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96163

APEX: Alaska Predator Ecosystem Experiment in Prince William Sound and the Gulf of Alaska

Project Number:	96163A-P
Restoration Category:	Research
Proposer:	David Cameron Duffy, Project Leader, University of Alaska Anchorage
Cooperating Agencies:	DOI, ADF&G, NOAA
Duration:	Five years
Cost FY 96:	$1,800,700
Cost FY 97:	
Cost FY 98:	
Geographic Area:	Prince William Sound, Gulf of Alaska
Injured Resource/Service:	Common Murre, Harbor Seal, Marbled Murrelet, Pacific Herring, Pigeon Guillemot, Black-legged Kittiwake

ABSTRACT

Several seabird species such as pigeon guillemot, marbled murrelet and black-legged kittiwake have not recovered from the *Exxon Valdez* oil spill. This project tests the hypothesis that ecosystem-level changes in the food environment of Prince William Sound may be responsible for nonrecovery of seabirds. Several other species such as harbor seal and Pacific herring have not recovered. All of these may be affected by changes in the forage fishes that provide the raw material that sustains the ecosystems of Prince William Sound. At a still larger scale, restoration efforts such as salmon hatcheries or enhanced fisheries may have effects at the ecosystem level that need to be identified, so that such efforts can be fine-tuned to ensure the long-term health and viability of Prince William Sound.

The Alaska Predator Experiment (APEX) will use seabirds as probes of the trophic (foraging) environment of Prince William Sound and will compare their reproductive and foraging biologies, including diet, with similar measurements from three areas in Cook Inlet. Like the Sound, the Inlet was injured by the oil spill, but in contrast, two of the sites appear to have healthy food resources, while a third, unoiled Inlet site does not. If we can understand the differences between the sites, we may be able to determine why certain species in the Sound have not recovered.

These measurements of seabird foraging and reproduction will be compared with hydroacoustic and net samples of fish to calibrate seabird performance with fish distribution and abundance. We will use fish samples to compare diet, energetics and reproductive parameters of the different forage-fish species to determine whether competitive and predatory interactions or different responses to the environment may be favoring the abundance of one fish species over another.

INTRODUCTION

The spill from the oil tanker *Exxon Valdez* resulted in significant mortality of several seabirds and in acute massive damage to Prince William Sound (PWS) and the Gulf of Alaska (GOA) (Piatt et al. 1990). Six years following the spill, several species have not recovered. This may be the result of lingering effects of the oil spill (toxicity of prey or sublethal effects of oil exposure to organisms). Or, other non-oil factors may be involved, such as predation, climate-driven ecosystem changes, or even 'random' perturbations.

Both to aid in the recovery of injured resources and to safeguard the long-term health of Prince William Sound and the upper Gulf of Alaska, we need to understand the ecological processes that control the ecosystem. This project focuses on the trophic interactions of seabirds and the forage species they feed on. We chose food as the focus because: 1) much of seabird population theory and several empirical field tests have identified food as an important limiting factor (Ashmole 1963; Cairns 1989; Birt et al. 1987; Furness and Birkhead 1984); 2) seabird/fish researchers in the PWS/GOA complex have concluded that major changes in food have occurred during the period (Springer 1993; Anderson et al. 1994; Piatt and Anderson 1995); 3) other factors such as oil toxicity and climate change might express themselves through the food supply; and 4) knowledge of the forage prey base is critical for other apex predators, such as marine mammals and predatory fish (Pitcher 1980, 1981; Lowry et al. 1989), as well as for any larger effort to manage the marine resources of Prince William Sound and the Gulf of Alaska in a sustainable manner.

We propose to study the distribution and abundance of prey species through acoustic sampling in relation to food, environmental conditions and possible competitors, then to examine the physical, behavioral and competitive factors that limit access to these forage species for seabirds. We will examine the reproductive consequences of such limitations for pigeon guillemots *(Cepphus columba)*, black-legged kittiwakes *(Rissa tridactyla)*, tufted puffins *(Fratercula cirrhata)*, common murres *(Uria aalge)*, and predatory fish. By examining the diet and reproductive consequences for a surface-feeder (kittiwake), a benthic diver (pigeon guillemot), and two pelagic divers (puffin and murre), we should be able to build up a picture of the forage base for the entire seabird community, setting the stage for a long-term, low-cost monitoring program. The study will make between-year comparisons within sites and within-year comparisons between sites in Prince William Sound and Lower Cook Inlet that have different food availability regimes. The comparisons between years will allow us to assess the degree of variability of different food regimes, while the between-site comparisons will allow us to assess the responses of seabird communities to these same regimes.

In addition, we will be using models to begin to relate oceanographic and spatial features of Prince William Sound and the Gulf of Alaska to changes in seabird diet and population trends. Models to be used include carbon-balance, patch-foraging, source-sink, and metapopulation.

NEED FOR THE PROJECT

A. Statement of Problem

Numerous seabird species have declined between surveys in the 1970's and the 1990's in Prince William Sound: cormorants (*Phalacrocorax* spp.), kittiwake, glaucous-winged gull (*Larus glaucescens*), Arctic tern (*Sterna paradisaea*), Kittlitz's and marbled murrelets (*Brachyramphus brevirostris* and *B. marmoratus*), tufted and horned (*F. corniculata*) puffins, and pigeon guillemot (Agler et al. 1994 a, b; Klosiewski and Laing 1994). Colony trends for kittiwakes in Prince William Sound have been inconsistent with colonies decreasing in the southern portion and increasing in the north (Irons unpubl. data). The population of pigeon guillemots in PWS has decreased from about 15,000 in the 1970's to about 3,000 in 1993 (Isleib and Kessel 1973; Sanger and Cody 1993). Based on censuses taken around the Naked Island complex, pre-spill counts were roughly twice as high as post-spill counts (Oakley and Kuletz 1993). Pigeon guillemots are listed as "Not recovering" in the 1994 *Exxon Valdez* Oil Spill Restoration Plan.

Common murres were among the species most damaged by the oil spill (Piatt et al. 1990), but most of the oiled birds nested outside PWS. Murres were also listed as "Not recovering" in the 1994 *Exxon Valdez* Oil Spill Restoration Plan, but have been upgraded to "recovering" because their reproduction has appeared normal since 1993 (Roseneau et al. 1995, 1996).

The best evidence for a shift in trophic resources for seabirds within Prince William Sound comes from pigeon guillemots. No long-term diet data sets exist for other species or, like black-legged kittiwakes, diet exhibits great year to year variability. In 1994, sand lance (*Ammodytes hexapterus*) accounted for only about 1% of prey items fed to guillemot chicks at Jackpot Island and about 8% at Naked Island; in contrast, in 1979 the sand lance component at Naked Island was about 55% (Kuletz 1983; Oakley and Kuletz 1993). Gadids were much more prevalent in the diet of guillemot chicks on Naked Island in 1994 (ca. 30%) than they were in 1979-1981 (< 7%) (Kuletz 1983).

Pre-spill studies of pigeon guillemots breeding at Naked Island suggest that sand lance are preferred prey during chick-rearing (Kuletz 1983). Breeding pairs that specialized on sand lance tended to initiate nesting attempts earlier and produce chicks that grew faster and fledged at higher weights than did breeding pairs that preyed mostly upon blennies and sculpins, at least in years when sand lance were readily available. Consequently, the overall productivity of the guillemot population was higher when sand lance were available.

The decline in the prevalence of sand lance in the diet of guillemots breeding at Naked Island might be a key element in the failure of this species to recover from the oil spill. The schooling behavior of sand lance, coupled with their high lipid content relative to that of gadids and nearshore bottom fish, might make this species a particularly high-quality forage resource for PWS pigeon guillemots. This is consistent with the observation that other seabird species (e.g., puffins, murres, kittiwakes) experience enhanced reproductive success when sand lance are available (Pearson 1968; Harris and Hislop 1978; Vermeer 1979, 1980; Monaghan et al. 1993) .

Initial field work in 1995 showed that sand lance burrow into sandy beaches in Prince William Sound where oil is still present (Duffy, pers. observ.). Sand lance spawn in the late winter and spring in sandy intertidal beaches and sandflats and their larvae occur in the top layers of inshore waters (McGurk and Warburton 1992), so that direct physical damage to sand lance breeding may have occurred and may be continuing. In addition, some sand lance populations may be dependent on particular estuaries (McGurk and Warburton 1992), so that damage to fish populations would have had only localized or checkerboard effects on seabird populations.

Similar patterns of damage may have occurred for the inshore-spawning herring (*Clupea pallasi*) and capelin (*Mallotus villosus*), important prey for seabirds (Baird and Gould 1985), with persistent effects on seabirds.

Several other factors may be at work. The major shifts seen in the northern Gulf of Alaska and North Pacific (Springer 1993; Piatt and Anderson 1995) may have favored pollock (*Theragra chalcogramma*), also an important seabird food (Springer and Byrd 1989) which has become one of the most abundant forage fish species currently available to seabirds (Parks and Zenger 1979; Brodeur and Merati 1993; Haldorson unpubl. data). Pollock may be an important competitor or predator of other forage fish species and may have suppressed populations of these species. Similarly, other species pairs may overlap in diet, such as herring and sand lance (McGurk and Warburton 1992) or pink salmon (Oncorhynchus gorbuscha) and sand lance (Sturdevant 1995 and unpubl.), raising the possibility that reductions in the trophic role of one species may 'release' others from competition for food.

B. Rationale

Both scientific theory and common sense suggest that ecosystems change over time and that changes to one species or other component of the ecosystem may reverberate through the entire ecosystem (Pimm 1984; Wolfe and Kjerfve 1986). Such changes have occurred in the North Pacific and Gulf of Alaska (Hatch et al. 1993; Springer 1993; Piatt and Anderson 1995). Climate variations, fishing, or an oil spill may trigger changes that can take years to become apparent (Duffy 1993). Similarly, restoration efforts following the *Exxon Valdez* oil spill might increase injured species that are predators or competitors of other injured species, preventing recovery several years after the oil was removed as an immediate cause. By studying only the species level, we may miss such effects. An ecosystem approach, such as the APEX study of the upper-trophic level predators of Prince William Sound, is designed to look for such indirect links and to improve our understanding of the ecological context lacking from single-species work (Wheelwright 1994). In conjunction with the Sound Ecology Assessment Project and the Nearshore Vertebrate Predators Project, ecosystem projects funded by the

Exxon Valdez Oil Spill Trustee Council, APEX will give us a basic understanding of the ecological processes that may affect future changes in upper trophic levels that may in turn affect restoration efforts and also help us to determine when we have finally restored a sustainable and healthy Prince William Sound.

C. Summary of Major Hypotheses and Objectives

Our objectives are: (1) to understand the relationship between forage fish and seabird populations, (2) to understand what factors determine the relative abundance of forage species, and (3) to develop a long-term monitoring effort for Prince William Sound and the northern Gulf of Alaska. These objectives are expressed through a series of hypotheses.

General hypothesis:
A shift in the Prince William Sound marine trophic structure has prevented recovery of injured resources.

Working Hypotheses

1. The trophic structure of PWS has changed at the decadal scale.
2. Planktivory is the factor determining abundance of the preferred forage species of seabirds.
3. Forage fish species differ in their spatial responses to oceanographic processes.
4. Productivity and size of forage species change the energy potentially available for seabirds.
5. Forage fish characteristics and interactions among seabirds limit availability of seabird prey.
6. Seabird foraging group size and species composition reflect prey patch size.
7. Seabird diet composition and amount reflect changes in the relative abundance and distribution of forage fish at relevant scales around colonies.
8. Changes in seabird productivity reflect differences in forage fish abundance, as measured in adult seabird foraging trips, chick meal-size and chick provisioning-rates.
9. Seabird productivity is determined by differences in forage fish nutritional quality.
10. Seabird species within a community react predictably to different prey bases.
11. Continuing damage from oiling is restricting recovery of some forage fish species.

Further development into working hypotheses and tasks is presented in the appendices for each FY 96 subproject.

D. Completion Dates

In 1996 and 1997, APEX will undertake a further test of the major assumption that food is affecting or limiting recovery of several seabird species, through a comparison of four sites in Prince William Sound (Shoup Bay, Naked Island, Eleanor Island, and Jackpot Island) and three sites in Cook Inlet: (the Barren Islands, the Chisik Islands, and Kachemak Bay) to assess interannual variability. At the end of the period, we will have a minimal sample size of three to test for such variability between the seven sites. Variability between years or sites will allow APEX to test the hypotheses. We plan the same timeline for comparison of diet and reproductive measures for seabirds at the four different sites within Prince William Sound and within Cook Inlet.

For forage fish, we expect that three years of sampling (FY 95-97) through hydroacoustics will allow us to determine if trends in distribution and relative abundance of forage fish can be detected within the Sound, and if these can be linked to seabird foraging and reproductive parameters. We will then reduce sampling levels to those that appear to give the most information per unit effort. For example, we may find that sampling within five kilometers of a kittiwake colony provides as much information as sampling within 40 km, or that single inshore samples in June for guillemot food are as effective as repeated samples.

We plan to use three years of data on forage fish energetics, diet and reproduction (FY 95-97) to assess between-year variability and to explore whether these can be linked to trends in hydroacoustic data. There after, we may be able to reduce sampling to a few selected variables for testing schemes for long-term monitoring. During FY 96-98, we will also undertake detailed studies of inshore fish schools and their behavior in relation to oceanographic and biological features.

By FY 99, we expect to have a prototype bird and fish monitoring scheme that can be field tested during FY 99 and FY 2000 through calibration with ongoing projects. We then expect the monitoring to continue as a separate project, as a means of providing early warning of developing problems in Prince William Sound.

COMMUNITY INVOLVEMENT

Community involvement in this project will take several forms. In 1997, we plan to seek student interns from spill-area communities to participate in the island-based seabird projects. This will allow a direct interchange of information between researchers and the communities. Second, with the help of Martha Vlasoff, Spill Area-wide Coordinator for Project 96052, we will be requesting that the Village Facilitators and communities share their knowledge of past changes in distribution and abundance of seabirds and forage fish in the Sound, as well as their suggestions on why such changes have occurred. These may help us develop further hypotheses that can be tested during our field studies.

One article on the Project has appeared in the Trustee Council Newsletter, as has a radio piece on National Public Radio. APEX also produced an informational brochure which will be widely distributed. We are also working with the Council to do a further series of short pieces as part of the Council's efforts. Members also will participate in the International Symposium on the Role of Forage Fishes in Marine Ecosystems in Anchorage in 1996 and in the International Symposium on Changes in Pacific Seabirds in Asilomar, California in 1998. Several PIs participated in the Pacific

Seabird Group Oil spill seabird restoration workshop in Girdwood in September-October 1995 and will be helping to write up the summary text.

PROJECT DESIGN

This section refers to the overall project design and organization. Further details of specific projects may be found in the appendices.

A. Objectives

Each objective number also refers to the hypothesis of the same number above.

1. Summarize and interpret existing historical data on change in forage fish populations.
2. Determine whether differences in diet exist between forage fish species and determine the consequences at the individual and population level.
3. Determine the distribution of forage species in relation to oceanographic processes.
4. Productivity and size of forage species change the energy potentially available for seabirds.
5. Determine if forage fish characteristics (water depth, school density, prey size) and interactions among foraging seabirds (kleptoparasitism, aggression) determine access to prey or prey schools for different seabird species.
6. Determine if seabird foraging group size and species composition correlate with prey patch size.
7. a. Determine the degree of correlation between seabird diet composition and amount and the relative abundance and distribution of forage fish at relevant scales around colonies.
   b. Determine the "relevant scales".
8. Determine if forage fish abundance predicts adult seabird foraging trips, chick meal-size and chick provisioning-rates.
9. Determine if differences in forage fish nutritional quality predict seabird reproductive productivity.
10. Determine if seabird species within a community react predictably to the different prey bases identified in Objective 1.
11. Determine if sand lance from beaches with persistent oil show signs of damage.

B. Methods

It is important to note that the methods presented here are overviews, details can be found in the individual descriptions of projects in the appendices. Also, APEX planning is extremely dynamic and changes are likely to occur in response to oceanographic or other events such as storms, catastrophic predation at certain colonies, extreme shifts in prey distribution, or the results of the projects themselves. Planning for many of the projects is still evolving. The lead project with responsibility for coordinating data sharing is given in bold face.

List of Projects

Project	PI	Short Title
A.	Haldorson	Fish population sampling
B.	Ostrand	Seabird foraging
C.	Sturdevant	Fish diets
D.	--	*not active in 1996*
E	Irons/Suryan	Kittiwake foraging and reproduction
F.	Hayes	Guillemot foraging and reproduction
G.	Roby	Seabird reproduction and energetics
H.	--	*not active in 1996*
I.	Duffy	Project leader
J.	Roseneau	Barrens nesting study
K.	--	*not active in 1996*
L.	Piatt, Anderson & Blackburn	Historical analysis
M.	Piatt	Cook Inlet studies
N	Romano	Captive feeding
O.	McDonald	Statistical support
P.	Anderson	Sand lance oiling damage

Methods by Objective

1. *Summarize and interpret existing historical data on change in forage fish populations.*

   Initial work on archived data strongly suggests major changes in community structure and species abundance over the last several decades. **Project 96163L** will use existing trawl and net sample data from NMFS and ADF&G to test for changes in forage fish communities over the last three decades.

2. *Determine whether differences in diet exist between forage fish species and determine the consequences at the individual and population level.*

   Initial data from 1994 and 1995 show significant overlaps in diet between forage fish species, suggesting the potential for competition which may be reflected by reciprocal body condition between species with high diet overlaps sampled together. **Project 96163C** will examine diet differences, using fish samples provided by **96163A** which will also be examining the condition of fish caught.

3. *Determine the distribution of forage species in relation to oceanographic processes*

Work in 1994 and 1995 indicated strong diurnal and depth components to the behavior of different fish species. **Project 96163A** will use acoustic sampling, net surveys, and oceanographic sampling to determine whether certain fish species respond predictably to environmental conditions, such as depth, water temperature, distance offshore, or salinity. Inshore sampling will coordinate methods and logistics with the SEA and NVP projects.

4. *Productivity and size of forage species change the energy potentially available for seabirds*

The 1995 results suggest that body condition of fishes changes with size, species, and date. **Projects 96163A and G** will examine this, A, using fish caught by sampling and G, using fish caught by birds.

5. *Determine if forage fish characteristics (water depth, school density, prey size) and interactions among foraging seabirds (kleptoparasitism, aggression) determine access to prey or prey schools for different seabird species*

Field work in 1995 suggested depth of prey, distance offshore and presence of other species affect the species' composition of seabird foraging flocks. **Project 96163B** will examine foraging in relation to the data collected by Project 96163A for Objective 3 above.

6. *Determine if seabird foraging group size and species composition correlate with prey patch size.*

Initial results failed to show such a correlation in 1995, but **Project 96163B** will continue to examine foraging in relation to the data collected by Project 96163A for Objective 3 above.

7. *a. Determine the degree of correlation between seabird diet composition and amount and the relative abundance and distribution of forage fish at relevant scales around colonies .*

At a meso-scale level, three Cook Inlet colonies in 1995 showed a correlation between food availability and seabird reproductive and foraging performance. The efforts in 1996 will be a joint project involving fish distribution data from 96163A, foraging data from projects 96163B and M, and diet data at colonies from projects 96163E, F, G, J, M. Data will probably be examined within Cook Inlet and within PWS, as well as across all study sites. **Lead to be determined. Project 96163I** will examine whether spatial distribution of colonies supports the subhypothesis that colony size and distribution are determined by food limitation.

b. Determine the "relevant scales".

Spatial scales will be determined from shipboard transects (Projects 96163B and M) and radiotracking (Project 96163E) of seabirds and from repeated sampling of fish (96163A and M); temporal scales will be determined retrospectively from times over which diet and growth of seabirds (Projects 96163E, F, G, J, M) and distribution and abundance of fish (Projects 96163A and M) change. **Project 96163O.**

8. Determine if forage fish abundance predicts adult seabird foraging trips, chick meal-size and chick provisioning-rates

   This will be a joint project involving fish distribution data from 96163A, foraging data from projects 96163B and M, and diet data at colonies from projects 96163E, F, G, J, M. At a meso-scale level, three Cook Inlet colonies in 1995 showed a correlation between food availability and seabird reproductive and foraging performance. **Lead to be determined.**

9. *Determine if differences in forage fish nutritional quality predict seabird reproductive productivity.*

   The 1995 field data show significant differences in diet quality and growth of seabirds based on differences in forage fish taken. Data on fish provisioning rates, growth, and diet of wild birds from projects 96163E, F, J, and M will be provided to **Project 96163G** to test this. In addition, **Project 96163N** will use fish provided by 96163M to undertake captive rearing of kittiwakes and puffins as an independent test of the field results.

10. *Determine if seabird species within a community react predictably to the different prey bases identified in Objective 1.*

    This objective will be examined between three sites in Cook Inlet by Projects **96163M** and 96163J and between these sites and Prince William Sound by these projects and 96163E and 96163F. Within species, **Projects 96163E**, J, and M will examine kittiwake response, and **96163F** and M will compare pigeon guillemots, **Projects 96163J** and M will compare common murres. Data on fish distributions will be provided by projects 96163A and M.

11. *Determine if sand lance from beaches with persistent oil show signs of damage.*

    Addressing a new objective, **Project 96163P** will compare biochemical evidence of damage of sand lance from two beaches with persistent oiling from the *Exxon Valdez* spill and from two unoiled beaches.

In addition, **Project 96163O** will assist with design and analysis of all projects. **Project 96163I** will also provide financial support for an international symposium on forage fish ecology to be held in Anchorage and will begin planning for an international symposium on changes in Pacific seabirds, to be held at Asilomar, California in 1998.

APEX: Pelagic Forage Species in Prince William Sound

Project Number:	96163A
Restoration Category:	Research
Proposer:	Lewis Haldorson and Thomas Shirley, UAF
Lead Trustee Agency:	NOAA
Cooperating Agencies:	USFWS, NOAA
Duration:	4 years
Cost FY 96:	$380 K
Cost FY 97:	$400 K
Cost FY 98:	$400 K
Geographic Area:	Prince William Sound
Injured Resource:	Multiple

INTRODUCTION

Prince William Sound (PWS) is one of the largest areas of protected waters bordering the Gulf of Alaska (GOA). It, and the nearby open waters of the Gulf, provide a foraging area for large populations of apex predators including piscivorous seabirds and marine mammals. These surface-dependent predators were severely impacted by the *Exxon Valdez* oil spill (EVOS); and many—especially common murres, marbled murrelets, pigeon guillemots and harbor seals—suffered population declines that have not recovered to pre-EVOS levels. Piscivorous seabirds and marine mammals in PWS are near the apex of food webs based on pelagic production of small fishes and macroinvertebrates. Recovery of apex predator populations in PWS depends on restoration of important habitats and the availability of a suitable forage base. Since the 1970's there apparently has been a decline in populations of apex predators in the pelagic plankton production system, and it is not clear if failure to recover from EVOS-related reductions is due to long-term changes in forage species abundance or to EVOS effects. In this proposal we describe research that will provide quantitative descriptions of the forage community in PWS .

Forage species include planktivorous fishes and invertebrates. Planktivorous fish species that occur in PWS and are known or likely prey of apex predators include Pacific herring (*Clupea pallasi*), Pacific sand lance (*Ammodytes hexapterus*), walleye pollock (*Theragra chalcogramma*), capelin

(*Mallotus villosus*) and eulachon (*Thaleichthys pacificus*). Among these, Pacific herring are commercially valuable in PWS and have been studied extensively by Alaska Department of Fish and Game (ADF&G) to facilitate management. Data available for Pacific herring include population size, year-class abundance, and growth. Walleye pollock are commercially valuable in the western GOA and the Bering Sea; consequently there are considerable data describing populations and biology in those areas, but relatively little information on pollock in PWS. The other fish species are not commercially important in Alaska and have received little study, although some scattered information allows a preliminary assessment of their life-history features, distributions and food habits.

Pacific herring populations in PWS are monitored through egg surveys, with subsamples aged to estimate year-class abundances. Through the 1980's herring abundances were relatively high in PWS, with cyclical strong year classes. In 1993 and 1994 herring populations were reduced sharply, adults had relatively high incidences of lesions caused by viral hemorrhagic septicemia (VHS), and the mean size at age was abnormally low. Apparently herring populations in PWS have been seriously stressed in recent years. Although linkage to the EVOS is not clearly demonstrated, herring declines may be due to post-EVOS changes in the pelagic production system of PWS.

In the western GOA and Bering Sea juvenile walleye pollock are planktivorous, and are preyed upon by apex predators. In Shelikof Strait in April walleye pollock comprised about 99% of midwater planktivores (Brodeur and Merati 1993). In PWS walleye pollock are probably important forage species. In a bottom trawl survey of PWS, walleye pollock were the most abundant species (Parks and Zenger 1979). In our acoustic survey of PWS in July and August of 1995, YOY pollock were by far the most abundant small pelagic fishes in PWS. Juvenile walleye pollock are very important constituents of the diets of piscivorous seabirds (Springer and Byrd 1989; Divoky 1981) and marine mammals (Lowry et al. 1989; Pitcher 1980, 1981).

Pacific sand lance occur throughout the GOA, and are important forage species wherever they occur. They are planktivorous, feeding on euphausiids and copepods, with euphausiids more important in winter months (Craig 1987). Throughout their range, calanoid copepods have generally been reported as their principal prey (Simenstad and Manuwal 1979; Rogers et al. 1979; Cross et al. 1978; Craig 1987). Pacific sand lance have been reported as prey for a variety of marine seabirds including common murres (Drury et al. 1981; Springer et al. 1984), puffins (Wilson et al. 1984), auklets (Vermeer 1979; Wilson and Manuwal 1984) and murrelets (Sealy 1975). They are also eaten by many marine mammals including harbor seals (Pitcher 1980) and Steller sea lions (Pitcher 1981). There is little information on the abundance and distribution of sand lance in the PWS area, but they are probably an important intermediate link in the food webs that support apex predators.

Two smelt species, capelin and eulachon, are probably important forage species in PWS. In a bottom trawl survey conducted in April, eulachon were the fifth most abundant species collected overall, but was the dominant species in depths over 200 fm. (Parks and Zenger 1979). Those fish were ready to spawn and apparently were intercepted while migrating to their spawning grounds in rivers. Eulachon are important forage species throughout Alaska, and may be the most important forage fish in the southern Bering Sea (Warner and Shafford 1981). Capelin spawn on nearshore sandy substrates. In the northern Gulf of Alaska (Kodiak) they spawn in May and June (Warner and Shafford 1978; Pahlke 1985). They are prey of many piscivorous seabirds (Baird and Gould 1984) and marine mammals (Fiscus et al. 1964).

Macrozooplankton; including euphausiids, shrimp, mysids, amphipods; are a central component in the diets of herring, sand lance, capelin and pollock, as well as young salmon (Clausen 1983; Coyle and Paul 1992; Livingston et al. 1986; Straty 1972). When aggregated in sufficient densities, macrozooplankton are fed on directly by marine birds (Coyle et al. 1992, Hunt et al. 1981; Oji 1980). Swarming behavior by breeding euphausiids (Paul et al. 1990b) and physical factors (Coyle et al. 1992; Coyle and Cooney 1993) may concentrate macrozooplankton and micronekton into aggregations of density suitable for efficient foraging by predators. Unfortunately, there is little information on the abundance, distribution and fluctuations of these key invertebrates in the EVOS impact region. In the GOA zooplankton abundance has varied on a decadal time scale (Brodeur and Ware 1992); and, superimposed on longer cycles, are interannual fluctuations as high as 300% (Frost 1983; Coyle et al. 1990, 1992; Paul et al. 1990a, 1990b, 1991; Paul and Coyle 1993). Such variability in abundance may affect populations of apex predators in PWS.

OBJECTIVES

1. Provide an estimate of the distribution and abundance of forage species in three core areas of Prince William Sound, including inshore and offshore areas.

2. Describe the species composition of the forage base and size distributions of the most abundant forage species.

3. Gather basic oceanographic data describing conditions in the study area, and salinity, temperature, and sigma-t profiles of the water column and water depth at all sites of data collection.

4. Describe processes that affect the availability of forage species to predatory birds.

MILESTONES

1. August 1996 - complete 15-20 day acoustic/net sampling survey.

2. December 1996 - Complete laboratory analyses of forage species catch compositions and length distributions from 1995 survey sampling.

3. February 1997 - Complete analyses of CTD data collected in 1996.

4. March 1997 - Complete analyses of acoustic data set collected in 1996.

METHODS

Acoustic Assessments

A major goal of the forage fish project is the evaluation of the distribution and abundance of forage fish relative to bird distribution and physical features affecting fish distribution. The main tool for measuring the distribution and abundance of forage fishes is hydroacoustics. Bird data will be collected by observers from other sub-projects concurrently with acoustic data to determine the relationship between bird distribution and acoustically measured fish densities. An understanding of the relationship between forage fish species and seabird distributions requires data collection at a variety of spatial and temporal scales. Hydroacoustics can measure horizontal and vertical abundance and biomass at scales not possible by traditional net sampling techniques. Acoustics has been used to map fish (Thorne and Blackburn 1974; Thorne et al. 1977; Thorne 1977; Thorne et al. 1982; Mathisen et al. 1978) and plankton using a variety of deployment techniques (Green et al. 1988; Green and Wiebe 1988; Green et al. 1989; Green et al. 1991). Acoustics have been used to examine fine-scale biological patchiness (Nero et al. 1990), aggregated migration pathways of Atlantic Cod (Rose 1993), forage fish distributional characteristics in Chesapeake Bay (Brandt et al. 1992) and the spatial patterns of a variety of aquatic populations (Gerlotto 1993; Baussant et al. 1993; Simard et al. 1993). In Alaskan waters, acoustics have been used to measure biomass relative to tidally-generated frontal features (Coyle and Cooney 1993) and the relationship between Murre foraging, tidal currents and water masses in the southeast Bering Sea (Coyle et al. 1992).

Hydroacoustics will provide the sampling density required to assess the highly aggregated forage fish schools distributed over mesoscale dimensions and to document individual interactions between avian predators and prey at very small scales. The broad size range of individual targets from zooplankton to apex predators requires multifrequency sampling and an extremely high dynamic range. The surveys will consist of line transects through areas in Prince William Sound using a BioSonics DT4000 digital transducer system, including 120 and 420 kHz down-looking transducers to measure the vertical distribution of zooplankton and fish and a side-looking 420 kHz transducer to measure abundance of near-surface targets. Side-looking deployment will be especially important for the study of fish distribution and abundance relative to foraging of surface-feeding seabirds. Specifications of the DT4000 include high dynamic range, low noise, GPS input, school classification software, target strength measurement, high resolution chirp transmission and complete raw data storage. The system includes visual editing software for efficient data analysis. All three transducers will be single-beam for reasons outlined below.

Accurate calibration is critical for both relative and absolute measures of fish abundance. The systems used in this study will be calibrated with U.S. Naval standard hydrophones prior to and after field use. In addition, the calibration parameters will be routinely checked during cruises with standard target spheres developed at the Marine Laboratory, Aberdeen, Scotland, and optimized for each frequency. The calm conditions in Prince William Sound and diagnostic programs developed for the new generation of digital transducers will facilitate field calibration. The diagnostic programs evaluate the echoes from standard targets and compare them with the expected returns based on hydrophone calibrations stored in the digital transducer memory.

Target strength measurements are required to compute absolute abundance and estimate the size of the acoustic targets. However, absolute abundance is not as critical an objective as relative abundance with respect to seabird foraging and reproductive success. Real-time *in situ* target strength information is often not obtainable with schooling fishes because individual targets are difficult to resolve and measure. Nevertheless, we intend to make every effort to estimate absolute abundance as accurately as possible emphasizing accurate calibration since accurate calibration is critical to absolute population estimates. Biomass—target strength relationships for herring, pollock and other fish of interest have been developed during numerous surveys (Thorne 1977; Thorne et al. 1982; Thorne et al. 1983; Thorne 1983; Traynor, NMFS, Northwest and Alaska Fisheries Center, personal communication) and use of these data supplemented with *in situ* data should allow absolute abundance estimation with reasonable accuracy.

While target strength is critical for absolute biomass estimates, estimation of fish length from target strength data is of limited value for the following reasons: 1) Accurate in situ target strength measurements of schooled fishes is not usually possible. 2) The inherent variability in target strength—fish length measurements is so great that the results are of limited value even when such measurements are possible. The small variation in the size of forage fish is swamped by the high variability in the target strength estimate.

Three types of acoustic systems have been used for target strength measurements: split beam, dual beam and single beam. Several comparisons between split-beam and dual-beam capabilities have demonstrated that mean target strength estimates by the two systems are similar but split beam yields the highest precision. However, split beam is limited to lower frequencies and has inherently lower single target resolution, which can seriously bias the results (Barange and Soule 1994). Split-beam would therefore be least suitable for the forage fish study.

While dual-beam would provide a viable alternative for the forage fish objectives, Hedgepeth (1994) has shown that single-beam systems provide very similar measurement capabilities with less complexity. Because *in situ* measurement of fish size provides only a minimal contribution to the objectives of this study, we propose to use single-beam acoustic systems rather than the more complex dual-beam system.

Programs will be written in quick basic for ship board use and a programmer will be on hand to modify programs as required. Acoustic data analysis will be done on UNIX work stations. This should provide the speed and data storage capability necessary for analyses of large data sets generated by the DT4000. However, a 1 G hard drive is necessary to insure sufficient space for any PC computations which may be necessary and a tape interface is needed to store and retrieve the data. Data management will be done on an INGRES data management system. Programs for data recovery and analysis on the UNIX system will be written in FORTRAN. The use of a work station should insure easy comparison between SEA and Forage Fish data bases.

BioSonics Inc. Subcontract
We have chosen BioSonics for the following reasons:

1. The equipment deployed will have the highest resolution of the available systems. All processing electronics are housed in the transducers, thus eliminating noise in the tow cable, a major limitation in the resolution of other systems.

2. All of the raw data will be stored digitally and can be recovered at any precision desired, without the use of analog taping equipment. This capability will be essential to our program of data subsampling in evaluating various survey designs for future work.

3. The low noise of the system should permit detection of individual zooplankton.

4. Visual editing software permits rapid and efficient data editing.

5. BioSonics has provided acoustic equipment for the SEA project. The application of BioSonics equipment for the forage fish project will insure easy comparison of data sets between the two projects.

Net sampling for identification of acoustic targets
Hydroacoustic sampling will be the primary method used to quantify the abundance of forage species in Prince William Sound. However, net sampling will be needed to identify the species comprising the hydroacoustic signals and to provide biological samples for life history, condition and energetics studies of forage species. For offshore sampling we will use a research-scale (100 m^2 opening) version of a mid-water commercial trawl, and a 1 M2 Tucker trawl (NIO net). For nearshore sampling we will use a beach seine, cast nets, and a Kodiak pair trawl.

Invertebrates
Macroinvertebrates will be preserved shortly after collection, and sorted by species later. The difficulties of identifying invertebrates to species will preclude working them up in the field. For example, there are likely to be at least five species of euphausiids in PWS. We will fix and preserve macrozooplankton samples from nets and sort and measure them in the laboratory.

Fishes
Fish larger than about 50 mm will be identified in the field. We will sort samples to species, and measure all fish, unless net hauls contain large numbers of individuals of some species. In the case of large catches we will randomly subsample and measure 100-200 individuals of each species. Length stratified subsamples of all forage fish species will be frozen and returned to the laboratory for future life history and energetics studies.

We will provide those samples requested by NMFS for food habits studies, and additional samples for other agencies for stable isotope and lipid analyses. Those agencies for whom we collect fishes and invertebrates must provide us with:

a) written directions as to the number of each species they require, and directions for preserving them.

b) all preservatives and sample containers, including shipping containers.

c) arrangements for sample shipping, and payment of all shipping charges.

Oceanographic data

We will collect oceanographic data at all of our survey stations and sampling sites. At each transect and collection site we will use a Seabird SEACAT CTD to sample the water column from the surface to 200 m depth, or to within 5 m of the bottom at shallower stations. This instrument has an internal data logger, and will record conductivity, temperature and depth. From this data we will produce vertical profiles of salinity, temperature and sigma-T at all stations. The data will also be available as ASCII files for agency biologists and SEAS researchers. We will compare our data to the more extensive data set compiled by SEAS researchers to determine if the distributions of forage species we observe are related to oceanographic features such as frontal zones, convergences, pycnoclines or major currents.

Field Study Plans

We propose to conduct one research cruise in July/August 1996 when bird species are at an important stage of their reproductive activity. This survey will be a 15-20 day cruise beginning as soon as possible after 10 July. The survey will have two components—nearshore and offshore—and will sample three areas intensively (Figure 1): 1) North (Valdez Arm, Port Fidalgo, Port Gravina); 2) Central (Naked Island, northern Knight Island); 3) South (Knight Island Passage, Whale Bay). In each area, sampling will be conducted for 5-6 days. An initial survey will occur in the first 2-3 days, followed by process-oriented sampling for 2-3 days.

Offshore Sampling

We will conduct offshore acoustic sampling following procedures developed in the 1995 program. In each of the three areas a series of transects spaced at two nautical mile intervals (Figures 2-4) will be sampled acoustically from an offshore acoustic vessel. A mid-water trawl vessel will accompany the acoustic vessel, and will sample acoustic targets as directed acoustic vessel. The mid-water trawl vessel will also conduct all CTD sampling in the offshore survey area.

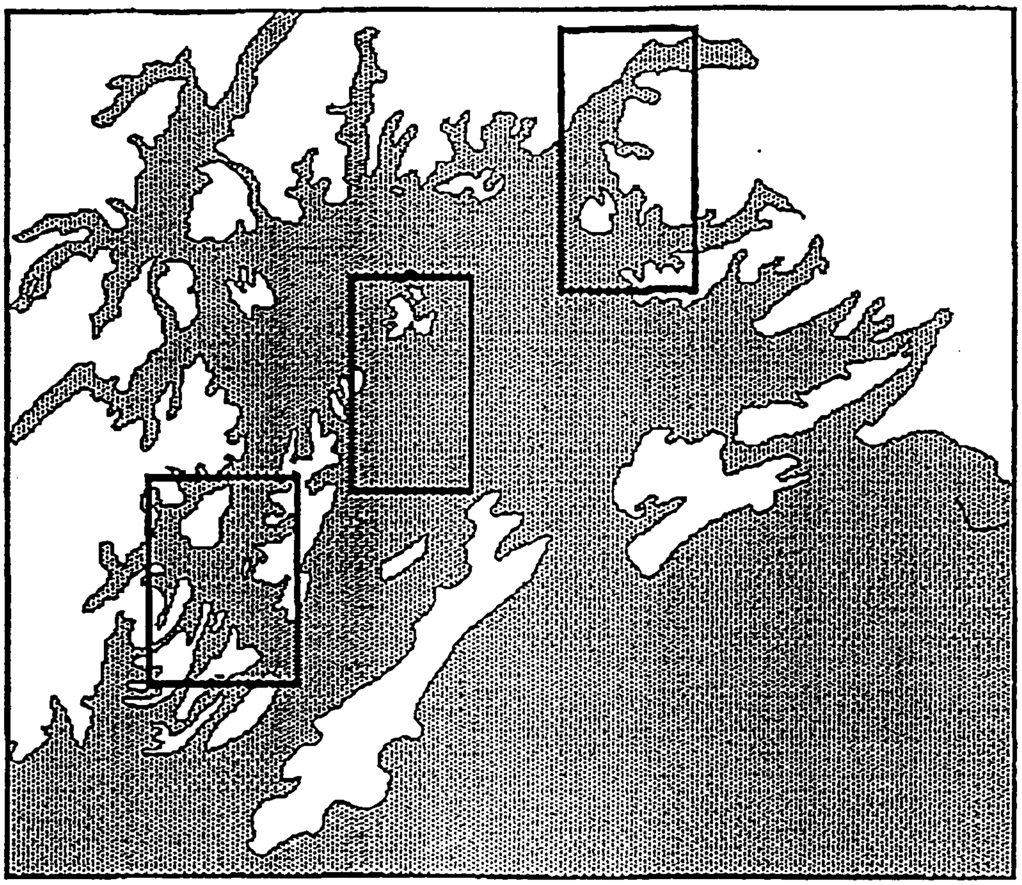
Nearshore sampling

Nearshore sampling will be conducted in coordination with the offshore sampling in each area. In each of the three areas, a series of 10-20 study sites will be pre-selected for detailed acoustic and net survey. Each study site will consist of a section of shoreline 4-10 km in length extending from the approximate mean low tide line out to 1 km. This section of shoreline will be surveyed acoustically by a series of transects roughly perpendicular shoreline and spaced at 0.5 km intervals. The acoustic transects will be conducted by an nearshore acoustic vessel, a seine vessel will accompany the acoustic vessel and will conduct net sampling to identify acoustic targets in the area.

Survey Coordination

Surveys will be planned cooperatively with biologists from USFWS, NMFS, and SEA project. At least two weeks prior to each survey, a cruise plan will be circulated to all participants, including all University project participants, agency biologists from USFWS and NMFS, and the SEA project, and the COTR. In planning for the two cruises, we will include provisions to house and feed one or two agency biologists. We will also provide work space and oceanographic information to the agency biologists who participate in the cruises.

Figure 1. Areas to be sampled hydroacoustically in the 1996 field season.



North, Central and Southern Study Areas in the APEX Sampling Program

Figure 2. Possible array of acoustic transects in the Naked Island/Eleanor Island area of intensive study. Spacing on transect lines is two nautical miles.

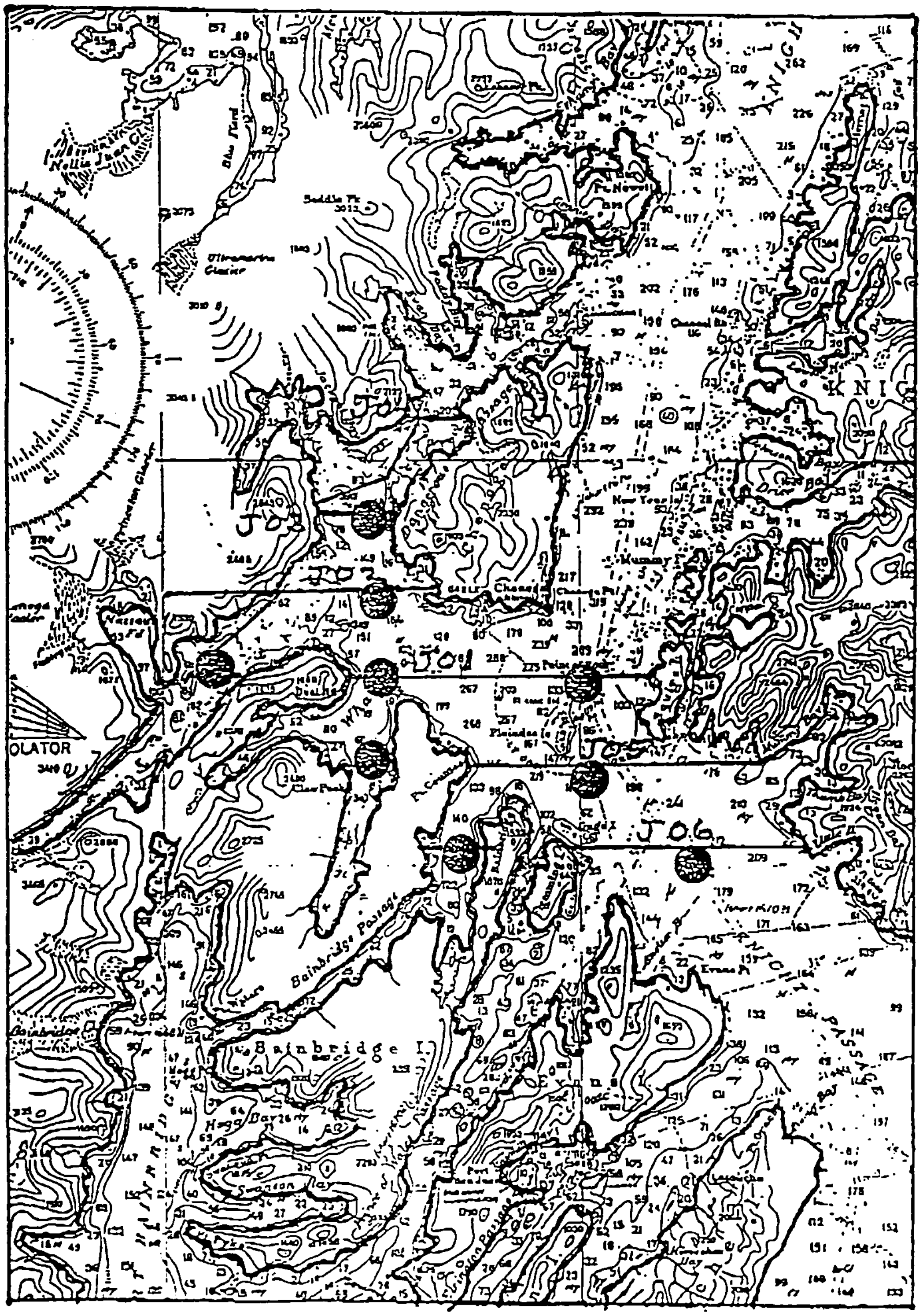


Figure 3. Possible array of acoustic transects in the Shoup Bay/Valdez Arm area of intensive study. Spacing on transect lines is two nautical miles.

