for these areas. The potential for conducting experimentally well-designed studies of oil impacts, possible mitigation approaches and restoration potentials on the Copper River Delta should be considered.

LITERATURE CITED

Baker, J.M., R.B. Clark, P.F. Kingston, et al. 1990. Natural Recovery of Cold Water Marine Environments After an Oil Spill. Presented at the 13th Annual Arctic and Marine Oil Spill Program Technical Seminar, June 1990.

Baker, J., R. Clark, and P. Kingston. 1990. Environmental Recovery in Prince William Sound and the Gulf of Alaska. Field observations. A supplement to the authors' scientific review, Natural Recovery of Cold Water Marine Environments After an Oil Spill. Presented at the 13th Annual Arctic and Marine Oil Spill Program Technical Seminar.

Broome, S.W. 1989. Creation and Restoration of Tidal Wetlands of the Southeastern United States. In: EPA ERL-Corvallis Wetland Creation and Restoration: The Status of the Science Vol. I & II. EPA/600/3-89/038a, b.

Broome, S.W., E.D. Seneca, and W.W. Woodhouse, Jr. 1986. Long-Term Growth and Development of Transplants of the Salt-Marsh Grass *Spartina alterniflora*. Estuarine Research Federation, p. 63-74.

Burns, K.A., and J.M. Teal. 1979. The West Falmouth Oil Spill: Hydrocarbons in the Salt Marsh Ecosystem. Estuarine and Coastal Marine Science 8:349-360.

Cairns, J., Jr., and A.L Buikema, Jr., eds. 1984. Restoration of Habitats Impacted by Oil Spills. Boston: Butterworth Publishers.

DeLaune, R.D., C.J. Smith, W.H. Patrick, Jr., et al. 1984. Effect of Oil on Salt Marsh Biota: Methods for Restoration. Environmental Pollution (Series A) 36, no. 3:207-227.

Dicks, B. 1975. Changes in the Vegetation of an Oiled Southampton Water Salt Marsh. In: Recovery and Restoration of Damaged Ecosystems. Proceedings of the International Symposium on the Recovery of Damaged Ecosystems, Blacksburg, Virginia, March 23-25, 1975. Edited by J. Cairns, Jr., K.L. Dickson, and E.E. Herricks. University Press of Virginia.

Ganning, B., D.J. Reish, and D. Straughan. 1984. Recovery and Restoration of Rocky Shores, Sandy Beaches, Tidal Flats, and Shallow Subtidal Bottoms Impacted by Oil Spills. In: Restoration of Habitats Impacted by Oil Spills, edited by J. Cairns, Jr., and A. Buikema, Jr. Boston: Butterworth Publishers.

Getter, C.D., G. Cintron, B. Dicks, R. R. Lewis III, and E.D. Seneca. 1984. The Recovery and Restoration of Salt Marshes and Mangroves Following an Oil Spill.

In: Restoration of Habitats Impacted by Oil Spills, edited by J. Cairns, Jr, and A. Buikema, Jr. Boston: Butterworth Publishers.

Restoration Planning Work Group. 1990. Restoration following the *Exxon Valdez* Oil Spill. Proceedings of the Public Symposium, Anchorage, Alaska, March 26-27, 1990.

Restoration Planning Work Group. 1990. Restoration Planning Following the *Exxon Valdez* Oil Spill. August 1990 Progress Report.

Seneca, E.O., and S.W. Broome. 1982. Restoration of Marsh Vegetation Impacted by the *Amoco Cadiz* Oil Spill and Subsequent Cleanup Operations at Ile Grande, France. Interim Report to Dept. of Commerce, NOAA, Washington, D.C.

Slocomb, J. 1991. Database search for possible marsh locations. State of Alaska, Department of Natural Resources. Anchorage, AK. 33 pp.

Zieman, J.C., R. Orth, R.C. Phillips, et al. 1984. The Effects of Oil on Seagrass Ecosystems. In: Restoration of Habitats Impacted by Oil Spills, edited by J. Cairns, Jr., and A. Buikema, Jr. Boston: Butterworth Publishers.