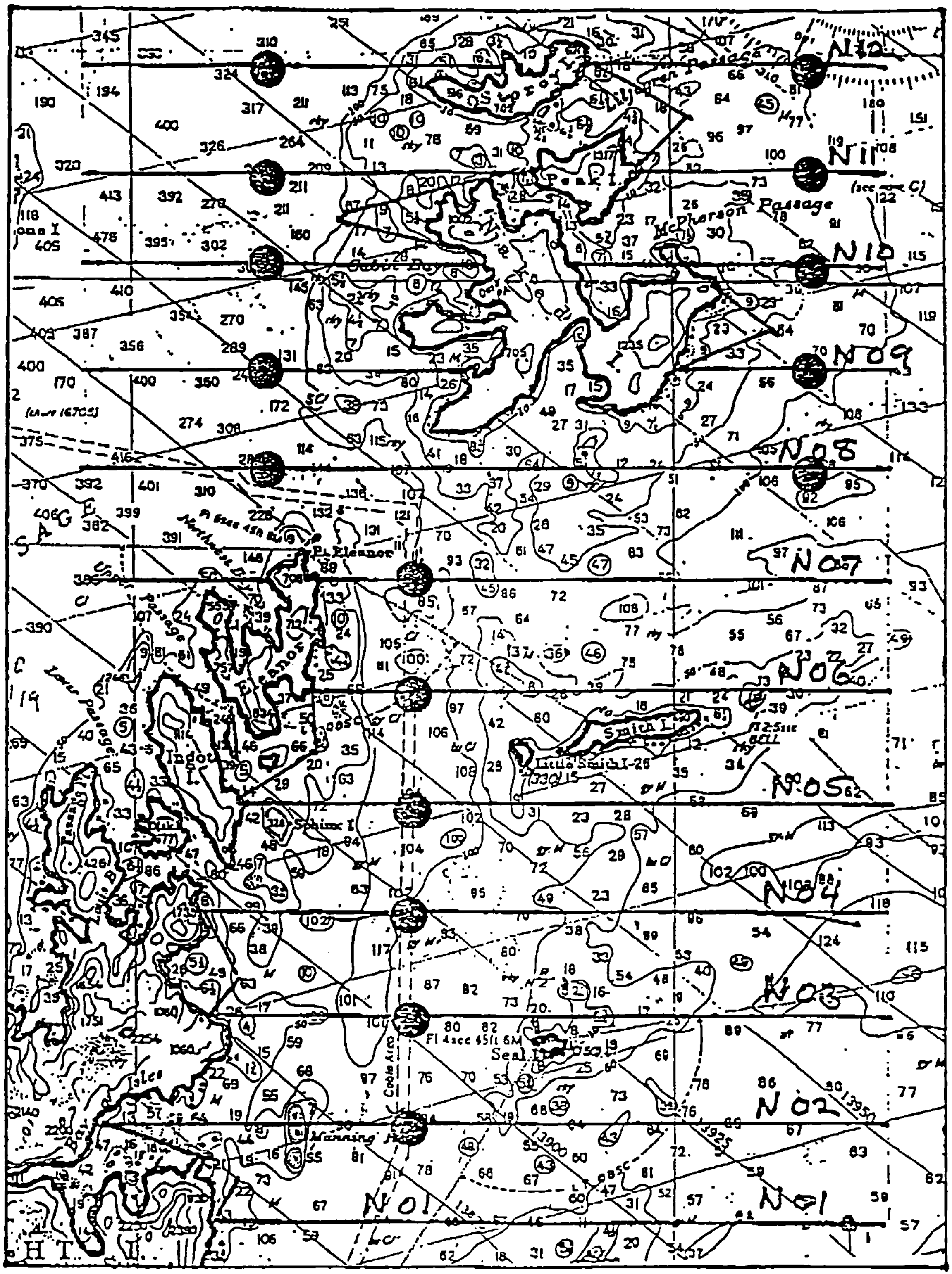
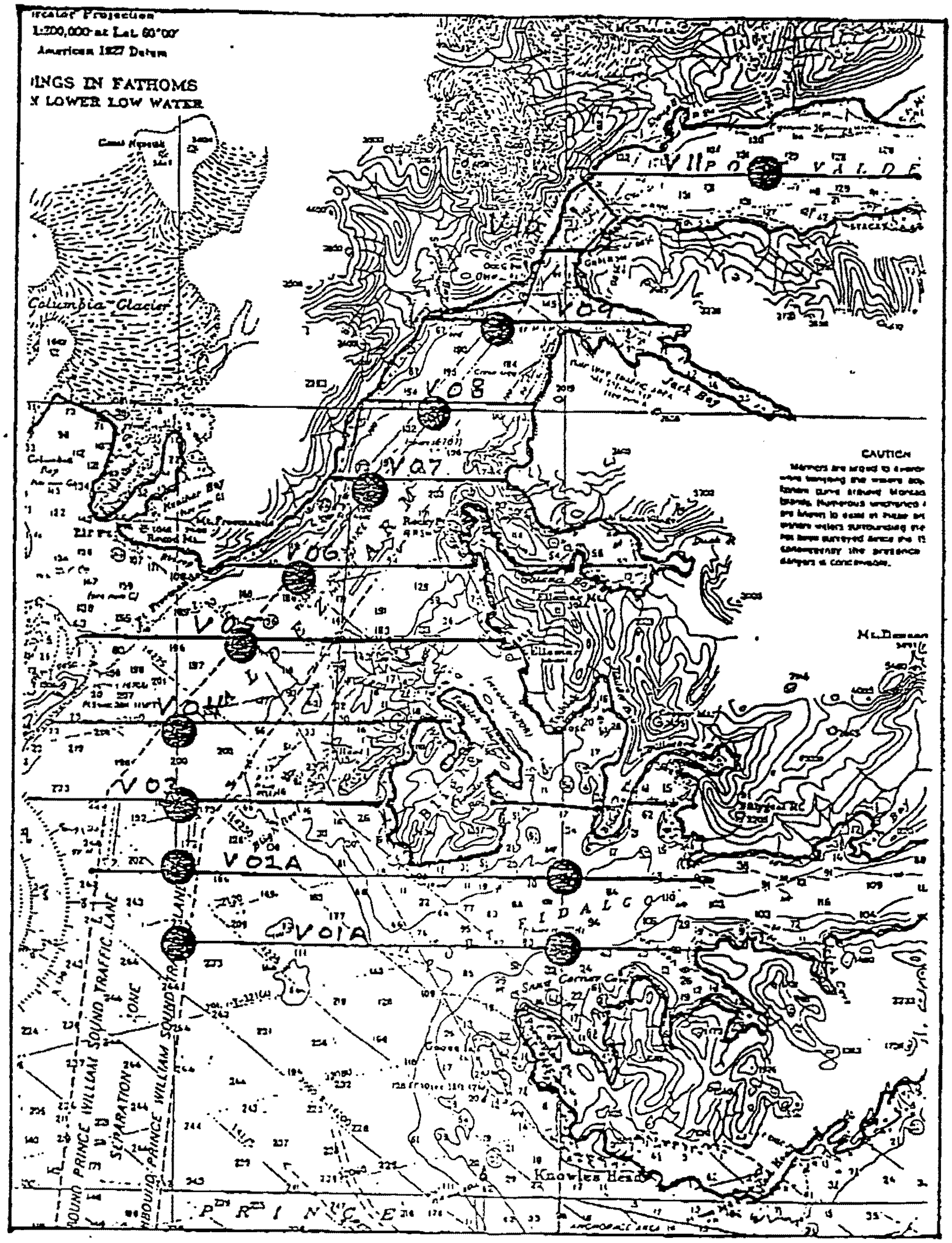


Figure 4. Possible array of acoustic transects in the Jackpot Island/Knight Island area. Spacing on transect lines is two nautical miles.



APEX: SEABIRD/FORAGE FISH INTERACTIONS

Project Number:	96163B
Restoration Category:	Research
Proposed By:	DOI
Duration:	5 years
Cost FY 96:	$132 K
Cost FY 97:	$138.8 K
Cost FY 98:	$145.8 K
Cost FY 99:	$70 K
Geographic Area:	Prince William Sound
Injured Resource:	Pacific Herring, Marbled Murrelet, Pigeon Guillemot.

ABSTRACT

The APEX project is investigating the general hypothesis that a shift in the marine trophic structure of Prince William Sound is preventing the recovery of piscivorous birds. This component contributes to that investigation by examining seabird foraging in relation to schooling forage fish. In 1995 we determined that most seabird species injured by the *Exxon Valdez* oil spill, did not forage on large schools of walleye pollock (*Theragra chalcogramma*), located in deep water, that make up the a large portion of the Sound's forage fish biomass. The exception was the Tufted Puffin (*Fratercula cirrhata*). Most seabirds foraged on schools in shallow water, near shore. Emphasis for 1996 and subsequent years, will be shifted to examining nearshore habitats. We will continue to examine foraging behavior and the relationship between seabirds and schooling forage fish in these habitats.

INTRODUCTION

This is an ongoing study which began with a pilot effort in 1994 to test field methods. In 1995, the study was expanded to look at seabird foraging in several habitats in three study sites within Prince William Sound.

During 1995 we sought to determine if forage fish characteristics and/or interactions among seabirds limited availability of prey. Our preliminary results indicated walleye pollock made up a large proportion of the forage fish biomass; however, few seabirds were associated with walleye pollock schools. Black-legged kittiwakes (*Rissa tridactyla*), marbled murrelets (*Brachyramphus marmoratus*), and pigeon guillemots (*Cepphus columba*) were observed over shallow water, near (<2 km) shore. Seabirds were observed foraging on schools of capelin (*Mallotus villosus*), sand lance (*Ammodytes hexapterus*), and juvenile herring (*Clupea pallasi*) located near the surface.

In 20 of 22 foraging flocks that we observed, black legged -kittiwakes and marbled murrelets were both present, suggesting a strong association between the species. These results indicated that marbled murrelets may serve as catalysts in the formation of foraging flocks, as observed by Mahon et al. (1992) in British Columbia. We suggest that murrelets force forage fish into tight schools and drive them to the surface where they become available to kittiwakes and other species.

We also examined intra- and interspecific aggression at foraging flocks. We found that kittiwakes lost 12% of their food catches to piracy. The rates of loss to intra- and interspecific piracy were both 6%.

NEED FOR THE PROJECT

A. Statement of Problem

The *Exxon Valdez* oil spill resulted in extensive mortality of seabirds and damage to other resources in Prince William Sound and the Gulf of Alaska (Piatt et al. 1990). Several of these resources had not recovered five years after the spill (Agler et al. 1990 a & b; Klosiewski and Laing 1994). The APEX project was initiated in 1994 to determine if a shift in the marine trophic structure has prevented the recovery of injured seabirds. Seabirds interact with the marine system principally through foraging; therefore, a study of the seabird/forage fish interactions and foraging behavior is a necessary component of the APEX project.

B. Rationale

A major objective of the *Exxon Valdez* Oil Spill Trustee Council (EVOS TC) is to secure the recovery of injured species. For each of the injured seabirds, a principle component of the restoration strategy is to "conduct research to find out why (the respective species) is not recovering" (EVOS TC 1994). APEX and this study play an essential role in gaining an understanding of why recovery is not occurring and identifying management activities that may aid recovery.

Our broad-scale studies from 1995 have allowed us to determine that the greatest portion of the forage fish biomass, walleye pollock, is not utilized by most seabirds. However questions remain concerning the dynamics of the association between seabirds and the forage fish that are utilized in shallow water, near shore.

We suggest that failure of the marbled murrelet population to recover following the *Exxon Valdez* oil spill (Agler et al. 1994 a, b; Klosiewski and Laing 1994) may have resulted in a secondary impact to black legged kittiwakes. We hypothesize that marbled murrelets function as catalyst for the formation of foraging flocks, making food resources available to kittiwakes. A depressed population of marbled murrelets could exacerbate food limitation for kittiwakes and other species. It is necessary to further investigate the role of marbled murrelets in initiating and maintaining foraging flocks to determine the extent they may be affecting foraging success of other species.

Duffy (1980) has suggested that if piracy is extensive, it may be a critical factor for nesting success. Our 1995 results indicate that piracy does occur, however it will take additional years of data to determine its effect.

C. Summary of Major Hypotheses and Objectives

The general hypothesis for this study is: forage fish characteristics and interactions among seabirds limit food availability. In 1996 we will investigate the following sub-hypotheses:

1. The formation of foraging flocks is correlated to tide cycle or time of day.

2. Interactions such as kleptoparasitism and aggression limit access to food within foraging flocks for less dominant individuals and species.

3. Marbled Murrelets initiate the formation of foraging flocks.

4. Seabirds select forage fish schools based on physical and biological characteristics of schools and the probability of a school being foraged upon can be determined through statistical modeling using empirical data.

D. Completion Date

31 December 1999.

COMMUNITY INVOLVEMENT

A community involvement and tradition knowledge program will be developed by the APEX project leader.

PROJECT DESIGN

The 1995 field season will be a continuation of on-going research. Based on preliminary results the focus of the study will shift to nearshore, shallow habitats. Techniques will be added to address new questions.

A. Objectives

In 1996 the Seabird/Forage Fish Interactions Study will focus sampling efforts in nearshore habitats. Data collection will be directed to addressing the following objectives:

1. Determine if the formation of foraging flocks is correlated to the tide cycle or time of day.

2. Determine if aggressive behavior among seabirds limit access to prey within foraging flocks.

3. Determine if marbled murrelets are the catalysts for the formation of foraging flocks.

4. Model the probability that a fish school will be foraged upon, through the development of a selection function.

5. Continue analysis of 1995 data and publish the results in peer-reviewed journals.

B. Methods

In 1996 we will collect data in association with the APEX forage fish study as well as the SEA herring studies. Sampling designs, field seasons, and observation platforms will be determined by these projects. Fish sampling techniques will continue to include hydroacoustics and the verification of acoustic targets by net sampling. Aerial surveys will be used to locate forage fish schools and foraging flocks. For descriptions, see the Forage Fish Assessment (96163A) and SEA's herring proposals.

Aerial surveys will greatly increase sample sizes of nearshore forage fish schools and foraging flocks. During flights we will record the location of each school, time of day, and if foraging birds are present.

We will conduct seabird and marine mammal surveys simultaneously with hydroacoustic surveys (hydroacoustic survey methods are described in proposal 95163A) employing techniques similar to those used to conduct population surveys in Prince William Sound (Klosiewski and Laing 1994). Seabird data will be collected at all times while during hydroacoustic sampling. All birds and mammals observed within 100 m of the starboard side of the vessel (that side which is scanned by side-viewing sonar) will be identified and recorded. Observers will calibrate their ability to estimate distances by viewing a duck decoy tied to the end of a fishing line twice weekly. Calibrations will be done for 100 and 300 meters. Bird observations will be made by scanning ahead of the ship with binoculars. Observations will be made before the ship's presence influences bird behavior. Data will be entered when the ship is closest to the point at which the birds were first observed. The perpendicular distance to each bird from the transect line will be estimated to the nearest meter and recorded.

Bird behavior will be recorded categorically as: (a) in the air, (b) on a floating object, © on the water, (d) following the boat, (e) foraging, or (f) potentially foraging. Foraging (e) is defined as actual observation of foraging behavior such as diving for food or holding food in the bill. Potentially foraging (f) is defined as >2 associated birds on the water or circling above. Data will be directly entered into a computer file. The data entry system will be programmed to record time and location of each observation. Locations will be recorded directly from the BioSonics geographical positioning system (GPS). Data will also be collected on all foraging flocks on either side of the vessel. Three foraging piscivorous seabirds will be used as the threshold number to define a flock. Data on estimated perpendicular distance to the flock, location, time of observation, and number of each species will be recorded using the computer program, *Birds*.

Additional data will be collected for all foraging flocks and the associated fish schools seen while conducting boat surveys. This will require diverting from the transect. After data have been obtained from foraging sites the transect will be resumed from the point of departure. For each sampled flock, conductivity, temperature and depth (CTD), hydroacoustic, GPS location, and behavioral data will be collected. The vessel will stop for the collection of behavioral data 150 m from the flock in order to minimize disturbance. Flocks will be assigned a classification based up criteria developed by Hoffman et al. (1981). These classifications are: 1) small short duration flocks over tightly clumped prey; 2) larger persistent flocks over more broadly dispersed prey; 3) flocks associated with sites where prey are concentrated by downwelling. Behavioral data will be collected for 15 minutes or until the flock breaks up. At persistent flocks, type 2, data will be recorded in 15 minute units. At large dispersed flocks, data will be collected for units of area to be determined at random. Data will be recorded by making auditory notes onto a cassette recorder and by video recording of behavior. Priorities for data collection are: 1) kleptoparasitic and piracy interactions with as much detail as possible; 2) foraging methods used by kittiwakes, including number of dives, time between dives, success of dives, inter- and intraspecific interactions; 3) foraging methods of other gulls, or alcids as per #1; 4) movements of the birds to and from the flock including the direction of birds carrying fish away. After behavioral data are collected the vessel will approach from a direction parallel to the transect with the flock 40 m off the starboard side of the ship (the side scanned by side-viewing sonar). A second pass will be made at a 90° angle to the previous pass, 25 m from the flock. Hydroacoustic equipment will record the chord length for both passes through the forage patch.

To determine if marbled murrelets initiate foraging flock formation and the influence of tides and time of day on flocks, we will conduct a separate survey. Using small, mobile boats, we will watch areas where forage flocks are known to occur and wait for their formation. As flocks begin to form data will be collected on the species that initiated the formation and the species that respond. An effort will be made to determine the distance at which birds become aware of the flock and alter their travel to join the flock. Position, state of tide, and time of day that the flock formed will be noted. We will determine forage species by observing what is taken by birds. We will observe type 1 flocks (Hoffman et al. 1981) for the duration of the flock's existence. It is not probable that the formation of a type 2 flock (Hoffman et al. 1981) will be observed; therefore, we do not plan to sample them. We will observe type 3 flocks (Hoffman et al. 1981) for the duration of the flock's existence or for one complete tide cycle, whichever is of shorter duration. In addition, behavioral data will be collected as described in the preceding paragraph.

Hydroacoustic data will be obtained from the Forage Fish Assessment component (96163A). These data will be aligned with the corresponding seabird data set, identifying schools which have seabirds associated with them. We will then generate addition data on distance to shore, depth of water, and distance to the nearest seabird colony for schools and birds by using of geographical information system software. The tide state will also be determined for each bird and school location. We will use these data to develop a selection function (Manly et al. 1993) to determine the probability that a school will have seabirds associated with it. Additionally, this procedure will determine the relative contribution of each variable included in the model.

C. Contracts and Other Agency Assistance

Safety training for the field crew, telephone services in the office and the field, film processing, postage and freight, publication charges, and maintenance and cleaning of cameras binoculars are services that will be contracted to the private sector.

D. Location

This study will continue to take place in Prince William Sound. Specific study sites will be determined at a APEX meeting this winter.

SCHEDULE

A. Measurable Project Tasks for FY 96

January-June 1996	Logistics planning; evaluation of 1995 data and manuscript writing; scheduling and coordination with other projects.
April 1996	APEX report due.
April-June 1996	Coordinate with SEA's herring study for data collection.
June-August 1996	Forage fish cruises.
August 1996-June 1997	Evaluation of field data and prepare manuscripts.
April 1997	APEX annual report due.

B. Project Milestones and Endpoints

June 1996	Submit manuscript on seabird foraging behavior for publication.
August 1996	Field work completed.
September 1996	Submit manuscript on seabird foraging patch selection based on resource selection function.
December 1996	Analysis of forage flock initiation data completed.
June 1997	Submit manuscript of characteristics fish schools associated with foraging flocks.

C. Project Reports

April 1996	APEX annual report due.
April 1997	APEX annual report due.
April 1998	APEX annual report due.
31 September 1999	APEX final report due.

COORDINATION OF INTEGRATED RESEARCH EFFORT

This study is an integral part of the APEX project and will provide key information to the synthesis report. This component will be developed in close association with the University of Alaska Fairbanks (96163A) and Lyman McDonald of Western EcoSystems Technology, Inc (96163O). Data collected will be used by the Forage Fish (96163A), Black-legged Kittiwakes (96163E), Pigeon Guillemots (96163F), Energetics (96163G), and Lower Cook Inlet (96163M) studies. Coordination will be made with the SEA project's herring studies (95320) for data collection.

ENVIRONMENTAL COMPLIANCE

No state or federal permits are required to conduct this study. The National Environmental Policy Act does not apply to this study.

APEX: Diet Overlap, Prey Selection, Diel Feeding Periodicity and Potential Food Competition Among Forage Fish Species

Project Number:	96163C
Restoration Category:	Research
Proposer:	Molly V. Sturdevant, NMFS
Lead Trustee Agency:	NOAA
Cooperating Agencies:	ADF&G; UAF, JCFOS
Duration:	4 years
Cost FY 96:	$76 K
Cost FY 97:	$80 K
Cost FY 98	$80 K
Geographic Area:	Prince William Sound
Injured Resource/Service:	Multiple

ABSTRACT

"Diet Overlap, Prey Selection, Diel Feeding Periodicity and Potential Food Competition Among Forage Fish Species," a component of the Alaska Predator Ecosystem Experiment (APEX), will continue to examine the feeding ecology of forage fish species in Prince William Sound (PWS). Work to examine trophic interactions among forage species began with an FY 94 pilot study, "Forage Fish Influence on Recovery of Injured Species: Forage Fish Diet Overlap" and the FY 95 APEX component, "Diet Overlap of Forage Species." Diet samples were collected opportunistically during field programs having other primary objectives. The 1996 study will increase the information available about trophic interactions among forage species through directed sampling. We will address the following objectives: 1) to assess the potential for prey resource competition between forage fish species pairs by testing for a difference in food habits and prey selection when fish occur in mixed schools compared to when they occur in monospecific schools; 2) to determine the principal feeding periods of each species and whether prey resources are partitioned among co-occurring species on a diel basis; 3) to describe diets of forage species recently recognized as important prey to some seabirds, such as demersal nearshore pricklebacks and daubed shanny; and 4) to improve sample collections of under represented, key forage species, particularly sand lance. These objectives will be addressed by modifying the 1996 field sampling program as follows:

1) actively target and direct sampling toward fish specific aggregations, in addition to sampling schools of fish opportunistically when encountered along survey transects; 2) collect diet samples systematically from fish aggregations over the 24-hour diel period; 3) expand the sampling area to include the nearshore region, as well as the offshore; 4) and sample with a variety of gear types in the nearshore region in addition to the midwater trawl used offshore. These objectives will be tightly linked to a study of the species composition, distribution and abundance of forage species in PWS (APEX 96163A).

INTRODUCTION

The APEX 1996 project will continue to examine how prey availability and condition affect the distribution, abundance, growth, and reproductive success of apex predators in PWS. Efforts to restore marine predators injured by the EVOS oil spill, particularly harbor seals, pigeon guillemots, marbled murrelets, and black-legged kittiwakes, could be enhanced through an understanding of the biology and population dynamics of their prey resources, forage fish. APEX focuses on the distribution, abundance and availability of forage fish consumed by piscivorous marine birds and mammals. These forage fish species may include pelagic species in the offshore region of PWS as well as demersal nearshore species. Potential prey in offshore assemblages include Pacific herring (*Clupea pallasi*), Pacific sand lance (*Ammodytes hexapterus*), capelin (*Mallotus villosus*), northern smoothtongue (*Leuroglossus schmidti*), eulachon (*Thaleichthys pacificus*), walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), tomcod (*Microgadus proximus*) and juvenile salmon (*Oncorhynchus* spp.); potential prey in nearshore assemblages may include these and other species, such as Pacific snake pricklebacks (*Lumpenus sagitta*) and daubed shanny (*L. maculatus*).

Factors controlling growth and survival of forage fish, such as their food habits and potential for competition, are not well understood. Information on the environmental variables and trophic interactions which determine the nutritional quality and relative availability of forage fish to apex predators is also sparse. The relative availability of high quality forage fish prey can influence the population dynamics of marine bird and mammals. An understanding of forage fish diets and trophic interactions can help to explain this variability.

Work to examine trophic interactions among forage species began with an FY 94 pilot study, "Forage Fish Influence on Recovery of Injured Species: Forage Fish Diet Overlap" (SEA 94163) and the FY 95 APEX component, "Diet Overlap of Forage Species" (APEX 95163). Both projects have contributed significant findings about forage fish trophic interactions. Substantial diet overlap among forage species pairs has been demonstrated (Willette et al. 1996; Sturdevant, 1996). Although prey composition changes seasonally, up to 60% similarity in prey biomass was observed among young-of-the year species pairs and within size classes of a single species in summer and fall. In spring, herring-pollock and juvenile pink-chum salmon pairs both had relatively high diet overlap, but partitioned available prey resources; copepods were the principal prey of herring and pollock, while fish larvae were the principal prey for salmon. Analyses of PWS forage fish diet studies are not complete, but some findings suggest that sand lance trophic interactions could impact several species. Collection of sand lance, particularly important in seabird diets, have been limited in PWS. Larval sand lance and herring in Port Moller shared a diet of various copepod life history stages (McGurk 1992). We found that pink salmon fry and sand lance collected together in spring also shared a diet consisting primarily of small copepods, similar to observations from studies in other areas (e.g., Sturdevant et al. 1995; Craig 1987). In one net haul, sand lance stomachs contained approximately four times the biomass of small copepods and 10 times the biomass of the pteropod, *Limacina*, as did pink salmon in spring. We have also noted that fine resolution identification of copepod prey species is important to assess forage fish trophic interactions. Both the surface swarming species, *Epilabidocera longipedata* (Johnson, 1934), and the diel vertical migrators, *Metridia ohkotensis* and *M. pacifica* (Hattori 1989), are consumed by herring and other forage species, indicating that trophic interactions could occur at several depths in the water column. Trophic interactions between forage species may occur over broad spatial and temporal scales.

While some information about trophic interactions among forage species has been gained from the above studies, the 1996 study will improve its quality through directed sampling. The 1996 forage fish diet component of APEX is designed to examine prey composition and selection, interspecific diet overlap, diel feeding periodicity and potential food competition among forage fish species in PWS. Information obtained from this study will contribute to understanding of the mechanisms affecting population and trophic dynamics of forage fish and their availability to apex predators. The diet overlap project is expected to require at least one additional year of sample collections (1997) and two years to complete processing of sample sets and reporting requirements.

NEED FOR THE PROJECT

A. Statement of the Problem

This food study is a sub-project of APEX (96163A-P), a multi-disciplinary project designed to understand the PWS food web and its effects on species injured by the *Exxon Valdez* Oil Spill (EVOS). The high sea bird mortalities associated with EVOS occurred during a period of decline in several sea bird populations (Piatt and Anderson 1996). While the environmental conditions which contributed to these declines have not been explained, damage assessment studies since the spill have associated continuing sea bird declines with the availability of forage fish prey. Reproductive failures were documented among black-legged kittiwakes from oiled areas (Irons 1996) and may be associated with food conditions. Greater declines of pigeon guillemots in oiled areas compared to non-oiled areas were associated with reduced deliveries of sand lance, a high-energy prey, to their chicks (Oakley and Kuletz 1993).

At the same time as the health of marine birds and mammals declined in PWS in the last few decades, unexplained, long-term shifts in the relative population abundances of prominent forage species, such as herring, pollock and sand lance, have occurred (Anderson et al. 1994). Enhancement facilities have simultaneously increased production of juvenile salmonids released into the sound. These population changes could be reflected in trophic interactions if the available food limits the carrying capacity of PWS. Incomplete knowledge of forage fish abundance and distribution, planktonic prey production and how prey resources are partitioned restricts efforts to estimate the carrying capacity of PWS (Cooney 1993). Partitioning of prey resources reflects the degree of habitat and diet overlap among forage species. For many forage fish species, particularly juvenile stages, food habits have not been completely described. This information is needed to characterize trophic niches, which must be determined before niche overlap can be examined and the potential for resource competition between species can be assessed. Understanding the interactions between forage fish species may help to explain changes in the food habits and reproductive biology of injured marine birds dependent on them.

B. Rationale

While the APEX project focuses on the summer nesting period of marine birds, a complete understanding of the influence of their forage species trophic niche must take into account the fish's entire life history and environment. Ideally, trophic studies should examine seasonal relationships over a broad area, include as many stages of the life history as possible, investigate diel feeding rhythms and behavior, and assess the dynamics of prey resources. These factors may contribute to an explanation of how co-occurring species partition resources and sustain healthy populations. Conversely, competition among species can be inferred from an observed shift in resource use, such as reduced absence from preferred habitat or failure to use a preferred prey resource (Sogard 1994); the shift is then reflected in some measure of health, such as poor condition or small size. Ultimately, survival may be affected and populations reduced. While a complete investigation of all of these factors is outside the scope of the APEX forage fish diet study, some aspects can be addressed in the 1996 field study.

Seasonal, ontogenetic, spatial or temporal partitioning of prey resources may occur among forage fish species inhabiting the same area. A species' preferred foraging habitat may change with changing hydrographic conditions and will reflect foraging behaviors that could also change ontogenetically. Species caught in the same area also may have foraged in different levels of the water column. This spatial segregation will be reflected by low dietary overlap. Niche overlap between age-1 herring and capelin, for example, was highest in the spring when both species foraged in the water column; after the water column stratified, herring switched to a surface-foraging mode in response to a newly available prey assemblage (Coyle and Paul 1992). Niche overlap between the two species then decreased as capelin continued to feed in the water column. Such trophic shifts also suggest that species which are not competitors during one season or life history stage may become competitors at another time.

Species sharing the same habitat may also partition resources on a temporal basis, for example by having different diurnal feeding rhythms. For example, juvenile herring are sometimes observed schooling in shallow water at the heads of bays (personal observation, APEX 1995). In these conditions, juvenile herring may compete with sand lance or demersal nearshore species for epibenthic or brackish water prey, or perhaps reduce dietary overlap by feeding at different tidal stages when the suite of available prey changes. Conversely, herring located in pelagic waters offshore may compete with juvenile pollock for planktonic copepod prey.

C. Summary of Major Hypotheses and Objectives

This study will address the potential for food competition between forage fish species and will continue to collect basic food habits information through stomach analysis. The 1996 objectives are: 1) to address the potential for prey resource competition between forage fish species pairs by testing for a difference in food habits and prey selection when fish occur in mixed schools compared to when they occur in monospecific schools; 2) to determine the principal feeding periods of each species and whether prey resources are partitioned among co-occurring species on a diel basis; 3) to describe diet overlap between forage species recently recognized as important prey to some seabirds, such as demersal nearshore pricklebacks and daubed shanny, which are consumed by pigeon guillemots; and 4) to improve sample collections of under represented, key forage species, particularly sand lance.

D. Completion Date

Fish stomach samples and epibenthic and planktonic prey samples collected during 1996 field season will be processed beginning in the late fall, 1996 and will be completed in 1997. Preliminary results will be reported in the 1997 annual report, but data analysis will not be completed before the 1998 annual report.

COMMUNITY INVOLVEMENT

Field work for the APEX project takes place in remote areas of Prince William Sound away from its communities. Unless residents can provide properly preserved forage fish samples for diet analyses from collections made during their traditional activities, or can volunteer on research vessels, the potential for community involvement in 96163C seems limited. However, residents may have traditional knowledge about areas or beaches where sand lance school, spawn or burrow. This information could be useful to APEX researchers in locating easily accessible index sites for collecting sand lance at regular intervals outside the field season. Residents might also assist by doing some of the collecting (e.g., digging up burrowed sand lance) for the project.

PROJECT DESIGN

The 1996 sampling program will continue research initiated under "Forage Fish Influence on Recovery of Injured Species: Forage Fish Diet Overlap" (SEA Project 94163) and "Diet Overlap of Forage Species" (APEX 95163). These studies were designed to examine diet overlap and prey selection among forage fish species. These two studies had different objectives and designs which influenced the extent of samples collected for diet analyses. The 1994 forage fish diet overlap study operated in conjunction with research on juvenile salmon and their predators. It examined diets of fish collected seasonally in three habitat types (shallow bay, moderate slope passage, steep slope passage) in southwestern PWS, but did not directly address other aspects of forage fish ecology. Samples of 12 species of forage fish were collected in three time periods (spring, early summer, late summer) at particular sites. In contrast, the APEX project focuses on forage fish and their trophic interactions with sea birds. It therefore operates under different spatial and temporal constraints than the original forage fish diet study. The APEX field season occurs during the birds' summer breeding periods (July-August). It was designed to estimate the abundance and distribution of forage species through hydroacoustic surveys along transects in three broad areas of the sound (North, Central and South). These areas were defined based on the their foraging distance from bird colonies. Birds were counted and their behavior in foraging flocks studied simultaneously with hydroacoustic surveys of fish. Fall, 1994 and summer and fall, 1995, samples of five forage species were collected by APEX. Stomach analysis of approximately 2500 samples from these two studies will be completed by summer, 1996. Results of the 1994 study will be summarized in a final report in 1996, while the 1996 annual report will contain partial results from the 1995 APEX diet study. Significantly more information will be gained in the 1996 study design through directed sampling on fish aggregations.

In future years, forage fish diet investigations may take advantage of samples collected by other projects with different sampling regimes and objectives than APEX. For example, forage fish samples collected opportunistically by SEA during the juvenile salmon growth study in 1995 could provide some diel feeding information (SEA 95320A). Although specific sites were sampled at regular intervals over the diel period, specific schools were not targeted. Data from these fish stomachs could supplement information about the diurnal feeding rhythms of forage species available through APEX. Future budgets could include money to process these archived samples.

A. Objectives

1. Assess the potential for prey resource competition between forage fish species pairs.

   This objective will be achieved by comparing food habits and prey selection of forage species which occur in mixed schools compared to when they occur in monospecific schools. A portion of sampling efforts will actively target appropriately identified fish aggregations in both the offshore and nearshore areas. Aggregations may be located in areas and at sites known from previous years' work or may be encountered opportunistically during hydroacoustic surveys. To assess available prey, plankton samples will be collected in offshore areas and both epibenthic and plankton samples will be collected in nearshore areas whenever diet samples are collected by net sampling. A shift in diet of species occurring in monospecific schools and mixed-species schools when similar prey are available will suggest that competition is occurring. A difference in condition could corroborate this finding.

2. Determine the principal feeding periods of forage species and whether prey resources are partitioned among co-occurring species on a diel basis.

This objective will be met by collecting diet samples systematically from specific fish aggregations over the 24-hour diel period. It will be tightly linked to objective 1, directed sampling.

3. Describe food habits and diet overlap of nearshore forage species.

   Demersal nearshore fish have recently been recognized as important prey to some seabirds. These include pricklebacks and daubed shanny, which are consumed by pigeon guillemots. This objective will be achieved by conducting nearshore surveys to assess forage fish abundance and distribution and collecting samples with a variety of nets (purse seine, beach seine, pair trawl, dip net) on detected aggregations (96163A, F).

4. Improve sample collections for diet analyses on under represented, key forage species.

   This objective will be achieved by sampling schools of fish opportunistically when encountered along survey transects and through directed sampling in both nearshore and offshore areas. Because sample sets from previous years collections contain gaps, the 1995 sampling program will continue to opportunistically collect information on basic diets and prey selection of forage fish species. Some species, particularly pollock and herring, have been relatively well-represented in past diet studies. However, relatively few sand lance, capelin, northern smoothtongue, and eulachon, among others, have been collected, particularly from mixed schools. Even if we are not able to adequately address the question of food competition for these species (objective 1), it is important that they be examined opportunistically because of their importance in seabird diets (e.g., Irons 1992; Hatch 1993). In addition to information with respect to competition, APEX can contribute valuable basic information on how food habits vary with life history stage, by season, and between geographic areas and years.

B. Methods

Sample Collection

The 1996 APEX field season will take place in cooperation with SEA juvenile herring studies during approximately two weeks in July. The offshore assessment of fish distribution, abundance and biomass via hydroacoustics will consist of a single 3-day survey along established APEX transects in each area of the sound (north, central, south). Midwater trawl net sampling will be conducted to ground truth school species composition. Nearshore surveys will also be conducted along newly established transects in each area. Schools detected hydroacoustically in the nearshore will be sampled primarily with purse and beach seines. Diet samples will be collected opportunistically during both offshore and nearshore transect operations. Also at this time, schools will be identified for subsequent directed sampling during two days of process-oriented studies, including investigations of feeding periodicity and comparisons of diets of fish in monospecific and mixed species schools (see objectives). Depending on time constraints, several schools will be sampled at four diel intervals (every six hours) in each area, both offshore and nearshore. Sympatric and allopatric aggregations of herring, pollock and sand lance species combinations will be targeted for trophic shift investigations.

Forage fish catch will be sorted, identified and enumerated, and size distribution data will be obtained on board the vessels. Where possible, at least 10 randomly selected specimens per species/age class combination will be collected for stomach analysis from each location sampled. Whole fish will be fixed in 10% saltwater-buffered formalin. The abdomens of fish 100 mm forklength (FL) will be slit to allow formalin to penetrate the body cavity and fix stomach contents. Specimens will be required for several APEX project components. If hauls do not contain enough specimens of key species, stomach samples will be removed and/or analyzed on board the vessel so that carcasses can be frozen for other purposes, or whole fish will be frozen and the stomach contents obtained in the laboratory later.

Prey resource samples (two replicates) will also be collected by APEX whenever diet samples are successfully collected. Zooplankton samples will be collected with a ring-net (0.5 m diameter, 243-micron mesh) towed vertically from 20 m depth to the surface. In the nearshore, epibenthic samples will be collected with an epibenthic sled also having 243-micron mesh cod end. The sled will be towed by hand in 1 m depths along a 10 m beach section adjacent to seine sites. All replicate samples will be preserved in 10% buffered formaldehyde solution in individual 500 ml sample bottles.

Laboratory Methods

Forage fish stomach samples and prey samples (zooplankton/epibenthic invertebrates) will be analyzed at the NMFS Auke Bay Laboratory. Laboratory protocols are the same as in 1994 and 1995 diet studies.

Fish Samples

Samples fixed in 10% buffered formaldehyde solution will be received in 250 ml, 500 ml or 4000 ml wide-mouth polyethylene bottles labeled by set number, date, time, latitude, longitude, geartype, species. An inventory and data summary detailing relevant sample collection information will be included with the samples. Fish stomach samples will be transferred to 50% isopropanol for preservation after fixation in formaldehyde solution for a minimum of six weeks, to allow shrinkage to stabilize. Stomach contents will be examined after fish samples have been in 50% isopropanol for a minimum of 10 days. Ten specimens per species/age class will be randomly selected for processing from each haul. The remainder of the fish in the sample bottle will be saved in 50% isopropanol in the original sample bottle. Whole fish will be blotted dry, weighed to the nearest 0.01 g and measured (standard fork length) to the nearest 0.5 mm. Fish showing evidence of regurgitation (gaping mouths and/or prey regurgitated into the fixative solution) will not be analyzed. Fish stomachs, including the region from the pharynx immediately behind the gills to the pylorus, will be excised from the body cavity. The foregut will be blotted dry and weighed full to an accuracy of 1.0 mg, the contents will be removed, and the empty stomach blotted and weighed again. Total stomach contents wet weight will be estimated by subtraction. Stomach fullness and prey digestion will be visually assessed and semiquantitative index values recorded. Relative fullness will be coded as: 1=empty, 2= trace, 3=25%, 4=50%, 5=75%, 6=100% full, and 7=distended. The fullness code provides an index of the amount of food consumed relative to the fish's stomach size. The state of digestion will be coded as: 0=fresh, 1=partially digested, 2=mostly digested, and 3=stomach empty. These codes provide indications of how recently the fish ate as well as general prey condition, which reflects the level of identification possible.

Prey items in the gut will be completely teased apart and identified to the lowest possible taxonomic level and enumerated. Prey identification efforts will concentrate on identifying copepods to examine prey selection by species, sex and life history stage and within large and small copepod size groups. Where possible, partially digested large copepods which cannot be completely identified will be distinguished as pristane-manufacturing species (*Neocalanus* spp., *Calanus* spp.) or non-pristane-manufacturing species (e.g., *Metridia* spp., *Epilabidocera longipedata*). After samples have been processed, gut contents will be placed in a labeled vial in 50% isopropanol.

Standard subsampling techniques will be employed when stomachs are so large and/or full that counting every prey item is not practical. The protocol for subsampling stomach contents was developed during 1994 sample processing and is patterned after general methods (Kask and Sibert 1976). We have compared total prey counts of important prey taxa to abundance estimates from various stomach subsampling methods and have developed a decision-making process. Stomach contents are initially scanned to determine the predominant prey categories present, the state of digestion of contents, and a rough estimate of total prey consumed. Consideration of stomach content qualities such as oiliness and 'mushiness' then allows a consistent choice of the most reliable and accurate method of subsampling for a given sample's condition.

Voucher specimens will be collected and maintained (preserved in 50% isopropanol) for each important taxonomic group. These will be used for reference and training purposes and possibly to obtain weights of prey categories for which literature values are unavailable or inappropriate. Individual prey codes and the number counted or estimated by subsampling will be recorded for each fish specimen.

Prey Resources

The composition of available prey resources will be estimated from laboratory analyses of ring net and epibenthic sled samples. A Hensen-stempel pipette and Folsom plankton splitter will be used to collect at least two random subsamples (1, 5, or 10 ml capacity) from each sample bottle after appropriate dilution. Samples will be diluted to achieve a minimum total count of 500 animals or 200 of the dominant taxon. Zooplankton and epibenthic invertebrates will be identified to the lowest practical taxon and enumerated in each subsample. Total biomass in each taxonomic group will be estimated by the product of average body blotted-dry weight and abundance. Literature values for average blotted-dry wet weight of each species or developmental stage will be used when available. When literature values are not available, mean blotted-dry wet weight will be determined by weighing a sample (n=50) of intact specimens. The composition of available prey will be described by pooling the data from epibenthic and zooplankton samples standardized to a 1 m^2 surface area.

C. Contracts and Other Agency Assistance

The major activities for this project include use of NOAA biological lab space and microscopes for sample analysis and storage, and computers for database management and statistical analysis. These activities will be integrated and supported by the normal operations of the Salmon Investigations Program at ABL. NOAA will contribute 3 months of salary for the Principal Investigator, beyond the 3 months funded by this study, for coordinating and managing the project. NOAA will also contribute one month of the Project Manager's and Program Manager's time. Fish and Game will provide three Fish and Wildlife Technician III positions for processing of stomach and prey samples. These personnel will be funded by EVOS and supervised by the APEX project manager and the PI at Auke Bay Lab.

D. Location

The field research for this project will take place in northern, central and southern PWS in offshore and nearshore areas. Samples will be analyzed at the National Marine Fisheries Service Auke Bay Laboratory in Juneau.

SCHEDULE

A. Measurable Project Tasks for FY 96

Start-up to Oct. 31:	Begin processing 1995 APEX diet samples collected in summer and fall
Nov. 1-Dec. 4:	Prepare oral-slide presentation summarizing 1995 diet sample results for APEX group "dry run" and scientific peer review committee
Dec.-Jan. 15:	Prepare summary poster for EVOS Annual Meeting poster session; Provide graphics and diet information for APEX summary presentation
Jan. 20-Mar. 8:	Prepare FY 96 proposal for APEX forage fish diet studies
Jan. 1-Mar. 15:	Complete annual report summarizing results from November, 1994 forage fish diet samples and APEX 1995 samples processed to date
Jan. 1-May 1:	Complete processing of 1994 Forage Fish Diet Overlap samples (project 94163); complete data entry and verification
Apr. 15-May 1:	Finalize data final report on project 94163
May 1-July 1:	As co-author, assist in analysis and write-up of 94163 final report

May 1-July 1:	Complete processing of 1995 APEX diet and plankton samples
May 1-July 1:	Purchase and prepare sampling supplies for the 1996 field season (project 96163)
July 10-July 25:	Participate in field season for APEX 1996 studies
Aug. 1, 1996-July 1997:	Process FY 96 diet samples
Nov. 13-Nov. 15:	International Symposium on the Role of Forage Fishes in Marine Ecosystems, Anchorage
Aug. 1-Dec. 31:	Analyze completed 1995 APEX diet samples; prepare summaries for EVOS Annual workshop
Jan. 1997:	Participation in EVOS Annual workshop
Apr. 15, 1997:	Deadline for 1996 Annual Report
July, 1997:	Complete processing of 1996 APEX diet and plankton samples

B. Project Milestones and Endpoints

Collecting detailed food habits data from fish is a slow, laborious process. Consistent results depend on the availability of adequately trained biological technicians who work as a team and remain on the project throughout its duration. Data are generally not completely available for several months after the samples are collected in a given field season; for extensive datasets, such as the 1994 Forage Fish Diet Overlap study, data may not be available for more than a year. When samples are complete, datasets from all projects and years will be synthesized to produce a complete picture of forage fish feeding ecology and trophic interactions. Milestones will be successful field seasons, completion of sample analyses and basic data summaries for annual reports and presentations. Endpoints will be publication of results.

C. Project Reports

Annual reports summarizing results of samples completed to date will be submitted by the April 15 annual deadline. Final reports will lag by at least a year. After the 1997 field season, the diet studies will require two years of funding to complete processing of samples, synthesize data, and prepare manuscripts containing interannual comparisons. Subsets of the data may be published as separate manuscripts. Data may be combined with other APEX projects (e.g., 96163A) for final manuscript publication.

For annual reports, forage fish diets will be summarized using three measures of prey composition. Diet composition will be expressed as proportion of total abundance, total prey biomass (wet weight) and frequency of occurrence of individual and pooled taxa. Prey resource composition will be expressed as a proportion of total abundance and total biomass. Prey biomass in each taxonomic group will be estimated as the product of prey abundance and average prey wet weight (blotted dry) obtained from the literature or direct measurements. Stomach fullness will be expressed as a proportion of fish body weight. These diet composition and prey resource measures will be the attributes used in further statistical analyses of food habits, diet overlap, prey selection, feeding rhythms and trophic shifts for final reports and publications. Factors in these analyses will include geographic area of the sound, habitat (nearshore-offshore), diel period, tidal stage, depth of samples, whether fish were collected with other species or not, and others.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

The APEX diet studies are highly integrated with other components of the APEX project, several components of the SEA project, the Nearshore Vertebrate Predator (NVP) study, and marine mammal projects. The juvenile herring study component of SEA will collect forage fish samples for APEX stomach analysis outside of the designated 2-week APEX field season. In addition to these supplemental samples, samples will be shared by multiple APEX components when the numbers collected are insufficient to provide each component with its required number of samples.

Trophic web information from the diet study will be used to establish the basic structure of future ecosystem models of PWS. These models will incorporate data on changing oceanographic regimes, primary and secondary productivity, fish distribution, fish diet overlap, prey selection and potential competitive interactions. They are necessary for understanding the recovery of predatory species and are useful in guiding recovery activities. Information from the APEX project in PWS and Cook Inlet geographic regions will also be integrated into the Ocean Carrying Capacity (OCC) program at Auke Bay Laboratory. This ecosystem study is entering its second year of surveys and sample collection in the Gulf of Alaska designed to assess trends in ocean productivity and their effects on salmonids. The OCC food habits studies of salmonids and non-salmonids, including forage fish, are being conducted under the direction of the APEX diet study PI.

ENVIRONMENTAL COMPLIANCE

The forage fish diet study is a laboratory-based project. Under the National Environmental Policy Act, no Environmental Impact Statement or Environmental Assessment is required.

APEX: KITTIWAKES AS INDICATORS OF CHANGE IN FORAGE FISH

Project Number:	96163E
Restoration Category:	Research
Proposed By:	DOI
Duration:	5 years
Cost FY 96:	$164.4 K
Cost FY 97:	$180 K
Cost FY 98:	$190 K
Cost FY 99:	$120 K
Geographic Area:	Prince William Sound
Injured Resource:	Piscivorous birds

ABSTRACT

Productivity and population size of black-legged kittiwakes are powerful indicators of forage fish availability. This subproject will use kittiwake activity budgets to estimate relative abundance of available forage fishes, kittiwake reproductive productivity to estimate relative abundance and quality of available forage fishes, and kittiwake diet to indicate relative composition of available forage fishes.

INTRODUCTION

Seabirds have long been recognized as potentially useful indicators of marine resources by many authors (Ashmole 1971; Boersma 1978; Crawford and Shelton 1978; Anderson and Gress 1984; Ricklefs et al. 1984; Cairns 1987; Croxall et al. 1988; Monaghan et al. 1989; Harris and Wanless 1990; Furness and Barrett 1991; Furness and Nettleship 1991; Hamer et al. 1991; Hunt et al. 1991). Availability of food resources affect foraging success, which in turn affects reproductive output. Several reproductive parameters have been proposed as useful indicators: breeding phenology, clutch size, breeding success, chick diets, chick growth rates, adult colony attendance, adult activity budgets, foraging trip duration, and adult mass (Cairns 1987, Croxall et al. 1988).

Although foraging behavior partially determines reproductive output, the nature of this relationship may be complex. Optimal foraging models predict precise behaviors that are assumed to maximize fitness (Schoener 1971, 1987; Pyke 1984, Stephens and Krebs 1986). In contrast to the idea of optimality, evidence indicates there is a range of foraging effort over which reproductive output is not affected (Costa and Gentry 1986; Burger and Piatt 1990; Irons 1992). For example, Cairns (1987) suggested that adult survivorship changes only when food is in very short supply, while activity budgets change only during medium and high levels of food availability. The phenomenon responsible for this uncoupling of foraging effort and reproductive output above threshold levels of food abundance has been termed a "buffer" (Cairns 1987; Burger and Piatt 1990). A buffer can be defined as the surplus capacity to forage. Buffers can be used to compensate for periods of low food availability so that reproductive output is maintained even though food is less available. Cairns (1987) also pointed out that activity budgets may be better than reproductive parameters as indicators of changes in food supply; the effects of food supply changes on reproductive output may be reduced by parents altering their foraging behavior to compensate for shortages. Burger and Piatt (1990) and Irons (1992) found evidence of this in common murres (*Uria aalge*) and black-legged kittiwakes (*Rissa tridactyla)*, respectively.

In addition to understanding how food shortages affect productivity of seabirds, it is important to understand how seabirds find their food in order to identify which processes break down during a food shortage. Many species of seabirds, including black-legged kittiwakes and marbled murrelets (*Brachyramphus marmoratus*), forage in flocks (Sealy 1973, Hoffman et al. 1981; Duffy 1983; Harrison et al. 1991) which apparently increases their foraging efficiency (Lack 1968; Morse 1970; Sealy 1973; Hoffman et al. 1981, Wittenburger and Hunt 1985; Gotmark et al. 1986, Harrison et al. 1991). The formation of seabird feeding flocks is enhanced by a form of information transfer termed "network foraging" (Wittenburger and Hunt 1985), which results in seabirds learning of and joining feeding flocks by observing the flight of other seabirds as they fly toward a feeding flock (Gould 1971; Sealy 1973; Hoffman et al. 1981). However, the importance of flock foraging has been questioned by Irons (1992), who found that much foraging by breeding kittiwakes occurred outside of foraging flocks.

Seabirds seek areas to feed where prey are concentrated by oceanographic features such as fronts, eddies, and upwellings (Murphy 1936; Ashmole 1971; Hunt and Schneider 1987), some of which are caused by current flow over underwater topographic features such as continental shelves, banks, and sills (Brown et al. 1979; Vermeer et al. 1987; Brown and Gaskin 1988; Cairns and Schneider 1990; Schneider et al. 1990a, b). In Prince William Sound, the irregular bathymetry and large tidal variation are likely to affect the distribution of forage fish and their availability to kittiwakes.

We propose to investigate the relationship between kittiwake foraging effort and reproductive parameters in different foraging environments and document the habitats and behaviors used by foraging kittiwakes. These results will aid in understanding the processes by which seabirds find food and how these processes are affected by changes in availability of forage fishes.

NEED FOR THE PROJECT

A. Statement of problem

Populations of marbled murrelets, pigeon guillemots, common murres, and black-legged kittiwakes decreased because of the oil spill and have not recovered. In Prince William Sound there is evidence that this lack of recovery is the result of a lack of food. We address the question, is food limiting the productivity of kittiwakes in Prince William Sound? Productivity of kittiwakes may be affected by prey in three ways: prey abundance may be inadequate, prey may be present but unavailable to birds, or prey may be of poor energetic value.

B. Rationale

By studying the reproductive performance and foraging behavior of black-legged kittiwakes, we can learn if they are food stressed, and if so, if it is because of lack of available food or lack of high quality food. Because kittiwakes are piscivorous like other impacted birds, it is likely that they would be affected by a lack of food in a similar manner as the other species. Kittiwakes are easier and less expensive to study than other impacted species, so that, by studying kittiwakes, we may identify the factors limiting the recovery of other species.

After it is determined how food is limiting, we can then begin to answer questions about why food is limiting and what, if anything, can be done about it.

C. Summary of Major Hypotheses and Objectives

1. Kittiwake activity budgets reflect relative abundance of available forage fishes.

2. Kittiwake productivity reflects the relative abundance and quality of available forage fishes.

3. Kittiwake diet reflects the relative composition of forage fishes.

4. Kittiwakes select foraging areas based on specific habitat characteristics.

D. Completion Date

The completion date coincides with the completion date of the APEX project.

COMMUNITY INVOLVEMENT

PROJECT DESIGN

A. Objectives

1. Determine relative amount and quality of food available to nesting kittiwakes by the following:

    a. Monitor reproductive parameters such as egg laying date, nesting success, clutch size, hatching success, brood size at hatching, growth rates, fledging success, brood size at fledging, adult attendance, and overall productivity.

    b. Monitor diets and foraging parameters such as foraging trip length, foraging trip distance, foraging areas, chick provisioning rates, and species and size of prey consumed.

    c. Monitor survival rates of adults.

2. Identify habitat characteristics of foraging areas used by kittiwakes (this objective will be done in cooperation with the APEX seabird foraging 96163B).

B. Methods

Egg-laying dates, clutch size, hatching success, fledging success and overall productivity data will be collected from the Shoup Bay and Eleanor Island colonies by setting up a series of representative plots throughout the colonies. Plots will be checked every three to five days throughout the nesting season. Clutch size will be recorded at 10 colonies in Prince William Sound (PWS) for which there are historical data. Hatching success and brood size at hatching will be recorded at four colonies in PWS: Shoup Bay, Eleanor Island, Naked Island and North Icy Bay. Overall productivity and brood size at fledging will be recorded for all 26 colonies in PWS.

Hatching success is calculated as the number of eggs hatched divided by the number of eggs laid. Fledging success is calculated as the number of chicks fledged divided by the number of chicks hatched. Overall productivity is calculated as the number of chicks in nests just before fledging divided by the number of nests built.

To determine growth rates, chicks of birds not used for radiotracking will be weighed to the nearest gram with 300 g and 500 g Pesola scales every five days from hatching to just before fledging. Chick growth rates of some radio-tagged birds will also be recorded to determine if they are different from chick growth rates of birds without radios. Chicks will be selected from accessible nests in several areas at Shoup Bay and all accessible chicks will be weighed at Eleanor Island. All accessible chicks will also be weighed at the North Icy Bay colony and the Naked Island colony. Growth rates will be calculated for the near-linear portion of the growth curve (i.e., 60–300 g) by dividing the weight gain by the number of days. For kittiwakes, this method yields results that are virtually identical to Ricklefs' (1967) maximum instantaneous growth rates (Galbraith 1983).

We will collect diet samples from adults at Shoup Bay, Eleanor Island, Naked Island and North Icy Bay colonies from July through August. Ten samples a week will be collected at Shoup Bay, five samples a week will be collected from Eleanor Island and five to ten samples will be collected once a month at Naked Island and North Icy Bay colonies. Diet samples will be taken from chicks by collecting food they regurgitate after we approach or handle them. We will take only one food sample from the chicks in a nest and we will sample each chick once during the nesting season if possible. All samples will be preserved in 70% ethyl alcohol for later analysis. Otoliths will be used to determine fish species and lengths (Messieh 1975; Springer et al. 1986). Fish ages will be determined from their lengths (pers. comm. E. Brown, Alaska Department of Fish and Game).

Data on foraging behavior and adult attendance will be obtained for radio-tagged birds. Breeding birds will be radio-tagged after capturing them at their nests with a noose-pole. Transmitters in 164–168 MHZ range will be attached to 30 adult birds at both Shoup Bay and Eleanor Island. The radio packages weigh about 11 grams, about 2.5% of a kittiwake's body mass and will be attached under the base of the tail (Anderson and Ricklefs 1987; Irons 1992). To aid in visual observations of the birds, each bird will be banded with a unique combination of color bands and the head, breast, and tail feathers will be dyed unique color combinations.

Data on the foraging trip length, trip distance and foraging area of radio-tagged birds will be collected by following individual birds with a 8m Boston Whaler during foraging trips. To select a bird to follow, we will wait near the colony until we detect a radio-tagged bird leaving the area; then we will follow it. We will follow only birds with chicks.

Following birds involves two people: a boat driver and an observer. We record the location and duration of flying, feeding, and resting behaviors for birds during entire foraging trips. Flying is recorded as either traveling or searching behavior; birds flying in one direction are considered traveling, and birds flying in circles or back and forth are considered searching. The number of feeding attempts is recorded for each bird; a feeding attempt is defined as a surface plunge or surface seize (Ashmole 1971). The number and locations of feeding sites are recorded using GPS, a bird is considered to be feeding in a different site if it moves more than one km between feeding attempts. Birds are considered to be resting when they are on the water and not feeding or when they are on land or flotsam. If we lose sight of a bird while following it, it will be recorded as lost.

Data on the foraging trip length and foraging areas of radio-tagged birds will also be collected by using remote receiving stations (RRSs). RRSs are composed of a 164 to 168 MHZ Advanced Telemetry Systems receiver connected to an Advanced Telemetry Systems data collection computer. The receiver and computer are powered by an 80 amp/hour lead-acid battery, which is charged by a three amp solar panel. The receiver and computer are housed in a waterproof, plastic "Pelican" case. The type of antenna used depends on the range desired; for the RRS set up at colonies a two element "H" antenna will be used, for all other locations a more powerful five-element Yagi antenna will be used. Antennae at all sites except the colonies will be attached to 10 meter extension poles; at the colony the RRS antenna will be mounted on a two meter pole. The RRSs monitor the frequency of each radio-tagged bird every 10 minutes. RRSs will be placed at the Shoup Bay and Eleanor Island colonies and at potential foraging areas to record the presence of radio-tagged birds. The ranges of the RRSs will be tested using a boat equipped with four radio transmitters attached to a kite and elevated 3, 15, and 30 meters above the water. The range boundaries of the RRSs will be approximate because of variation in the strength of the transmitters and the heights that birds fly.

Locations of feeding flocks and feeding behavior of radio-tagged birds will be recorded while following radio-tagged birds. A feeding flock will be defined as two or more surface-feeding birds feeding by surface plunging or surface seizing within 10 meters of each other (i.e., presumed to be feeding on the same school of fish) within one minute.

Chick provisioning rates will be obtained from chicks at Shoup Bay and Eleanor Island colonies. Data will be collected by observing chicks at 20 nests for several hours and recording each time a chick is fed by an adult.

Habitat characteristics of foraging areas will be collected while following birds on foraging trips. Data on distance from colony, distance from shore, number and species of foraging birds and mammals, number of foraging flocks, water depth, temperature, salinity, tidal stage, and current flow will be collected.

Adult survival rates will be determined from marked birds at Shoup Bay. Approximately 600 birds were individually colored banded in 1991. To determine survival rates, birds will be observed for a two to three week period in May until all birds are sighted. These data will be compared to data collected in 1994 to determine how many birds did not return to the colony.

Analyses

One-way ANOVAs will be used to compare all behavioral data and growth rates of chicks from four colonies (SAS 1988). Tukey multiple comparison tests will be used to determine significant differences between locations and years (SAS 1988). The chi-square 2x2 test for differences in probabilities (Zar 1984) will be used to compare clutch sizes, hatching success, fledging success, nest attendance, brood sizes, brood reduction, and overall productivity. Student's t-test (Zar 1984) will be used to compare growth rates of chicks that are reared by radio-tagged birds and chicks that are reared by birds without radios, and to compare chick-provisioning rates. Distances that birds fly, recorded while following the birds, will be measured using Atlas GIS. The maximum distance that radio-tagged birds fly to feed is defined as the distance from the colony to the farthest feeding site.

The total cumulative distance that a radio-tagged bird flies on a foraging trip is defined as the total length of its path during a trip. The pursuit and handling time will be combined with search time to analyze time budgets of radio-tagged birds because both are insignificant compared to time spent searching (Irons 1992). Frequency of occurrence of prey in the diet samples will be used to determine the relative importance of each species. Means are reported $\pm$ one standard error. Results will be considered significantly different at P=0.10.

C. Contracts and Other Agency Assistance

This project will require a contract for analysis of diet samples and safety training of field personnel.

D. Location

We propose to study of black-legged kittiwakes at 24 colonies in Prince William Sound, Alaska (61° 09' N, 146° 35' W). PWS is a 10,000 km^2 body of protected water located along the north coast of the Gulf of Alaska. Two colonies will be studied intensively, Shoup Bay and Eleanor Island. In 1993, the Shoup Bay colony was the largest in the Sound, with 4200 breeding pairs and Eleanor Island supported 190 breeding pairs. Both colonies have a sufficient number of accessible nests to permit obtaining both adults for radio-tagging and chicks for recording growth rates.

SCHEDULE

A. Measurable Project Tasks of FY 96

October 1995 - April 1996
- analyze 1995 data,
- prepare for and attend EVOS seabird restoration workshop,
- prepare for and attend annual EVOS review,
- prepare for and attend annual EVOS science workshop,
- prepare presentation and attend Pacific Seabird Group Conference,
- prepare 1996 detailed project description,
- prepare 1997 detailed project description,
- prepare 1995 annual report,
- prepare publications on pertinent results,

April - May 1996
- prepare for field season

May - August 1996
- field work

August 1996- March 1997
- analyze 1996 data,
- prepare for and attend EVOS sponsored Forage Fish Symposium

prepare for and attend annual EVOS review,
prepare for and attend annual EVOS science workshop,
prepare presentation and attend Pacific Seabird Group Conference,
prepare presentation and attend AAAS Conference
prepare 1998 detailed project description,
prepare publications on pertinent results,

March 1997
annual Report

B. Project Milestones and Endpoints

This component provides annual information on the relative availability of forage fish to birds. This information is needed for all years of the APEX project, therefore, the endpoint is the same as the APEX project.

C. Project Reports

Annual reports will be submitted by March 15 of each year. The final report will be submitted as part of the final report of the APEX project. Papers will be published as appropriate throughout the duration of the study.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

The coordination of this component is largely with other components of the APEX project, although we have been coordinating with Evelyn Brown, (SEA project 96320T) in respect to her data on the distribution, movements, and behavior of young herring in Prince William Sound. We have also coordinated with Mark Willette, of the SEA project, concerning the consumption of herring by birds. We have discussed collaborating with Ted Cooney on a publication combining his data on the river/lake phenomenon with our historical data on kittiwake productivity. We routinely share equipment and personnel with the Nearshore Vertebrate Predator Project, whenever it enhances the overall efficiency of EVOS projects.

The Fish and Wildlife Service, as part of its normal agency management of seabirds, has monitored the kittiwake colonies in PWS and has had an intensive monitoring site at Shoup Bay. The Service is donating all the data collected as part of its normal agency management to the EVOS-funded APEX project. In addition, the Service is collecting specific information requested by the APEX project (the Service is providing about $80 K worth of services and data). In the future, the role of the Service in the APEX project may diminish as funds are cut. The Service is experiencing unprecedented declines in funding and the trend may continue into the future.

ENVIRONMENTAL COMPLIANCE

No state or federal permits are required to conduct this study. The National Environmental Policy Act does not apply to this study.

APEX: CONSEQUENCES OF PREY DISTRIBUTION AND ABUNDANCE FOR PIGEON GUILLEMOTS

Project Number:	96163F
Restoration Category:	Research
Proposed By:	DOI
Duration:	5 years
Cost FY 96:	$148.3 K
Cost FY 97:	$170 K
Cost FY 98:	$180 K
Cost FY 99:	$120 K
Geographic Area:	Prince William Sound and Kachemak Bay
Injured Resource:	Pigeon Guillemot

ABSTRACT

This project will compare the diet and productivity of pigeon guillemots at two locations in Prince William Sound and one location in Kachemak Bay to determine if the abundance and distribution of schooling pelagic fish such as sand lance and herring limit the population size and productivity of pigeon guillemots.

INTRODUCTION

A great deal of attention has been given to the relationship between numbers of seabirds and the temporal and spatial aspects of their prey (e.g., foraging range of birds, predictability vs. patchiness of prey, abundance of prey during and outside the breeding season). Lack (1967) believed that populations of marine birds are regulated by density-dependent factors such as food supply outside the breeding season, while Ashmole (1963) argued that it is availability of food during the breeding season that is limiting, because at this time the adults feeding young are constrained to forage within a certain distance of their colony. Lack (1967) noted that pelagic feeders tend to nest in large colonies and inshore feeders, in smaller, less dense colonies. Likewise, Diamond (1978) showed that migrant species tended to be more numerous than resident species. Both related these observations to the relative sizes of the available foraging areas. Pelagic feeders would obviously have a larger foraging area than would inshore feeders; also, migration to an alternate feeding area during the nonbreeding season would be equivalent to using a larger area during the breeding season.

Birt et al. (1987) found evidence of prey depletion within the normal foraging depths of double-crested cormorants *(Phalacrocorax auritus)* around Prince Edward Island. Furness and Birkhead (1984) also tested the idea of prey depletion by considering the size of seabird colonies relative to their spatial distribution; they generally found a negative correlation between the size of a colony and the number of conspecific colonies within the foraging range of the species for northern gannets, shags, black-legged kittiwakes, and Atlantic puffins. The results of both studies provide support for Ashmole's hypothesis that seabird populations are limited by intraspecific competition for food during the breeding season.

Cairns (1989) proposed a hinterland model of population regulation of seabird colonies that was based on the idea that colony size is related to the amount of foraging habitat used by a colony. This model suggests that seabirds from neighboring colonies use non overlapping foraging zones and that the population of a colony is a function of the size of these zones. In her study of Galapagos penguins (*Spheniscus mendiculus*), Boersma (1976) found that chicks raised on an island grew faster than those on the nearby mainland and related this to the fact that adults nesting on a small island can forage over twice as much area as those along a coast.

Pigeon guillemots (*Cepphus columba*) forage in the nearshore environment within a few kilometers of the colony, feeding on both demersal and schooling fish. Differences in the diet of guillemot chicks probably reflect local differences in the availability or abundance of prey. Schooling fish such as sand lance (*Ammodytes hexapterus*), herring (*Clupea pallasi*), and capelin (*Mallotus villosus*) may be subject to temporal and spatial fluctuations in abundance. Nearshore demersal fish probably constitute a more predictable food source. At Naked Island the proportion of sand lance in the diet of guillemot chicks has declined dramatically since 1979, and gadids, which were generally not present in the diet before the *Exxon Valdez* oil spill, now make up a much larger component of the diet (Oakley and Kuletz 1994; Hayes 1995).

At numerous colonies around Naked Island, the number of breeding birds has decreased considerably since 1979. In the absence of schooling fish, guillemots must rely more heavily on demersal fish. Competition for these demersal fish over the limited shallow-water foraging area surrounding Naked Island may be preventing some adults from breeding or successfully raising their young. However, at Jackpot Island, where a large portion of the chick diet is schooling fish (herring and sand lance), the percent of breeding birds in the population appears to be much higher. Nest sites, not food, may be limiting the number of guillemots at this small island.

The post-spill decline in sand lance in the diet of guillemots breeding at Naked Island might be a key element in the failure of this species to recover from the oil spill. Pre-spill studies of pigeon guillemots breeding at Naked Island suggest that sand lance are a preferred prey during chick-rearing. In 1979–1981 some breeding guillemots at Naked Island specialized on sand lance; today there are no such specialists, probably because this resource is too scarce and patchy. Breeding pairs that specialized on sand lance tended to initiate nesting attempts earlier and produce chicks that grew faster and fledged at higher weights than did those of breeding pairs that preyed mostly upon blennies and sculpins in years when sand lance were readily available (Kuletz 1983). Consequently, the overall productivity of the guillemot population was higher when sand lance were available. The high lipid content of sand lance relative to that of gadids and nearshore demersal fish (D. Roby, personal communication), might make this species a particularly high-quality forage resource for PWS pigeon guillemots. This is consistent with the observation that other seabird species (e.g., puffins, murres, kittiwakes) experience enhanced reproductive success when sand lance are available (Pearson 1968; Harris and Hislop 1978; Hunt et al. 1980; Vermeer 1979, 1980). This component, in conjunction with the Seabird Energetics component of APEX (96163G), will help assess the relative importance of sand lance and other forage fish resources in maintaining productive colonies of guillemots in south central Alaska.

NEED FOR THE PROJECT

A. Statement of problem

The population of pigeon guillemots in Prince William Sound (PWS) has decreased from about 15,000 in the 1970's (Isleib and Kessel 1973) to about 5,000 in 1994 (Agler et al. 1994). There is some evidence (Oakley and Kuletz 1993) suggesting that this population was in decline before the *Exxon Valdez* oil spill in March of 1989. An estimated 2,000 to 3,000 pigeon guillemots were killed throughout the spill zone immediately after the spill (Piatt et al. 1990). Based on censuses taken around the Naked Island complex (Naked, Peak, Storey, Smith, and Little Smith Islands), pre-spill counts (ca. 2,000 guillemots) were roughly twice as high as post-spill counts (ca. 1,000 guillemots); also, relative declines in the numbers of guillemots were greater along oiled shorelines than along unoiled shorelines (Oakley and Kuletz 1994). The population has not recovered since the oil spill.

B. Rationale

Numerous baseline data on pigeon guillemot populations in PWS and their reproductive and foraging ecology have been collected both before and after the *Exxon Valdez* oil spill. Continuation of these efforts is essential for monitoring any trends in the PWS populations. There is a critical need for this information to understand the constraints that currently limit the recovery of pigeon guillemots populations affected by the oil spill.

PROJECT DESIGN

A. OBJECTIVES

To determine if a lack of schooling forage fish limits the population size and productivity of pigeon guillemots by testing the following hypotheses:

1. Guillemot colonies are larger in areas where forage fish are readily available to feed to their young than in areas where forage fish are less available.
2. Guillemots are limited by nesting habitat in areas where forage fish are readily available, but are limited by food in areas where forage fish are not available in large schools.
3. Productivity of individual pairs feeding primarily on forage fish is higher than that of pairs feeding primarily on demersal fish.

B. METHODS

Pigeon guillemots will be censused in early June (in the early morning at or around high tide) at the principal study sites. The Naked Island census will include other islands (Peak, Storey, Smith, and Little Smith) in the Naked Island Complex.

All accessible guillemot nests on Naked and Jackpot islands will be used for collecting growth rate and productivity data. Nests that are observable from blinds or boats will be used for determining provisioning rates and diet. All guillemot adults and chicks that are handled will be banded (one USFWS metal band and three color plastic bands). Any breeding adults that are handled will be marked with dyes or permanent markers to make these birds more visible on the foraging grounds.

Nest checks will be made at five-day intervals from just before hatching through fledging. Nest status will be determined and morphometric data acquired from all accessible chicks during each visit. Blood samples for biomarker analyses will be collected using standard protocols developed by Roby for the pigeon guillemot component of the Nearshore Vertebrate Predators Project. Blood samples will be taken from chicks on three successive visits, the first one from any given chick being taken when it is approximately 20 days of age. Blood samples and morphometrics will be obtained from all adults that are handled.

Throughout the nestling period, feeding observations will be made at selected nests or groups of nests during eight-hour observation periods beginning at 0600 or 1400. These observations will be made from strategically-located blinds or from boats anchored offshore. Opportunistic feeding observations will be made at other sites and at other times of the day, whenever possible. Observers will record the following information when known: type of fish to lowest possible taxon; size of fish to nearest one-half bill length; time of adult's arrival at and departure from the colony; time of delivery; and direction of adult's approach and departure.

Samples of chick meals will be obtained whenever they are found in or near the nests and by intercepting adults with mist nets in front of the nest entrances. These samples will be used for positive identification of fish types delivered to guillemot chicks and for analyses of energy content in Roby's lab. The weight and standard length will be obtained from each fish.

Foraging areas will be determined by following guillemots returning to forage after making a delivery at the colony. This can be done during the feeding observations by using VHF radio communications between observers in blinds and others in boats stationed offshore, or during dedicated watches specifically for this purpose. Observations of flight directions of guillemots (with and without fish) will be made from strategic locations around Naked Island (and possibly Peak and Storey) to locate and assess the importance of other foraging areas to the guillemots. Observations of guillemots on their foraging grounds will be made to look for any evidence of aggressive interactions or possible defense of "feeding territories," which would suggest competition for food.

Fish traps will be set and checked regularly at several locations, including those where guillemots are known to forage. Beach seine sets will be made regularly at the same locations used for fish traps. Samples of fish from each seine will be taken. The weight and standard length will be obtained from fish caught in the traps and the beach seine hauls.

In conjunction with S. Jewett of the Nearshore Vertebrate Project, we will obtain data on the abundance and distribution of benthic fish along portions of the shoreline of Naked Island and in the vicinity of Jackpot Island. This data will be collected by SCUBA divers along randomly selected transects.

In conjunction with E. Brown's work of spotting fish schools and plotting their locations, we will attempt to coordinate our efforts with hers. With advance notice of her schedule, and via radio communications between boat and plane, she may be able to tell us the locations of fish schools, which we can ground-truth for species composition.

Prototype nest boxes will be placed at various locations around the periphery of Jackpot and Naked islands before, or very early in, the breeding season.

C. CONTRACTS AND OTHER AGENCY ASSISTANCE

The transport of equipment, supplies, and fuel to and from the field camps will be contracted to a local business operating within PWS.

The energy content analyses will be done through Dr. Roby's lab.

D. LOCATION

The two primary study sites in PWS will be at Naked and Jackpot islands. Similar work will also be conducted at several guillemot colonies along the southern shore of Kachemak Bay.

SCHEDULE

January-May 1996	Planning and preparation for 1996 field season.
March 15 1996	Report of 1995 results to project leader.
June-August 1996	In the field.
September 1996	Clean & store boats & equipment, Begin data analysis.
September 1996-April 1997	Data analysis and report writing.
March 15 1997	Report of 1996 results to project leader.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

The Forage Fish Assessment component (96163A) will provide the Pigeon Guillemot component with data on the distribution, abundance, and species composition of schooling fish in the nearshore environment, while the Seabird/Forage Fish Interactions component (96163B) will provide pertinent data on the foraging behavior of guillemots in relation to these schools. The Pigeon Guillemot and APEX Seabird Energetics (96163G, D. Roby PI) components are closely tied; virtually all the data collected during each nest visit will be used by both projects. Dr. Roby is also one of the principal investigators of the pigeon guillemot component of the Nearshore Vertebrate Project, and in support of that project, we will collect blood samples from guillemots during our routine nest checks. All logistics for field camps at Naked, Eleanor (kittiwakes), and Jackpot islands will be coordinated (i.e., same barge for transport of equipment, supplies, and fuel) and all transport expenses shared.

APEX: Diet Composition, Reproductive Energetics, and Productivity of Seabirds in the EVOS Area (Submitted Under the BAA)

Project Number:	96163G (formerly 95118-BAA)
Restoration Category:	Research (continuing)
Proposed By:	Oregon State University (PI - Daniel D. Roby)
Lead Trustee Agency:	NOAA
Cost FY 96:	$160 K
Cost FY 97:	$168 K
Cost FY 98:	$176 K
Cost FY 99:	$70 K
Duration:	5 years
Geographic Area:	Prince William Sound (Naked Island, Jackpot Island, Shoup Bay, Eleanor Island) and Lower Cook Inlet (Kachemak Bay, Barren Islands)
Injured Resource/Service:	Multiple resources

ABSTRACT

Reproduction in seabirds is frequently limited by parents' ability to allocate energy to the breeding effort. This study is designed to examine potential energetic factors (diet composition, diet quality, provisioning rates) that constrain the productivity of seabirds in the EVOS area, with special emphasis on those species that are failing to recover to pre-spill population levels. The results will help identify those forage fish resources that limit seabird numbers and require enhancement for full recovery.

INTRODUCTION

Reproductive success in seabirds is largely dependent on foraging constraints experienced by breeding adults. Previous studies on the reproductive energetics of seabirds have indicated that productivity is energy-limited, particularly during brood-rearing (Roby 1991a). Also, the young of most seabird species accumulate substantial fat stores prior to fledging, an energy reserve that can be crucial for post-fledging survival in those species without post-fledging parental care (Perrins et al.

1973; but see Schreiber 1994). Data on foraging habitats, prey availability, and diet composition are critical for understanding the effects of changes in the distribution and abundance of forage fish resources on the productivity and dynamics of seabird populations.

The composition of forage fish is particularly relevant to reproductive success because it is the primary determinant of the energy density of meals delivered to nestlings. Parent seabirds that transport chick meals in their stomachs (e.g., kittiwakes) or in a specialized pouch (e.g., auklets) normally transport meals that are close to the maximum load. Seabirds that transport chick meals as single prey items held in the bill (e.g., guillemots, murres, murrelets) experience additional constraints on meal size if optimal-sized prey are not readily available. Consequently, seabird parents that provision their young with fish high in lipids are able to support faster growing chicks that fledge earlier and with larger fat reserves. This is because the energy density of lipid is approximately twice that of protein and carbohydrate. Also, forage fish are generally very low in carbohydrate, and metabolism of protein as an energy source requires the energetically expensive process of excreting the resultant nitrogenous waste. While breeding adults can afford to consume prey that are low quality (i.e., low-lipid) but abundant, reproductive success is largely dependent on provisioning young with high quality (i.e., high-lipid) food items. If prey of adequate quality to support normal nestling growth and development are not available, nestlings either starve in the nest or prolong the nestling period and fledge with low fat reserves.

Forage fish vary considerably in lipid content, lipid:protein ratio, energy density, and nutritional quality. Much of the energy content of prey consumed by seabirds is in the form of neutral lipids, especially triglycerides and wax esters, and wax esters in particular are known to be difficult to digest (Nevenzel 1970, Lee et al. 1972, Benson et al. 1972, Sargent 1976, Clarke 1984, In press). In some seabird prey, such as lanternfishes (Myctophidae) and eulachon (*Thaleichthys pacificus*), lipids may constitute over 50% of dry mass (A. R. Place, unpubl. data; J. Piatt, unpubl. data; S. Payne, unpubl. data); while in other prey, such as juvenile walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus macrocephalus*), lipids are frequently less than 5% of dry mass (J. Wejak, unpubl. data; J. Piatt, unpubl. data). This means that a given fresh mass of lanternfish or eulachon may have 3-4 times the energy content of the same mass of juvenile pollock or Pacific cod.). By increasing the proportion of high-lipid fish in chick diets, parents can increase the energy density of chick meals in order to compensate for the low frequency of chick feeding (Ricklefs 1984, Ricklefs et al. 1985).

Lipid content (% dry mass) of forage fishes collected in Prince William Sound and Lower Cook Inlet during the 1995 breeding season have recently been measured in my laboratory. Pacific herring (Clupeidae) had the highest average lipid content (30%), but values for 1+ age class fish varied over a wide range (5-48%). Average lipid content of sand lance (Ammodytidae) was lower (24%) and the range of values was not as great as in herring (11-32%). Younger age class sand lance generally were lower in lipids and adult males were lower than adult females. Average lipid content of capelin (Mallotus villosus) was lower than sand lance (13%), but the range was similar (3-24). The 1995 results also indicate that among these three species of forage fishes, lipid content can vary widely with location, season, sex, reproductive status, and age class.

NEED FOR THE PROJECT

A. Statement of Problem

Three seabird species that were damaged by the Exxon Valdez oil spill (EVOS) are failing to recover at an acceptable rate: pigeon guillemot (*Cepphus columba*), common murre (*Uria aalge*), and marbled murrelet (*Brachyramphus marmoratus*).

Damage from the spill to a fourth species of seabird, black-legged kittiwake (*Rissa tridactyla*), is equivocal, but recent reproductive failures of kittiwakes within the spill area may be due to longer term ecosystem perturbation related to the spill (D. Irons, pers. comm.). The status of pigeon guillemots and marbled murrelets in Prince William Sound (PWS) and the Northern Gulf of Alaska has been of concern for nearly a decade due to declines in numbers of adults observed on survey routes (Laing and Klosiewski 1993). All of these damaged or potentially damaged seabirds are piscivorous and rely to a greater or lesser extent on pelagic schooling fishes during the breeding season.

The failure of these seabirds to recover has been attributed to low reproductive success, but there is a troubling lack of information on the factors ultimately responsible for low productivity. One prevalent hypothesis is that changes in the abundance and species composition of forage fish resources within the spill area has resulted in reduced energy provisioning rates that are below the optimum for growing nestlings. Concurrent population declines in some marine mammals, particularly harbor seals, have also been blamed on food limitations. Seabirds, unlike marine mammals, offer the possibility of directly measuring diet composition and feeding rates, and their relation to productivity. Thus the piscivorous seabirds breeding in PWS present an opportunity to assess the relationship between the relative availability of various forage fishes and the productivity of apex predators. Whether these changes in forage fish availability are related to or have been exacerbated by EVOS is unknown.

This study is a component of the APEX Project (Project 96163A-P) and is relevant to EVOS Restoration Work because it is designed to develop a better understanding of how shifts in the diet of seabirds breeding in EVOS area affect reproductive success. By monitoring the composition and provisioning rates of seabird nestling diets, prey preferences can be assessed. Measuring provisioning rates is crucial because even very poor quality prey may constitute an acceptable diet if it can be supplied at a high rate. Understanding the diet composition, foraging niche, and energetic constraints on seabirds breeding within the spill area will be crucial for designing management initiatives to enhance productivity in species that are failing to recover from EVOS. If forage fish that are high in lipids are an essential resource for successful reproduction, then efforts can be focused on assessing stocks of preferred forage fish and the factors that impinge on the availability of these resources within foraging distance of breeding colonies in the EVOS area. As long as the significance of diet composition is not understood, it will be difficult to interpret shifts in the utilization of forage fishes and develop a management plan for effective recovery of damaged species.

B. Rationale

There is a definite need for information on the relationship between diet and reproductive success for pigeon guillemots, common murres, and marbled murrelets, all seabird species that are failing to recover from EVOS at an acceptable rate (1994 Exxon Valdez Oil Spill Restoration Plan). However, the latter two species pose serious problems for studies of diet composition in the spill area. For common murres it is difficult to collect quantitative data on diet composition, feeding rate, meal size, and chick growth rates without seriously reducing productivity because this species nests in dense colonies on narrow ledges where human activity can cause high losses of eggs and chicks. Murre chicks also leave the nest site to go to sea at only c. 21 days post-hatch, when they are only 20% of adult mass. Marbled murrelet nests are usually located high in mature conifers and are very difficult to locate. Most nest visits by parents provisioning young occur at night, so monitoring chick diets is highly problematic.

Guillemots are the most neritic members of the marine bird family Alcidae (i.e., murres, puffins, and auks), and like the other members of the family, capture prey during pursuit-dives. Pigeon guillemots are a well-suited species for monitoring forage fish availability for several reasons: (1) they are a common and widespread seabird species breeding in the EVOS area (Sowls et al. 1978); (2) they primarily forage within 5 km of the nest site (Drent 1965); (3) they raise their young almost entirely on fish; (4) they prey on a wide variety of fishes, including schooling forage fish (e.g., sand lance, herring, pollock) and subtidal/nearshore demersal fish (e.g., blennies, sculpins; Drent 1965; Kuletz 1983); and (5) the one- or two-chick broods are fed in the nest until the young reach adult body size. Guillemots carry whole fish in their bills to the nest-site crevice to feed their young. Thus individual prey items can be identified, weighed, measured, and collected for composition analyses. In addition, there is strong evidence of a major shift in diet composition of guillemot pairs breeding at Naked Island. Sand lance were the predominant prey fed to young in the late 1970s (Kuletz 1983), but currently sand lance is a minor component of the diet (D. L. Hayes, unpubl. data). In contrast, guillemots breeding in Kachemak Bay continue to provision their young predominately with sand lance, and sand lance is particularly prevalent in the diet at breeding aggregations (A. Prichard, unpubl. data). Jackpot Island in southwestern Prince William Sound supports the highest nesting densities of guillemots anywhere in the Sound. The high availability of juvenile herring to guillemots nesting at Jackpot Island is apparently responsible for this breeding aggregation. Thus availability of high quality schooling forage fishes (herring, sand lance) may be crucial for maintaining high nesting densities of guillemots.

Black-legged kittiwakes also breed abundantly in the spill area and rely largely on forage fish during reproduction. Unlike guillemots, kittiwakes are efficient fliers, forage at considerable distances from the nest, and capture prey at or near the surface. Although kittiwakes are highly colonial, cliff-nesting seabirds, they construct nests and can be readily studied at the breeding colony without causing substantial egg loss and chick mortality. Like guillemots, kittiwakes can raise one- or two-chick broods, and chicks remain in the nest until nearly adult size. Kittiwake breeding colonies at Shoup Bay, Eleanor Island, and Seal Island in PWS are easily accessible so that chicks can be weighed regularly without resorting to technical climbing. Kittiwake colonies at Gull Island, Chisik

Island, and the Barren Islands are not as accessible as the PWS colonies, but acquiring sufficient data on reproductive performance for comparison with PWS colonies is feasible. Diets fed to kittiwake chicks in PWS and Lower Cook Inlet consist primarily of high-quality schooling forage fish (i.e., sand lance, herring, capelin), although low-quality forage fishes (e.g., juvenile walleye pollock) are also taken.

The proposed research is the first focused study to investigate the bioenergetics of piscivorous seabirds in the EVOS area as it relates to productivity and trophic interactions. The research will result in a fundamental advance in our understanding of the significance of prey composition for seabird reproduction, as well as for marine mammals in the EVOS area. The research will also provide new information relevant to several additional areas of study: (1) comparative biochemical composition and physiological condition of forage fishes, (2) factors such as age class, sex, size, and reproductive status as they influence the nutritional quality of forage fishes, (3) responses of breeding seabirds to shifts in prey availability, and (4) the energetic consequences of foraging on different prey with differing energy content. This research will be the first to (1) measure the nutritional quality of various forage fishes used by breeding seabirds in the EVOS area, (2) use data on diet composition and provisioning rates to construct energetics models of chick growth and survival, and (3) monitor fat deposition rates of individual seabird chicks on differing dietary regimes by repeated, noninvasive analysis. In addition, the results will have broader implications for our understanding of dietary constraints on reproductive success in other piscivorous seabirds damaged by the spill (common murre, marbled murrelet) and will enhance our understanding of the adaptive significance of prey preferences in these seabirds. These results are crucial for understanding the factors constraining recovery of marine birds and mammals damaged by the spill.

C. Summary of Major Hypotheses and Objectives

The proposed research addresses two of the 10 major hypotheses of APEX:

8. Changes in seabird reproductive productivity reflect differences in forage fish abundance as measured in adult seabird foraging trips, chick-meal size and chick-provisioning rates.
9. Seabird reproductive productivity is determined by differences in forage fish nutritional quality.

These two hypotheses address the two primary factors responsible for energy provisioning rates to nestling seabirds, which in turn have a direct bearing on fitness through variation in reproductive output. Another variable, parental investment, is assumed to remain constant among breeding sites and years. This assumption may need to be tested in the future by measuring parental energy expenditure rates while provisioning young.

The overall objective of the proposed research is to determine the energy content and nutritional value of various forage fishes used by seabirds breeding in the EVOS area, and to relate differences in prey quality and availability to nestling growth performance and productivity of breeding adults.

The proposed research will emphasize pigeon guillemots and black-legged kittiwakes for practical reasons, but prey composition and quality will be evaluated for common murres and marbled murrelets as data and samples permit.

D. Completion Date

The anticipated completion of this project will be early in FY 2000, at the end of calendar year 1999. This will allow adequate time to complete data analysis and manuscript preparation following the last field season in 1998.

COMMUNITY INVOLVEMENT

The study species for the proposed research are not subject to subsistence use by local residents, so the traditional knowledge base on their reproductive ecology and population demography is limited. Nevertheless, every effort will be made to identify qualified local residents who can be hired as field assistants and technicians. Residents of Chenega have expressed an interest in participating in studies of river otters in the Jackpot Island area, and this may present an opportunity to inform local residents of research on guillemots at Jackpot Island and on kittiwakes at nearby Icy Bay. In addition, this component of APEX remains committed to taking advantage of whatever opportunities present themselves to inform local residents of our activities and the rationale behind our research.

PROJECT DESIGN

A. Objectives

1. To determine the nutritional quality of various forage fish species consumed by seabirds in the EVOS area as a function of size, sex, age class, and reproductive status, including:
   a) lipid content
   b) water content
   c) ash-free lean dry matter (protein) content
   d) energy density (kJ/g fresh mass)

2. To determine dietary parameters of nestling pigeon guillemots and black- legged kittiwakes (and other seabird species as conditions permit) breeding in the EVOS area, including:
   a) provisioning rate (meal size X delivery rate)
   b) taxonomic composition of diets
   c) biochemical composition of diets
   d) energy density of diets

3. To determine the relationship between diet and the growth, development, and survival of seabird nestlings. Variables measured will include:
    a) growth rates of total body mass and body size (wing length)
    b) fledgling body mass and fat reserves
    c) fledging age
    e) daily survival rates of nestlings from hatching to fledging

4. To use bioenergetics approaches to quantify the contribution of specific forage fish resources to the overall productivity of seabird breeding pairs and populations, as well as the level of prey exploitation by piscivorous seabirds in the EVOS area. Parameters to be measured include:
    a) relative contribution of each forage fish species to overall energy intake of nestlings
    b) gross foraging efficiency of parents
    c) conversion efficiency of food to biomass in chicks
    d) net production efficiency of the parent/offspring unit
    e) estimates of population-level requirements for forage fish resources during brood-rearing

B. Methods

The proposed research approach utilizes a combination of sample/data collection in the field (in conjunction with other APEX components in PWS) and laboratory analyses. Sample collection and field data collection will be conducted concurrently during the 1996-1998 breeding seasons at three sites where pigeon guillemots breed and at 4-6 kittiwake breeding colonies, all within the EVOS area. A minimum of 40 active and accessible nests of each species will be located and marked prior to hatching at each of the study colonies during the three breeding seasons. These nests will be closely-monitored until the young fledge or the nesting attempt fails.

Fresh samples of forage fishes used by guillemots will be collected for determination of species composition and proximate analysis using the following three techniques, in order of importance: (1) capturing adults carrying forage fish as they approach or enter the nest and retrieving samples from adults, (2) opportunistically collecting uneaten meal samples found in nest crevices, and (3) retrieving samples from chicks shortly after being fed by parents. Supplemental samples of guillemot forage fishes will be collected using beach seines and minnow traps deployed in guillemot foraging areas and by netting specimens at low tide during spring tide series.

Kittiwakes transport chick meals in the stomach and esophagus, so chick diet samples will consist of semi-digested food. Kittiwake meal samples are normally collected when chicks regurgitate during routine weighing and measuring. Additional diet samples will be collected by capturing adult kittiwakes as they return to feed their young and forcing them to regurgitate the contents of their esophagus. Fresh specimens of forage fishes used by kittiwakes will be provided from net sampling (APEX Component 96163A).

Fresh fish samples and kittiwake regurgitations will be weighed (ñ 0.1 g) in the field on battery-powered, top-loading balances, placed in whirl-pacs, and immediately frozen in small, propane-powered freezers that will be maintained at each of the study sites. Samples will be shipped frozen to Dr. Alan Springer's laboratory at the Institute of Marine Science, where they will be sorted, identified, sexed, aged, and measured in preparation for proximate analysis. Samples will then be shipped frozen to my laboratory at Oregon State University, proximate analyses will be conducted. Forage fish specimens will be dried to constant mass in a convection oven at 60oC to determine water content. Lipid content of a subsample of dried forage fish will be determined by solvent extraction using a soxhlet apparatus and hexane/IPA 7:2 (v:v) as the solvent system. Lean dry fish samples will then be ashed in a muffle furnace at 550oC in order to calculate ash-free lean dry mass by subtraction. Energy content of chick diets will be calculated from the composition (water, lipid, ash-free lean dry matter, and ash) of forage fish, along with published energy equivalents of these fractions (Roby 1991).

Chick provisioning rates for pigeon guillemots and black-legged kittiwakes in PWS and Lower Cook Inlet will be determined by monitoring active nests to determine meal delivery rates throughout the 24 h period. Average meal mass will be determined for guillemots by collecting individual prey items from adults as they arrive at the nest site to feed their young. Average meal mass for black-legged kittiwakes will be determined by weighing chicks at 2-hour intervals during watches to determine meal delivery rates. Average meal size, taxonomic and biochemical composition of the diet, and average energy density of chick meals will be determined as part of analyses of diet samples collected from guillemots and kittiwakes.

Active kittiwake nests will be checked daily or every other day during the hatching period in order to determine hatching date. Disturbance of active guillemot nests during the incubation period will be minimized because of the risk of nest abandonment. Consequently, hatching dates will not be known precisely and wing length will serve as a surrogate for age. In the case of two-chick kittiwake or guillemot broods, siblings will be marked as soon after hatching as possible so that individual growth rates can be monitored throughout the nestling period. Nestlings will be weighed and measured regularly (minimum of every five days) to determine individual growth rates throughout the nestling period. During the fledging period, nestlings will be weighed every other day in order to more precisely measure fledging mass and age. Body mass, wing length, culmen length, tarsus length, and primary feather length will be used to develop a condition index for each chick at 30 days post-hatch.

The relationship of diet composition to the physiological condition of breeding adults will be assessed by capturing breeding adult kittiwakes and guillemots during the chick-rearing period and calculating a condition index using body mass and morphometric measurements.

Data on nestling body mass, wing chord, and primary feather length will be separated by year and colony for each species, and fit to logistic growth models. Growth constants (K), inflection points (I), and asymptotes (A) of fitted curves will be statistically analyzed for significant differences among years and colonies. Gross foraging efficiency of adults will be calculated from daily energy expenditure by the following equation:

$$([M \,.\, F \,.\, D] + DEE) / DEE = GFE,$$

where M is average chick meal mass in grams, F is average frequency of meal delivery in meals day-1 parent-1, D is energy density of chick meals in kJ/gram, DEE is adult daily energy expenditure in kJ/day, and GFE is adult gross foraging efficiency in kJ consumed/kJ expended. Daily energy expenditures of guillemots and kittiwakes have been measured previously using the doubly-labeled water technique and are available in the published literature (Birt-Friesen et al. 1989), but it may be desirable to directly measure field metabolic rates of adults at study sites in PWS and Lower Cook Inlet to test the hypothesis that daily energy expenditure of adults feeding young varies among sites and years. Comparison of food conversion efficiency of chicks from different colonies fed different diets will provide an estimate of the relative energetic efficiency of diets composed of various forage fishes. The net production efficiency of the parent/offspring unit will be calculated for each diet and each year for both species using the equation:

$$CFCE / ([DEE \,.\, 2] + [M \,.\, F \,.\, D]) = TNPE,$$

where CFCE is chick food conversion efficiency in grams of body mass gained per gram food ingested, TNPE is the total net production efficiency of the parent/offspring unit in grams gained by chicks per kJ of energy expended by both parents, and other variables are as described above.

C. Contracts and Other Agency Assistance

Laboratory analyses of the biochemical composition and energy content of forage fishes will be conducted in the laboratory of the PI at Oregon State University. Some new laboratory equipment will need to be purchased for the proposed research with funds provided by the grant because not all equipment that was in the PI's laboratory at University of Alaska Fairbanks is currently available at OSU. A part-time laboratory technician will be hired to help the PI and graduate research assistant with performing of routine laboratory analyses.

Species identification, aging, sexing, and other preliminary analyses of forage fishes will be subcontracted to the Institute of Marine Science at the University of Alaska Fairbanks, where the expertise is available to perform this task.

D. Location

Field work will be focused in PWS (Naked, Jackpot, and Eleanor islands, and Shoup Bay) and Lower Cook Inlet (south shore of Kachemak Bay, Gull Island, Chisik Island, and the Barren Islands) during FY 96. The PWS study sites that were used in 1995 will again serve as study sites in 1996. These sites are identical to those seabird breeding sites that are being used by other components of APEX.

Field work on pigeon guillemots will be conducted at breeding colonies on Naked Island, Jackpot Island (both in PWS), and in Kachemak Bay. Approximately 500 guillemots nest along the shores of Naked Island (Sanger and Cody 1993). The Naked Island field camp in Cabin Bay is an excellent base for field studies on guillemots, and Naked Island supports a high proportion of the total breeding population of guillemots in PWS (Sanger and Cody 1993). In addition, Naked Island has been the site of long term studies of guillemot reproductive ecology since 1979 by the Fish and Wildlife Service (Kuletz 1983). Jackpot Island supports about 42 breeding pairs of guillemots nesting at the highest densities known in PWS (G. Sanger, D. L. Hayes, pers. comm.). Both Naked Island and Jackpot Island were the site of intensive studies of guillemot nesting success during the 1994 and 1995 field seasons and have been selected for continued studies (APEX Component 95163 F). Kachemak Bay will serve as a third study site for guillemots. The breeding population of guillemots on the south shore of Kachemak Bay between Mallard Bay and Seldovia has been the site of intensive studies by Alex Prichard, a UAF graduate student, of guillemot breeding biology and productivity for the last two years. Results to date indicate that the guillemot prey base in Kachemak Bay is largely sand lance, and is perhaps similar to the prey base at Naked Island 15-20 years ago. Consequently, the Kachemak Bay guillemot study site provides an excellent reference site for guillemot studies in PWS.

Field work on kittiwakes in PWS will be conducted at two breeding colonies, one at Shoup Bay (off Valdez Arm) which supports approximately 1600 breeding pairs of black-legged kittiwakes and another at Eleanor Island (adjacent to Naked Island) which supports about 200 breeding pairs. The Shoup Bay colony is the site of continuing long-term studies of kittiwake nesting ecology in PWS by the Fish and Wildlife Service and Eleanor Island has been selected as a site for intensive study for comparison purposes (APEX Component 96163E). Both colonies include adequate numbers of readily accessible nests. In Lower Cook Inlet, kittiwake breeding colonies at the Barren Islands (high productivity), Gull Island (moderate productivity), and Chisik Island (low productivity) will be monitored for diet and reproductive success.

SCHEDULE

A. Measurable Project Tasks for FY 96

Field work was conducted solely in Prince William Sound in 1995, and will be conducted in both PWS and Lower Cook Inlet during the 1996, 1997, and 1998 breeding seasons. Data collection during four field seasons will be necessary in order to provide minimal information on interannual variation in diet composition and reproductive success.

Guillemots and kittiwakes normally lay eggs from late May to late June and raise their young during July and the first half of August. Field crews will be set up at each of the study sites by mid-June. Active, accessible nests of the two study species will be located and marked during June and early July, prior to hatching. Samples of chick meals and measurements of chick feeding rates will be collected throughout the nestling period. Chicks will be monitored throughout the nestling period in order to determine growth rates, fledgling mass, fledging age, and survival until fledging.

Following the field season, chick meals will be analyzed in the lab in order to determine the taxonomic and biochemical composition of guillemot and kittiwake diets and their relationship to chick growth and survival. These analyses will be completed before the next field season in order to determine the results prior to collecting additional samples from the field.

Following the analysis of samples collected during the 1998 field season, data collected during the four field seasons will be analyzed for relationships between diet composition and reproductive success by May 1999. The results of these analyses of diet composition and its relation to productivity and chick growth will be prepared in manuscript form and submitted by the end of FY 99.

B. Project Milestones and Endpoints

Objective 1 will have been largely met by April 1997. Objectives 2 and 3 will not be achieved until April 1999, although results from any particular breeding season will be available by the following April. Objective 4 will not be achieved until the completion of this component of APEX in December 1999.

C. Project Reports

A draft annual report for this component of APEX will be submitted by 15 March for incorporation into a synthesis Annual Report for the APEX Project by 15 April. This schedule of annual report preparation will apply to 1996-98 field seasons. The final report for this component of APEX will be submitted 15 December 1999. The bulk of the final report will be excerpted from the doctoral dissertation of the Ph.D. student on this project. This student will be strongly encouraged and directly assisted by the PI to submit for publication in the peer-reviewed scientific literature portions of the results from this research as warranted.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

The research described in this proposal is a component of the APEX Project (96163A-P) and dove-tails nicely with new and continuing research to assess factors limiting recovery of seabird populations damaged by EVOS. It is also relevant to efforts toward developing seabird models as upper trophic level sentinels of changes in the availability of forage fishes, such as sand lance, juvenile pollock, herring, and capelin. The proposed research approach utilizes prey composition, reproduction rates, and energetics models to help identify and quantify the present level of forage fish availability within the PWS and Lower Cook Inlet ecosystems. This approach is necessary because evaluation of the stocks of various forage fishes is extremely complex due to temporal and spatial variability and unpredictability in the distribution of forage fishes in PWS.

Studies of foraging, reproduction, and population recovery following the EVOS are on-going for pigeon guillemots, common murres, and marbled murrelets. Black-legged kittiwakes are currently being used as indicators of ecosystem function and health within PWS (APEX Component 96163E), and are the subjects of a similar study on the Barren Islands (APEX Component 96163J). This proposal complements and enhances other proposed studies on pigeon guillemots and black-legged kittiwakes, without duplication of effort. The PI on the present proposal has been and will continue to work closely with David Irons (PI on APEX Component 96163E "Kittiwakes as Indicators of Forage Fish Availability), D. Lindsey Hayes (PI on APEX Component 96163F "Factors Affecting Recovery of PWS Pigeon Guillemot Populations"), David Roseneau, (PI on APEX Component 96163J "Reproductive Success by Murres and Kittiwakes on the Barren Islands"), and John Piatt (PI on APEX Components 96163M "Lower Cook Inlet Forage Fish Studies" and 96163N "Black-legged Kittiwake Feeding Experiment") in developing protocols for collecting field data so as to minimize project cost and maximize data acquisition. Irons and Hayes are both with the Migratory Bird Branch, U.S. Fish and Wildlife Service and Piatt is with the Alaska Science Center, National Biological Service. Irons has had extensive experience working in the field with kittiwakes nesting in PWS, and is project leader for on-going studies of the reproductive success and status of kittiwakes and guillemots in PWS. Hayes was in charge of the field crew working on pigeon guillemots at Naked and Jackpot islands during the 1994 breeding season and at Naked Island during the 1995 breeding season, and has extensive field experience with nesting guillemots. Piatt and Roseneau have had extensive experience with seabird research in Alaska. Close coordination with the research teams of Irons, Hayes, Roseneau, and Piatt will be essential for the success of the proposed research.

APEX Components E, F, J, M, N, and the present component (G) all require information on chick feeding rates, chick meal size, and taxonomic composition of chick diets in order to meet their objectives. Collecting these data is extremely labor intensive and the cooperation of these six components in collecting these data will greatly enhance sample sizes. The six components also require data on chick growth performance (body mass in relation to wing and flight feather development), nestling survival, mass and condition of fledglings, and fledging age. Again, cooperation and coordination between these components will greatly enhance sample sizes and the power of statistical tests and inferences. The field crews for the six components will work together to insure that data collection methods and procedures are consistent.

In order to understand dietary factors responsible for poor reproductive performance of seabirds in the EVOS area, it is essential to conduct simultaneous shipboard work (hydroacoustic surveys in conjunction with net sampling) to assess the distribution, abundance, and species composition of forage fishes in seabird foraging areas. That research was funded by the Trustees Council beginning in 1994 (Project 94163) and the continuation of this project (APEX Component 96163A) will be invaluable for interpretation of data on diets collected as part of the present proposal. In addition, the integrated studies that comprise the SEA Program (95320A-Y) will provide an important foundation for understanding ecosystem function in PWS as it relates to seabird/forage fish interactions.

ENVIRONMENTAL COMPLIANCE

No state or federal permits are required to conduct this subproject. The National Environmental Policy Act does not apply to this study.

APEX: PROJECT LEADER

Project Number:	96163I
Restoration Category:	Research
Proposed By:	David Cameron Duffy, Project Leader, University of Alaska Anchorage.
Duration:	5 years
Cost FY 96:	$140 K
Cost FY 97:	$150 K
Cost FY 98:	$150 K
Cost FY 99:	$150 K
Cost FY 00:	$170 K
Geographic Area:	Prince William Sound, Cook Inlet
Injured Resource/Service:	Common Murre, Harbor Seal, Marbled Murrelet, Pacific Herring, Pigeon Guillemot, subtidal organisms, sediment.

ABSTRACT

This subproject provides scientific leadership and coordination of 12 subprojects, allowing the integrated testing of hypotheses that food limits recovery of various seabirds following the *Exxon Valdez* oil spill. The Project Leader coordinates efforts between subprojects studying fish acoustic and net sampling, fish life history characteristics, observations of birds at sea, and studies of food and nesting success at colonies.

INTRODUCTION

This component of the APEX project provides scientific oversight and coordination between the subprojects of the project.

NEED FOR THE PROJECT

A. Statement of Problem

Several resources injured in the *Exxon Valdez* oil spill have not recovered. While continuing damage is a possibility, there is evidence that a shift in the food available for several injured species may now be restricting their recovery. An integrated project, incorporating several trophic levels, is necessary to efficiently approach this problem.

B. Rationale

The APEX Project evolved from a varied group of projects that all focused on availability of forage fish as a factor in the non-recovery of resources injured in the *Exxon Valdez* oil spill. The EVOS Trustee Council felt that an integrated ecosystem approach would achieve greater research efficiency by exploring the topic across several levels of the food chain. In late 1994, David Cameron Duffy was hired to serve as the half-time Project Leader to achieve this coordination.

C. Summary of Major Hypotheses and Objectives

This subproject does not directly test hypotheses. It has as its objective coordination of the APEX Project and the testing of its hypotheses through coordinated field work and modeling of the results.

D. Completion Date

December 2000

COMMUNITY INVOLVEMENT

See cover proposal

PROJECT DESIGN

A. Objectives

1. Insure the selection, development and funding of projects which will allow tests of the main hypotheses of the APEX Project.
2. Identify population or ecosystem models to direct coordinated research efforts.
3. Insure publication of APEX project results.
4. Insure through coordination archiving and exchange of data from project.
5. Develop tentative methodology for future monitoring.
6. Coordinate with other EVOS Trustee Council projects and other research efforts.

B. Methods

1. Selection, development and funding of projects which will allow tests of the main hypotheses of the APEX Project.

   APEX has been a very dynamic project, having undergone extensive changes since January 1995, in response to the results of the 1995 field season. The Project Leader, working with PI's identifies gaps in the emerging APEX Program and then initiates projects to fill these. Projects that have been added in this fashion include the historical review (96163L) and Cook Inlet research (96163M) in FY 95 and the sand lance pollution study (96163P), feeding experiments (96163N), and statistical support (96163O) components in FY 97. At the same time, two projects, predatory fish diet (95163K) monitoring and puffin monitoring (95163D) were dropped in 1996.

   In addition, we work with individual PIs to help integrate their projects. For example, 1996 saw a shift to more intensive studying of food and foraging of Pigeon Guillemots which required a shift in the models being tested. Similarly, it became apparent that the nutrient studies needed 'ground-truthing' through captive studies, so we worked with PIs to establish the species and goals of the project. The sand lance study came directly from field observations of this fish species burrowing on oiled beaches in 1995. Finally, there was concern about the level of statistical expertise in designing joint research projects, so a statistician was awarded a subproject to assist in integrating other subprojects.

2. Identify population or ecosystem models to direct coordinated research efforts.

   The Project Leader will work closely with the PIs to identify models that can be used to increase our understanding of the data gathered. Models will be needed that function at a variety of scales from foraging at schools of fish (Duffy 1986; Erikstad et al. 1990; Piatt 1990), through relationships between food availability and reproductive performance (Anderson et al. 1982; Cairns 1990; Williams and Croxall 1990) to community-level models that examine food consumption (Birkhead and Furness 1984; Cairns 1989), or population dynamics at colonies (Coulson and Thomas 1985), between colonies (Danchin and Monnat 1992; Buckley and Downer 1994) or at the population level (Simon 1984; Migot 1992).

   At present, we appear to be focusing on testing models at the nest/colony level applied to seabirds by Cairns (1987), based on functional response models of Holling (1965) and to source-sink models (Pulliam 1988) and metapopulation models (Gilpin and Hanski 1991) One productive line of attack is to consider colonies at the outsides of estuaries as 'sources', producing seabirds that emigrate to other colonies, farther in the estuaries (PWS, Cook Inlet), that produce few young, serving as 'sinks'. Under this model, reproduction at many colonies might be irrelevant, with the regional population sustained only by a few colonies such as the Barrens at the mouth of Cook Inlet or Porpoise Rocks at the mouth of PWS or Shoup Bay in Valdez Arm. Any such regional patterns could then be tied to spatial models of primary productivity. For example, if the flow of water is primarily north past the entrance to Montague Passage, few nutrients would be available for the immediate marine ecosystem, compared to the Barrens, where tides flow both north and south, bringing nutrients from the upper estuary.

Beyond this, in collaboration with the Fish and Wildlife Service, this project will explore the utility of a series of trophic models of colony size and distribution (Birkhead and Furness 1984; Cairns 1989), using GIS technology.

3. Insure publication of APEX project results.

The first annual report will include a list of planned paper topics.

4. Insure archiving and exchange of data from the APEX project.

APEX PIs will contribute to on-going Trustee efforts to provide metadata descriptions of databases. In addition, through a pilot project with ADF&G on the trophic interactions of harbor seals and forage fish, we will explore how to gather and share spatial data through a GIS system. If this appears useful as a means of testing our core hypotheses, APEX GIS efforts may be expanded in future years.

5. Develop tentative methodology for future monitoring

While we have suspended work on two of our first-year monitoring projects on the diets of predatory fish and of puffins in PWS, we will continue to examine existing APEX methodology that is inexpensive and correlates well with other, more expensive or intensive sampling methods or that can be incorporated into models that examine environmental variability.

6 Coordinate with other EVOS Trustee Council projects and other research efforts.

Please see the section: Coordination of Integrated Research Effort below.

C. Contracts and Other Agency Assistance

Limited contracting for communications will be conducted if the UAA email situation does not improve.

D. Location

Limited field work for collection of sand lance and visiting of field sites will take place in PWS and Cook Inlet, with support of the USFWS. Most of the administrative work will occur in Anchorage, with some work in Juneau, Cordova, Seward, and Fairbanks.

SCHEDULE

A. Measurable Project Tasks for FY 96

1995

December 1-3	Review of APEX Project

1996

January	EVOS Restoration Annual Workshop
April 15	First Annual APEX Project Report

B. Project Milestones and Endpoints

December 1995	Review of Project, Approval of APEX by Trustee Council
January 1996	First Meeting of Inshore Sampling Working Group, a cooperative effort with the other two EVOS ecosystem projects.
November 13-15, 1996	International Symposium on the Role of Forage Fishes in Marine Ecosystems, Anchorage (Brenda Baxter, Coordinator)
1998	International Symposium on Changes in Pacific Seabirds, Pacific Seabird Group, Asilomar, CA (David C. Duffy, Convenor)

C. Project Reports

A first annual report will be presented in April 1996. Subsequent reports will appear yearly.

COORDINATION OF INTEGRATED RESEARCH EFFORT

APEX is in itself a major integrated research effort, spanning 15 principal investigators at 12 institutions, agencies, or private businesses. Details of integration at the individual project level may be found in the appendices for each project.

At the level of coordination between APEX and the other two Trustee-funded ecosystem projects, there are several efforts underway. Following initial meetings with Brenda Baxter and Evelyn Brown of SEA (Sound Ecology Assessment) at the AAAS meetings in Fairbanks in October, and a meeting with Leslie Holland-Bartels and the Nearshore Vertebrate Predator Principal Investigators, PIs from the three groups met in January at the annual meeting, to establish ways to pool sampling effort for studying inshore fish schools. The group will share sampling platforms (planes and ships) and standardize acoustic and net sampling techniques and hardware for fish.

Coordination with Dr. Jeep Rice of NOAA's Auke Bay Fisheries Laboratory was instrumental in setting up Project 96163P, Assessment of the PAH contamination of populations of the forage fish, *Ammodytes* sp., inhabiting clean and oil impacted sediments. Auke Bay will also assist with analysis if initial screening indicates damage.

In coordination with Dr. Kathy Frost of ADF&G, Tracey Gotthardt, a UAA graduate student, will collate harbor seal foraging data with APEX data on distribution and changes in forage fish in Prince William Sound and the northern Gulf of Alaska. This effort will help us build up a "trophic landscape" of PWS, to ask "what are the spatial patterns of prey consumption by upper-level predators?", and to determine whether such predators co-vary in abundance. It will also serve as a pilot for data management and sharing within APEX.

ENVIRONMENTAL COMPLIANCE

No state or federal permits are required to conduct this subproject. The National Environmental Policy Act does not apply to this study.

APEX: BARREN ISLANDS SEABIRD STUDIES

Project Number:	96163J
Restoration Category:	Research and restoration
Proposer:	DOI-FWS
Lead Trustee Agency:	USFWS
Cooperating Agencies:	NBS and NMFS
Duration:	5 years
Cost FY 96:	$83.5 K
Cost FY 97:	$115.3 K
Cost FY 98:	$120.4 K
Geographic Area:	Cook Inlet
Injured Resource/Service:	Common Murre, Recreation and Tourism

ABSTRACT

As part of the FY 95 APEX seabird - forage fish study (Project 95163), we conducted a pilot project to collect information on common murres *(Uria aalge)*, black-legged kittiwakes *(Rissa tridactyla)*, and tufted puffins *(Fratercula cirrhata)* at the East Amatuli Island - Light Rock colony in the Barren Islands during mid-June - early September 1995 (Project 95163J). The work was done because capelin *(Mallotus villosus)*, an important forage fish species scarce in the northern Gulf of Alaska since the late 1970's, were abundant near these islands during FY 93-94. The presence of large stocks of capelin and a variety of other fishes (e.g., Pacific sand lance, *Ammodytes hexapterus,* and walleye pollock, *Theragra chalcogramma*) frequently utilized by seabirds provided an opportunity to study seabird - forage fish relationships and natural ecological processes that might help explain why populations of some seabirds have not increased during the 6-year interval following the T/V *Exxon Valdez* oil spill. Data collected during FY 95 included information on nesting chronology, productivity, growth and feeding rates of chicks, time budgets of adults, and types and amounts of food fed to chicks. Although data are still being analyzed, preliminary results have demonstrated that sufficient information can be collected at this northern Gulf of Alaska colony to help conduct a multiyear, multispecies analysis of seabird productivity and energetics. Data obtained during FY 96 - FY 98 will be used to test 3 important APEX project hypotheses: (a) composition and amounts of prey in seabird diets reflect changes in relative abundance and distribution of forage fish near the

nesting colonies; (b) changes in seabird productivity reflect differences in forage fish abundance as measured by amounts of time adult birds spend foraging for food, amounts of food fed to chicks, and provisioning rates of chicks; and (c) seabird productivity is determined by differences in forage fish nutritional quality.

INTRODUCTION

The APEX Barren Islands seabird studies (Project 96163J) are designed to collect data on three key species of fish-eating seabirds: common murres *(Uria aalge)*, black-legged kittiwakes *(Rissa tridactyla)*, and tufted puffins *(Fratercula cirrhata)* at the Barren Islands colonies during the FY 96 - FY 98 field seasons. Results of the work will be used in a multiyear, multispecies analysis of seabird productivity and energetics that is designed to help identify and define ecological processes that may be influencing seabird recovery within the T/V *Exxon Valdez* oil spill area. These data will also be used to test three key APEX project hypotheses: (a) composition and amounts of prey in seabird diets reflect changes in relative abundance and distribution of forage fish near the nesting colonies; (b) changes in seabird productivity reflect differences in forage fish abundance as measured by amounts of time adult birds spend foraging for food, amounts of food fed to chicks, and provisioning rates of chicks; and (c) seabird productivity is determined by differences in forage fish nutritional quality. Field work will be conducted at the East Amatuli Island - Light Rock colony during about 10 June-10 September each study year. Types of information collected annually will include data on nesting chronology, productivity, feeding and growth rates of chicks, time budgets of adults, and types and amounts of food fed to chicks (data types will vary slightly between species—see below). Fish and invertebrates brought to chicks will also be collected for stable isotope and nutrient analyses.

The Barren Islands seabird studies were integrated into the APEX seabird - forage fish ecological processes project because capelin *(Mallotus villosus)*, an important forage fish species scarce in the northern Gulf of Alaska since the late 1970's (see Piatt and Anderson 1995; P. Anderson, unpubl. data), were abundant in Barren Islands waters during FY 93-94 (Roseneau et al. 1995, 1996). The presence of large concentrations of capelin near the islands during these years, and their reoccurrence in FY 95 (D.G. Roseneau, unpubl. data) suggest that stocks of these important forage fish are beginning to rebound in the northwestern Gulf of Alaska. The current abundance of capelin at the Barren Islands, combined with the presence of other fishes utilized by seabirds (e.g., Pacific sand lance, *Ammodytes hexapterus* and walleye pollock, *Theragra chalcogramma*; D.G. Roseneau and A. B. Kettle, unpubl. data), continues to provide an opportunity to collect information on seabird - forage fish relationships needed for a multiyear, multispecies analysis of seabird productivity and energetics that will increase understanding of ecological processes and help test 3 APEX hypotheses (hypotheses 7, 8, and 9; also, see below).

We conducted a pilot study at the Barren Islands in FY 95 to determine whether the kinds and amounts of data needed for an analysis of productivity and energetics of several species of seabirds could be collected at the East Amatuli Island - Light Rock colony (95163). The pilot project successfully met all study objectives; sufficient amounts of data were collected on all targeted variables. Furthermore, opportunities are available to share data and logistical costs with other studies. An EVOS-sponsored common murre restoration monitoring project will be conducted at the Barren Islands colonies during FY 96-97 (Project 96144). This study requires a large vessel to support population counts of birds, and the vessel can easily supply most of the transportation needs for the FY 96-97 field seasons at no additional cost to the project (e.g., transportation of equipment, supplies, and personnel between Homer and the Amatuli Cove field camp). An on-going Minerals Management Service - National Biological Service (MMS-NBS) and APEX seabird ecosystem study, lead by J. Piatt, NBS, will be collecting information on seabirds, fisheries resources, and oceanographic conditions in the Barren Islands and lower Cook Inlet regions during FY 96-98. This project and a National Marine Fisheries Service - Alaska Dept. of Fish and Game (NMFS-ADF&G) sea lion study that will be collecting fisheries data in the Barren Islands during FY 96 will provide additional opportunities to coordinate efforts and share data that will compliment and benefit the work.

NEED FOR THE PROJECT

A. Statement of Problem

Many seabirds were killed during the T/V *Exxon Valdez* oil spill (e.g., Piatt et al. 1990; ECI 1991), and populations of several species have still not recovered (e.g., Agler et al. 1994a,b; Klosiewski and Laing 1994) or have only partially recovered from the event (e.g., although common murre productivity is now within normal limits at the Barren Islands, population numbers have remained little changed at these injured colonies since the spill—Roseneau et al. 1995, 1996; D.G. Roseneau and A.B. Kettle, unpubl. data). There is a need to understand seabird - forage fish relationships and ecological processes that may be influencing seabird recovery within the spill area.

B. Rationale

The study is one of several coordinated components of the APEX seabird - forage fish project (96163). The work was integrated into the APEX study because data on common murre, black-legged kittiwake, and tufted puffin productivity, nesting chronology, feeding and growth rates of chicks, time budgets of adults, and types and amounts of fish fed to chicks are needed from the Barren Islands colonies for use in a multispecies productivity and energetics analysis that will help identify and define ecological processes within the Prince William Sound (PWS) and lower Cook Inlet (LCI) sections of the spill area.

C. Summary of Major Hypotheses and Objectives

The study addresses 3 APEX project hypotheses: (a) composition and amounts of prey in seabird diets reflect changes in relative abundance and distribution of forage fish near the nesting colonies; (b) changes in seabird productivity reflect differences in forage fish abundance as measured by amounts of time adult birds spend foraging for food, amounts of food fed to chicks, and provisioning rates of chicks; and (c) seabird productivity is determined by differences in forage fish nutritional quality. Project objectives are to collect and analyze the kinds and types of data needed to help test these hypotheses.

D. Completion Date

Annual reports will be submitted to the APEX project leader by 15 March 1997 and 15 March 1998. Field work will be completed in FY 98, and a final report summarizing the FY 95-98 findings will be submitted to the APEX project leader in FY 99.

COMMUNITY INVOLVEMENT

Large format, computer-generated color posters summarizing annual results will be prepared and submitted to the Trustee Council for public display each year after data have been analyzed (similar posters showing preliminary results from two FY 95 pilot studies—95163K and J—were given to the Trustee Council after public display at the 16-18 January 1996 Restoration Workshop). The posters are easy to transport and can be used by Trustee Council staff for a variety of purposes, including public displays at oil spill community meetings and schools. Abstracts of annual findings and the posters will also be available on-disk for inclusion in any on-line products that the Trustee Council may develop for public use. Field activities will be photographed and a file of 35 mm color slides will be compiled for Trustee Council use at community meetings and in public newsletters, displays, and on-line information services. Copies of annual and final reports will be available to the public in Homer and Anchorage. Study results will also be presented at public Trustee Council-sponsored meetings and workshops, and published in scientific journals.

PROJECT DESIGN

A. Objectives

The project objective is to collect data on the same murre, kittiwake, and puffin variables targeted in FY 95 (nesting chronology, productivity, growth and feeding rates of chicks, time budgets of adults, and types and amounts of prey fed to chicks) at the East Amatuli Island - Light Rock colony for use in a multispecies, multiyear analysis of seabird productivity and energetics that will help identify and define ecological processes within the PWS and LCI sections of the spill zone.

B. Methods

The study will be conducted at the East Amatuli Island - Light Rock colony (see Fig. 1). As demonstrated during the FY 95 Barren Islands pilot project (95163J), limiting work to this location conserves funds and maximizes data collection opportunities (i.e., compared to study designs that include working at Nord Island). Methods for collecting and analyzing data were tested during the FY 95 work, and, based on results, they will be used with only slight modifications during the FY 96-98 studies. Methods will be reviewed and coordinated with other APEX investigators annually to ensure that the objectives of the APEX seabird - forage fish ecological processes study are being met.

Data Collection

Data will be collected by 4 personnel stationed at the FWS Amatuli Cove camp during about June 10 - September 10 each year (the camp leader has 6 years of experience working at the East Amatuli Island - Light Rock colony). Personnel will commute to study plots by hiking and boating. Murre and kittiwake productivity and nesting chronology data will be collected from the same sets of plots used to obtain this information during the FY 93-94 restoration monitoring studies (93049 and 94039; see Roseneau et al. 1995,1996) and the FY 95 pilot project (95163J). These plots contain about 340 murre and 370 kittiwake nest sites and they sample a wide range of nesting habitats. Methods will follow those used during FY 95. Eleven murre plots (COMU/LPP1-11) and 12 kittiwake plots (BLKI/LPP1-12) will be checked every 2-3 days, weather permitting, and nest sites will be observed from 2 vantage points for the presence or absence of eggs and chicks (in the case of murres, incubating and brooding postures will also be used to help determine if pairs have eggs or chicks). Observations will begin before eggs are laid and end after fledging peaks. Plot boundaries and nest sites will be located by using photographs and plot maps, and data will be recorded on forms using standard codes (e.g., E = egg, IP = incubation posture). Several measurements of productivity will be calculated from the information (e.g., numbers of eggs laid and hatched, numbers of chicks fledged per plot, per pair, and per total number of adults). The data will also be used to calculate timing of nesting events (e.g., first laying dates, and mean and median laying, hatching, and fledging dates).

Information on any factors that might adversely affect the reproductive success of murres and kittiwakes will also be collected during the productivity-chronology work (e.g., avian predation events, disturbance by humans, adverse weather conditions). During predation events or other episodes causing adults to flush from the nesting cliffs, efforts will be made to record losses of eggs or chicks.

Data will be collected on feeding rates of murre and kittiwake chicks and time budgets of adults. This information will be obtained by monitoring at least 20 murre and 10 kittiwake nest sites in plots established for these purposes during FY 95 (sample sizes were determined in consultation with D. Roby, UAF, and J. Piatt, NBS). Basic methods for collecting these data have been described by Burger and Piatt (1990). A schedule will be set up for collecting data that includes maximum and minimum tide cycles (as per J. Piatt's recommendation for FY 95 work) and murre and kittiwake pairs will be watched closely during morning hours (the best time of day, based on FY 95 data) for 4-6 hr day^{-1}, 4-6 times during the chick rearing period. During these intensive nest site watches, records will be kept on all food deliveries to chicks and lengths of time adults spend away from nest sites. Data will be used to calculate weekly and seasonal chick feeding rates and time budget indices for adults of both species.

Fish brought to murre chicks will be identified as often as possible during the study to obtain basic information on prey species-composition. Blocks of time averaging about 8-10 hrs wk^{1} will be set aside to specifically watch for birds returning to nest sites with fish in their bills. Fish will be observed with the aid of spotting scopes and binoculars and identified to species or basic prey groups (e.g., capelin, sand lance, herring, gadids, flatfishes, pricklebacks, other fishes, unidentified fishes) using field characteristics (e.g., colors, tail and fin shapes; observers conducting this part of the study have experience identifying fish hanging from murre bills). Because kittiwakes do not carry fish in their bills, accessible nests will be monitored and after chicks have been fed, they will be gently captured and encouraged to regurgitate food (kittiwake chicks readily regurgitate prey when they are handled and the procedure does not harm the nestlings). About 10-15 regurgitated meals will be collected each week during the nestling period, providing a total of 50-70 samples, which will be sufficient to quantify prey types fed to chicks and detect seasonal changes in diets (69 samples were obtained in FY 95; this technique has helped identify shifts in presence-absence of sand lance at colonies in the Chukchi Sea; D.G. Roseneau, unpubl. data). Regurgitated food will be weighed to provide information on meal sizes. Prey samples will be preserved in 5-10% buffered formaldehyde for about 24 hrs and then transferred to 50% ethanol and saved for later identification in the lab (see Hatch and Sanger 1992; this method was successful in FY 95—24 hrs in the formaldehyde solution firmed up tissues, but did not degrade otoliths). Samples will be analyzed by A. M. Springer, Institute of Marine Sciences, UAF, using previously published techniques (e.g., see Springer et al. 1984, 1986).

Data collected on tufted puffins will include information on nesting chronology, burrow densities, numbers of active burrows, numbers of occupied burrows producing chicks, chick growth and feeding rates, and types of prey fed to chicks. These data will be obtained from 5 previously-established study plots on East Amatuli Island in August after chicks are about 1 week old (disturbing burrows earlier in the nesting season often results in abandonment). Hatch dates will be initially estimated by observing percentages of adults returning to the island during 1000-1300 hrs that have prey in their bills (in previous years, chicks were about 1 week old on these plots when about 20% of the adults were returning with bill-loads of food). To supplement this information, small samples of 5-10 burrows will be checked each week in other sections of the colony to help refine hatch dates. Several indicators will be used to check occupancy of burrows on study plots (e.g., presence of guano, matted vegetation, evidence of fresh digging). Active burrows will be marked with survey flags and 30 chicks will be carefully removed and weighed and measured about every 5 days until they reach fledging age (wing chord will be the primary measurement). An additional 20 chicks on 2 other plots will be weighed and measured 3 times during the chick-rearing period to measure effects of disturbance at the more frequently visited plots. Just before fledging begins, data on burrow densities, occupancy rates, and numbers and sizes of chicks will be collected from four 3-m wide transects totaling 270 m^2 that have been monitored every year since 1986. Information on feeding rates will be collected by setting up a blind and recording the number of times adults deliver food to nestlings in about 10 active burrows during blocks of time averaging about 8-10 hrs wk^{-1} during the chick-rearing period. Prey items brought to chicks will be obtained from about 150 active burrows outside of the study plots about twice per week during the nestling period by temporarily blocking burrow entrances for 3-hr periods with wire-mesh screens (adults usually drop their bill-loads in front of blocked burrow entrances; e.g., Hatch and Sanger 1992). Fish and invertebrates collected in this manner will be weighed, measured, and frozen, or preserved in 5-10% buffered formaldehyde for 24 hrs and then transferred to 50% ethanol for later identification in the lab (see Hatch and Sanger 1992). Frozen specimens will be sent to D. Roby (96163G) and J. Piatt (96163M) for nutrient and stable isotope analyses.

Some information will also be collected on glaucous-winged gulls (*Larus glaucescens*) and cormorants (*Phalacrocorax* spp.) during the project. Data will include counts of birds, nests and their contents, and timing of nesting events. This information will be shared with J. Piatt (96163M).

Because water temperatures are an important factor influencing both seabirds and their prey (see Springer et al. 1984), water temperature data will be collected near the East Amatuli Island - Light Rock colony at regular intervals throughout the study. A data logger - probe or comparable digital unit will be set up near the colony to provide hourly and daily records of sea surface temperatures (SST). SST will also be measured with calibrated hand-held thermometers around East Amatuli Island on a weekly basis during late June - early September. Special attention will be paid to the late July - mid-August period, because during FY 94-95, these types of on-site data detected a positive 2° C late summer shift in SST that J. Piatt, NBS, confirmed via analysis of satellite imagery.

Data Analysis

Standardized methods used during FY 93-94 common murre restoration monitoring studies (93049 and 94039) and the FY 95 Barren Islands pilot project (95163K) will be used to analyze FY 96-98 murre and kittiwake productivity-chronology data. Nest sites with incomplete observation records (e.g., data gaps of more than 7 days between pre- and post-event observation dates; insufficient data to indicate chicks fledged) will be eliminated from the database. The remaining data will then be analyzed to obtain chronology and productivity information, using plots as sample units (e.g., first laying dates, and mean and median laying, hatching, and fledging dates; numbers of eggs laid and hatched and chicks fledged per plot, per pair, and per total number of adults). Median hatch dates will be used as the primary measurement of chronology. Laying and hatching dates will be calculated for each site as midpoints between pre- and post-event observations, and chick ages will derived from hatch dates obtained during nesting chronology calculations (see above) and direct observations of chicks. At murre sites where the range of possible laying dates is smaller than the range of possible hatching dates, hatch dates will be calculated by adding 32 days to laying dates (see Byrd 1986; Dragoo and Dragoo 1994). At kittiwake sites, 27 days will be added to laying dates to calculate hatch dates (see Dragoo and Dragoo 1994). Murre chicks reaching an age of 15 days old and kittiwake chicks that are at least 33 days old before disappearing from nest sites will be counted as "fledged" unless information is available indicating that they died from natural causes (see Hunt et al. 1981; Byrd 1986, 1989; Dragoo and Dragoo 1994).

Because productivity is an important measurement being used to help assess the recovery status of common murres (see Proceedings of the Science for the Restoration Process Workshop, April 13-15, 1994), murre productivity data will be compared with FY 95 information and data from FY 89-94 damage assessment and restoration monitoring studies (see Roseneau et al. 1995, 1996). ANOVA and Tukey HSD multiple comparisons tests will used to check for significant differences among years, and Kendall's Tau test will be run to check for trends.

Data on murre, kittiwake, and puffin chick-feeding rates and amounts of time adults spend away from nests foraging for food will be analyzed in a manner that will provide chick-feeding frequency and time budget indices for these species. In each case, calculations will be made for the nestling periods and weekly increments within these intervals (weekly increments will help identify seasonal changes that may occur during the chick-rearing period). For feeding frequencies, the numbers of times chicks are fed will be divided by hours (e.g., 35 feedings in 30 hrs = 1.17 feedings hr^{1}, 35 feedings in 40 hrs = 0.88 feedings hr^{1}). Time-budgets will be calculated in a similar fashion as percentages (e.g., 6 hrs spent away from the nest during a 30-hr block of time = 20% of time absent and assumed foraging for food). Data may additionally be manipulated in slightly different ways to fit the needs of other APEX investigators (e.g., D. Roby, 96163G; J. Piatt, 96163M; D. Irons, 96163E).]

Identifiable fish fed to murre chicks will be reported as percentages of numbers in several basic prey categories (e.g., capelin, sand lance, herring, gadids, flatfishes, pricklebacks, other species). Calculations will be made for the entire chick-rearing period and weekly intervals of time. For example, during the first week of the nestling period, 70% of the fish brought to chicks may be successfully identified, and 80% of the identifiable items may be capelin, while 20% belong to other categories (e.g., 10% sand lance and 10% gadids). In contrast, during the second week, 70% of the fish may be identifiable and of those, 50% may be capelin and 50% cod). Because common murres only deliver 1 fish per feeding, combined numbers of identified and unidentified fishes will be used to calculate chick feeding rates (see above).

Information on food delivered to kittiwake and puffin chicks will be treated in a similar manner. However, in addition to calculating percentages of numbers in various fish and invertebrate prey categories (e.g., capelin, sand lance, gadids, squid, euphausiids), these data will also be reported by weight (in some cases, weights will be estimated from average weights of subsamples of prey).

Two variables will be used to describe puffin chick growth rates: wing growth reported as cm day^{-1} and body weight reported as gm day^{1}. Actual hatch dates will not be known, because burrows will not checked until chicks are about 1 week old (see above). Chick ages will be estimated by using the first wing measurement and a growth equation reported by Amaral (1977). Growth rates of individual chicks will be determined by linear regression of wing measurements obtained when chicks are 10-40 days old; growth is nearly linear during this period (A. B. Kettle and P. D. Boersma, unpubl. data). Data may be manipulated in slightly different ways to fit the needs of other APEX investigators (e.g., 96163G; 96163M; 96163E).] The median hatch date, derived from chick growth information, will be used to measure nesting chronology.

Growth rate data and other information obtained on puffins during FY 96-98 (e.g., timing of nesting events, proportion of active vs. inactive burrows, number of chicks per occupied burrow) will be compared with FY 94-95 data and information collected on the same plots in previous years, as it becomes available (e.g., mid-1970's - early 1980's and 1990-1993; these data are being prepared for publication by A. B. Kettle and P. D. Boersma).

Water temperature data will be reported in degrees C by location, date, and time, and summarized in tabular form. The information will also be divided into seasonal time blocks (e.g., weeks and months).

C. Contracts and other Agency Assistance

1. Contracts: A contract with the Student Conservation Association is used each year to obtain the services of 2 SCA volunteers to help field crews collect data. Collecting data on seabirds in the Barren Islands is a labor intensive effort and the SCA program is a cost-effective source of volunteers. These positions also provide important training opportunities for high school and college students seeking jobs in resource-related fields).

2. Existing Agency Programs: The Alaska Maritime National Wildlife Refuge will furnish all office and warehouse space, computers, and radio communications services needed for the project. The refuge will also donate up to 2 months of the project manager's time (G.V. Byrd, AMNWR supervising biologist). In addition, the refuge will provide several pieces of field equipment (e.g., back-up outboard motors, hand-held and base radios, survival suits) and miscellaneous camping supplies for the work, and emergency medical consultation services for field personnel under its refuge-wide remote emergency medical services contract.

D. Location

The FY 96-98 studies will be conducted at the East Amatuli Island - Light Rock colony in the Barren Islands, about 100 km south of Homer in the northwestern Gulf of Alaska. No communities will be affected by the study.

SCHEDULE

A. Measurable Project Tasks for FY 96-98

1 Feb.-30 Apr. 1996:	Review study plan, coordinate protocols with other APEX investigators, arrange hiring of temporary employees, contract for SCA volunteers and transportation, begin purchasing equipment/supplies.
1 May-9 June 1996:	Finalize logistical needs, purchase/pack equipment/supplies, train volunteers.

10-11 June 1996:	Load vessel, depart Homer, travel to study area.
12-15 June 1996:	Set up camp at East Amatuli Island.
16 June-10 Sept. 1996:	Collect data.
11-13 Sept. 1996:	Pack equipment/supplies, load vessel, return to Homer.
14-15 Sept. 1996:	Unload vessel.
16-20 Sept. 1996:	Unpack equipment/supplies, clean equipment, store gear.
21 Sept.-31 Dec. 1996:	Compile and analyze data.
1 Jan.-15 Feb. 1997:	Complete analyses, prepare draft report of FY 96 results.
16 Feb. 1997:	Submit draft report to APEX Project Leader for review.
15 Mar. 1997:	Submit final draft of annual report to APEX Project Leader.
20 Mar.-30 Apr. 1997:	Review study plan, coordinate protocols with other APEX investigators, arrange hiring of temporary employees, contract for SCA volunteers and transportation, begin purchasing equipment/supplies.
1 May-9 June 1997:	Finalize logistical needs, purchase/pack equipment/supplies, train volunteers.
10-11 June 1997:	Load vessel, depart Homer, travel to study area.
12-15 June 1997:	Set up camp at East Amatuli Island.
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14-15 Sept. 1997:	Unload vessel.
16-20 Sept. 1997:	Unpack equipment/supplies, clean equipment, store gear.
21 Sept.-31 Dec. 1997:	Compile and analyze data.
1 Jan.-15 Feb. 1998:	Complete analyses, prepare draft report of FY 97 results.

16 Feb. 1998:	Submit draft report to APEX Project Leader for review.
15 Mar. 1998:	Submit final draft of annual report to APEX Project Leader.
20 Mar.-30 Apr. 1998:	Review study plan, coordinate protocols with other APEX investigators, arrange hiring of temporary employees, contract for SCA volunteers and transportation, begin purchasing equipment/supplies.
1 May-9 June 1998:	Finalize logistical needs, purchase/pack equipment/supplies, train volunteers.
10-11 June 1998:	Load vessel, depart Homer, travel to study area.
12-15 June 1998:	Set up camp at East Amatuli Island.
16 June-10 Sept. 1998:	Collect data.
11-13 Sept. 1998:	Pack equipment/supplies, load vessel, return to Homer.
14-15 Sept. 1998:	Unload vessel.
16-20 Sept. 1998:	Unpack equipment/supplies, clean equipment, store gear.
21 Sept.-31 Dec. 1998:	Compile and analyze data.
1 Jan.-15 Feb. 1999:	Complete analyses, prepare draft report of combined FY 95-98 results.
16 Feb. 1999:	Submit draft report to APEX Project Leader or review.
15 Mar. 1999:	Submit final report to APEX Project Leader
16-30 Mar. 1999:	Respond to comments, submit final version of report to APEX Project Leader.

B. Project Milestones and Endpoints

September 1996	FY 96 Field work completed at East Amatuli Island.
March 1997	Final draft of FY 96 results submitted to APEX Project Leader.
September 1997	FY 97 Field work completed at East Amatuli Island.
March 1998	Final draft of FY 97 results submitted to APEX Project Leader.

September 1998	FY 98 Field work completed at East Amatuli Island.
March 1999	Final draft of combined FY 95-98 results submitted to APEX Project Leader.

C. Project Reports

See above Milestones

COORDINATION OF INTEGRATED RESEARCH EFFORT

The FY 96-98 Barren Islands seabird studies are fully coordinated and integrated with other components of the APEX seabird - forage fish project. The recently completed FY 95 pilot studies were designed in consultation with other APEX investigators (e.g., D. Roby, 95163G; D. Irons, 95163E) and J. Piatt, 95163M, during FY 94-95. The initial study design, now modified slightly for FY 96 use, is currently being discussed with these investigators to ensure that it will fulfill their data needs. The study design will also be subject to annual review, and similar discussions to coordinate efforts and standardize protocols will be held each year before field seasons begin. Information on murre, kittiwake, and puffin productivity; feeding and growth rates of chicks; amounts of food fed to chicks; and time budgets of adults will be transmitted to D. Roby for use in his energetics study (96163G). Roby will also receive data on prey species fed to chicks and specimens of prey for nutrient analysis. D. Irons (96163E) will be sent a variety of information on kittiwakes, including timing of nesting events, and several measurements of productivity (e.g., fledglings nest^{-1}, fledglings single and double chick nests^{-1}) and growth rates of chicks (e.g., all chicks combined, and "a" and "b" nestlings). During the field work, J. Piatt, 96163M, will be given information on observations of feeding concentrations of birds and whales to help him locate schools of forage fish during his hydroacoustic and trawl surveys. Data obtained on all of the murre, kittiwake, puffin, gull, and cormorant variables will also be shared with and analyzed in cooperation with Piatt. Piatt will also be sent specimens of fish for stable isotope analysis.

The Barren Islands seabird project is also closely coordinated with a recently approved Trustee Council-sponsored murre restoration monitoring study that will be conducted at the Barren Islands in FY 96-97 (Project 96144). During these field seasons, the vessel used to support population counts of birds at the colonies will also be available to transport equipment, supplies, and personnel between Homer and the East Amatuli Island field camp at no additional cost to the project.

An on-going joint NMFS-ADF&G sea lion study being conducted in the Barren Islands is also coordinated with the Barren Islands seabird project. D. Merrick, NMFS, will be making additional hydroacoustic-trawl surveys within a 16 km radius of the Sugarloaf Island sea lion rookery in late June - mid-July. As in FY 95, he will share information from these surveys with the seabird studies.

ENVIRONMENTAL COMPLIANCE

No permits are required for the study, and based on review of CEQ regulation 40 CFR 1500-1508, this project has been determined to be categorically exempt from the requirements of NEPA, in accordance with 40 CFR 1508.4.

Figure 1

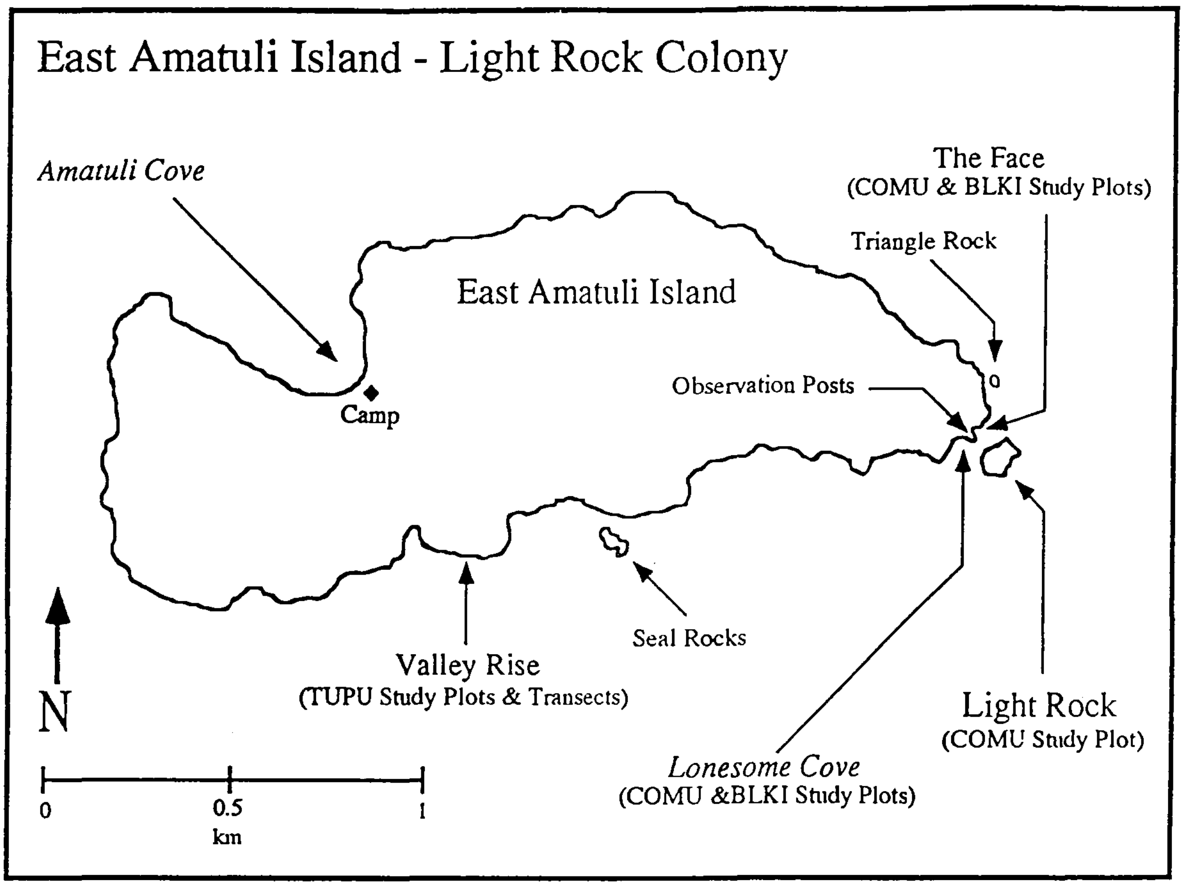


Figure 1. The FY 96 - FY 98 Barren Islands study area showing locations of common murre (COMU), black-legged kittiwake (BLKI), and tufted puffin (TUPU) study plots.

APEX: ANALYSIS OF HISTORICAL DATA ON TRAWL CATCHES OF FORAGE FISH IN THE GULF OF ALASKA, 1953-1995.

Project Number:	96163L
Restoration Category:	Research
Proposed By:	National Biological Service
Lead Trustee Agency:	DOI
Cooperating Agencies:	NOAA, ADF&G
Duration:	3 years
Cost FY 96:	$97.4 K
Cost FY 97:	$95 K
Cost FY 98:	$95 K
Geographic Area:	Prince William Sound, Kenai Peninsula, Lower Cook Inlet, Kodiak Island Group, and Alaska Peninsula to Unimak Pass
Injured Resource:	Multiple resources

ABSTRACT

The purpose of this study is to compile, analyze and review data on forage fish species collected in small-meshed trawls conducted in the Gulf of Alaska by the Alaska Department of Fish and Game and the National Marine Fisheries Service from 1953 to 1995. Over 10,000 individual sampling tows are in the current database (ADF&G 5,836; NMFS 4,352). Preliminary analysis of these data reveal that fish communities have changed dramatically during the past 40 years in six biologically distinct areas from Prince William Sound to Unimak Pass.

INTRODUCTION

An estimated 250,000 seabirds were killed by *Exxon Valdez* oil pollution (Piatt et al.1990). Based on comparisons of pre-spill (1970's) and post-spill (1989–1994) data, long-term effects on seabirds attributed to oil pollution included: I) population declines, ii) reduced breeding success, and iii) delayed breeding phenology. However, some purported effects of the spill may have been due in large part to natural changes in the Gulf of Alaska marine ecosystem-in particular, declines in forage fish abundance (Piatt and Anderson 1996). The rate at which seabird populations will recover from effects of oil mortality is unknown, but it is probably linked to population dynamics of forage fish species.

It appears that marine fish communities changed markedly in the Gulf of Alaska during the past 20 years. Coincident with cyclical fluctuations in sea-water temperatures, the abundance of small forage species (e.g., shrimp, capelin) declined precipitously in the late 1970's while populations of large predatory fish (e.g., pollock, cod, and flatfish) increased dramatically (Anderson et al. 1994). Seabird diets shifted from mostly capelin in the 1970's, to mostly sand lance and juvenile pollock in the late 1980's (Piatt and Anderson 1995). A variety of seabirds and marine mammals both inside and outside of the oil spill zone exhibited signs of food stress (population declines, reduced productivity, die-offs) throughout the 1980's and early 1990's.

The purpose of this study is to compile and analyze available unpublished and published data to: i) examine historical trends in the species composition and abundance of forage fish communities in the Gulf of Alaska during the past 40 years, and, ii) create a database and archive it on CD-ROM for future analyses by other investigators, and iii) based on the results and conclusions of this study, identify possible research projects to test hypotheses about ongoing and future changes in forage fish communities.

The project was initiated in FY 95. Our first accomplishment was to identify and assimilate data sources that were appropriate for analysis. Most of these data presently reside in separate agency databases, and they will eventually be merged. A significant shrimp trawl dataset from Cook Inlet was entered into electronic format. A UNIX program was developed to interface between the master database at NMFS in Seattle and the working NMFS database in Kodiak in order to maintain synchrony between datasets. Databases were checked for errors and corrected in both master and subordinate databases.

Preliminary analyses of databases were conducted. In all, over 411 species and species groups were identified in trawl samples from 1953 to 1994. In addition to several shrimp species, many other important forage species are represented in the top 20 entries on the list of rank order of abundance. Among those of interest in this study are: capelin, sandfish, juvenile pollock, eulachon, juvenile cod, and possibly jellyfish (Scyphozoa).

Once complete, the database can be analyzed to examine historical trends for individual species or species groups, and to examine changes in community structure. For example, preliminary analysis shows that capelin were abundant throughout the Gulf of Alaska until the early 1980's, when catch rates declined precipitously. Few capelin were caught in the 1980's and 1990's. In terms of distribution, capelin were once abundant in the Shelikof region and along the east coast of Kodiak. Highest catches were associated with large bays. Only isolated catches of less than 50 kg were found from Prince William Sound, along the Kenai coast, or in lower Cook Inlet.

In FY 96, we will acquire statistical and GIS software to properly analyze the species abundance data for spatial and temporal variability. We anticipate needing assistance of individuals with mapping and statistical expertise to get us up to speed quickly in the organization of this complex dataset. With the acquisition of analysis tools such as a database server with Symmetric Data Processing capabilities, it is anticipated that a workstation running on Windows NT will provide a suitable platform for more intense data analysis that will take place in the future years of this project.

NEED FOR PROJECT

A. Statement of Problem

Assessing the effects upon, and recovery of, species injured in the *Exxon Valdez* oil spill depends on our understanding of natural changes in the Gulf of Alaska marine ecosystem. At present, compelling data from a 21-year time series of scientific trawl catches at one site (Pavlov Bay) in the western Gulf of Alaska (Anderson *et al.* 1994; Piatt and Anderson 1995) provides the basis for assumptions about long-term changes in forage fish communities. This change in community composition was accompanied by almost a 50% decrease in overall fish biomass and has profound implications for interpreting changes in population biology of dependent predators.

The Pavlov Bay study is the longest continuous survey conducted at a single site in the Gulf of Alaska by the National Marine Fisheries Service (NMFS). Unfortunately, we do not know how applicable these observations are to other areas of the Gulf of Alaska—in particular, the area affected by the *Exxon Valdez* oil spill.

B. Rationale

It is desirable to analyze and synthesize historical data on forage fish species for several reasons: i) they are required for interpretation of long-term trends in populations and trophic relations of higher vertebrate species, ii) they are needed to verify and supplement the site-specific data available on trends in forage fish from Pavlov Bay, iii) they will provide a historical basis for predicting future trends in forage fish populations, and, iv) they will likely suggest what kinds of research should be conducted in the future to test hypotheses about forage fish populations.

C. Summary of Major Hypotheses and Objectives

One of our initial primary objectives is to amalgamate a complete database from ADF&G and NMFS data sources. Once this objective has been completed, we will proceed with intensive analyses of the data set. The first hypothesis to be examined is: Was there a shift in the Gulf of Alaska ecosystem during the late 1970's that led to the decline of some species and increasing abundance of others? Analyses will focus on defining trends for individual forage species of importance to vertebrate predators, and statistically assessing changes in fish community structure. Further analyses will examine potential mechanisms (e.g., changes in oceanography) involved in the reorganization of fish communities in the Gulf of Alaska. Formulation of other objectives and hypotheses and will be based on the results of exploratory data analysis conducted in FY 96.

D. Completion Date

Compilation and analysis of such a large and complex dataset will require considerable time and effort. We anticipate that the project can be completed by the end of FY 98. This includes time needed to prepare final reports, submit several publications to peer-reviewed journals, and to "publish" a CD-ROM of the data in ASCII comma-delimited format for use by other researchers.

COMMUNITY INVOLVEMENT

Community involvement in corroborating ecosystem changes identified in the formal database would be helpful. For example, this could take the form of local knowledge used to confirm the decline of spawning capelin runs, the decline of subsistence take on crustacean resources, etc. We anticipate that results of this study will be of wide interest to communities throughout the study area, i.e., the Gulf of Alaska from Prince William Sound to Unimak Pass.

PROJECT DESIGN

A. Objectives

1. Acquire outstanding data identified as useful but not yet entered into electronic format, and get it onto a computer database.

2. Combine all data sets into a common ASCII comma-delimited database for analysis by all the co-investigators.

3. Start exploratory data analysis using relational database software and statistical analytical tools.

4. Transform datasets into a GIS mapping database for geographical analysis with ARC-INFO (or equivalent).

5. Produce a paper for publication on the first phase of the project, describing some species trends and extent of changes in the GOA ecosystem during the last three decades.

B. Methods

Most of the data used in the analyses derive from small-meshed sampling gears used during trawls for shrimp in the Gulf of Alaska between 1953 and 1995. Also included for analysis were hauls conducted by the International Pacific Halibut Commission (IPHC) when small mesh liners were added to their standard sampling gear. Almost all of the small mesh tows of ADF&G and NMFS since 1971 have been conducted with the same sampling gear, i.e., the 61' high-opening shrimp trawl. This gear as described by Wathne (1977) is designed to sample the water column from 0.4 to 5 meters above the sea floor and has an opening of about 10 m wide.

Surveys were designed to sample shrimp (biomass) abundance. However, other benthic and pelagic species were quantified by weight and, in later years, by numbers as well. Most surveys were conducted in the months that dense aggregations of pandalid shrimp form in relatively deep water prior to mating and spawning (Anderson 1991). Early research had shown that shrimp concentrate in depths greater than 70 m (Ronholt 1963; Anderson, 1991). As a consequence, all survey tows were restricted to depths greater than 55 m in years after 1970 in order to target primarily on shrimp.

Stations were sampled during daylight hours using 32 to 50 mm mesh trawls. Tow duration was approximately 30 minutes; average tow length for the forty years (NMFS database) being 2.18 km (s.d.=0.46 km). Biomass estimates are conservative for small species because they are not fully vulnerable to capture (Anderson 1991). Survey catches were sorted by species and all species were weighed separately. Occasionally catches were so large that sub-sampling of the catch was employed, using the method described by Hughes (1976). Subsamples were counted to obtain the average weight of individuals. All shrimp, juvenile fish (mostly Pleuronectidae) were combined, weighed, and subsampled for species composition. The subsampled species groups were then counted and weighed using a triple-beam scale to the nearest gram. The extrapolated weights of each species were added to those of the adults of the same species.

In the early years (1953-1962), only primary commercial species were enumerated, and usually the top four or five species in a catch were recorded. Gradually as the surveys were designed to provide more useful information to a broader user group, more data were collected. Since 1970, everything in survey catches were sorted and sampled. In general, haul data contain details on the location, time, depth, temperature, and gear type employed for a given sampling. Catch data usually identified species to the lowest taxon possible, the total weight of the species caught and the number of individuals.

Fishes and invertebrates observed during these small-mesh surveys and the relative importance of species and species groups within the areas surveyed is largely a function of the sampling gear deployed. Trawls are size-selective, and different species have different likelihoods of capture. The degree to which the "apparent" distribution and abundance differ from the actual is unknown. Therefore, estimates of species trends will be representative only for those species, and sizes of species which are vulnerable to the trawl (Alverson et al. 1964).

Some of the data collected in the early years do not have good position information in the on-line data sets. However, original working charts are available and depending on time and funds, these on-line data could be upgraded for future use.

The focus of this study will be directed towards the relative abundance and distribution of forage species mentioned above. Many of the main study species are true forage species such as capelin, sandfish, and eulachon. Many others serve a dual role acting as forage when they are juveniles and then as predators when they grow in size. Examples of this latter group are cod, pollock, and flatfish. One of the declining species that has been studied is the longsnout prickleback which may be an important forage species only during its juvenile phase. Other species, including jellyfish, will be examined in future analyses to assess evidence for large-scale changes in community structure.

C. Contracts and Other Agency Assistance

Personal Services contracts will be used to provide assistance for entering data into electronic format. Some funds may be used to pay overtime associated with these tasks. Other specialized tasks such as the analysis of data by use of GIS programs will require the talents of a mapping professional, again by personal services contract. Details of these contracts have not yet been established.

D. Location

Elements of the project will take place at Homer, Anchorage, Kodiak, and possibly Cordova. The majority of the data analysis and GIS work will take place in Kodiak.

SCHEDULE

A. Measurable Project Tasks for FY 96

Start-up to April 1:	Get identified source data into electronic format.
April 2 to May 30:	Decide on common format for combined database and produce comma-delimited data tables.
June 1 to October 1:	Start exploratory data analysis and structuring of data for GIS work.
October 2 to March 31:	Complete first draft peer-reviewed paper.
April 1997:	Annual report on FY 96 work.

B. Project Milestones and Endpoints

For FY 96:

1. Combination of the diverse datasets into ASCII comma-delimited tables.

2. Exploratory data analysis starts / GIS data entry starts.

3. Produce first peer-reviewed paper on species changes.

4. Develop working hypotheses on results of exploratory analysis.

5. Plan analyses geared to addressing hypotheses.

Subsequent years of work will consist of detailed analyses of data geared towards testing specific hypotheses, production of peer-reviewed publications, and production of CD-ROM database.

C. Project Reports

First peer-reviewed paper will be produced in early 1997. Subsequent papers and progress reports will follow on schedule.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

Close coordination has been developed between ADF&G and NMFS in the production of the combined data set. NBS has provided assistance and direction in the development of this research project. It is also anticipated that the NBS will be providing assistance in the GIS phase of the project, and with planning of strategies for data analysis and reporting.

This project would not have been conducted as a normal function of the ADF&G and NMFS agency programs. Funding for maintaining shrimp surveys has been reduced and almost eliminated due to the demise of the commercial fishery. Focus of the research is now directed toward defining abundance of both commercial and non-commercial species and understanding the role of pelagic species. No formal funding for this work is currently anticipated in either agency.

ENVIRONMENTAL COMPLIANCE

Not applicable to this project.

APEX: Numerical and Functional Response of Seabirds to Fluctuations in Forage Fish Density

Project Number:	96163M
Restoration Category:	Research (new)
Proposed By:	National Biological Service
Lead Trustee Agency:	DOI
Cooperating Agencies:	ADF&G
Duration:	6 years
Cost FY 96:	$214 K (additional $160 anticipated funding from Minerals Management Service (MMS))
Cost FY 97:	$374 K (reflects anticipated loss of MMS funding)
Cost FY 98:	$389 K (level funding, plus 4% for inflation)
Cost FY 99:	$405 K (level funding, plus 4% for inflation)
Cost FY 00:	$120 K (data analysis, reporting)
Geographic Area:	Cook Inlet, Gulf of Alaska
Injured Resource:	Multiple resources

ABSTRACT

Present-day conditions in the Gulf of Alaska ecosystem, particularly with regard to forage fish, may not favor the recovery of seabirds lost to the *Exxon Valdez* oil spill. A key question is whether the density and quality of available forage fish are adequate to support seabird population growth. This long-term study is designed to measure the foraging (functional) and population (numerical) responses of six seabird species to fluctuating forage fish densities at three colonies in Cook Inlet. This involves at-sea surveys (hydroacoustics, trawling, seining) of forage fish while measuring aspects of seabird breeding biology and foraging behavior at adjacent colonies.

INTRODUCTION

Some seabird populations in the Gulf of Alaska have declined markedly during the past few decades (Hatch and Piatt 1995; Piatt and Anderson 1996). Whereas human impacts such as those from the *Exxon Valdez* oil spill can account for some proportion of these declines (Piatt *et al.* 1990c; Piatt and Naslund 1995), natural changes in the abundance and species composition of forage fish stocks have also affected seabird populations (Decker et al. 1994; Piatt and Anderson 1996). Marine fish communities in the Gulf of Alaska changed dramatically during the past 20 years (Anderson et al. 1994). Coincident with cyclical fluctuations in sea-water temperatures, the abundance of small forage fish species such as capelin (*Mallotus villosus*) declined precipitously in the late 1970's while populations of large predatory fish such as walleye pollock (*Theragra chalcogramma*) and cod (*Gadus pacifica*) increased dramatically. Correspondingly, capelin virtually disappeared from seabird diets in the late 1970's and were replaced by juvenile pollock and other species in the 1980's (Piatt and Anderson 1996). Seabirds and marine mammals exhibited several signs of food stress (population declines, reduced productivity, die-offs) throughout the 1980's and early 1990's (Merrick et al. 1987; Piatt and Anderson 1996). Similar trends in oceanography, seabird population biology and prey availability have been noted in the Bering Sea, although the cycle there appears to be offset by 4-5 years from events in the Gulf of Alaska (Decker et al. 1994; Springer 1992).

Factors that regulate seabird populations are poorly understood, but food supply is clearly important (Cairns 1992b). In many cases, anthropogenic impacts on seabird populations cannot be distinguished from the consequences of natural variability in food supplies (Piatt and Anderson 1996). Thus, 'management' of seabird populations remains an uncertain exercise. For example, how can we enhance recovery of seabird populations lost to the *Exxon Valdez* oil spill if food supplies in the Gulf of Alaska limit reproduction? Would commercial fishery closures reduce or increase food availability to seabirds? What are the minimum forage fish densities required to sustain seabirds, and how do we maintain those critical densities?

We will attempt to answer some of these questions by studying seabird and forage fish interactions in lower Cook Inlet. Upwelling of oceanic water at the entrance to Cook Inlet creates a productive marine ecosystem that supports about 2-3 million seabirds during summer. More seabirds breed here than in the entire northeast Gulf of Alaska (including Prince William Sound) and concentrations at sea (up to 90 kg/km^2) are among the highest in Alaska (Piatt 1994). For these reasons, the greatest damage to seabirds from the *Exxon Valdez* oil spill occurred in lower Cook Inlet (Piatt et al. 1990).

Pilot studies were initiated in 1995. The overall objective was to quantify and contrast seabird-forage fish relationships at three seabird colonies in lower Cook Inlet: Chisik Island, Gull Island (Kachemak Bay), and the Barren Islands. The abundance and species composition of forage fish schools around each colony were quantified with hydroacoustic surveys, mid-water trawls, and beach seines. At each colony, we measured breeding success, diet composition, and foraging effort of several seabird species including: common murres, black-legged kittiwakes, pigeon guillemots, pelagic cormorants, glaucous-winged gulls, tufted puffins and horned puffins. Preliminary analyses indicate that the types and quantities of forage fish available to seabirds at each colony differed significantly, and this influenced breeding success of seabirds at each colony.

This research program will be continued in 1996, but refined and expanded where appropriate. For example, we will increase hydroacoustic sampling of nearshore habitats, try some new fishing techniques (pair trawls, cast-nets, gill-nets), increase study effort on some species of seabirds (pigeon guillemots, puffins, cormorants) and forage fish (sand lance), and attempt radio-telemetry studies of seabird foraging behavior. The basic components of this study will not change, however, and we will measure the same fundamental parameters of forage fish and seabird biology for the duration of the study (1996–1999).

NEED FOR THE PROJECT

A. Statement of the Problem

Research has provided few clear examples of how aspects of seabird population biology or feeding ecology vary with changes in prey availability (Hunt et al. 1991). Consequently, it has been difficult to assess the degree to which the *Exxon Valdez* oil spill affected seabirds because natural changes in forage fish stocks may have also contributed to declines and reduced productivity of seabird populations. It is currently impossible to predict whether seabird populations will (or can) recover from losses incurred from the spill. The basic problem is that known ecological relationships between seabirds and forage fish are largely descriptive—few or no quantitative data exist to model functional relationships in the spill area.

B. Rationale

Functional relationships between seabird predators and their prey are poorly known because the vast majority of seabird research has been conducted on colonies without benefit of concurrent studies at sea on prey availability and seabird foraging behavior (Hunt et al. 1991). The response of seabirds to environmental change can vary widely among species, and is influenced by a host of physical and biological factors. Differential adaptations of seabirds for exploiting plankton and fish, widely-varying foraging abilities and breeding strategies, and complex relationships between oceanography and prey dispersion, abundance, and behavior all serve to complicate our interpretation of changes in seabird population biology. Therefore, in order to assess the potential for recovery of seabirds affected by the *Exxon Valdez* oil spill, a concurrent, multi-disciplinary study of oceanography, forage fish, and seabirds is required. This project will parallel the PWS study, but differs in having two oiled sites: one very productive site (The Barrens) and the second site where food appears to have recovered (Kachemak Bay), as well as one unoiled site where food is scarce.

C. Summary of Major Hypotheses and Objectives

We are attempting to define relationships between seabird population dynamics and food supply. For any species, this relationship can be characterized by quantifying components of the "numerical (population) response" and "functional (foraging) response" of seabirds to variations in prey density (Holling 1959; Murdoch and Oaten 1975; Piatt 1987). The "numerical response" includes components of population biology such as adult survivorship, clutch size, and reproductive success. The "functional response" includes components of foraging such as feeding rate, time spent foraging, and foraging range.

The overall objective of this study is to quantify components of seabird reproductive and foraging biology at colonies while simultaneously measuring the distribution, density and species composition of forage fish schools in adjacent waters. It has been hypothesized (Table 1) that these components are non-linear functions of prey density and sensitive to different thresholds of prey density (Piatt 1987; Cairns 1987, 1992a, b). Data collected in this study will allow us to characterize response curves and thresholds for several different seabird species and then go on to test other hypotheses about seabird-forage fish relationships (Table 2). For example, is seabird recovery from the *Exxon Valdez* oil spill limited by current forage fish densities? Do different seabird species have different thresholds to prey density? Can some species adjust foraging effort to compensate for fluctuating prey densities? Can seabirds compensate for differences in prey quality? Do weather and oceanographic conditions influence prey distribution and therefore seabird foraging success? None of these questions (hypotheses) can be addressed without a clear understanding of the underlying functional and numerical responses.

D. Completion Date

Marine ecosystems can vary markedly over time and between geographic areas, so our approach of studying three different colony areas simultaneously during several breeding seasons is an appropriate and cost-effective research strategy. We anticipate that it will take a minimum of five summers (FY 95–99) of field research to quantify the functional and numerical responses of seabirds to fluctuations in forage fish density. It will require a minimum of two additional years (FY 2000–2001) to analyze data and publish the findings of the study in scientific journals.

COMMUNITY INVOLVEMENT

Gull Island in Kachemak Bay is owned by the Seldovia Native Association (SNA). Limited subsistence use occurs during summer, with occasional egging and harvesting of juvenile birds (Fred Elvsaas, pers. comm.). It is also a major tourist attraction for visitors to Homer. Permission to work on and around the island was obtained in 1995 with the provision that annual reports of findings be made available to the SNA. In 1996, we plan to visit the SNA in Seldovia to discuss our work, and present an overview of our research in lower Cook Inlet at the next Kachemak Bay Science Symposium in Homer. We also plan to inform the local tour boat operators about our activities so that our presence at the island can be explained to visiting tourists. Chisik Island and the Barren Islands are managed by the Alaska Maritime National Wildlife Refuge. We have employed tourist charter vessels from Homer to support field camps at these colonies. Chisik Island supports a small, seasonal fishing community and we have chartered small vessels for research there, and informed most of the summer residents about the purpose of our activities. The cannery on Chisik has provided logistic and material support, and we expect that relationship to expand over time.

PROJECT DESIGN

A. Background

Concurrent or coordinated studies of seabird breeding biology, feeding ecology, prey abundance and oceanography are remarkably few (e.g., Safina and Burger 1985, 1988; Monaghan et al. 1989, 1994; Hamer et al. 1991, 1994; Uttley et al. 1994). Following a collapse of capelin stocks and concern (Brown and Nettleship 1984) about the possible consequences for Atlantic Puffins (*Fratercula arctica*), detailed studies of the relationships between oceanography, capelin (*Mallotus villosus*), cod (*Gadus morhua*), common murres (*Uria aalge*), Atlantic puffins, and baleen whales were conducted in eastern Newfoundland in 1981-1985 (Montevecchi and Piatt 1984, 1987; Piatt and Nettleship 1985; Burger and Simpson 1986; Schneider and Piatt 1986; Cairns et al. 1987, 1990; Piatt 1987, 1990; Schneider and Methven 1988; Methven and Piatt 1989, 1991; Piatt et al. 1989; Schneider 1989; Burger and Piatt 1990; Schneider et al. 1990; Nettleship 1991; Piatt and Methven 1992).

Results of these studies provide an empirical basis for hypotheses about relationships between seabirds and their prey in a variable marine environment (Table 1). Relationships between population biology and feeding ecology can be quantified within an established framework of predation theory (Holling 1959; Murdoch and Oaten 1975; Piatt 1987). Adult survival and reproductive success (the "numerical response") of higher vertebrates depends largely on the rate at which food (energy) can be extracted from the environment (the "functional response").

For individual seabirds, the functional response incorporates all parameters relating to the capture of prey (Table 1). Studies have demonstrated or hypothesized that these parameters are non-linear functions of prey density that operate over time-scales of hours to days, and spatial scales of meters to kilometers. For example, foraging time declines with increasing prey density (Cairns et al. 1987; Monaghan et al. 1989, 1994) allowing more free time for other activities (Burger and Piatt 1990). Similarly, as prey densities increase, foraging ranges may contract by 10's of km (Cairns et al. 1990; Monaghan et al. 1994) resulting in a considerable reduction in foraging energy expenditure (Cairns et al. 1987) and greater prey harvests in the vicinity of colonies (Cairns et al. 1990).

Numerical response parameters for seabirds (Table 1) are, in the absence of stochastic mortality events (e.g., oil mortality), a direct function of food availability over longer time scales (months and years) and larger spatial scales (100's to 1000's of kilometers). Thus, population change in seabirds reflects day-to-day foraging success integrated over reproductive time-periods and the area over which populations are distributed (Cairns 1987, 1992a, b; Piatt 1987).

The numerical and functional responses of individual species to changes in prey density are almost always non-linear, frequently sigmoidal, and species-specific with regard to absolute density thresholds (Holling 1959; Murdoch and Oaten 1972; Piatt 1990; Piatt and Methven 1991). In other words, some seabird species may prosper at low levels of prey density while others require much higher densities (Piatt 1987, 1990). Cairns (1987) further hypothesized that components of the numerical and functional response in individual species of seabirds are sensitive to different levels (thresholds) of prey density. For example, adult survivorship (Fig. 1) is probably quite high over a wide range of medium to high prey densities, but at some low, critical level, adult survival diminishes rapidly. In contrast, when seabirds are constrained to forage locally during the breeding season and food demands are high (for both adults and chicks), then moderate to high prey densities are required to maintain high breeding success (Fig. 1).

Some species may be able to buffer against variation in their numerical and functional response by adjusting their foraging effort as prey densities fluctuate (Piatt 1987, 1990; Burger and Piatt 1990; Uttley et al. 1994; Monaghan et al. 1994). Other species may have little buffering capacity because they are pushed to their limits even under normal circumstances (Goudie and Piatt 1991; Hamer et al. 1994). Thus, in some species (e.g., murres), chick feeding rates or breeding success may not be affected over a wide range of prey densities because adults simply spend more time foraging to compensate for the change in prey density. Components of numerical and functional responses which may be buffered (Table 1) are therefore less sensitive indicators of prey fluctuations (Burger and Piatt 1990).

Numerical and functional responses are scale-dependent, and may be evident only when examined over appropriate temporal or spatial scales (Schneider and Piatt 1986; Piatt 1987, 1990). Weather, wind, and oceanographic processes profoundly influence the biology and distribution of prey species (Schneider and Methven 1988; Methven and Piatt 1991), and may largely determine the temporal and spatial scales at which seabird foraging occurs (Schneider 1989). Although physical processes can influence the density and availability of prey to seabirds, they should not change the basic direction and form of numerical and functional responses (Table 1), and probably have minimal effects on thresholds—which are largely a species-specific function of seabird body size and behavior (Piatt 1987 1990; Goudie and Piatt 1991).

The challenge is to measure the form and scale of seabird responses to prey fluctuations in light of variability in the marine environment. Quantifying responses of higher vertebrates in the field can be difficult because of logistical difficulties in measuring key parameters (Goss-Custard 1970), and the lack of power to manipulate predator and prey densities over the full range of possibilities (Piatt 1990). For seabirds, it requires the coordination of studies on breeding biology and behavior at colonies, and studies of seabird and prey dispersion at sea in relation to local oceanography.

B. Objectives

1. To describe and quantify the numerical and functional responses of seabirds (Table 1) to seasonal and annual fluctuations in local prey density at three colonies in lower Cook Inlet.

2. To describe spatial distributions of seabirds and prey, and measure the absolute densities of some prey schools, around three seabird colonies in lower Cook Inlet.

3. To test a number of hypotheses (Table 2) about how responses of different seabird species vary with regard to prey characteristics and oceanographic conditions.

4. To gather baseline data for lower Cook Inlet on: i) seabird populations, breeding biology, diets, and distribution; ii) prey distribution, relative abundance, and composition; and, iii) basic oceanographic parameters.

C. Methods

Measuring Responses:
A variety of techniques can be used to measure the numerical and functional responses of seabirds to prey density (Table 1), and all have been field-tested or refined in previous studies. The basic elements of the study require:

1. Hydroacoustic and fishery (trawl, gill-net, trap) sampling of an appropriate area around a colony study site (e.g., Piatt 1987, 1994; Piatt et al. 1990a; Hunt et al. 1993). Because potential foraging area increases geometrically with distance from the colony, the areal extent of surveys must balance the need for sampling of important foraging areas within the range of birds, with practical limitations of time and resources. Fish catches are needed to groundtruth hydroacoustic surveys and to assess species and age-class composition of prey schools (Piatt 1987; Schneider and Methven 1988).

2. Concurrent measures of physical parameters such as wind speed, sea state, sea surface temperature and salinity, and salinity-temperature profiles of the water column (e.g., Schneider and Methven 1988; Piatt et al. 1990a; Hunt et al. 1993).

3. Measuring components of the numerical response (Table 1). Most of these parameters can be easily measured at the colony by direct observation or measurement (e.g., Gaston et al. 1983; Harris and Wanless 1988; Wanless et al. 1982). Use of remote surveillance equipment can be helpful for measuring some parameters—reducing disturbance and increasing the intensity of observations (e.g., Piatt et al. 1990b). Estimating survival is a more time-consuming activity. It requires banding and re-sighting of adults in subsequent years (Sydeman 1993; Hatch et al. 1994).

4. Measuring components of the functional response (Table 1). Diet components require collection of adult and chick prey items, at colonies and at sea (e.g. Piatt 1987; Burger and Piatt 1990). Study of aggregation behavior require simultaneous surveys of seabird and prey dispersion at sea (Piatt 1990, 1994; Piatt et al. 1990a). Aspects of seabird foraging behavior (range, dive times and depths, activity budgets, chick feeding rates) can be studied by a combination of observations at colonies and the use of remote sensing equipment—in particular radio telemetry (e.g., Wanless et al. 1988, 1991; Monaghan et al. 1994; Uttley et al. 1994), time-depth recorders (TDR's; Croll et al. 1992; Burger et al. 1993), and activity budget recorders (Cairns et al. 1987, 1990).

As a practical matter, it takes a minimum of one year to obtain a numerical response data point (e.g., breeding success vs prey density) from one colony. However, many functional response parameters can be measured against prey density on a daily basis, and so multiple data points can be obtained within a breeding season. Response curves cannot be characterized unless an adequate number of data points are obtained both above and below threshold values (Hassell and May 1974). For example, one might measure murre breeding success and local prey density over 15-20 years, but if murres always had high breeding success (because seasonal prey densities never fell below threshold levels), then one could not properly characterize a numerical response curve for murres nor determine the threshold prey density required for successful breeding (Fig. 2). For this reason, it would take a minimum of about 15-20 years, and perhaps much longer, to assess the threshold prey densities required to support seabirds at a single colony site (Table 1, Fig. 2). In contrast, it should only require a few years to characterize functional response thresholds to varying prey density.

Study Design:
The approach used in this study will be to quantify the numerical and functional responses of seabirds at spatial scales ranging from fine (m to km, Gull Island in Kachemak Bay) to moderate (1-100's km, lower Cook Inlet). Similarly, and where possible, variability in response parameters will be measured at small (daily, seasonal) and moderate (annual) temporal scales. At fine and moderate spatial scales, six species of seabirds will be studied simultaneously at three

different colonies in lower Cook Inlet. Species to be studied include two surface-feeding seabirds (kittiwake and glaucous-winged gull), two pelagic-diving seabirds (common murre and puffin), and two benthic-diving seabirds (cormorant and guillemot). Some of these species forage mostly near shore (<5 km) whereas others feed more offshore (± 60 km; Piatt 1994).

Studies will be carried at Gull, Chisik and Barren islands in lower Cook Inlet (Fig. 3). Gull and Chisik islands provide an excellent contrast for studies of numerical and functional responses because they: i) have a similar suite of breeding species; ii) have markedly different population dynamics (Slater et al. 1994); and, iii) differ markedly in their local oceanographic regimes. Whereas Gull Island seabird populations have increased by 40–80% over the last decade (Fig. 4), Chisik Island populations have declined by similar magnitudes during the same time period. Breeding success of kittiwakes at Gull Island has been consistently high during the past decade (1983–1994), whereas breeding success of kittiwakes at Chisik Island, and indeed throughout the Gulf of Alaska (GOA), has been very low during the same period. Kittiwakes have failed at Chisik in almost every year (n=10) of study since 1970. The Barren Islands have not been studied as well, but they share a similar suite of species and breeding success has varied between poor and excellent during the past 20 years (Manuwal 1980; Boersma et al. 1993; Roseneau et al. 1994).

The Alaska Coastal Current enters Cook Inlet around the Barren Islands (Fig. 5), leading to intense upwelling of cold, nutrient-rich waters onto shallow shelf areas of southeast Cook Inlet (Piatt 1994). This apparently enhances fish production on the shelves, which in turn supports high densities of coastal and shelf species of seabirds around the Barren Islands and in Kachemak Bay. In contrast, warm southward-flowing waters on the west side of Cook Inlet support lower densities of seabirds (Agler et al., unpubl. data), and presumably lower densities of forage fish species. During the course of this study, oceanographic features will be characterized by taking temperature-salinity profiles of the water column and sea surface, and from AVHRR satellite imagery.

The distribution and abundance of prey species will be measured hydroacoustically (using a BIOSONICS DT4000 digital echosounder) and with trawls (bottom, midwater) over an area extending at least 60 km away from the colonies and including all of lower Cook Inlet (Fig. 3). This is an expansion of the area studied in 1995, and will be possible using the USFWS Research Vessel *Tiglax,* which will be available for this work from July 14–26 in 1996. Trawling with be conducted from a different vessel (ADF&G *Pandalus*) during the time that hydroacoustic surveys are conducted from the *Tiglax*. Shoreline habitat (<100 m from shore) within the core study areas (Fig. 3) will also be hydroacoustically surveyed in a small vessel (11 m) at the same time. To examine variability at fine temporal and spatial scales, transects will be conducted around Gull Island repeatedly during the breeding season. A subset of transects from the large-scale and fine-scale surveys will be randomly selected to extrapolate total abundance of prey and seabirds within foraging range of each colony. Prey specimens collected from trawls and seabird chicks will be examined to assess species composition, sex-ratios, body condition, and energetic content. In addition to trawling, we will sample nearshore fish schools using beach seines, a Kodiak pair-trawl, gill-nets and cast-nets.

It would be desirable to measure as many response parameters (Table 1) as possible at Gull, Chisik and Barren islands. Based on our experience in 1995, efforts will concentrate on measuring those parameters that are most important and logistically feasible. For the numerical response, basic data will be gathered (where possible) on clutch size, brood size, hatching success, and/or fledging success to obtain some measure of overall breeding success for all six seabird species. Chick growth rates and fledging weights will be measured for a few species (e.g., kittiwakes, murres, puffins). To obtain these data, field camps will be established on the Chisik and Barren islands, and Gull Island will be visited frequently by boat.

To measure functional response parameters, we will focus our efforts on Gull and Chisik islands and coordinate with the AMNWR to collect similar data at the Barren Islands. Seasonal variability in activity budgets and chick feeding rates will be assessed through a combination of direct observations at the colonies (blind watches), use of video cameras, and a pilot study using radio telemetry to monitor colony attendance and foraging activity (e.g., Wanless et al. 1988, 1991; Monaghan et al. 1994; Uttley et al. 1994). Aggregation behavior and foraging ranges will be assessed from the pelagic surveys and radio telemetry. Diet information will be obtained by collecting chick meals at the colonies. Traditional dietary analyses will be supplemented with studies using stable isotope ratio analyses (Hobson et al. 1994). Whole prey obtained from seabirds and by net-sampling will be analyzed for proximate lipid content (Montevecchi and Piatt 1984).

Hypothesis Testing:
Data gathered over many years on numerical and functional responses of seabirds to variations in prey density (Table 1) can be used to test a variety of hypotheses (Table 2) about how seabirds respond to changes in their marine environment.

At the largest scales of study, we wish to know whether long-term changes in forage fish abundance are due to changes in marine climate (hypothesis 1; Anderson et al. 1994), and whether these changes are responsible for seabird population declines (hypothesis 2; Piatt and Anderson 1996). As oceanographic conditions may cycle over periods of 18 years (Royer 1993), it would probably take at least 1-2 cycles to assess relationships between oceanography, forage fish, and seabird population changes. However, some historical data for the past 20 years are available already (Piatt and Anderson 1996), and analysis of more historical data might be adequate to test hypothesis 1.

We can test hypothesis 3 (Piatt and Anderson 1996) in the absence of historical information if we establish present-day forage fish densities and measure numerical and functional responses to prey fluctuations around colonies impacted by the *Exxon Valdez* oil spill. As described above, this might require 15-20 years of study at any one colony. However, this study is designed to measure and contrast the functional and numerical responses of coexisting seabird species at thriving and failing colonies. This greatly increases the probability of obtaining sufficient data to characterize responses over a range of high and low values and decreases the time needed to do so from 15-20 years to perhaps 5-10 years (Table 2).

Hypotheses (3-5) about the exact form of numerical and functional responses (Cairns 1987), differences between species in their responses (Goudie and Piatt 1991), and variability in responses (Piatt and Anderson 1996) can all be tested within the course of the proposed study. Similarly, with concurrent studies of oceanography, it should be possible to also test hypotheses (7-11) about how weather and oceanographic conditions influence prey density and distribution in the water column, and ultimately seabird foraging success (e.g., Schneider and Methven 1988; Methven and Piatt 1991; Hatch et al. 1993).

The remaining hypotheses can be tested by special studies. Prey species will be collected from trawls and chick meals and analyzed for proximate composition (Montevecchi and Piatt 1984, 1987) to determine if they differ significantly in quality (hypothesis 12). Such analyses have already been completed for 10 forage fish species from the Gulf of Alaska (96163 G; Piatt et al., in prep.). Effects of differing prey quality on chick growth, foraging effort, and breeding success (hypotheses 13-15) require directed studies at colonies. Finally, the hypothesis (16) that different forage fish have different schooling characteristics can be tested by detailed hydroacoustic and trawl surveys of forage fish in Kachemak Bay.

D. Contracts and Other Agency Assistance

An Interagency Agreement will be established with the Alaska Department of Fish and Game for $40,000. This will be used to charter the R/V *Pandalus*, a 20 m research vessel based in Homer. As in 1995, the charter provides a vessel with mid-water trawl capabilities, accommodations for 4 researchers, a crew of 3 including Captain, deckhand and cook, and food while at sea. This vessel will be used to trawl for fish schools located on hydroacoustic surveys in June-August.

A Research Work Order will be established with the University of California, Irvine for $23,300 in FY 96. This will support a post-doctoral student (Alexander Kitaisky), working under supervision of Dr. George Hunt Jr., to be involved with field work and data analysis from June-November 1996. Kitaisky's expertise is in seabird growth, energetics, and feeding ecology and he will be responsible for research in this area. We plan to continue collaboration with Hunt and Kitaisky for the duration of this project (1996-1999).

A Research Work Order will be established with the University of Alaska, Fairbanks for (up to) $20,000 for use of the Kasitina Bay Research Lab located on the south side of Kachemak Bay. This marine laboratory will provide field accommodations for up to 12 biologists, laboratory facilities for analyses of fish and seabird collections, and working space for data entry and analyses. The lab is supported by full-time staff with expertise in vessel maintenance and piloting, as well as on-site logistic support (small boats, vehicles, communications, etc.). Public dock facilities are located near the laboratory.

A Special Services Contract for up to $25,000 will be established with a local business in Homer to repair and outfit a vessel for research in lower Cook Inlet. An 11 m vessel was obtained in 1995 at no cost from the U.S. Navy in Adak. Although the hull (31 foot) and engines (twin 200 h.p. Volvo diesels) are in good condition, the vessel requires an overhaul and outfitting for research work (davit for hydroacoustics, A-frame for CTD and plankton tows, etc.).

E. Location

As noted above, research will be based out of the Kasitina Bay Research Lab in Kachemak Bay. Research will be conducted at and around Gull Island in Kachemak Bay, Chisik Island in western Cook Inlet, and the Barren Islands at the mouth of Cook Inlet. Communities that may have an interest in results of the study include Anchor Point, Homer, Seldovia, English Bay, Port Graham, and Kodiak.

SCHEDULE

A. Measurable Project Tasks for FY 96

January-April: Preparations for field work, equipment acquisition, hiring personnel, establish contracts and work orders

May: Initiate seabird and hydroacoustic surveys in Kachemak Bay. Trawl sampling in mid-May. Set up field camps and/or study plots and gather data on seabird populations and productivity on Chisik, Gull, and Barren Islands.

June: Continue pelagic surveys, and colony observations. Trawling in Kachemak Bay on mid-June. Test other fishing methods (pair-trawl, gill-nets, etc.). Colony censusing and plot monitoring.

July: Continue pelagic surveys, and colony observations. Initiate pilot studies using radio telemetry. Trawling and hydroacoustic surveys in lower Cook Inlet, July 14–26 using *M/V Tiglax* and *R/V Pandalus*. Initiate colony observations on chick feeding activity and adult attendance.

August: Continue pelagic surveys, colony observations, telemetry studies, feeding rate and attendance observations, and fish sampling.

September:	Field work ends in mid-September. Field camps removed from Chisik and Barren Islands. Hydroacoustic surveys and nearshore fish sampling continue to end of September.
October-April 97:	Data analysis and compilation of results.
February-March:	Preparations for FY 97 research.
February 1997:	Annual Report on FY 96 research.
April 1997:	Initiate field work for 1997.

B. Project Milestones and Endpoints

The entire project revolves around our ability to accomplish objective 1: To describe and quantify the numerical and functional responses of seabirds to seasonal and annual fluctuations in local prey density at three colonies in lower Cook Inlet. Objective 3 will require at least three years of work before attempting to summarize conclusions. Objectives 2 and 4 will necessarily have been accomplished if objective 1 is achieved. At a minimum, to do this requires that in each year of the project we have:

1. Obtained quantitative measures of clutch size, brood size, hatching success, fledging success, or overall breeding success for each of six seabird species breeding at the three study colonies.

2. Obtained quantitative estimates of relative acoustic biomass of forage fish within foraging range of the three study colonies.

3. Obtained quantitative measures of fish school composition and absolute estimates of identified forage fish school densities in each study area.

4. Obtained quantitative estimates of seabird diet composition, chick feeding rates, adult foraging effort, and adult foraging dispersion at each of the three study areas.

With these minimum data collected in each year, it should be possible by the year 1999 to plot numerical and functional response parameters against acoustic estimates of prey density to resolve the characteristics (shape, threshold) of seabird responses to varying prey density.

C. Project Reports

February 15, 1997:	Annual Report and Summary of work accomplished in summer 1996, and preliminary findings.

February 15, 1998:	Annual Report and Summary of work accomplished in summer 1997, and preliminary findings.
March 15, 1998:	Interim Report to summarize research findings from work in summers, 1995-1997. To include more extensive analyses of results and conclusions, especially from 1995-1996 work.
February 15, 1999:	Annual Report and Summary of work accomplished in summer 1998, and preliminary findings.
February 15, 2000:	Annual Report and Summary of work accomplished in summer 1999, and preliminary findings.
April 15, 2001:	Draft Final Report of field research, 1996-1999.
September 1, 2001:	Final Report.

In addition to the above, results will be published opportunistically in conference proceedings and scientific journals as analysis and synthesis take place. The first anticipated product will be for the International Conference on the Role of Forage Fish in Marine Ecosystems, to be held in Anchorage in November of 1996. Results of 1995-1996 work will be compiled for a paper in proceedings of this meeting.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

This long-term study plan addresses a number of research issues related to management and conservation of seabirds in Alaska as addressed by the U.S. Fish and Wildlife Service (USFWS) 'Seabird Management Plan' (USFWS Region 7, Migratory Bird Management). The proposed work will complement and be coordinated with: i) long-term studies conducted by the Alaska Maritime National Wildlife Refuge (AMNWR, USFWS Region 7), which includes annual monitoring of seabird productivity at 9 major seabird colonies throughout Alaska; ii) research being conducted by the National Marine Mammal Laboratory (Seattle) on forage fish abundance and composition around Stellar sea lion rookeries in Alaska; iii) ongoing studies of seabird populations in areas of oil and gas development conducted by the Minerals Management Service (MMS) in Alaska and the National Biological Service (NBS); and, iv) ongoing studies of marine fish and oceanography conducted by the University of Alaska, Fairbanks out of the Kasitina Bay Marine Lab in Kachemak Bay.

In FY 96, additional funding from Minerals Management Service is anticipated to equal $160,000 (budget pending). This represents the second and final year of funding for seabird studies in lower Cook Inlet obtained under Interagency Agreement between NBS and MMS. Base funds from NBS to support the principal investigator in FY 96 are anticipated to equal

$90,000 (budget pending), and most of this will be directed to the Cook Inlet study. Owing to Congressional budget cuts, both MMS and NBS funding are likely to be reduced from levels anticipated for FY 96. Logistic support from the AMNWR in FY 96, including use of the 40 m research vessel "Tiglax" for 12 days, and other equipment use (Boston Whaler, zodiacs, vehicles, etc.), is valued at approximately $70,000.

ENVIRONMENTAL COMPLIANCE

Permits for fish collections are required from the State of Alaska (ADF&G). No other permits or environmental evaluations are required to carry out the proposed research.

Table 1. Characteristics and measurement of seabird numerical and functional response parameters.

Measurable Parameters	Hypothesized Relationship to Prey Density				Measurement Time		Methods
	Direction	Form	Threshold	Buffer	Parameter	Response	
Numerical Response							
Adult survivorship	positive	-exponential	low	no	2 year	15-20 years	Banding/re-sighting
Juvenile survivorship	positive	-exponential	moderate	no	2-5 year	15-20 years	Banding/re-sighting
Clutch size	positive	-exponential	moderate	maybe	1 year	15-20 years	Visual observations (VO)
Brood size	positive	-exponential	moderate	maybe	1 year	15-20 years	VO, Remote camera observation
Hatching success	positive	sigmoidal	moderate	yes	1 year	15-20 years	Visual observation
Fledging success	positive	sigmoidal	moderate	yes	1 year	15-20 years	VO, Remote camera observation
Breeding success	positive	sigmoidal	moderate	yes	1 year	15-20 years	VO, Remote camera observation
Chick growth rate	positive	sigmoidal	moderate	yes	1 year	15-20 years	Direct measurement
Chick fledging weight	positive	sigmoidal	moderate	yes	1 year	15-20 years	Direct measurement
Functional Response							
Adult foraging time activity	negative	logarithmic	low	no	days	3-5 years	VO, Radio telemetry, TDR's
Adult free time activity	positive	-exponential	moderate	no	days	3-5 years	VO, Radio telemetry
Adult meal size	positive	sigmoidal	moderate	yes	days	3-5 years	Adult collections
Adult body mass	positive	-exponential	low	no	days	3-5 years	Adult collection/capture
Dive time, frequency, depth	negative	logarithmic	moderate	no	days	1-2 years	TDR's, Radio telemetry
Prey capture rate	positive	-exponential	moderate	yes	hours	1-2 years	Aquarium observations
Aggregative response (tracking)	positive	sigmoidal	moderate	no	hours	1-2 years	At-sea bird/hydroacoustic surveys
Aggregation index (group size)	positive	-exponential	low	no	hours	1-2 years	At-sea bird surveys
Foraging range	negative	logarithmic	moderate	no	days	3-5 years	At sea surveys, Radio telemetry
Adult diet diversity	negative	logarithmic	low	no	days	3-5 years	Collections, Stable isotopes
Chick diet diversity	negative	logarithmic	low	no	days	3-5 years	Collections, Stable isotopes
Chick feeding rate	positive	sigmoidal	moderate	yes	days	3-5 years	VO, Remote camera observations
Chick meal size	positive	-exponential	low	yes	days	3-5 years	Chick meal collections

Table 2. Hypotheses about relationships between seabirds, forage fish, and oceanography.

Hypothesis	Measurement	Scale of Study	
		Temporal	Spatial (km²)
1. Long-term changes in forage fish abundance and species composition in Alaska are a function of ocean climate	Hydroacoustic and trawl surveys; Predator diets; Oceanographic studies; Analyze historical data	18-36 Years	10,000's
2. Seabird breeding failures and population declines are due to changes in forage fish density/composition	Numerical and functional response to changes in prey density (see Table 1); Historical data	18-36 Years	10,000's
3. Seabird recovery from Exxon Valdez oil spill is limited by existing forage fish density/composition	Numerical and functional response to existing prey densities; Contrast thriving and failing colonies	5-10 Years	1,000's
4. Seabird species have different thresholds and/or respond to different levels of prey density	Contrast functional and numerical response of different seabird species	2-3 Years	100's
5. Large seabirds have more free time to adjust foraging effort as prey density fluctuates	Contrast functional response of different seabird species	2-3 Years	100's
6. Variability in numerical and functional response higher in low density specialists	Contrast variablity in functional and numerical response of different seabird species; Historical data	5-10 Years	100's
7. Prey density/distribution at sea surface is a function of thermocline/pycnocline depth	Hydroacoustic/trawl surveys; Oceanographic parameters	2-3 Years	10's
8. Weather (wind, sea state) affects foraging success of seabirds	Functional response parameters in relation to weather; Prey disperion and mixing of water column	1-2 Years	10's

Table 2 (cont.). Hypotheses about relationships between seabirds, forage fish, and oceanography.

Hypothesis	Measurement	Scale of Study	
		Temporal	Spatial (km²)
9. Annual variability in weather accounts for annual variability in foraging and breeding success	Functional and numerical response in relation to seasonal weather	5-10 Years	100's
10. Kittiwake (BLKI) foraging success limited by availability of prey at the sea surface	Contrast numerical and functional response of BLKI with diving species (murre, puffin, cormorant) at the same colony; Measure prey at surface	3-5 Years	100's
11. Prey availability for all seabirds limited by vertical distribution rather than overall abundance	Hydroacoustic and bird surveys, oceanography, Functional response	3-5 Years	100's
12. Prey species differ in quality (primarily energy content)	Collect prey from trawls, seabirds, and measure proximate composition	1-2 Years	N/A
13. Seabird chick growth limited by prey quality (energy content)	Experimental study of chick growth on low and high quality diets	2-3 Years	Colony
14. Seabirds work harder (adjust time foraging) to feed on low quality prey	Contrast functional response at colonies dependent on low and high quality prey	2-3 Years	Colonies
15. Seabird breeding success limited by prey quality (energy content)	Contrast colonies dependent on low and high quality prey using historical data and directed studies	2-3 Years	Colonies
16. Forage species have different schooling behaviors/densities	Hydroacoustic/trawl surveys	1-2 Years	10's
17. Seabird prey capture rate depends on schooling characteristics of prey	Laboratory/aquarium study of foraging behavior	1 Year	N/A

Fig. 1. Hypothesized form of numerical and functional responses of seabirds to variations in prey density. From Cairns (1987).

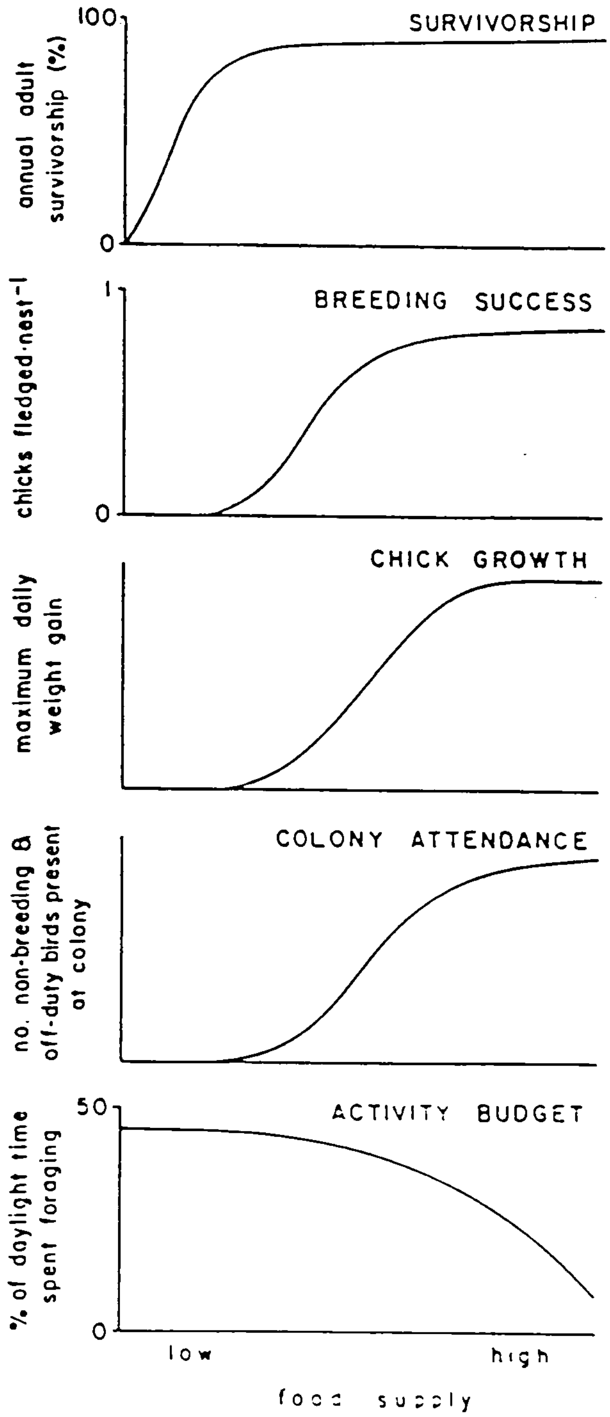
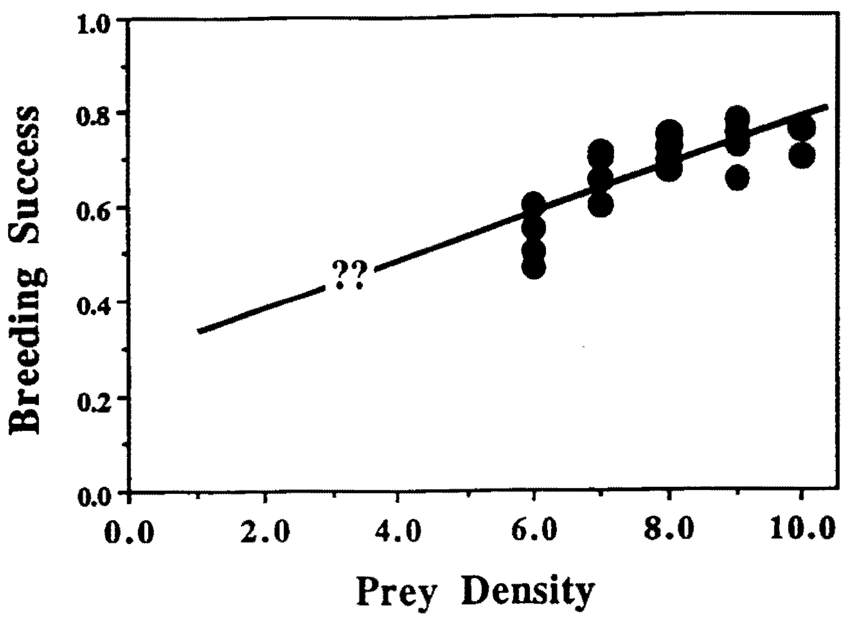


Fig. 2. Hypothetical results of a 15–20 year study of seabird breeding success versus prey density at a consistently successful colony (top graph), and at a colony with widely-ranging levels of breeding success (bottom graph).



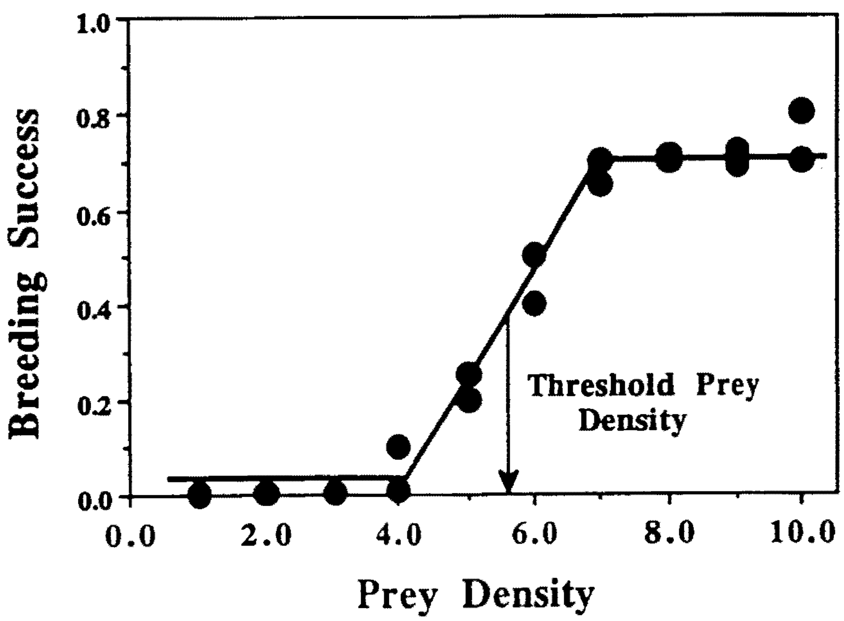


Fig. 3. Study areas in lower Cook Inlet. Seabird breeding biology and foraging behavior will be studied at Gull, Chisik and Barren islands. Minimal seabird foraging ranges (40 km) from colonies are shown as shaded areas, and represent core study areas around each colony. Solid lines indicate potential cruise track for 1996 hydroacoustic surveys to be conducted from the M/V "Tiglax".

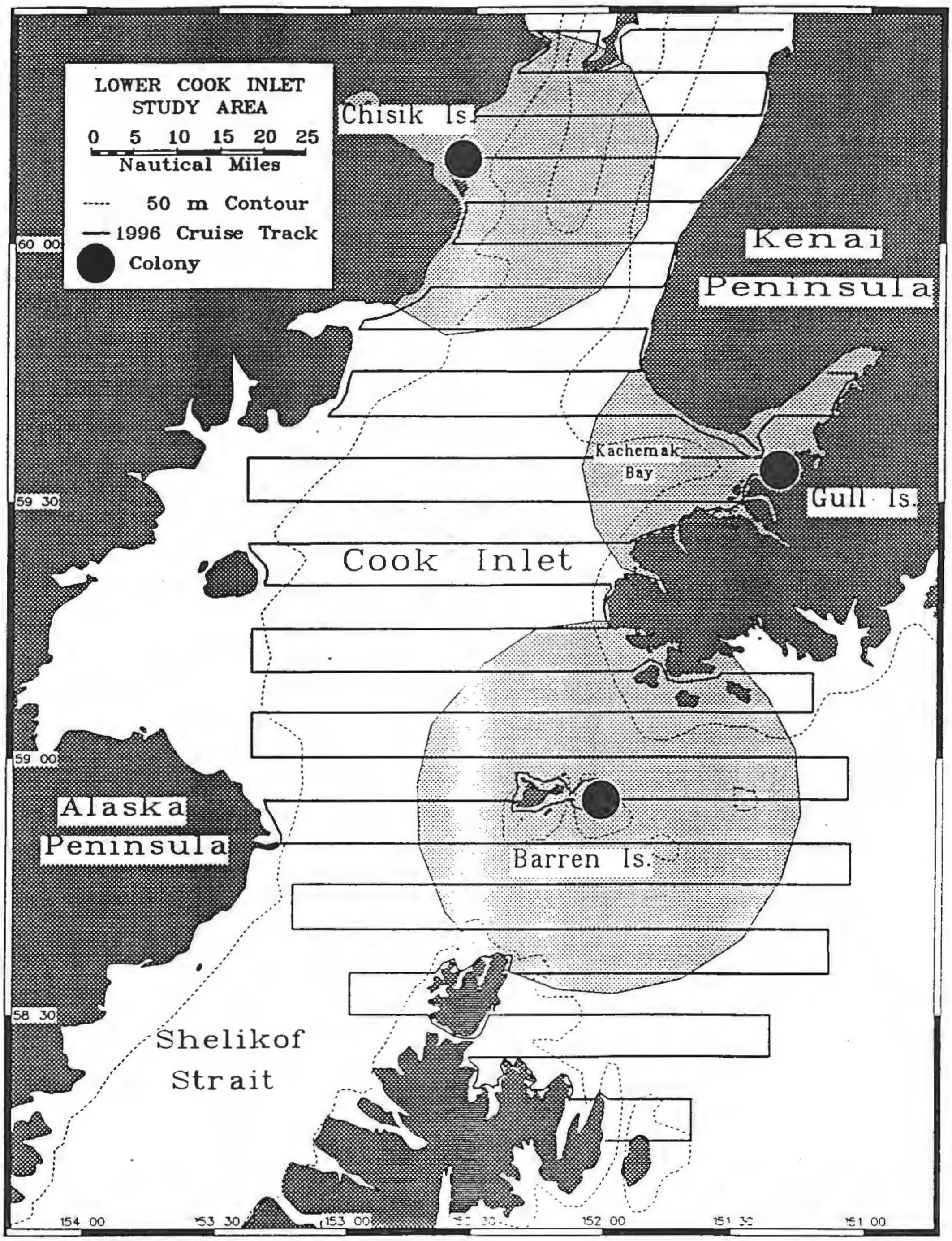


Fig. 4. Seabird population trends at Chisik and Gull islands. Counts for all species were scaled to the percentage of maximum numbers ever observed on all-island counts or study plots (from Slater et al. 1994). Most recent whole-island counts for all species combined were 13,000 and 22,000 individuals at Gull and Chisik islands, respectively.

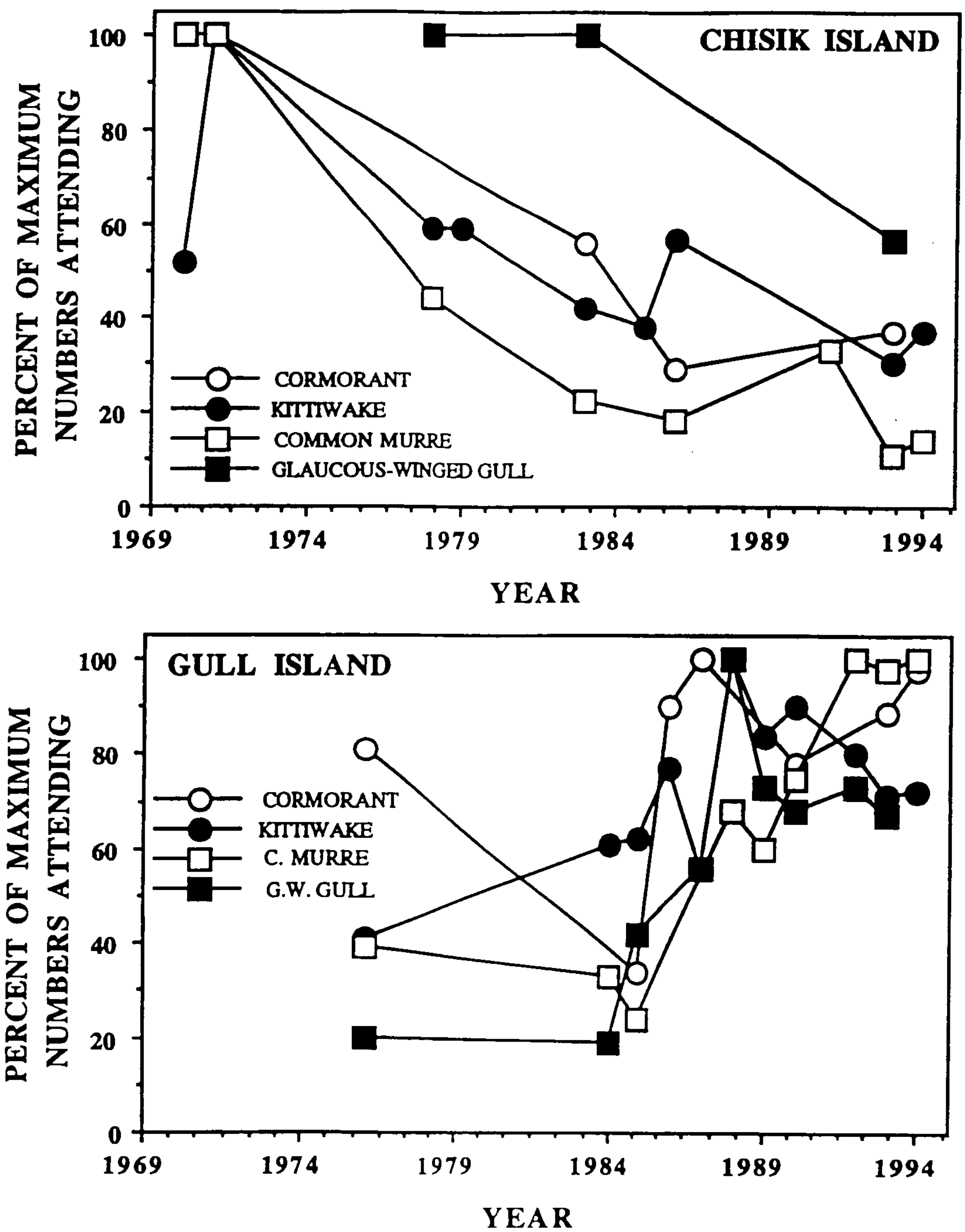
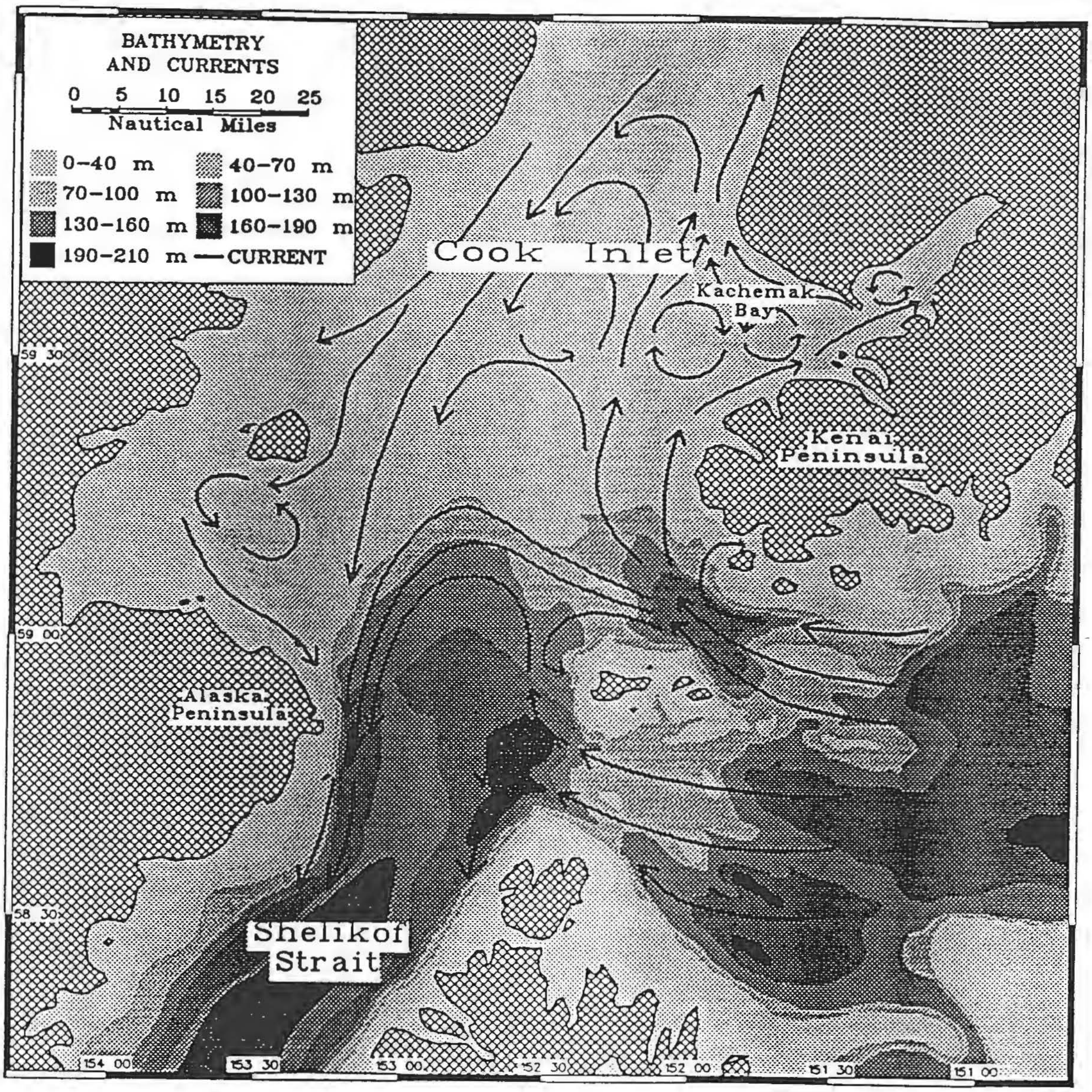


Fig. 5. Bathymetry and prevailing summer currents in lower Cook Inlet (from Piatt 1994; after Burbank 1977, Muench et al. 1978).



APEX: Effects of Diet Quality on Postnatal Growth of Seabirds: A Controlled Experiment

Project Number:	96163N
Restoration Category:	Research
Proposer:	National Biological Service
Duration:	3 years
Cost FY 96:	$20 K
Cost FY 97:	$30 K
Cost FY 98:	$15 K
Geographic Area:	Barren Islands, Kachemak Bay, Lower Cook Inlet
Injured Resource:	Multiple

ABSTRACT

Declines in the availability of high quality forage fishes (herring, sand lance, capelin) have apparently contributed to the lack of recovery of some fish-eating seabirds (murres, guillemots, murrelets) that were injured by the *Exxon Valdez* oil spill. This experimental study will test the hypothesis that diet quality (lipid content, energy density, lipid:protein ratio) constrains the growth, development, and survival of young piscivorous seabirds.

INTRODUCTION

Reproductive success in seabirds is largely dependent on foraging constraints experienced by breeding adults. This study is relevant to the management of declining seabirds and marine mammals in the *Exxon Valdez* oil spill area because it is designed to develop a better understanding of how shifts in the diet of breeding seabirds affect reproductive success. Understanding the role of diet quality as a constraint on productivity of seabirds breeding in the EVOS area will be highly relevant for designing management initiatives to enhance productivity in declining species. If forage fishes that are high in lipids are an essential resource for successful reproduction, then efforts can be focused on assessing stocks of preferred forage fishes and the factors that impinge on the availability of these resources within foraging distance of breeding colonies in the EVOS area. As long as the significance of diet composition is not understood, it will be difficult to interpret shifts in the utilization of forage fishes and develop a management plan for effective enhancement of critical food resources.

The proposed research is the first experimental study to investigate the effects of diet quality on growth and development of nestling kittiwakes and puffins. The research will result in a fundamental advance in our understanding of the significance of prey composition for both Black-legged Kittiwake (*Rissa tridactyla*) and Tufted Puffin (*Fratercula cirrhata*) reproduction, as well as for other pelagic seabirds and marine mammals that breed in the EVOS area. The research will also provide new information relevant to several additional areas of study: (1) comparative biochemical composition and nutritive quality of key forage fishes, (2) factors such as age class, sex, size, and reproductive status as they influence the nutritive quality of forage fishes, and (3) the energetic consequences to seabirds of foraging on different prey with differing energy content. This research will be the first to (1) use captive feeding trials to investigate the relationship between nutritive quality of the diet and growth performance of kittiwake and puffin chicks, and (2) relate differences in prey quality to food requirements in kittiwakes and puffins. In addition, the results will have broader implications for our understanding of dietary constraints on reproductive success in other seabirds in the EVOS area (i.e., Common Murre, Pigeon Guillemot, Marbled Murrelet) and will enhance our understanding of the adaptive significance of prey preferences in these seabirds. These results are crucial for understanding the factors limiting populations of marine birds and mammals in the EVOS area.

NEED FOR PROJECT

A. Statement of Problem

Recent declines among populations of top trophic level predators in the Northern Gulf of Alaska have been linked to decreasing availability of forage fishes. Several species of seabirds, including Black-legged Kittiwakes, Common Murres (*Uria aalge*), and Pigeon Guillemots (*Cepphus columba*), have experienced population declines in the EVOS area in recent years. Total breeding failure has been recorded at several sites (Chisik I., Middleton I., etc.) A lack of high quality, lipid-rich forage species to provision nestlings has been hypothesized as a factor in these declines. Also, in some areas Tufted Puffins have undergone a marked change in species composition of prey (Piatt and Anderson 1995), apparently in response to changing prey availability. Determining the relative nutritional value of particular forage fishes for seabirds breeding in the EVOS area will be necessary to assess the impact of changes in forage fish availability on seabird productivity.

B. Rationale

A major change in the taxonomic composition of puffin diets has been observed in the Northern Gulf of Alaska during the past 20 years. Specifically, adult Tufted Puffins and a variety of other seabird species switched from diets dominated by oily fishes, like capelin and sand lance, to those dominated by juvenile walleye pollock and other gadids (Piatt and Anderson 1995). Juvenile pollock are lower quality than other prey found in diets of nestling seabirds, due to lower lipid content and energy density (kJ/g) than fishes such as capelin or sand lance (Baird 1991; J. Piatt, unpubl. data). The energy density of juvenile pollock is c. 2.2 kJ/g wet mass, whereas that of capelin and sand lance varies from 2.6-4.9 kJ/g wet mass, depending on sex and age class (J. Piatt, unpubl. data).

Adult birds that rely on low quality prey to provision their young may experience lower productivity. If an adult were to provide the same amount of energy to its young in the form of juvenile pollock as it could by provisioning with sand lance or capelin it would have to deliver nearly twice as much food. This may not be possible due to time and energy constraints, unless pollock are readily available close to the colony. Consequently, slower growth and lower fledging weights would be expected in nestlings fed primarily pollock diets, resulting in fewer birds surviving to fledge and a reduction in post-fledging survival.

The proposed research will provide a better understanding of the relationship between diet quality and seabird productivity. Captive nestlings fed controlled diets of either pollock or sand lance will be used to compare the effects of low lipid: protein and high lipid and protein ratio diets. Also, by comparing results gathered from two different seabird species we will gain insight into differences in dietary requirements among seabirds.

C. Summary of Major Hypotheses and Objectives

Our primary hypothesis is that seabird diets consisting of high-lipid forage fishes (herring, sand lance, capelin) result in higher growth rates, shorter development times, and fledglings with larger energy reserves when compared to nestlings fed low-lipid forage fishes (walleye pollock, Pacific cod, tomcod). Nestlings will be raised in captivity on carefully controlled diets (either sand lance or juvenile walleye pollock) in order to unambiguously test the diet quality hypothesis as a constraint on production of young seabirds. The specific hypotheses to be tested by this research are (1) that sand lance are of significantly higher nutritional value for seabird nestlings than juvenile walleye pollock, (2) that lipid content is the main factor influencing nutritional quality of sand lance and juvenile pollock, (3) that chicks fed on sand lance will grow faster and fledge earlier at higher body mass and with larger fat reserves than those fed on juvenile pollock, even under conditions of similar caloric intake, and (4) that differences in growth performance due to diet quality will be more pronounced in a rapidly growing seabird (kittiwake) than in a slow growing seabird (puffin).

The overall objective of the proposed research is to determine the relationship between diet quality and the growth and development of seabirds damaged by the *Exxon Valdez* oil spill. Emphasis will be placed on examining the role of lipid content and lipid:protein ratios on postnatal growth in Black-legged Kittiwakes and Tufted Puffins.

D. Completion Date

This project will be completed in June 1998, after two breeding seasons and sufficient time to complete laboratory analyses, analyze data, and prepare manuscripts for publication.

COMMUNITY INVOLVEMENT

Every effort will be made to identify native or local undergraduates as candidates for the field assistant.

PROJECT DESIGN

A. Objectives

1. Determine the effect of differences in lipid content (% wet mass) of forage fishes on the growth and development of seabird nestlings.
2. Determine the effect of differences in lipid:protein ratios of forage fishes on the growth and development of seabird nestlings.
3. Determine if there are interspecific differences among seabirds in growth response of nestlings to variation in diet quality.

B. Methods

The research design utilizes a combination of captive feeding experiments and laboratory analyses. Captive feeding trials will be conducted during the 1996 and 1997 breeding seasons. In 1996, a sample of kittiwake chicks (N = 20) and puffin chicks (N = 20) will be removed from their nests at 5-8 days post-hatch and placed in individual indoor cages for captive feeding experiments. Kittiwake thermoregulation is well-developed at 6-8 days post-hatch (Barrett 1978). Puffin chicks are independent of parental brooding at 5 days post-hatch (Wehle 1983) and thereafter can be maintained in captivity at ambient temperatures without an artificial heat source. Tufted Puffin chicks readily adapt to captivity if kept by themselves in a dark container to simulate burrow conditions and take food (whole fish) from the hand within hours of being placed in cages (Wehle 1983). Black-legged Kittiwake chicks have been successfully raised in captivity (D. Roby, unpubl. data). Cages will consist of covered plastic buckets with bedding in the bottom. In 1997, the captive feeding trials will be completed by raising a sample of 10 kittiwake chicks and 10 puffin chicks. In addition, if a large enough sample size is obtained for both species in 1996, captive feeding trials utilizing Common Murres will be attempted in 1997.

The sample of chicks from each species will be divided into three diet treatment groups: (1) juvenile walleye pollock (*Theragra chalcogramma*) diet sufficient to support normal growth (N = 15 chicks per species), (2) iso-caloric diet of Pacific sand lance (*Ammodytes hexapterus*) (N = 15 chicks per species), and (3) iso-biomass diet of sand lance (N = 15 chicks per species). This will yield a 3 (treatment) X 2 (species) experimental design, with 15 chicks per cell. Variables to be measured daily in captive chicks include: (1) total body mass, (2) wing length, primary length, culmen length, and tarsus length.

When captive-reared chicks reach fledging age (c. 35 days post-hatch for kittiwakes [Barrett and Runde 1980] and c. 45 days post-hatch for puffins [Wehle 1983]) they will be sacrificed and frozen in portable propane freezers for later body composition analysis in the lab at OSU. Total body water, lean mass, total body fat, ash-free lean dry mass, ash mass, and ratio of body fat to lean dry mass (fat index) will be compared among the diet treatment groups. Carcasses will be weighed, partially thawed, plucked, and reweighed to determine plumage mass. Plucked carcasses will be air-dried at 60° C to constant mass in a forced convection oven in order to determine moisture content. Dried carcasses will be ground and homogenized by passing repeatedly through a meat grinder. Aliquots of the dried homogenate will be extracted in a Soxtec HT-12 soxhlet apparatus using petroleum ether as the solvent system in order to determine fat content. Extracted aliquots will then be ashed in a muffle furnace at 550°C to determine ash content. Body composition of birds from the captive-feeding experiments will be compared to determine the effects of energy intake and diet composition on the allocation of assimilated resources to growth in lean mass and fat reserves. Tissue samples of these birds will be made available to Dr. John Piatt for further analysis using stable isotope techniques.

Data on chick age-specific body mass, wing chord, and primary feather length will be separated by diet and fit to logistic growth models. Growth constants (K), inflection points (I), and asymptotes (A) of fitted curves will be statistically analyzed for significant differences among treatments and species. Food conversion efficiency of nestlings as a function of age will be calculated for captive-reared chicks by regressing the change in body mass over a 24 hour period against the mass of food consumed during the period. Comparison of food conversion efficiencies of chicks will provide an estimate of the relative energetic efficiency of diets composed of the two forage fish species provisioned at different rates.

Samples of juvenile pollock and sand lance that were fed to captive kittiwake and puffin chicks will be shipped frozen to Roby's laboratory at Oregon State University (96163G), where they will be subjected to proximate analysis. In the lab, forage fish specimens will be reweighed, identified to species, aged, sexed, measured, and reproductive status (gravid, recently spawned, nonreproductive) determined. Forage fish specimens will be dried to constant mass in a convection oven at 60° C to determine water content. Lipid content of a subsample of dried forage fish will be determined by solvent extraction using a soxhlet apparatus (Soxtec HT-12) and hexane/isopropyl alcohol 7:2 (v:v) as the solvent system. Lean dry fish samples will then be ashed in a muffle furnace at 550°C in order to calculate ash-free lean dry mass by subtraction. Energy content of chick diets will be calculated from the composition (water, lipid, ash-free lean dry matter, and ash) of forage fish along with published energy equivalents of these fractions (Roby 1991).

C. Contracts and Other Agency Assistance

The field portion of this research will be carried out by Marc Romano, a M.S. candidate in the Department of Fisheries and Wildlife at Oregon State University, with the aid of a volunteer field assistant. The volunteer field assistant will be an upper division undergraduate student who is majoring in the area of biology or wildlife. Dr. John Piatt of the National Biological Service, Alaska Science Center in Anchorage will serve as field supervisor, providing logistical support and hiring the volunteer. Proximate analysis of samples collected during the field season will be supervised by Dr. Dan Roby. Romano will conduct analyses in Roby's laboratory at OSU.

D. Location

The proposed captive-rearing experiment will be conducted at the Kasitsna Bay Laboratory of the Institute of Marine Science, University of Alaska Fairbanks, located in Kachemak Bay, Alaska. Arrangements have been made with the University to provide living space for two researchers (Marc Romano and a volunteer assistant), and laboratory space to conduct the controlled feeding trials.

Chicks to be used in the study will be collected from either East Amatuli Island in the Barren Islands group or Chisik Island in Lower Cook Inlet. A field camp will be established by the Alaska Maritime National Wildlife Refuge on East Amatuli and field crew members will assist in collecting the birds.

SCHEDULE

A. Measurable Project Tasks for FY 96

March-May:	Preparations for field work, equipment acquisition, hiring personnel.
May:	Begin catching fish to be used as food during captive feeding trials. This will continue throughout the summer as needed.
June:	Personnel will arrive at Kasitsna Bay prior to hatching of kittiwakes and puffins in Lower Cook Inlet. Begin marking accessible nests to obtain chicks for captive feeding experiment.
July-September:	Feeding experiment will continue until birds reach fledging age.
October-April 97:	Laboratory analysis of diet samples and fledgling carcasses.
February 1997:	Annual Report on FY 97 research.

B. Project Milestones and Endpoints

The three project objectives will be completed by the termination of the project in September 1998.

C. Project Reports

February 15, 1997:	Annual Report and Summary of work accomplished in summer 1996, and preliminary findings.
February 15, 1998:	Annual Report and Summary of work accomplished in summer 1997, and preliminary findings.
September 1, 1998:	Final Report.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

This research will serve to aid in the long-term management of seabird populations in relation to changes in forage fish stocks. The findings of this project will be of use to both the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS), among others. The proposed work will complement and be coordinated with: i) long-term research conducted by Dr. John Piatt and the National Biological Service (NBS) on the response of seabirds to fluctuations in forage fish densities (Project Number 96163M); ii) annual studies conducted by the Alaska Maritime National Wildlife Refuge (AMNWR, USFWS Region 7) in Lower Cook Inlet and the Northern Gulf of Alaska; and iii)studies supported by the *Exxon Valdez* Oil Spill Trustees investigating seabird-forage fish interactions in Prince William Sound.

ENVIRONMENTAL COMPLIANCE

Scientific collecting permits will be required from both the federal and state regulatory agencies (U.S. Fish and Wildlife Service and Alaska Department of Fish and Game). In addition, special permission from the EVOS Restoration Office will be required to conduct the proposed research. We are currently securing the required permits and permission.

APEX: STATISTICAL REVIEW

Project Number:	96163O
Restoration Category:	Research
Proposer:	Dr. Lyman L. McDonald, Western EcoSystems Technology
Lead Trustee Agency:	USFWS
Cooperating Agencies:	NOAA, UAF, OSU
Duration:	4 years
Cost FY 96:	$20 K
Cost FY 97:	$21 K
Cost FY 98:	$22 K
Cost FY 99:	$30 K
Geographic Area:	Prince William Sound and Cook Inlet
Injured Resource/Service:	Common Murre, Pigeon Guillemot, Marbled Murrelet, Pacific Herring

ABSTRACT

Non-standard statistical problems in the Alaska Predator Ecosystem Experiment (APEX) in Prince William Sound, Alaska, include severe logistical constraints on field sampling plans, analysis of data with unequal length transects, spatially-correlated data, and estimation of ratios of random variables. My responsibility as a biometrician is to provide review of and advice for study designs in order to help insure that appropriate statistical inferences can be made during the analysis phase of the studies. I will also provide advice and assistance during statistical analysis of data and report preparation.

INTRODUCTION

Alternative sampling designs considered for collection of the 1995 acoustic survey data included random placement of survey lines, stratified random placement of survey lines and systematic placement of survey lines. Each of these sampling plans was considered with and without adaptive sampling procedures. The basic sampling plan adopted was a systematic sampling plan with a random starting point for the first transect (resulting in east-west lines which were parallel and uniformly spaced). Data on adjacent lines in the systematic sampling plans are potentially correlated. Current analyses for abundance and distribution of forage fish and foraging sea birds are following statistical procedures specifically developed for spatially correlated data.

NEED FOR THE PROJECT

A. Statement of Problem

I will help provide solutions to non-standard statistical problems arising in the Alaska Predator Ecosystem Experiment (APEX) in Prince William Sound, Alaska. These problems include design of defensible sampling plans in the face of severe logistical constraints, analysis of data with unequal length transects, analysis of spatially correlated data, and estimation of ratios of random variables. My responsibility as a biometrician is to provide review of and advice for study designs in order to help insure that appropriate statistical inferences can be made during the analysis phase. I will also provide advice and assistance during statistical analysis of data and report preparation.

B. Rationale

Constraints on sampling designs for acoustic survey of nearshore forage fish and foraging sea birds continue to call for non-standard study designs and statistical analyses. I will work with the APEX Principal Investigators to design future data collection methods; in particular collection of data on abundance and distribution of nearshore forage fish offers significant challenges. Data collection methods will call for close coordination of sampling efforts in the SEA and NVP projects. I am working in a similar capacity on the EVOS Trustee's Nearshore Vertebrate Predator (NVP) project and can provide continuity between sampling methods to yield comparable data of mutual interest to these two projects.

C. Summary of Major Hypotheses and Objectives

I will interact with the Principal Investigators of the various segments of the APEX to insure that appropriate statistical procedures are used to test the hypotheses of interest. In particular, my specialty includes analysis and modeling of resource selection by animals and I will be working closely with William Ostrand of the USFWS to quantify and model habitat and food selection by sea birds. The other primary area of interaction will be with Lew Haldorson and Ken Coyle in estimation of abundance and distribution of forage fish, based on the spatially correlated data collected in 1995 and future field seasons.

D. Completion Date

Completion dates will depend on completed interactions with the various segments of the APEX. Sampling protocols, standard operating procedures, draft reports, and final reports will be issued as appropriate with individual Principal Investigators.

COMMUNITY INVOLVEMENT

Community involvement will be the responsibility of the individual Principal Investigators.

PROJECT DESIGN

Not Applicable

SCHEDULE

A. Measurable Project Tasks for FY 96

Start-up to May 1:
Continue spatial analysis of 1996 acoustic survey data. Interact with Principal Investigators to develop sampling plans for 1996 field season.

May 1–August 31:
Interact with Principal Investigators during data collection.

September 1–November 30:
Initial analysis of field data.

December 1–April 1, 1997:
Annual report on FY 96 work.

B. Project Milestones and Endpoints

Not Applicable

C. Project Reports

Not Applicable

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

I am a member of the Nearshore Vertebrate Predator Project. Sampling of nearshore forage fish will be coordinated between the two projects.

ENVIRONMENTAL COMPLIANCE

Not Applicable

APEX: ASSESSMENT OF THE PAH CONTAMINATION OF POPULATIONS OF THE FORAGE FISH, *Ammodytes* sp., INHABITING CLEAN AND OIL IMPACTED SEDIMENTS

Project Number:	96163P
Restoration Category:	Research
Lead Trustee Agency:	NMFS
Duration:	3 years
Cost FY 96:	$20 K
Cost FY 97:	$22 K
Cost FY 98:	$24 K
Geographic Area:	Prince William Sound
Injured Resource/Service:	Marbled Murrelet, Pigeon Guillemot

ABSTRACT

Together with herring (*Clupea pallasi*), the sand lance (*Ammodytes hexapterus*) serves as a major food for seabird species in Prince William Sound. Impacts on the populations of these fish from oiled sediment could result in numerous other losses to the ecosystem and non-recovery of species injured after the *Exxon Valdez* oil spill. It is well know that long-term impacts from spilled oil are primarily in the benthic environment. Sand lance is one of the few species of fish that actually inhabits sediments, burrowing down several inches to escape predation. Previous studies with this organism have documented its sensitivity to petroleum hydrocarbons, bioaccumulation of specific compounds, and avoidance of a preferred sediment type when oiled.

This investigation is designed to determine if populations of this species continue to be damaged by residual oils from the spill persistent in substrates in Prince William Sound. Spill sediments contain higher levels of specific polycyclic aromatic hydrocarbons (PAHs), which are known to induce the CYP1A locus and result in production of the P450 1A detoxification enzyme. NOAA researchers in Seattle have shown that higher levels of P450 in various fish species are associated with PAH-contaminated sediments, and with histological and reproductive damage.

This study will compare the response of a unique detection system to extracts from approximately 20 individual fish from each of four beaches in Prince William Sound, two unoiled by the spill and two with persistent evidence of oil. Each extract will be applied to three replicate cell culture wells, each containing about one million genetically engineered cells (101L cells). After 18 hours of

exposure, the combined cytoplasm of the cells is tested for the amount of light produced, using a luminometer. The firefly plasmid attached at the CYP1A1 site of this human cell will produce luciferase as a function of the concentration and potency of the organic compound. Previous studies with extracts of mussel tissue and sediments have shown that the response to PAH mixtures is additive, thus the response is equivalent to the total impact from PAH mixtures.

This sensitive screening approach will be followed by detailed chemical analyses by the staff of the Auke Bay NOAA Laboratory, when samples are shown to contain significant amounts of inducing compounds. These findings will allow assessment of the level of exposure of different populations of sand lance to PAHs from spilled oil. Investigations of forage fish populations by other researches can be combined with our data to determine if high exposure areas are correlated with reduced, or damaged sand lance populations.

INTRODUCTION

Sand lance are an important forage fish for seabirds in many high-latitude marine ecosystems, such as the British Isles (Bailey et al. 1991; Monaghan 1992), North Norway (Furness and Barrett 1985), Labrador (Elliott et al. 1990), and the eastern United States (Safina and Burger 1985). Changes in sand lance abundance have been shown to affect seabird reproduction and populations (Monaghan et al. 1989; Uttley et al. 1989) and may interact with or affect other forage fish species (Grosslein et al. 1980) over wide areas (Sherman et al. 1981).

Sand lance are particularly vulnerable to oil-contaminated sediment, because they burrow down in the substrate at times when not feeding, to escape predators, and spawn in the upper intertidal (Pinto et al. 1984). Such habits would make the species particular vulnerable to oil spills.

Sand lance bioaccumulate certain hydrocarbons and are relatively sensitive to petroleum hydrocarbons, either in soluble or dispersed form (Anderson et al. 1985, 1987). Behavioral studies have been conducted to determine the type of sediment this fish prefers, and how this preference is modified when the most preferred sediment type is contaminated by oil (Pinto et al. 1984). Where there are sediments of the type preferred by sand lance that have been oiled by the *Exxon Valdez* oil spill, we would expect to find animals that contain higher amounts of certain polycyclic aromatic hydrocarbons (PAHs), than in clean regions. There will be variability in the levels of contamination between specimens, so a relatively large number of individuals will need to be analyzed from each location. Chemical analyses are both expensive and time consuming, and they could be wasted if the fish do not contain significant amounts of PAH contamination.

This project is unique because it will apply a relatively new screening tool to the assessment of sand lance contamination. Vertebrates and even some invertebrates possess a detoxification enzyme called P4501A that is induced when the CYP 1A site on the chromosome is triggered by a molecular complex including the Ah-receptor, and specific PAHs. This induction has been shown to be related to the degree of PAH contamination in sediments and the impacts on fish from that region (Stein et al. 1995). It is possible, but even more tedious than PAH analyses, to determine the amounts of P4501A in fish. Our approach will use a unique cell line that demonstrates the presence of key PAHs, such as benzo(a)pyrene and dibenzo(a,h) anthracene, by producing a luminescent enzyme that can be easily quantified. Organic extracts (dichloromethane, DCM) of individual fish can be applied to one million human cells, which will produce an amount of luminescent enzyme (luciferase), which is a function of the combined concentrations of specific PAHs and their potential to induce P450.

By comparing at least 20 fish, each, from two clean sites and two locations suspected of being contaminated, the degree of tissue contamination and the differences between sites can be assessed. Extracts of tissue samples producing significant P450 induction in the Reporter Gene System (P450 RGS) will be analyzed for concentrations of specific PAHs by Dr. Stan Rice and the staff of the Auke Bay NOAA laboratory. The report on the first year of this project will provide an assessment of the degree of PAH contamination of each sand lance population, both from P450 RGS analyses and chemical characterization of specific PAHs. This information may be used in combination of forage fish population data collected by other researchers, to examine possible correlations.

Sand lance populations showing significant contamination may either be reduced in numbers or may exhibit histological or reproductive damage. If significant contamination is exhibited, additional sampling periods will be required to determine the rates of decrease in contamination levels. High levels of contamination in these forage fish would mean they represent a source of continuing PAH contamination to many components of the marine ecosystem.

NEED FOR THE PROJECT

A. Statement of Problem

The last compartment of the marine environment to retain contamination from an oil spill is generally the subtidal sediments. Infaunal marine invertebrates, such as worms and bivalves, are often the organisms most likely to be impacted the longest and most likely to demonstrate tissue contamination. However, the key forage fish, *Ammodytes* sp. (sand lance), is not only subject to oil contamination in the same way, but it is a potential route of contamination transfer from the sediments to valued fish and bird predators. Contamination of this fish, that burrows into the sediment, will lead to the continued transport of toxic polycyclic aromatic hydrocarbons (PAHs) from the oiled sediments to salmon, halibut, diving birds, and other predators. In addition, effects on sand lance populations from such exposure will reduce the food supply to the predators, causing other major problems.

B. Rationale

An investigation of the possible contamination of populations of sand lance from two presumed clean locations and two sites suspected of being contaminated by the oil spill is proposed. To save time and expense, a new PAH screening test (P450 RGS) will first be used to evaluate the levels of PAHs in a least 20 fish from each site. The organic extracts that demonstrate significant (10 times background) PAH contamination will be chemically characterized at the NOAA Auke Bay Laboratory. Data will be used to compare the contamination levels of the four populations, and assess the significance of the resulting PAH contamination.

C. Summary of Major Hypotheses and Objectives

Objectives

1. Identify two populations of sand lance in clean locations, and two in oil contaminated locations. To be done by APEX coworkers.

2. Collect, freeze and ship at least 20 individuals from each population to the Columbia Analytical Services laboratory in Kelso, WA for extraction by EPA method 3550.

3. Screen the 80 extracts for the quantities of P450-inducing PAHs.

4. Obtain confirmation of contamination levels and analyses of specific PAH on selected samples from the NOAA laboratory in Auke Bay.

5. Evaluate the significance of the levels of PAH contamination in each population.

Null Hypotheses

1. There will be no significant differences between the levels of P450 RGS-inducing PAHs in the tissues of sand lance from the four separate populations.

2. There will be no significant differences between the levels of specific PAHs in the tissues of sand lance from the four separate populations.

3. There will be no correlation between the P450 RGS induction measured in sand lance and the chemical characterization of specific PAHs.

4. There will be no correlation between the contamination (either means of measurement) in sand lance populations, and measurements of population size or health.

D. Completion Date

Analyses of the 80 tissue samples will occur within 60 days after the last sample is shipped from Alaska. Preliminary results in levels of contamination may be produced in as little as 14 days after receipt of samples. I can not estimate the time required for the Auke Bay lab to conduct chemical characterization of any samples we identify as containing contamination. This may be a continuing project for the NOAA lab. We plan to provide a complete report of the project in writing and in an oral presentation in January of 1997. Depending upon the findings, there may be a need to continue monitoring certain populations of sand lance that have demonstrated significant PAH contamination or for more detailed sampling protocol to detect spatial differences in contamination.

COMMUNITY INVOLVEMENT

See Project leader's subproposal.

PROJECT DESIGN

A. Objectives

As shown above, the objectives of the project are to collect 20 or more sand lance from four separate populations (2 presumed contaminated), extract the tissues, apply them to the P450 RGS assay, and identify contaminated fish. Samples showing significant contamination will be chemically characterized by the Auke Bay lab. The project report will compare the levels of the four populations and evaluate the significance of contamination.

B. Methods

Researchers in Alaska, who have had experience collecting sand lance, will select the exact locations and conduct the collections. Tissue extractions will be by standard EPA methods. The screening of tissue (or sediment) extracts by use of the P450 RGS method is described by Anderson et al. (1995). Routine chemical analytical methods will be used at the Auke Bay lab to characterize the concentrations of specific PAHs.

C. Assistance

The detailed characterization of specific petroleum hydrocarbons in the tissues of selected sand lance specimens will require the assistance of Dr. Stan Rice and the staff of the NOAA Auke Bay laboratory.

D. Location

The specific sites for collection of sand lance will be left to the Project Leader and other Principal Investigators in the Alaska. Based on NMFS's data, two sites in PWS that have shown no past or present evidence of petroleum contamination will be used as reference sites. Two sites documented to have persistent oiling will be selected from the NMFS database. Sand lance will either be netted with dip nets or excavated from the intertidal at low tides.

SCHEDULE

A. Measurable Project Tasks for FY 96

April 1:	Begin database and field searching for the best possible sand lance sites that may demonstrate differences between clean and contaminated sediments.
July 1:	Complete shipment of all fish samples to Kelso WA for extraction.
September 1:	Report on the P450 RGS induction in most if not all of the 80 specimens and send selected extracts to Auke Bay.
December 15:	Provide final report on results of FY 96 investigation.

B. Project Milestones and Endpoints

1. The written and oral reporting of the FY 96 findings will be the milestones for FY 96.

2. If there is no significant contamination found in sand lance at any of the sites, the project may end. This is particularly true if there are no other known sites where contamination by oil would be higher.

3. If either significant tissue contamination or possible impacts on the populations are observed, there may be a need to continue the project.

C. Project Reports

An interim report, primarily containing data will be submitted by October 1, 1996. The Final FY 96 Project Report will be submitted by December 15, 1996.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

I will be coordinating with the APEX scientists collecting the sand lance and also with Dr. Stan Rice at the Auke Bay lab regarding subsequent chemical analyses, if needed.

ENVIRONMENTAL COMPLIANCE

Not Applicable

96165

Genetic Discrimination of Prince William Sound Herring Populations

Project Number:	96165
Restoration Category	General Restoration
Proposer:	Alaska Department of Fish and Game
Lead Trustee Agency:	Alaska Department of Fish and Game
Cooperating Agencies:	None
Duration:	3 years
Cost FY 96:	$103,900
Cost FY 97:	$120,000
Cost FY 98:	$ 97,000
Geographic Area:	Prince William Sound
Injured Resource/Service:	Pacific herring

ABSTRACT

The Prince William Sound herring fishery has been in catastrophic decline since 1992. The Alaska Department of Fish and Game recovery effort includes incorporating a knowledge of genetically derived population structure into harvest management. In this continuing project we are delineating the structure of Prince William Sound population(s) and related North Pacific populations using both nuclear and mitochondrial DNA analyses. Tests for temporal and spatial diversity within years and temporal stability across years will be done.

INTRODUCTION

Pacific herring *Clupea pallasi* are a major resource in Prince William Sound from both a commercial and ecological perspective. The timing of the *Exxon Valdez* oil spill (EVOS) overlapped the annual spring migration of herring spawners to near shore staging areas. Over 40% of the herring spawning, staging, and egg deposition areas and over 90% of the documented summer rearing and feeding areas were lightly to heavily oiled prior to the spawning events. As a result, herring encountered oil during each of their four life stages in 1989 and, to a lesser extent, in 1990. Adult herring traversed oil sheens and mousse while traveling northward and eastward. Eggs were deposited on oiled shorelines and were "dipped" in sheen through tidal action while incubating. Larvae that hatched contained lipophilic petroleum hydrocarbons in their yolk sacs and encountered sheen near the surface while in their most sensitive state. Post-larval or juvenile herring swam through and remained near lightly to heavily oiled shorelines, regularly encountering sheen, mousse and dissolved oil components through the summer while feeding in shallow near shore bays and passes.

The Prince William Sound herring fishery has been in catastrophic decline since 1992. In 1993, the total observed spawning population was less than one-third of preseason predictions; and the average sizes of herring in each age class were some of the smallest on record. Only limited commercial herring fishing occurred. Preliminary pathology results implicated viral hemorrhagic septicemia (VHS) as a potential source of mortality and stress. In 1994, as in 1993, the spawning population was below preseason predictions. No recovery was evident in 1995. Aerial surveys since 1993 indicated that the population was below threshold harvest levels. The ex-vessel value of the herring fisheries in 1992 was $12.0 million. In 1993, the ex-vessel value dropped to $2.0 million, and herring abundance was so low that no commercial harvest has been permitted since.

Alaska Department of Fish and Game is mobilizing a recovery effort that includes pathology, genetics, early life history, and oceanographic investigations. The Department drafted a stock model (Brown and Wilcock 1994) to provide a basis for restoration management. However, that model is based upon several assumptions about the population structure of and recruitment to Prince William Sound spawning groups. This proposal was designed to evaluate those assumptions which include genetic homogeneity of herring stocks within the Sound and no recruitment to those stocks from outside of the Sound.

Incorporating genetically derived population structure is crucial to the success of any fisheries or restoration program. Consistent exploitation of mixed populations has to lead to the demise of the least productive stocks. Unfortunately, defining the population structure of herring has been particularly difficult. There is evidence that herring home (Wheeler and Winters 1984), but straying may also be substantial. Morphological and meristic differentiation of herring from discrete geographic regions has been used as evidence for the existence of genetically distinct populations, but much of this variation may be environmentally mediated and has not been confirmed with genetic data (Safford and Booke 1992; King 1985).

Allozyme electrophoresis has proven to be the most useful tool for delineating the population structure of many commercially important species in Alaska. But, previous surveys of herring using this technique have generally revealed differentiation only over broad geographic regions (Grant 1984; Grant and Utter 1984; cf., Grant et al. 1987) or between spawning populations within the same area that are temporally isolated (Kornfield et al. 1982). Allozymes define two distinct races of Pacific herring (Asian/Bering Sea and eastern North Pacific), with further subdivision between Gulf of Alaska and more southerly North Pacific stocks (Grant and Utter 1984). Also, allozyme markers were used to describe genetic divergence among local spawning populations of Pacific herring in the vicinity of northern Japan (Kobayashi et al. 1990).

Additional techniques to study the structure of natural populations have became available in recent years as a result of advances in molecular biology. Restriction fragment length polymorphism (RFLP) analysis of mitochondrial DNA provided some evidence of genetic differentiation among

Atlantic and Pacific herring (Kornfield and Bogdanowicz 1987; Schweigert and Withler 1990; Dahle and Eriksen 1990); however the utility of these and more recently developed techniques to detect fine genetic structure in Pacific herring has not been properly assessed. Peer reviewers of preproposal 95165 recommended that, of the molecular techniques then considered by our laboratory, that we focus upon microsatellite markers (in nuclear DNA) as being potentially most useful markers for investigation of fine structure. In consideration of those comments, and in consideration of the fact that nuclear and mitochondrial loci evolve in response to different pressures, we propose to use a combination of both mitochondrial and microsatellite approaches to more accurately define the stock structure of herring from the EVOS-affected area (e.g., Taylor and Bentzen 1993; Bentzen et al. 1994). The data can also be used to estimate the population composition of non-spawning aggregations contributing to the fisheries in Prince William Sound.

NEED FOR THE PROJECT

A. Statement of Problem

The Prince William Sound herring fishery is in serious decline. The lack of commercial harvest since 1993 has had severe negative impacts on individual fishermen as well as the economies of the communities within Prince William Sound.

B. Rationale

Pacific herring is a major resource in Prince William Sound (PWS) from both commercial and ecological perspectives. During the last 15 years the five commercial herring fisheries in PWS had an average annual combined ex-vessel value of $8.3 million (Donaldson et al. 1993). Pacific herring provide important forage for many species including some species severely injured by the *Exxon Valdez* oil spill. Predator species include humpbacked whales, seals, sea lions, gulls, sea ducks, shorebirds, halibut, salmon, rockfishes, and other fishes. In addition, several thousand pounds of herring and herring spawn-on-kelp are harvested annually for subsistence purposes and form an important part of the local native culture of the villages of Chenega and Tatitlek.

The goal of this project is to improve the accuracy of current stock assessment methods, thus improving resource management. Improved accuracy of stock distribution information will allow fishery managers to make fine adjustments of fishing quotas to harvest the maximum available surpluses with the lowest possible risk of over harvest, damage to the resource, or economic loss to the fishing industry. This information is also needed to help interpret oil spill damage results. Because commercial and subsistence herring harvests represent substantial contributions to local economies, intensive management is expected to benefit all communities in PWS. Restoration efforts can be directed and evaluated through improved fishery management and continued resource monitoring.

C. Summary of Major Hypotheses and Objectives

The major hypothesis of the Brown and Wilcock (1994) stock model that we plan to test are that (1) genetic homogeneity exists within Prince William Sound and (2) the Prince William Sound population is genetically isolated from other Gulf of Alaska populations. The working objectives of this study are to:

1. Screen population samples (collected from spawners) using both nuclear and mitochondrial DNA approaches. Techniques will include both RFLP analysis of mitochondrial regions amplified by polymerase chain reaction (PCR) and analysis of microsatellite loci (analysis of regions with variable number of tandem repeats, VNTR).

2. Evaluate the null hypothesis that a single panmictic population of herring exists in Prince William Sound. Tests will include four putative population samples from both spatial and temporal isolates within the Sound.

3. Evaluate the structure of Prince William Sound populations within the context of the structure of adjacent spawning aggregates (up to four), including a comparison from across the known genetic barrier of the Alaska Peninsula.

4. Evaluate the structure of Prince William Sound and related North Pacific populations for inter-annual stability.

D. Completion Date

The duration of this project was anticipated to be two and one-half years (see Projects 94165 and 95165). This period was to cover field collections from two spawning seasons and subsequent laboratory analysis. We anticipated that laboratory analysis would be complete in FY 95 and reporting to be complete in FY 96.

However the start date, and thus the completion date, of this project have been elusive. The Trustee Council first made funds available during FY 94 (Project 94165). The field season that year was truncated due to the surprise run failure, inadequate samples were obtained to meet project most project objectives, and project start was deferred one year. No Trustee Council funds were spent on the project in FY 94. We are in the middle of the field season for FY 95 (Project 95165) at the writing of this proposal, 96165. Some spatial isolates from within Prince William Sound have been successfully sampled, but temporal isolates remain elusive because of the current run failure. Sampling from outside of the Sound is in progress and appears adequate. We will initiate laboratory analyses with the aid of a contractor, but we are certain that FY 95 sampling will not be complete enough to meet all four project objectives.

At least two years of complete sampling are required to confirm year-to-year stability of population structure. For example, Kornfield et al. (1982) observed within-year temporal variation and within-year spatial variation in Atlantic herring populations that were not stable across year classes. Such annual variation may indicate substructure variability due to changes in larval flushing/larval retention patterns like those described in Brown and Wilcock (1994). Thus, management recommendations made on only one year's genetic data may not be valid. Based upon sampling difficulties due to the run failure, we now believe that reporting of this project will not be complete until the end of FY 98. The cover sheet for this proposal reflects place-holder budgets for FY 97 and FY 98, and those requests will be made if annual project results and Chief Scientist recommendations so indicate.

COMMUNITY INVOLVEMENT

Laboratory analyses and reporting are technical pursuits that will be conducted by or supervised by Ph.D. scientists. Wherever possible, local-hire will be used to fill field positions required for sampling or routine laboratory positions. The project will be moved to the Alaska SeaLife Center in Seward, should the project duration overlap with the availability of that facility. Again, local hire will be used when possible, and ADF&G plans to participate in all of the educational and outreach programs scheduled for the Center.

PROJECT DESIGN

A. Objectives

Our overall objective is to provide a genetic basis for the stock model used by Alaska Department of Fish and Game to manage and restore the depleted herring resource in Prince William Sound. We propose to test for genetic heterogeneity among spawning aggregations of Pacific herring within Prince William Sound, adjacent to Prince William Sound, and between year classes within and adjacent to the Sound. Achieving this objective will provide information to enable resource managers to better understand herring population dynamics and develop harvest strategies that will speed the recovery process. In addition, it will aid local resource users to make appropriate pre-season plans based on accurate and precise herring projections.

The working objectives of this study are to:

1. Screen samples collected from spawning aggregates using both nuclear and mitochondrial DNA approaches. Techniques will include both RFLP analysis of mitochondrial regions amplified by polymerase chain reaction (PCR) and analysis of microsatellite loci (analysis of regions with variable number of tandem repeats, VNTR).

2. Evaluate the null hypothesis that a single panmictic population of herring exists in Prince William Sound. Tests will include four putative population samples from both spatial and temporal isolates within the Sound.

3. Evaluate the structure of Prince William Sound populations within the context of the structure of adjacent spawning aggregates (up to four), including a comparison from across the known genetic barrier of the Alaska Peninsula.

4. Evaluate the structure of Prince William Sound and related North Pacific populations for inter-annual stability.

B. Methods

1. Field Collections

Earlier versions of this proposed project focused solely upon populations within Prince William Sound. Peer reviewers recommended expanding the project to include outgroups from the Gulf of Alaska and the Bering Sea and to include tests for inter-annual stability (cf., Kornfield et al. 1982, see below).

Field collections of spawning Pacific herring will target eight representative sites within and adjacent to Prince William Sound. The collection sites within Prince William Sound will be chosen to maximize the potential genetic differentiation among temporally and spatially isolated spawning aggregations. Tissue extracts from muscle, liver, eye, and heart will be collected and preserved in liquid nitrogen until transport to -80° C freezers for archival to facilitate the option for allozyme electrophoresis at a later time. Two years of sampling will be conducted at each site to test for inter-year stability of genetic diversity measures.

The within-Sound sampling effort will target Rocky Bay, a southcentral spawning isolate; Port Gravina, a southeast isolate; and Tatitlek Narrows, a northeast isolate. Samples will be collected from both early- and late-spawning stocks in Rocky Bay. Early- and late-spawning isolates will be collected from Port Chalmers and archived for analysis during subsequent years (if further analysis of temporal isolation is deemed appropriate). One-hundred individuals will be subsampled from each aggregation during the sampling for Trustee Council Project 95166 *Herring Natal Habitat.* Consequently, age and other data will be collected from the individuals analyzed for genetic variation, facilitating further correlation analyses between population data and genetic variation.

Sampling outside of Prince William Sound will include Kodiak Island, populations thought to share an ancestral tie with Prince William Sound populations (John Wilcock, Alaska Department of Fish and Game, personal communication) and a Bering Sea population known to be genetically isolated from the other Gulf of Alaska stocks (Grant and Utter 1984). One-hundred individuals will be collected from up to four of these outgroup populations.

2. Genetic Analysis

The preproposal for this project included allozyme analysis as well as DNA analysis because allozymes have previously been shown to discriminate temporally isolated populations such as those observed in Prince William Sound (cf., Kornfield et al. 1982), and they delineate a restriction in gene flow between Bering Sea and Gulf of Alaska populations (Grant and Utter 1984). Peer reviewers recommended that year one of the study focus on techniques such as microsatellite analysis to maximize the probability of identifying genetic differences (as described herein). Through further public review we decided that we should collect and archive samples for allozyme analysis because the area affected by EVOS is adjacent to the genetic barrier zone identified by allozymes and the loss of the opportunity to compare allozyme results to DNA results would be irretrievable (W. S. Grant, National Marine

Fisheries Service, personal communication). Depending upon year-one results, allozymes may be reconsidered for subsequent analyses.

Alaska Department of Fish and Game plans to seek assistance from an outside laboratory for the genetic analyses following standard State of Alaska procurement procedures for FY 95 analyses. A request for proposal will be issued for the molecular analyses to be conducted under a Reimbursable Services Agreement (RSA) with an Alaskan University or under contract from another outside laboratory. At this writing the request for proposal is pending final Trustee Council approval for Project 95165, and no analyses have been done.

Because mitochondrial and nuclear genomes evolve in response to different pressures, it is expected that the successful respondent will incorporate both approaches into the year-one screen described in this proposal. The investigator will be expected to focus upon an analysis of microsatellite loci at the recommendation of the Trustee Council's chief scientist. Details of the specific molecular techniques to be investigated will be chosen based on: 1) a review of the current literature and recently available research results, and 2) qualifications and expertise of respondents.

Alaska Department of Fish and Game plans to evaluate the option of conducting FY 96 analyses in-house (e.g., following methods described in Trustee Council Proposal 96191) after reviewing the results of project 95191 and other Department obligations.

C. Contracts and Other Agency Assistance

Alaska Department of Fish and Game laboratory staff is fully committed to other projects during the period that FY 95 analyses will be conducted. Laboratory analysis will be awarded through an RSA or through a contract awarded through the State of Alaska procurement process. FY 96 analyses may also be awarded to a contractor, depending upon an evaluation of FY 95 results and an evaluation contract efficiency.

Alaska Department of Fish and Game Genetics Laboratory has utilized the services of subcontractors on a number of Trustee Council projects. Four outside contractors were utilized for laboratory components of Trustee Council Projects 94191 and 94255. All of the laboratory analysis for Trustee Council Project 94320D was awarded on contract to a collaborating agency with a similar genetics program, Washington Department of Fish and Wildlife. Contracting some projects has increased efficiency of conducting our Trustee Council-funded research. However, costs of contracting have generally exceeded the costs of in-house research; the major exception is that graduate student research funded at universities agreeing to a 20% overhead cap has been cost-effective.

Contracting laboratory analysis will become less efficient for the department with the completion of laboratory facilities at the Alaska SeaLife Center in Seward, and future contracts to outside-of-Alaska laboratories will only be awarded if the work cannot be done in the Seward facility. Some of the university subcontractors are submitting proposals to conduct projects as principal investigators (see genetics proposals to the Trustees by University of Alaska and University of

Montana), and we look forward to the potential opportunity for collaboration on those projects. We propose to continue using graduate student research as an effective tool for developmental research, and we will consider other opportunities for contracting if they present useful advantages to the State of Alaska and Trustee Council restoration program.

D. Location

Field research will be conducted primarily within the confines of Prince William Sound; exact locations will depend upon the distribution of spawning herring. Sampling outside of Prince William Sound will be conducted by ADF&G area staff as appropriate. Laboratory sampling, archival, and data analysis will be conducted at the ADF&G area office in Cordova and regional office in Anchorage.

SCHEDULE

A. Measurable Project Tasks for FY 96

Start-up of 95165 to May 30, 1995:	Collection of samples
May 30 - June 15:	Award contract for FY 95 samples
June 15 - December 30:	Complete laboratory analysis
January - April, 1996:	Evaluate lab results, plan for 1996 sampling
April - May 30, 1996:	Collection of samples
May 30 - June 15:	Award contract or begin laboratory analysis of 1996 samples in house
June 15 - December 30:	Complete laboratory analysis
January - April, 1997:	Evaluate lab results, plan for 1997 sampling
April 1997:	Annual report for FY 96

B. Project Milestones and Endpoints

December 30, 1995:	Complete screen of population samples collected during 1994-1995
April 30, 1996:	Complete evaluation of population structure of populations collected during 1994-1995
December 30, 1996:	Complete screen of population samples collected during 1996
April 30, 1997	Evaluation of population structure of Prince William Sound and other related populations collected through 1996; planning for mop-up sample collection for spawning aggregates missed in previous years
December 30, 1997:	Complete screen of population samples collected during year three
April 30, 1998:	Complete evaluation of stability of population structure across years

C. Project Reports

April 30, 1996: annual report in the form of manuscript submitted to journal.

April 30, 1997: annual report.
April 30, 1998: final report in the form of manuscript submitted to journal.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

A. Existing Agency Program

The Alaska Department of Fish and Game spends approximately $500.0K from State of Alaska general funds annually on genetics studies. For this project, salaries and benefits of principal investigators J. Seeb and L. Seeb are fully funded by general funds; project leader S. Merkouris is funded for two months from Trustee Council funds.

The Department remains heavily committed to the conduct of this study and other EVOS studies, even though limited personnel resources mandate that we seek assistance from an outside source for the FY 95 laboratory analyses described herein. Approximately $50.0K of State of Alaska general funds was programmed for the study of saltwater-mediated mosaicism as the mechanism for embryo mortalities identified during implementation of Trustee Council Projects 93003 and 94191 (Miller et al. 1994). State of Alaska general funds support the basic operation of and enhancements to the genetics laboratory for EVOS projects including the procurement of an Applied Biosystems Incorporated automated DNA sequencing system capable of subambient temperature operation required for studies of genetic variation including RFLP analysis ($132.0K).

Staff scientists and technicians are trained in an array of genetics analyses including allozyme and PCR-based mitochondrial and nuclear approaches. The Department maintains fourteen -80° C freezers in area offices throughout the state for archival of genetic samples for allozyme and DNA analyses.

B. Other Coordination

Collection of specimens and biological data will be coordinated by ADF&G's ongoing herring research program in Prince William Sound and with the EVOS project 96166 Herring Natal Habitats. Tissue archival and biometric analyses will be coordinated among all Trustee Council projects related to genetics including 96320D, 96191, and 96255.

Sharing of project results will be used to evaluate and revise current strategies for management of commercial herring fisheries if warranted. Project results will also be used to improve our understanding of results from previous oil spill damage assessment studies.

Data collection techniques will be coordinated through the inter-agency consortium of laboratories that cooperates on similar projects of conservation genetic nature on salmonids and other marine fish in the North Pacific Ocean. Alaska Department of Fish and Game is hosting the annual inter-agency meeting in Anchorage during May, 1995, where participating scientists will coordinate approaches.

ENVIRONMENTAL COMPLIANCE

The studies proposed provide for data collection and field sampling programs. No environmental effect of these programs occurs beyond that of traditional fisheries management data collection activities. These activities are within existing collecting permits or Federal special use permits issued to the Department of Fish and Game for scientific data collection. No other permits or other coordination activities are involved. This project received a categorical exclusion under the National Environmental Policies Act.

96166

EXXON VALDEZ Oil Spill Trustee Council
FY 96 Detailed Project Description

Herring Natal Habitats

Project Number:	96166
Restoration Category:	General Restoration
Proposer:	ADF&G
Lead Trustee Agency:	ADF&G
Cooperating Agencies:	University of Alaska
Duration:	Continue population monitoring until Pacific herring population in Prince William Sound has recovered; close out egg loss in FY96
Cost FY 96:	$444,100
Cost FY 97:	$300,000
Cost FY 98:	$150,000
Cost FY 99:	0
Cost FY 00:	0
Cost FY 01:	0
Cost FY 02:	0
Geographic area:	Prince William Sound
Injured Resource/Service:	Pacific Herring

ABSTRACT

The 1989 Exxon Valdez oil spill coincided with the spring migration of Pacific herring *Clupea pallasi* to spawning grounds in Prince William Sound (PWS). Studies of oil spill injuries to herring documented damage from oil exposure in adult herring, reduced hatching success of embryos, and elevated levels of physical and genetic abnormalities in newly hatched larvae. The PWS herring spawning population has drastically declined since 1993, and pathology studies implicated viral hemorrhagic septicemia (VHS) and ichthyophonus as potential sources of mortality as well as indicators of stress. The current project will continue to provide estimates of spawning herring abundance through SCUBA and hydroacoustic studies, and to investigate the lethality of suspected pathogens and the role of environmental contaminants in disease transmission through laboratory and field studies.

INTRODUCTION

The Exxon Valdez oil spill coincided with the spring migration of Pacific herring *Clupea pallasi* to spawning grounds in Prince William Sound (PWS). Adult herring swam through oiled waters on their way to nearshore staging areas. Studies of oil spill injuries to herring were initiated in 1989 and research continued through 1992. Significant histopathological damage was measured in adults collected in oiled areas in both 1989 and 1990 confirming exposure of the fish to toxins. Oiling of over 40% of the spawning areas (42 of 98 miles used) caused elevated levels of physical and genetic abnormalities in newly hatched larvae and reduced hatching success of the embryos. Over 80% of the summer rearing and feeding areas of herring were oiled in 1989, based on oil trajectory and historic fisheries records from 1914 to the present.

In 1993, the herring population in PWS collapsed. The total observed spawning population was less than one third of preseason predictions and the average sizes of herring in each age class were some of the smallest on record. The total commercial harvest for that year was one of the lowest on record. Pathology studies from the spring of 1993 implicated viral hemorrhagic septicemia (VHS) as a potential source of mortality and stress. In 1994, the total observed spawning population was below threshold biomass required to conduct commercial harvest and no fishing occurred. Pathology studies indicated the presence of both VHS and a second potentially lethal pathogen, ichthyophonus. Pathology studies continued in 1995 and will include laboratory investigations of the lethality of suspect pathogens and the role of environmental contaminants in disease transmission.

This project will provide a direct measure of adult herring abundance necessary for monitoring recovery of the injured PWS herring population. The project will also develop embryo survival models that will improve the accuracy of spawn deposition biomass estimates. The project will be conducted in several parts. ADF&G will perform the field collection and data analysis constituting the continuation of herring spawn deposition surveys. A second field component will be continuating investigation of the feasibility and cost effectiveness of estimating biomass of spawning herring using acoustic surveys as an alternative to spawn deposition surveys. Acoustic surveys will be subcontracted through a competitive bid process and will rely on ADF&G base funding for much of the vessel and personnel costs. The University of Alaska (UA) will perform 1) data analysis and modeling of egg loss data collected through 1995, 2) modeling of embryo survival, and 3) modeling of recruitment in relation to biological and environmental variables. A new component of this project will be entry of aerial survey, harvest, spawn deposition, and egg loss data into a geographic information system (GIS) database.

During spawn deposition surveys, SCUBA divers will estimate the abundance and distribution of herring eggs. This information will be incorporated with aerial observations of spawn distribution and basic biological information (age composition, sex ratios, average size, and fecundity) to estimate adult spawning biomass. Estimates of spawning biomass are used to forecast spawning returns the following year and form the basis of herring fishery management in PWS.

Biomass of herring migrating to PWS spawning grounds will also be estimated acoustically by expanding echo integrated voltages by analytically determined target strengths. Dual or split beam *in situ* measurements and fish species composition and average size from seine hauls will be used to evaluate and correct for target strength assumptions. Acoustic biomass estimates will be compared with spawn deposition biomass estimates to examine issues relating to accuracy, reliability, and cost effectiveness of these methods.

A model which predicts egg loss will provide an indirect means to estimate the number of herring embryos physically removed from spawning areas by predation and wave action. Results from egg loss studies through 1995 will be used to identify important factors to include in models that can predict egg loss. Estimation of egg loss is useful for two purposes: (1) to improve the accuracy of spawn deposition biomass estimates by accounting for eggs lost between the time of spawning and the time of spawn surveys, and (2) to enable estimation of total embryo survival. Total embryo survival to the larval life stage will be used as the initial input of population abundance in life history models developed under project 96320, Sound Ecosystem Assessment (SEA). Data collected for this component of the current project will also be used to test hypotheses outlined in the Natal Habitat section of SEA.

Since it is not practical to measure all sources of egg morality each year, total embryo survival models will be used to relate mortality to more easily measured or estimated variables and characteristics of spawning habitat. Factors directly affecting the survival of embryos to larvae include wave action, predation, dessication during low tide, occurrence of cytogenetic abnormalities (which result in nonviable hatched larvae), pathogens, and pollution (which may elevate cytogenetic abnormality levels). These sources of direct mortality may be modified by environmental and biological variables such as wind direction, severity of storms, number of predators, availability of eggs to predators, type of substrate on which eggs are deposited, height of tidal fluctuation, water temperature, and air temperature. The degree to which these factors affect survival depends largely upon the characteristics of the habitat selected for egg deposition.

NEED FOR PROJECT

A. Statement of Problem

Adult Pacific herring on their way to PWS spawning area swam through oil from the *T/V Exxon Valdez* oil spill, eggs incubated in the oil, and larvae and juvenile herring may have been exposed to oil in rearing and feeding areas. Histopathological damage was found in adult herring collected in oiled areas in both 1989 and 1990, mortality of young herring was significantly greater in oiled areas in 1989 and 1990, and sublethal effects were measurable in larvae and adults in 1989 and 1990. Persistent sheening and suspended oil-sediment droplets leaching from beaches and cleaning operations in 1989 and 1990 continued to expose adult and juvenile herring to oil. Laboratory exposures of pre-spawning adult herring to oil show high concentrations of oil in the ovarian tissue. Laboratory studies measuring the effect of known doses of oil on newly hatched larvae provided a direct link between estimated doses of oil measured in PWS and the level of injury observed in samples collected from the field. In addition, measurements of oil in mussel tissue collected adjacent to spawning beds was significantly correlated to several indices of injury in herring larvae from those beds, the highest correlation being with the genetic injury endpoints.

Although herring survival varies tremendously under normal conditions, abundance for the 1989 year class was extremely low and results to date strongly implicate the oil spill as a major cause. One hypothesis is that injury to germ tissue caused by exposure to oil would result in non-viable embryos and larvae. A pilot experiment to measure the ability of herring from this age class to produce viable offspring was conducted in 1992 and hatching success of eggs collected from fish spawning in previously oiled areas was less than half that of eggs collected from fish spawning in pristine areas. Additionally, there were approximately twice as many abnormal larvae from fish spawning in previously oiled areas.

In 1993, the total observed spawning population was less than one third of preseason predictions and the average sizes of herring in each age class were some of the smallest on record. The total commercial harvest for that year was one of the lowest on record. Pathology studies from the spring of 1993 implicated viral hemorrhagic septicemia (VHS) as a potential source of mortality and stress. In 1994, the total observed spawning population was below threshold biomass required to conduct commercial harvest and no fishing occurred. Pathology studies indicated the presence of both VHS and a second potentially lethal pathogen, ichthyophonus. Pathology studies have continued in 1995 and will include laboratory investigations of the lethality of suspect pathogens and the role of environmental contaminants in disease transmission.

B. Rationale

This project provides estimates of spawning herring abundance and a better understanding of some of the factors which contributed to the collapse of the population. This information is needed for monitoring recovery of the injured Prince William Sound (PWS) herring population. Project results can be used to judge recovery of the herring resource, including recovery to population levels sufficient for sustainable commercial harvest, and can also serve as the basis for setting harvest strategies. In addition, this project provides information about the abundance and survival of early life history stages which will improve our understanding of the ecological importance of herring in the PWS ecosystem.

C. Summary of Major Hypotheses and Objectives

The primary goal of this project is to monitor the recovery of Pacific herring which spawn within PWS, while a secondary goal is to improve our understanding of significant causes of mortality during early life history stages. Although project 96166 has not been included as a component of SEA, this secondary goal directly addresses the main hypothesis of the Natal Habitat portion of SEA which states that high energy coastal storms, temperature extremes, and predation control density independent mortality and modify processes causing density dependent mortality of herring embryos. The effect of these physical and biological processes on the survival of the embryos varies with habitat.

The following subhypotheses are posed to direct the implementation of field work that will test components of this main conjecture:

A. High energy storms cause formation of waves that physically remove eggs from herring spawning grounds. Waves remove eggs directly by dislodging them from vegetation to which they have been adhered and indirectly by dislodging vegetation containing attached eggs.

1. Egg loss is positively correlated to the duration and intensity of wind-generated waves.

2. Egg loss due to wave action is modified by the species of vegetation to which eggs are attached, the water depth in which eggs are deposited, and egg density.

3. Site specific wave action is correlated with regional climatological conditions.

B. Temperature extremes cause increased egg mortality. Elevated spring temperatures and increased ultraviolet radiation from increasing spring sunlight cause increased morphologic and cytogenetic abnormalities in herring embryos and reduce the number of viable larvae.

1. Egg mortality in the intertidal zone increases with air temperatures $< 0^{\circ}C$ and $> 13.5^{\circ}C$.

2. Egg mortality increases with continuous exposure to water temperatures $< 4^{\circ}C$.

3. Incidence of cytogenetic and morphologic abnormalities and proportion of nonviable hatched larvae are increased at the upper and lower extremes of the ranges of temperature, salinity, and ultraviolet radiation typically occurring in PWS.

C. Birds are the single most important predators on herring eggs.

1. The distribution, timing, and abundance of gulls, seaducks, and shorebirds is positively correlated with the dispersion, timing, and abundance of herring spawn. Species composition of avian predators is dependent on spawn location and timing of spawn.

2. Herring spawn is a major component in the diet of bird species foraging in herring spawn.

3. Viable herring eggs are preferred prey compared to dead and decaying spawn.

4. Avian consumption of spawn is greatest in the intertidal zone and varies with tidal height.

5. Egg loss resulting from avian predation occurs at higher rates in years when eggs are scarce.

D. Completion Date

The egg loss component of the project will be completed in FY96. However, monitoring of the abundance, age composition and size composition of the PWS Pacific herring spawning population will be continued until the population has recovered.

COMMUNITY INVOLVEMENT

Since the dramatic decline of the PWS herring spawning population in 1993 there has been vigorous public support for herring research from PWS communities as well as various pkrivate and professional organizations. The Public Advisory Group (PAG) for the Trustee Council has also voiced support for these studies. Spawn deposition surveys have been recognized by commercial fishermen, fishery managers, and peer reviewers as a valuable tool for stock assessment in the absence of direct methods of estimation. Accurate and precise estimates of stock abundance are needed for ecosystem based studies of processes that affect abundance. In addition to peer review through the EVOS process, herring stock assessment and embryo survival studies have received critical review through the intensive SEA research planning and public review effort. The ecosystem approach to PWS studies adopted by the SEA planning group recognized the commercial and ecosystem importance of herring and included them as a co-target species for study along with pink salmon.

Some people from communities in PWS will have an opportunity to directly participate in this project by providing logistical support for field sampling. Two vessels will be chartered as research platforms for spawn deposition surveys, while one or more purse seine vessels will be chartered to capture fish for various purposes (e.g. identification of acoustic targets, disease studies, biological characteristics of spawning population).

FY 96 BUDGET

Personnel	186.1
Travel	4.2
Contractual	199.5
Commodities	10.0
Equipment	2.4
Subtotal	402.2
Gen. Admin.	41.9
Total	444.1

PROJECT DESIGN

A. Objectives

The overall goal of this project is to monitor the spawning population of Pacific herring in PWS to determine when this injured population has recovered. The project has seven specific objectives in FY96:

1. Estimate the biomass of spawning herring in PWS using SCUBA diving spawn deposition survey techniques such that the estimate is within ± 25% of the true value 95% of the time, and describe the age, sex and size composition of the spawning population.

2. Investigate the feasibility of estimating biomass of spawning herring using acoustic surveys and net sampling.

3. Compare estimates from spawn deposition with estimates from acoustic surveys.

4. Test a model of the relationship of spawn timing, spawner density and abundance to egg distribution and density.

5. Test a model relating sound-wide embryo survival to habitat utilized, egg density, and meteorological conditions.

6. Test a model relating historic recruitment success to biological and environmental variables.

While the overall goal of the project will not change in future years, specific objective might be altered to better achieve this goal. Estimation of the spawning herring population biomass, as well as its age,sex and size composition, will continue to be the most important objective of this project.

B. Methods

Spawn Deposition Survey and Biomass Estimation

The survey design of the existing ADF&G spawn deposition project was modified for NRDA studies in 1989 to more accurately assess response of the PWS herring population to the *T/V Exxon Valdez* oil spill. Beginning in 1989, the spawn survey was conducted to obtain biomass estimates within ± 25% of the true biomass 95% of the time. Study design alterations included increasing the number of (1) SCUBA divers, (2) survey transects, and (3) skiff and diver surveys used to correct aerially mapped spawning area boundaries.

Biomass estimates based on spawn deposition surveys consist of three major components: (1) a spawn deposition survey; (2) age-weight-length (AWL), sex ratio, and fecundity sampling; and (3) egg loss determination.

Spawn Deposition Survey Design. Survey design has been described in detail by Biggs and Funk (1988), and closely follows the two-stage sampling design of surveys used in British Columbia (Schwiegert et al. 1985) and Southeast Alaska (Blankenbeckler and Larson 1982, 1987). These surveys use random sampling for the first stage (transects) and systematic sampling for the second stage (quadrants within transects). Random sampling for the second stage is not feasible because of underwater logistical constraints (Schwiegert et al. 1985). Additionally, our surveys will be stratified by area to account for geographic differences and the potential of sampling discrete herring stocks. Areas surveyed may include Southeast, Northeast, North Shore, Naked Island and Montague Island (Figure 1).

Mean egg densities along each transect will be combined to estimate an average egg density by area. Spawning bed width along each of the transects will be used to estimate average spawning bed width by area. Average width, average density, and total spawning bed shoreline length (from aerial surveys) will be used to estimate total number of eggs deposited in each summary area surveyed. Average fecundity and sex ratio, derived from AWL sampling, and estimates of total number of eggs deposited will be used to calculate herring population numbers and biomass. Based on variances obtained from the 1984, and 1988 to 1992 surveys, a minimum sampling goal of 0.035 % of all potential transects within the spawning area should ensure that the estimated biomass is within 25% of the true biomass 95% of the time. Based on the size of the sampling quadrant, there are 3,163 potential transects per kilometer. Therefore, 100 km of herring spawn would require 110 transects to meet our goals for accuracy and precision. Confidence intervals will be calculated assuming that total egg estimates follow a normal distribution.

Spawn Deposition Survey Sampling Procedure. The general location of spawning activity will be determined from milt observed during scheduled aerial surveys that are part of an existing agency program. This information will be compiled and summarized on maps showing spawning locations and the number of days on which milt is observed. Total linear miles of shoreline containing herring spawn will be estimated from aerial survey maps and corrected by skiff and diver reconnaissance at the time of dive surveys. Skiff surveys will be performed close to shore at low tide by both walking along exposed intertidal areas and by viewing the shoreline from the skiff.

Each shoreline area containing herring spawn will be divided into the narrowest resolvable segments on the map scale (approximately 0.18 km). The total number of potential transects will be calculated from the total shoreline km of observed spawn. A minimum of 0.035% of all potential transects will be selected for dive surveys. Random numbers will be assigned to each potential transect and rounded to the nearest number divisible by 0.18 km to enable mapping of shoreline segments. Shoreline segments will be randomly selected and used to locate transects. Each transect selected will be assigned a sequential transect number and charted on waterproof field maps.

Diving on herring spawn will begin about 5 days after spawning has ceased to allow water turbidity due to milt to decrease and for the large numbers of sea lions usually present near spawning herring to disperse. Two three-person dive teams will complete the surveys. Each team will consist of a lead diver to count eggs (typically the person most experienced at this survey task), a second diver to record data, and a third diver on the surface performing as a tender. Diving and tending duties will be rotated daily. Based on information from previous PWS surveys, two diving teams can generally complete 6 to 12 transects daily under favorable weather conditions and in areas with average spawning density and distribution. A sample size total of 100 or more transects will require from 10 to 20 days of diving, depending upon weather and location of spawn. This time includes collection of diver calibration samples for a team of experienced divers. If inexperienced divers are hired, training will require about one additional week.

Location for each survey transect will be fixed as the dive skiff approaches the shore and before bottom profiles, bottom vegetation, or herring spawn are visible from the skiff. The tender will choose a shoreline feature to use as a reference point such as a tree, rock, or cliff located above the high tide line within the randomly selected shoreline segment. The sampling transect will extend seaward perpendicular to shore from this fixed reference point along a compass course.

Divers will estimate the numbers of eggs deposited within a sampling quadrant placed at regular intervals along the length of the transect. The sampling quadrant will consist of a 0.1 m^2 PVC pipe frame with a depth gauge and compass attached. The first quadrant location will be randomly selected within the first 5 meters of spawn. Succeeding quadrant locations will be systematically spaced every 5 meters along the compass course until the apparent end of the spawn is found. Within each quadrant, the lead diver will estimate the number of eggs in units of thousands (K) within the quadrant, communicating the numbers through hand signals to the second diver to record. Number of eggs as well as vegetation type, percent cover, substrate, and depth will be recorded using a large weighted carpenter's pencil on water-proof plastic paper data forms attached to a clipboard. Divers will verify the end of the spawn by swimming at least an additional 20 m past the end of the spawn until a steep drop-off is encountered or vegetation is no longer present. Becker and Biggs (1992) documented methods used for diver surveys in greater detail including sample data forms, key codes for vegetation types, standard operating procedures for ADF&G diving, chemical recipes for sample preservatives, and other practical information.

Diver calibration samples will be collected throughout the dive survey and stratified by diver, vegetation type within four broad categories, and by egg density over three broad categories. Both divers will independently estimate the number of eggs on removable vegetation in each calibration quadrant. All egg-containing vegetation within the quadrant will be removed and placed in numbered mesh bags. The number of loose and attached eggs left after removal will be estimated by the lead diver and recorded. Based on accuracy estimated for previous survey results, approximately 80 calibration samples will be needed for each uncalibrated diver (less than three years survey participation) and 40 for each calibrated diver (three or more years survey participation). One quarter of the total samples will be taken for each of the four vegetation categories: eelgrass (EEL), fucus (FUC), large brown kelp (LBK), and hair kelp (HRK). One third of the calibration samples will be stratified over three ranges of egg densities: low (0-20,000), medium (20,000-80,000), and high (>80,000) within each vegetation category. Calibration samples will be preserved in Gilson's solution and labelled (Becker and Biggs 1992).

Biomass Estimation. Analysis of the spawn deposition survey data will be similar to methods used in 1988 (Biggs and Funk 1988), 1989-1992 (Biggs et al. *in press*). The biomass estimator will be

$$B = TB', \tag{1}$$

where

B = estimated spawning biomass in tonnes,
T = estimated total number of eggs (billions) deposited in an area, and
B' = estimated tonnes of spawning biomass required to produce one billion eggs.

Estimates for T and B' will be derived from separate sampling programs and will be independent. The estimated variance for the product of the independent random variables T and B' will be (Goodman 1960)

$$Var(B)=T^2Var(B')+B^2Var(T)-Var(T)Var(B'), \tag{2}$$

where

Var(B')	=	an unbiased estimate of the variance of B', and
Var(T)	=	an unbiased estimate of the variance of T.

Total Number of Eggs (T). The total number of eggs deposited in an area will be estimated from a two-stage sampling program with random sampling at the primary stage, followed by systematic sampling at the secondary stage, using a sampling design similar to that described by Schwiegert et al. (1985). To compute variances based on systematic second stage samples, it will be assumed that eggs will be randomly distributed in spawning beds with respect to the 0.1 m^2 sampling unit. While this assumption will not be examined, in practice the variance component contributed by the second sampling stage will be much smaller than that contributed by the first stage, so violation of this assumption would have little effect on the overall variance. The total number of eggs (T), in billions, in an area will be estimated as

$$T=N\hat{y}10^{-6}/(1-R), \tag{3}$$

where

L	=	the shoreline length of the spawn-containing stratum in meters,
N	=	$L/0.1^{0.5}$ = the total number of possible transects,
$0.1^{0.5}$	=	0.3162 m = width of transect strip,
$\hat{y}$	=	average estimated total number of eggs (thousands) per transect,
10^{-6}	=	conversion from thousands to billions of eggs, and
R	=	estimated proportion of eggs disappearing from the study area from the time of spawning to the time of the survey.

Average total number of eggs per transect strip (in thousands) will be estimated as the mean of the total eggs (in thousands) for each transect strip using

$$\hat{y}=\frac{\sum_{i=1}^{n}\hat{y}_i}{n}, \tag{4}$$

where
and

$$\hat{y}_i = M_i \bar{y}_i, \tag{5}$$

n	=	number of transects actually sampled,
i	=	transect number,
M_i	=	$w_i/0.1^{0.5}$ = number of possible quadrants in transect i,
w_i		spawn patch width in meters measured as the distance along the transect between the first quadrant containing eggs and the last quadrant containing eggs, and
$\bar{y}_i$	=	average quadrant egg count in transect i (in thousands of eggs).

Average quadrant egg count within a transect, $\bar{y}_i$, will be computed as

$$\bar{y}_i = \frac{\sum_{j=1}^{m_i} y_{ij}}{m_i}, \tag{6}$$

where

j	=	quadrant number within transect i,
m_i	=	number of quadrants actually sampled in transect i, and
y_{ij}	=	adjusted diver-estimated egg count (in thousands of eggs) from the diver calibration model for quadrant j in transect i.

The variance of T, ignoring the unknown variability in R, is similar to that given by Cochran (1963) for three stage sampling with primary units of equal size. In this case the expression is modified because the primary units (transects) do not contain equal numbers of secondary units (quadrants), and the variance term for the third stage comes from the regression model used in the diver calibration samples. Therefore the estimated variance of T, conditioned on R, is

$$Var(T) = \frac{[N^2(10^{-6})^2[\frac{(1-f_1)}{n}s_1^2 + \frac{f_1(1-f_2)}{\sum_{i=1}^{n} m_i}s_2^2 + \frac{f_1 f_2}{\sum_{i=1}^{n} m_i}s_3^2]]}{(1-R)^2}, \tag{7}$$

where

variance among transects,

$$s_1^2 = \frac{\sum_{i=1}^{n} (\hat{y}_i - \hat{y})^2}{n-1} = \tag{8}$$

$$s_2^2 = \sum_{i=1}^{n} M_i^2 \sum_{j=1}^{m_i} \frac{(y_{ij} - \bar{y}_i)^2}{n(m_i - 1)} = \tag{9}$$

variance among quadrants,

$$s_3^2 = \sum_{i=1}^{n} \sum_{j=1}^{m_i} Var(y_{ij}) = \tag{10}$$

sum of the variances of the individual predicted quadrant egg counts from the diver calibration model,

$$f_1 = \frac{n}{N} = \tag{11}$$

proportion of possible transects sampled, and

$$f_2 = \frac{m_i}{M_i} = \tag{12}$$

proportion of quadrants sampled within transects (same for all transects).

Diver Calibration. Divers will be calibrated to correct systematic biases in their estimates of numbers of eggs. This calibration consists of the derivation of the relationship between diver estimates of eggs within a quadrant and actual counts obtained in the laboratory on the same eggs. Calibrations will be performed for each combination of diver and vegetation category as defined by the structural and phylogenetic similarities of egg-bearing plants. The four vegetation categories are designated eelgrass, fucus, hair kelp and large brown kelp (Becker and Biggs, 1992).

Diver bias will be determined using methods described in an as-yet unpublished report of the 1994 calibrations (personal communications, Ed Debevec, ADF&G, Cordova). The analysis will follow that described in the 1994 detailed project description in that the distribution of the random component will be assumed to be lognormal. However, the choice of random component (dependent vs. independent variable) will be reversed from that of previous analyses and diver estimate rather than laboratory egg count will be assumed lognormally distributed. Analysis of variance of Log(Diver Estimate), along with graphical methods, will be used to assess the significance of year, diver, and vegetation factors. The final model relating diver estimates to laboratory egg counts will be that which is simplest but retains suitable precision and lack of bias. Within the analysis of variance, attempts will be made to account for the repeated measures nature of the diver estimates, possibly using a split-plot analogy. Prediction of laboratory counts from the diver estimates made in the main spawn survey will, as a result of the designation of dependent and independent variables, be made in an inverse way. Variances of predicted laboratory counts will be estimated by the bootstrap method.

Spawning Biomass per Billion Eggs (B'). Data from the herring sampling program for AWL, sex ratio, and fecundity will be used to estimate the relationship between spawning biomass and egg deposition. Once the age composition and sex ratio of a spawning population will be determined, the average weight of the females in that population will be calculated. The relationship between fecundity and female weight will be used to calculate total numbers of eggs deposited and tonnes of herring spawners. The tonnes of spawning biomass required to produce one billion eggs (B') will be estimated as

$$B' = \frac{\bar{W}S}{F(\bar{W}_f)} 10^3, \qquad (13)$$

where

$\bar{W}$ = estimated average weight in grams of all herring (male and female) in the spawning population in an area,

S = estimated ratio of total spawning biomass (male and female) to female spawning biomass,

$F(\bar{W}_f)$ = estimated fecundity at the average weight of females in the spawning population in an area, in numbers of eggs, and

$$10^3 = \text{conversion factor} = \frac{10^{-6}}{10^{-9}} = \frac{\text{grams to tonnes}}{\text{eggs to billions}}$$

Because average weight, sex ratio and fecundity will be all estimated from the same herring samples, the estimates will be not independent. The variance of B' is approximately:

$$
\begin{aligned}
Var(B') = (10^3)^2\Big(& \Big[\frac{S}{F(\bar{W}_f)}\Big]^2 Var(\bar{W}) \\
& + \Big[\frac{\bar{W}}{F(\bar{W}_f)}\Big]^2 Var(S) \\
& + \Big[\frac{\bar{W}S}{F(\bar{W}_f)^2}\Big]^2 Var(F(\bar{W}_f)) \\
& + 2Cov(\bar{W},S)\Big[\frac{S}{F(\bar{W}_f)}\Big]\Big[\frac{\bar{W}}{F(\bar{W}_f)}\Big] \\
& - 2Cov[\bar{W},F(\bar{W}_f)]\Big[\frac{S}{F(\bar{W}_f)}\Big]\Big[\frac{\bar{W}S}{F(F(\bar{W}_f))^2}\Big] \\
& - 2Cov[S,F(\bar{W}_f)]\Big[\frac{\bar{W}}{F(\bar{W}_f)}\Big]\Big[\frac{\bar{W}S}{F(\bar{W}_f)^2}\Big]\Big).
\end{aligned}
\qquad (14)
$$

Because S will be estimated from pooled or single AWL samples (depending on availability of fish), it will not be possible to estimate the covariance terms containing S, $Cov(\bar{W},S)$ and $Cov[S,F(\bar{W}_f)]$. Because the term involving $Cov[\bar{W},F(\bar{W}_f)]$ has been shown to be very small in previous analyses and probably contributes little to Var(B'), these covariance terms will not be included in the estimate of Var(B').

Herring Age, Weight, Length, Sex, and Fecundity:

The largest portion of this project element has traditionally been part of an existing agency program conducted annually by ADF&G using volunteer commercial seine vessels to capture herring for basic biological sampling. Because commercial herring fishing not likely to be open again in 1996, AWL samples will be collected from major concentrations of spawning herring using purse seine vessels under short term vessel charter in conjunction with acoustic surveys. Sampling will generally occur soon after concentrations of herring appear in nearshore areas and are accessible to purse seines. Samples will be taken periodically from major herring concentrations throughout PWS during the spawning migration. AWL samples collected during the peak of spawning in each summary area, as determined from aerial survey sightings of milt and herring schools, will be used to estimate age and sex composition as well as average herring size from all major biomass concentrations in each area.

AWL sampling will be stratified by date and area for test fishing catches in each spawning area. Sample size for each stratum will be set to simultaneously estimate proportions by age when sampling from a multinomial population (Thompson 1987). The goal will be to select the smallest sample size for a random sample from a multinomial population such that the probability will be at least 1-α (precision = 0.05) that all the estimated proportions will be simultaneously within 5% (accuracy = 0.05) of the true population age proportions. A sample size of 450 herring per stratum will be set to ensure that this level of precision and accuracy would be obtained for any number of age classes and proportions when less than 5% of the collected scales will be unreadable. Wilcock et al. (*In press*) provide a thorough description of PWS herring AWL sampling program procedures.

From an analysis of 5 years of fecundity data for PWS herring (personal communication, Tim Baker, Alaska Department of Fish and Game, Anchorage), Baker found that for a given year the relationships between herring weight and fecundity were very similar among areas, but less so among years for a given area. Year was found to be significant as were all interaction terms with year in an analysis of co-variance. As a result, we determined that it is probably important to collect fecundity data from PWS every year, but within a year, samples can be pooled across areas. Fecundity samples will be subsampled from all female herring in AWL samples and stratified by fish length. Egg and gonad weights will be measured and used to calculate average fecundity at the average female weight ($F(\bar{W}_f)$) from expression (12).

A fecundity sampling goal was set such that fecundity estimates would contribute no more than 1% to the confidence interval width of the biomass estimate. This was achieved for surveys from 1988 through 1990 and 1992 during which area stratum sample sizes ranged from 100 to 400 fecundity samples and the standard error represented from 1.5 to 2.8% of the mean fecundity estimate. A sample size of 150 to 200 herring pooled across areas should be sufficient to maintain the coefficient of variation below 2.0%. To collect females over the range of possible sizes, we will sample 20 to 30 fish within each 10 mm length category from 181 to 250 mm standard length. In addition, we will collect 20 to 30 females 180 mm or smaller if available.

The female gonad weight will be assumed to be the equivalent of the weight of the ovaries removed from each female. Gonadal somatic index will be defined as the percentage of total herring weight represented by gonad weight and will be calculated by dividing the gonad weight by body weight of each fish sampled.

Mean Weight and Sex Ratio. Mean weight and sex ratio will be estimated from AWL samples collected from each spawn deposition summary area. AWL samples collected during peak spawning in each area will be pooled to estimate mean weight and sex ratio for that area. Average weight and sex ratio for PWS will be estimated as a weighted average of estimates from all areas. Average weight and sex ratio for each area will be weighted by the escapement biomass estimate based on spawn deposition surveys for that area.

Sex ratio, S, will be calculated as the ratio of the number of herring of both sexes in AWL samples to the number of females. The binomial distribution is applicable to estimating the proportion, p, of females in AWL samples, where $S = 1/p$. The variance of S is

$$Var(S) = \frac{S^2(S-1)}{n}, \quad (15)$$

where n is the number of fish in the AWL sample.

Fecundity for Biomass Estimates. Average fecundity for PWS will be estimated from a fecundity-weight relationship as $F(\bar{W}_f)$, and used in equation 12 to estimate biomass from spawn deposition. The variance of estimated average fecundities will be approximated by the variance of predicted means from the fecundity-weight linear regression (Draper and Smith 1981)

$$Var[F(\bar{W}_f)] = s^2\left[\frac{1}{n} + \frac{1}{q} + \frac{(\bar{W}_f - \bar{WF})^2}{\sum (W_i - \bar{WF})^2}\right], \quad (16)$$

where

s^2	=	the residual mean square from the fecundity-weight linear regression,
$\bar{W}_f$	=	the average weight of female fish in the spawning population,
$\bar{WF}$	=	the average weight of females in the fecundity sample,
W_i	=	the weights of individual females in the fecundity sample,
n	=	the total number of females in the fecundity sample from each area, and
q	=	the total number of females in the representative AWL sample or pooled samples from the corresponding area.

A linear relationships between female body weight and fecundity will be used because Hourston et al. (1981) found that female body weight at spawning explained 70% of the variation in fecundity among individuals while length and age only explained another 2% of the variation.

A secondary purpose for determining average fecundity annually, will be to obtain information about natural fluctuations in reproductive potential in relation to fish size, fish growth, and environmental conditions. This information will be important for ecosystem studies such as project 96320 (SEA) that will test hypotheses about constraints to fishery production in PWS. For example, sea surface temperature appears to be an important natural factor affecting reproductive potential of herring. Tanasichuk and Ware (1987) found that sea surface temperatures 60 to 90 days before spawning best accounted for variations in size specific fecundity for herring in British Columbia, Canada. Using five years of PWS fecundity data, Biggs et al. (*in press*) showed egg production to be a function of fish body weight and to be strongly correlated with sea surface temperatures 13 to 15 months prior to spawning. Egg weight was best correlated with sea surface temperatures 4 to 9 months prior to spawning and fecundity decreased as water temperatures increased.

Acoustic Survey and Biomass Estimation

Standard acoustic techniques (Urick 1975; Thorne 1983b; Ehrenberg and Lytle 1972) for echointegration and dual beam processing of target strength will be used to independently estimate the biomass of herring present near spawning grounds during the spring migration. Energy reflected from fish concentrations will be measured and converted to fish density using measurements of energy reflected from single fish (target strength) and knowledge of the sample volume (transducer directivity). Net sampling will be conducted to subsample the acoustic targets to verify species, size and obtain other biological information on the insonified fish (Thomas 1992).

The acoustic survey will employ one commercial purse seiner under short term vessel charter to assist in searching for herring schools and to conduct net sampling. The scientific echosounding equipment will be located aboard the ADF&G research vessel *Montague* for acoustic mapping of biomass. The acoustics vessel will be outfitted with either a BioSonics 70 or 120 Khz echo sounder with a dual beam pre-amplified transducer mounted on a 1.2 m BioSonics Biofin in a down-looking configuration. The Biofin will be towed at a depth of about 2 m at approximately 5 m off to one side of the vessel. The catching vessel will be equipped with a seine approximately 30 m deep typical of the gear-type used in the commercial sac roe herring fishery.

Survey Design. The acoustic survey will be a multistage sampling design (Cochran 1967). Historical information about location of spawning, aerial surveys of herring schools, and wide scale searches using ship's searchlight (sweeping) and down-looking echosounders will be used to locate concentrations of herring schools in a first stage search. The second stage of sampling will be to map school groups and measure the density using the scientific echosounder. Acoustic survey transects will be run in a zigzag fashion over the school groups and will be replicated during both day and night for large school groups.

Acoustic Parameters. Target strength information for herring will be derived from average length to target strength (in decibels) per kg fish after Thorne (1983a). Thorne's (1983a) empirical relationship assumes the following logistical equation:

$$\gamma = \frac{\bar{\sigma}}{\bar{W}} = a\bar{l}^{\,b} \qquad (17)$$

where σ is the mean acoustic backscattering coefficient, W is the mean weight (in kg), l is the mean length (in cm), and a and b are constants. Values for the constants (a and b) are obtained from data for a variety of fisheries presented by Thorne using a linear regression of $\log_{10} l$ versus 10 log (σ/w), where 10 log (σ/w) is referred to in Thorne (1983a) as "target strength per kg." Average herring length and weight data will be compiled from samples obtained by the purse seine catcher vessel. These measured data will be applied to Thorne's (1983a) empirical relationship to obtain the ratio $\gamma = \sigma/w$ and the mean backscatter coefficient (σ). As a cross check, *in situ* measurements of target strength from dual beam acoustic data will be generated and compared with Thorne's (1983a) empirical formula.

Biomass estimation. Herring biomass will be calculated for each zigzag survey. The general calculation of the population density using echointegration for a single cell *jk* on a transect is given as

$$\beta_{jk}=\rho_{jk}\,\overline{w}_{jk}=\frac{C(ei)_{jk}\cdot P_{jk}}{\frac{\overline{\sigma}_{jk}}{\overline{w}_{jk}}} \qquad (18)$$

where β_{jk} is the population density (mass per unit volume), ρ_{jk} is the density of scatterers, w_{jk} is mean weight of scatterers, C is acoustic constant (calibration settings ie., gain etc.) ei_{jk} is the mean of the voltage squared, P_{jk} is percentage of cell *jk* within the water column, and σ_{jk} is mean backscattering coefficient for targets within cell *jk*.

The biomass for a region of surface area A is determined by using a set of line transects along which a total of nrs point estimates of biomass per unit area is obtained. Specifically,

$$B=\frac{\sum_{j=1}^{nrs}\sum_{k=1}^{nst}\beta_{jk}}{nrs}\cdot A \qquad (19)$$

where nrs is number of reports (along the line transects), nst is number of depth strata, and A is survey area.

Herring biomass estimates will follow Thorne (1983a), assuming that σ_{jk}/w_{jk} is independent of cell *jk*, hence, for all *jk* σ_{jk}/w_{jk} is a constant γ, and γ is given by equation 1. With this assumption, equation 4 simplifies to:

$$\beta_{jk}=\frac{C}{\gamma}(ei)_{jk}P_{jk} \qquad (20)$$

and the herring biomass B in an area is given as

$$B=\frac{C}{\gamma}\,\frac{\sum_{j}\sum_{k}(ei)_{jk}P_{jk}}{nrs}\cdot A \qquad (21)$$

Egg Loss Study

Analysis of previously collected information on the proportion of eggs lost through physical removal and the mortality rate of remaining eggs will be summarized and reported in FY96. Important factors in egg loss will be identified through this analysis and used to guide future study design to estimate egg loss indirectly through modeling and annual measurement of these important factors.

Prior to 1994, an assumed constant of 10% egg loss for surveys generally conducted 5-6 days after spawning was used based upon values recommended in the literature (Haegele et al. 1981, Blankenbeckler and Larson 1982). Other investigators (J. Schweigert, personal communication, Canadian Department of Fisheries and Oceans, Nanaimo, B.C.; Biggs et al. *in press*) estimated egg loss rates, but did not include collection of data to relate egg loss to habitat, environmental conditions or predation. Beginning in 1994, egg loss study design for this project has included modifications to identify important factors in egg loss to facilitate modeling. Identification of important factors included measurements to describe habitat characteristics, physical and oceanographic environmental conditions, and avian predation. In 1995, wave energy at spawning sites and local meteorological conditions were also recorded in conjunction with egg loss estimates.

Measurements of physical conditions and observations of habitat characteristics gathered for egg loss sites during previous field seasons will be tested for correlations with meteorological conditions and with rates of egg loss to address hypotheses A and B. Physical measurements and observations included air and water temperature, salinity, precipitation, wind speed and direction, wave height and wave direction and were collected by survey divers during each egg loss site visit. Gradient, substrate and vegetation were collected at each site during setup. Electronic recording instruments were also used to gather data on environmental conditions including temperature, wave height, and tide height at fixed locations during incubation. The University of Alaska will incorporate these physical and meteorological data into egg loss and embryo survival models.

For the current proposed project, regional meteorological and oceanographic data will be gathered from shipboard surveys, moored instrumentation, and existing data products from government agencies. Project personnel will work with SEA investigators for the acquisition and archival of data products. These measurements will be used to model the effect of meteorological conditions on wave activity and the resulting effects on egg loss and embryo survival. Data analysis will be the primary responsibility of the University of Alaska with assistance and support from project personnel and SEA investigators.

Egg Loss Data Analysis. Development and selection of appropriate statistical analyses for egg loss are currently in progress. If no refinements to previous techniques are deemed appropriate, an exponential decay model will be used to estimate loss in numbers of eggs over time for bias corrected similar to that used for the 1990 and 1991 data:

$$ADJ_{ijk} = e^{\alpha} e^{trans_j} e^{depth_k} e^{\tau_{jk}(days_{ijk})} e^{\epsilon_{ijk}}, \qquad (22)$$

where

α = a constant,
ADJ_{ijk} = adjusted egg density estimates,
$trans_j$ = parameters representing the effect of transect j,
$depth_k$ = parameters representing the effect of depth k,
τ_{jk} parameters controlling the functional form of the relationship between egg density and time (number of days after spawning),
$days_{ijk}$ = the number of days after spawning occurred, and
ε_{ijk} = normally distributed random variable with mean = 0 and variance = σ^2.

A multiplicative model will be chosen because egg numbers will be expected to vary with location (transect) and depth. All interactive terms will be included in the model. After a logarithmic transformation, equation 22 became

$$\log_e(ADJ_{ijk}) = \alpha + trans_j + depth_k + \tau_{jk}(days_{ijk}) + \epsilon_{ijk}. \tag{23}$$

In logarithmic form, the model comprised a linear analysis of covariance (ANCOVA) with two factor effects (transect and depth) and 1 covariate (number of days after spawning). SAS (1987) procedure for general linear models (GLM) will be used to obtain least squares estimates of the parameters. Estimates of eggs over time (days) were then made for each transect and depth.

The egg survival model used to track the data collected in 1989 through 1991 in PWS took the form of the following analysis of covariance (ANCOVA)

$$\begin{aligned} \arcsin(s) = \mu + treat_j + depth_k + day_i + treat*depth_{jk} + \\ day*treat_{ij} + day*depth_{ik} + day*treat*depth_{ijk} + \\ trans(treat)_{l(j)} + \epsilon_{ijkl}. \end{aligned} \tag{24}$$

Future analyses may include replacing the treatment term used to differentiate between oil and control areas with a treatment term for habitat type. The egg loss and current egg survival models will eventually be synthesized into an embryo survival model that incorporates habitat type, predation, and the relationship of meteorological conditions on wave action. The ultimate goal, as outlined in the NHP portion of the SEA plan, will be to build a sound-wide embryo survival model relating habitat type, egg density, predation, and meteorological conditions.

Systematic bias in diver estimates at egg loss sites will be assumed to be the same as diver estimates for spawn deposition surveys and the model used will be identical.

C. Contracts and Other Agency Assistance

Through a competitive bidding process, one or more purse seine vessels will be chartered to capture fish for species and size composition of acoustic targets, AWL/fecundity samples, spawning adult herring for histopathology samples (project 96320S), and reproductive impairment samples for (project 96074). Depending upon the duration of the work and other competing uses, the ADF&G *R/V Montague* may be used as a sampling platform and as a scientific acoustics vessel either at no charge or at a standard rate of $1,200/d. In the event the *R/V Montague* is not available for use, another vessel will be secured on short term vessel charter agreement. This field work will occur over approximately 2 weeks during mid-April.

Two vessels will be chartered through a standard competitive bid process as research platforms for spawn deposition surveys. These vessels will be used to house and transport SCUBA divers and their equipment. This portion of the project will last approximately 3 weeks from early to mid-April through early-May.

Biometric and computer programming assistance for egg loss and recruitment studies will be contracted with the University of Alaska through a Reimbursable Services Contract.

D. Location

This project will be conducted entirely within PWS. Project results will directly affect the management of PWS herring fisheries. All major PWS communities, including Cordova, Seward, Valdez and Whittier, are directly affected by these fisheries since these communities house not only commercial fishers but also the various support services relating to vessel and gear repair and storage, as well as fish processing. Many native villages in PWS, such as Tatitlek and Chenega, also depend upon PWS herring for subsistence needs. Another benefit of the project will be the information gained during egg loss studies which may be extremely valuable in assessing critical habitat and energy needs of migratory birds using PWS.

SCHEDULE

A. Measurable Project Tasks for FY 96

December	Finalize FY96 Detailed Project Description
February	1995 Biomass estimates - Dept. Forecast and Stock Assessment Reports
April	<u>Before onset of spawning:</u>
	Conduct acoustic survey (5-7 d)
	Collect AWL, fecundity, disease, genetic stock ID, and bioenergetics samples
	<u>After onset of spawning:</u>
	Initiate dive surveys
	Assist reproductive impairment sample collection
May	Submit FY97 Draft Detailed Project Description
	Complete dive surveys
	Begin lab processing of diver calibration calibration and fecundity samples
June	Complete calibration sample processing samples
September	Finalize estimate of spawning biomass
November	Finalize projection of 1997 run biomass
April 1997	Submit FY96 annual report - biomass estimate
June 1997	Submit Final report for Egg Loss study

B. Project Milestones and Endpoints

The following milestones and endpoints will be achieved over the life of the project:

September 1996	Objective 1:	Finalize estimate of spawning biomass of herring in 1996 using spawn deposition methodology.
October 1996	Objective 2:	Finalize acoustic estimate of spawning biomass of herring in 1996 & decide whether to continue or modify program.
December 1996	Objective 3:	Test egg distribution\density model
January 1997	Objective 4:	Test embryo survival model
February 1997	Objective 5:	Test recruitment success model

C. **Project Reports**

Scientific and technical aspects of the study will be subject to an internal peer review process within ADF&G's Commercial Fisheries Management and Development Division (CFMDD). Work plans, study design, and annual status reports will be subject to the peer review process established by the EVOS Board of Trustees and Chief Scientist. Significant findings presented in status reports and final reports will be submitted for publication in peer reviewed journals and presentation at scientific symposia as they are obtained. A final report will be submitted for FY96 by April 15, 1997.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

Project 96166 will be integrated closely with project 96320, SEA. Data management will be coordinated as outlined in SEA for integration of results. Other components of SEA will require sharing of information. Juvenile Herring Growth and Habitat Partitioning (96320T) will require location and abundance of spawn as well as information about age and size structure of sampled catches. Physical measurements taken for project 96166 may be useful to project 96320M. Information about spawn distribution will also be useful in drafting a study design for herring larval advection studies.

Project 96166 will also share information and resources with Project 96165, Herring Genetic Stock Identification in PWS. Additional samples required for this project beyond FY96 collections will be collected during AWL sampling and results will be used to refine our definition of stock structure. This improved stock definition will aid in recovery monitoring and the formulation of fisheries harvest strategies.

Other projects which will rely on sharing of resources with project 96166 for sample collection include Reproductive Impairment (96074), Somatic and Spawning Energetics of Herring/Pollock (96320U), and Disease Impacts on PWS Herring Populations (96320S).

Finally, integration of research will require data sharing and coordination with Project 96163, Forage Fish Influence on Injured Species. Herring are an important forage species. Herring and other forage fish are predators, competitors, and prey for each other at various stages throughout their life histories. Understanding the population dynamics of all forage species will lead to a better understanding of food availability, population fluctuations, and breeding success of birds and mammals that prey on them.

ENVIRONMENTAL COMPLIANCE

These activities are within existing collecting permits or Federal special use permits issued to ADF&G for scientific data collection. This project received a categorical exclusion under the National Environmental Policies Act (NEPA). Federal OSHA regulations covering hazardous materials handling and disposal, and lab safety training for personnel working with preservation chemicals will be followed. No other permits or other coordination activities are involved.

96170

Isotope Ratio Studies of Marine Mammals in Prince William Sound

Project Number:	96170
Restoration Category:	Research
Proposer:	University of Alaska Fairbanks
Lead Trustee Agency:	Alaska Department of Fish and Game
Cooperating Agencies:	
Duration:	3 Years
Cost of FY 96:	$150,400
Cost of FY 97:	$148,000
Cost of FY 98:	$127,000
Geographic Area:	Prince William Sound/Gulf of Alaska
Injured Resource/Service:	Harbor seals, nearshore ecosystem species, seabirds

ABSTRACT

This project contributes to the studies by the ADF&G personnel to determine the reasons for the decline of harbor seal and steller sea lion populations in Prince William Sound (PWS). In addition, it contributes to the SEA program being conducted by the Prince William Sound Science Center and the Institute of Marine Science, UAF, to describe the food chains supporting important commercial fish species impacted by the Exxon Valdez Oil Spill. We seek to better describe the trophic interactions and trophic status of marine mammals, birds and their prey species. The integrating methodology for this wide range of tasks is the use of stable isotope ratios as natural tracers of carbon and nitrogen transfers through the food webs. Through a mix of captive animal studies, comparison of isotope ratios in archived and current marine mammal tissues and their potential prey species in the PWS, insight into environmental changes causing the decline may be possible. We also will supply the isotope ratio determinations for other projects using this technique in the PWS ecosystem. Over the 12 months of FY 96 funding we anticipate the analysis of approximately 10,000 samples in these related projects.

INTRODUCTION

Over the past two decades, isotope ratio analysis has emerged as a powerful tool in ecosystem research both on the process scale and as a validation technique for large-scale ecosystem models (Michener and

Schell, 1994). In relevant applications to this study, Schell et al (1989a) described a geographic gradient in isotope ratios in biota across the Alaskan Beaufort Sea and the Bering-Chukchi seas and showed that this gradient could be applied to describing bowhead whale natural history. The isotopic gradient arises from the primary producers in the ecosystem and is passed up food chains to label consumers clear up to the top predators. Saupe et al. (1989) describes the parallel shifts in $\delta^{13}C$ in euphausiids and copepods across this region and Schell et al (1989b, 1993) discussed the effects of the gradient in forming oscillations in isotope ratios in whale baleen. Hobson and Welch (1992) used isotope ratios to describe the trophic relationships of birds and mammals to the available prey species in the Canadian Arctic. Further extension to benthos by Dunton et al (1991) and to fishes (Vinette, 1992) has confirmed that the isotopic trends are evident across the entire food web. In contrast to the primarily geographic control on carbon isotope ratios, nitrogen isotope ratios are influenced by trophic level. Vinette (1992) has shown that the $\delta^{15}N$ of euphausiid and copepods in the Bering, Chukchi and Beaufort seas are statistically indistinguishable but that when pelagic and benthic species of known feeding habits are compared, a predictable enrichment in ^{15}N occurs of about 3.3°/oo per trophic level increase. By assembling the trophic spectrum of species within an ecosystem it is possible to ascribe trophic status within the ecosystem. Hobson and Welch (1992) were able to used $\delta^{15}N$ values in the Barrow Strait - Lancaster Sound region to identify the roles of arctic cod (*Boreogadus saida*) and other prey species to top consumers. Higher trophic levels showed little change in $\delta^{13}C$ but varied by an average of 3.8 /oo between levels. Recently, Sease et al (1993) showed preliminary data that confirmed that sea lions occupy a high trophic status in North Pacific food webs and reflect a geographic gradient between Prince William Sound and the Washington coast. Schell (in press) has further shown that in the Bering sea lions are not as high in trophic status as spotted seals and span a wide trophic range between individuals. Whereas an individual animal may show little temporal change in trophic status as indicated by $\delta^{15}N$ values or regional feeding as evidenced by carbon isotope ratios along the length of vibrissae, there have been remarkable differences from one animal to the next in the few individuals examined to date. In comparing vibrissae with several years of growth, it is readily evident that some sea lions feed over at full trophic levels apart. This study expands upon our growing data base to provide a similar assessment of the trophic energetics of harbor seals in Prince William Sound and to assist other EVOS studies by providing isotope ratio analysis and interpretation for their studies.

Funding for this work resumed in February 1995 (no interim funds from Oct. 94 were allocated) and as a result only preliminary findings are available at this time. We have completed the first major suite of prey species isotope ratio analyses and collected a wide spectrum of marine mammal samples from native harvests and through strandings and collections being conducted by the Alaska Department of Fish and Game. We have met with the chief veterinarian of the Mystic Marine Life Aquarium and they have kindly agreed upon protocols for undertaking experiments on captive sea lions and harbor seals aimed at determination of whisker growth rates, diet fractionation factors arising from differing types of prey species, and seasonal cycles in isotope ratios arising from physiological effects. In addition, as part of a synergistic study on Bering Sea marine mammals, we have also conducted the first set of measurements of whisker growth rates on juvenile sea lions being raised at the Vancouver Aquarium in cooperation with Dr. Andrew Trites of the University of British Columbia.

NEED FOR THE PROJECT

A. Statement of the Problem

Harbor seals were undergoing an unexplained decline in numbers before the oil spill and the decline was further accelerated by the disaster. Since that time the population has not recovered and is still at a low level although now perhaps finally stabilized. No definitive cause and effect relationships have been found for the decline or failure to recover. This project uses stable isotope ratios as natural tracers to test hypotheses regarding shifts in diet or trophic status in the past decade as underlying reasons for the decline.

A second need for this project is to provide isotope ratio analyses for this study and other restoration projects needing isotope abundance information. We anticipate receiving a total of approximately 10,000 samples for isotope ratio analysis in the coming year.

B. Rationale

Carbon isotope ratios serve as conservative tracers of energy supply between trophic levels (phytoplankton to zooplankton to fishes to top consumers). Seals, cetaceans, birds, etc., acquire the isotope ratios in proportion to the amount of food derived from each differing source. This, in turn, is reflected in the composition of body tissues and in keratinous tissues (claws, feathers, baleen, whiskers) as a temporal record when multiple sources of food are consumed over time and space. This allows the discerning of important habitats and food resources in animals that seasonally migrate or undergo periods of hyper- and hypotrophy.

Nitrogen isotope ratios reflect both the food sources and the trophic status of that animal. As nitrogen in food is consumed and assimilated by a consumer, the heavy isotope is enriched by approximately 3 ä with accompanying loss of the lighter isotope through excretion. The enrichment occurs with each trophic step and thus allows the construction of conceptual models and food webs and the assignment of relative trophic status to species for which dietary data are sparse. The data obtained from these measurements are unique in that they trace materials actually assimilated and thus can be used for more accurate ecosystem modeling.

The availability of macrozooplankton forage for salmon, herring, and their predators varies in space and time because of changes in the physico-chemical processes in Prince William Sound. In the SEA context, the latter is known as the Lake/River processes (SEA hypothesis number 2). When macrozooplankton are not available, macrozooplankton consumers are forced to switch prey, the Predator/prey relationships (SEA hypothesis number 3) shift in time and space. These shifts represent fundamental changes in the way the PWS ecosystem produces commercial species (i.e. herring and salmon). A better understanding, particularly a quantitative understanding, is a prerequisite to determining protocols for restoration and recovery of these species.

It can be postulated that the natural stable isotope abundances of PWS biota will shift because of changes in trophic level, food web structure, and primary productivity in the context of the SEA hypotheses, thus providing an independent tool to verify, quantify and model ecosystem processes. The tracer nature of the approach will enable the integration of ecosystem components. It will enable us to monitor both "top down" (predation) and "bottom-up" (food supply) controls on herring and salmon production.

C. Summary of Major Hypotheses and Objectives

The major hypothesis to be tested is that:

The isotope ratios of harbor seals are derived from prey taken from the Prince William Sound ecosystem. Changes in the trophic structure of the food webs arising from either the oil spill or natural cycles will be evident through changes in isotope ratios in potential prey and seals.

The objectives of this study are divided into three elements:

1. A research component on marine mammals focusing on the trophic energetics and ecosystem dynamics of harbor seals conducted by Dr. Schell, Principal Investigator (PI), in cooperation with ADF&G personnel working as part of the marine mammal program. An additional effort using captive animals to calibrate the response to changing isotopic composition in diet and to determine vibrissae growth rates will also be undertaken. This will entail the analysis of approximately 3000-4000 samples for carbon and nitrogen isotope ratios, a major increase over last year reflecting the very successful collection of samples from over 100 seals.

2. A research component focusing on lower trophic levels having direct application to the testing of hypotheses regarding fisheries resources. This work will be conducted in cooperation with Dr. T. Kline of the Prince William Sound Science Center and is described in detail in his Detailed Project Description. Our own work on this aspect will entail analysis of over 1000 samples collected in the vicinity of marine mammal haulouts and feeding areas. It will also include samples from outside of PWS to provide information of potential shifts in isotope ratios arising from migrations. Dr. Kline estimates the need for analysis on approximately 2000 samples. Analytical costs for these latter samples are included in the separate proposal by Dr. Kline.

3. A service/research component supplying analytical services for carbon and nitrogen isotope ratios to other PI's involved with EVOS studies. This effort will entail consultation and analysis of selected samples to build upon the data base and to integrate the food web studies into a cohesive picture of the trophic dynamics. This task is anticipated to require approximately 20% of the analytical and research effort and has been embraced enthusiastically by other research components. We already have samples from 9 sea otters and collections of sea birds and prey are currently underway.

The ancillary work from other participants will be coordinated through the UAF Stable Isotope Facility and will consist of approximately 1000 samples. If there appears to be more than 1000 external samples collected, the PI will prioritize samples in consultation with the investigators. All work will be performed cooperatively and the data shared as outlined in the Detailed Project Descriptions of the cooperating studies.

D. Completion Date

This project is anticipated to be complete in 1998. The service aspects of the mass spectrometry for isotope ratios may continue beyond that date if demand warrants.

COMMUNITY INVOLVEMENT

The community involvement in this project is essential in that a large fraction of the samples will be provided via native harvests of marine mammals. Kate Wynne, of the USFWS has collected seal whiskers and tissues for this study in the past and we anticipate this assistance will continue.

PROJECT DESIGN

A. Objectives

The objectives to be completed during the period of this proposal are essentially the same as in our FY 95 proposal and include:

1. Collect samples of harbor seal vibrissae through continued cooperative work with the Alaska Department of Fish and Game in Prince William Sound.

2. Collect samples of harbor seal prey species including forage fishes, salmon and herring in the vicinity of major haul-outs and high population densities. Samples of seal tissues will be collected from native hunters. These samples will be obtained through assistance by ADF&G personnel monitoring harvests and through the efforts of T. Kline.

3. Perform stable isotope ratio analyses on tissues and organisms collected during the sampling program. Through the use of **carbon** isotope data on taxa collected over geographical regions, the presence/absence of **isotopic gradients** useful in sorting out habitat dependencies will be determined.

4 Assist other research programs in the Prince William Sound ecosystem study by conducting stable isotope ratio analyses on samples provided and aid the interpretation of results. This effort will require approximately 20% of the analytical and research effort.

5. Through the use of **nitrogen** isotope ratios in collected taxa, assign **trophic status** to species in each region. Compare trophic status with predictive models based on conceptual food webs.

6. Determine temporal changes in harbor seal trophic status and food dependencies by comparing isotope ratios along the lengths of vibrissae with prey availability and their isotope ratios. Through the use of captive animals being fed known diets, establish the relationships between whisker growth rate and temporal changes and the fractionation factors between the $\delta^{13}C$ and $\delta^{15}N$ values of diet and consumer.

7. Compare the isotope-ratio derived food web models to predictions by the lake-river hypothesis and others being tested by the SEA project as an independent means of validation.

METHODS

The primary work will be divided into the sampling program and the subsequent analytical and synthesis tasks. Sampling of tissues for stable isotope analysis has been described for both bulk tissues (muscle, blubber) and temporally variable tissues (whiskers, claws, etc.) (Schell, et al. 1989; Michener and Schell, 1994).

1. Analytical — Vibrissae from seals either from Prince William Sound or captive animals are noted as to location in the face. The whisker is then segmented at 2.5 mm intervals with a razor and the subsamples placed in vials for later grinding and mass spectrometry. The subsamples obtained are dried and powdered for homogeneity and the isotope ratios of carbon and nitrogen determined with a Europa 20/20 mass spectrometer system. The sample is flash combusted at high temperature and the nitrogen and carbon dioxide gases separated and purified by gas chromatography. These are subsequently led into the mass spectrometer by capillary and the isotope ratios determined. The analytical replicability for the entire sampling process is better than $\pm 0.05^{0}/oo$ for both $\delta^{13}C$ and $\delta^{15}N$.

2. Sampling — The acquisition of samples for isotope analysis will be conducted through several channels. Forage fish, pollock and other commercial species will be obtained through cooperative programs with the National Marine Fisheries Service, the Alaska Dept. of Fish and Game, and from the Prince William Sound Science Center. As part of the cooperative effort with Dr. Kline, samples will be recorded and the analyses run on a coordinated suite of specimens collected over the geographic regions of the Sound and over the seasons. This will allow "within taxa" comparisons to determination shifts in trophic levels and discrimination of the effects of geographic shifts of isotope ratios in primary producers.

   Samples of marine mammals, birds, etc., have been and will be obtained from archived materials, strandings, native harvests and in some cases, collection in the field. This effort will be closely coordinated with the US Fish and Wildlife Service, ADF&G, and the EVOS-sponsored efforts having field programs. Our experience in 1994 has already produced a wide variety of samples and there is reason to anticipate that 1995 will be even more productive as the requests for materials are communicated to field researchers. The small amounts of sample required for isotopic analyses means that little effort for preservation or transport is required.

The application of isotope ratio work with marine mammals is relatively new and the technique is still in a process of calibration. We have been offered the opportunity to conduct captive animal experiments at the Memorial University of Newfoundland and the Mystic Aquarium in Connecticut using harp seals and harbor seals. We plan to conduct measurements of whisker growth rates and correlation experiments between seals and diets of known composition. Seal vibrissae will be marked and growth rates measured over the seasonal cycles to determine if physiological effects are translated into differing isotope ratios. This work will comprise only a limited amount of the total effort but will be essential, given this relatively new field of application. This work will be conducted by Ph.D. student Amy Hirons as part of her dissertation program. This project will support travel costs to Memorial University to establish experiment protocols and to acquire data and information from cooperating investigators.

Tissues samples for analysis from cooperating investigators will be supplied to the PI in the form of dry powdered material to expedite handling and analysis. If samples must be prepared by the personnel in the PI's laboratory, a charge for preparation will be made to the investigator or a reduced number of samples will be run depending upon the difficulties involved. Similarly, glass fiber filtered samples will be charged at double the normal sample rate because of the accelerated destruction of the combustion furnace tubes from the melted glass particles. Since almost all sample materials are dried tissues, no significant problems are anticipated in this respect.

3. Synthesis of data — The plots of isotope ratios of carbon and nitrogen along the lengths of vibrissae from harbor seals are known to show oscillations in isotope ratios in response to dietary changes over the season (Schell, 1993-4 data). As new data with supporting natural history information are acquired, the values at specific intervals will be compared with potential prey for likely matches. These will be compared with observational data and known feeding habits. From this information, sampling can be constrained to the most probable food sources and further directed analyses performed to confirm or deny conceptual food web structure. In cooperation with ADF&G personnel, the stable isotope data will also be compared with fatty acid compositions in seal blubber to determine if other proxies for dietary components can be established.

   Additional synthesis efforts will be made in conjunction with modeling projects associated with the SEA program. The data we acquire is very valuable in that it is an independent means of validating food web and energy flow models to top consumers. If isotopic data are in conflict with that projected from the model calculations, it is usually the model that is off the mark. Although a complex ecosystem such as Prince William Sound with strong interactions between land and sea can give rise to varied isotopic abundances in the biotic components, the strong integrating effects that occur in building the "whole body" are very amenable to stable isotope tracers.

C. Contracts and Other Agency Assistance

None

D. Location

The research effort will be conducted in Prince William Sound with contrasting data obtained from samples from the Kodiak Island area and in the coastal Gulf of Alaska near Cordova. Comparative work involving prey items and marine mammals from outside Prince William Sound will be made on cruises of opportunity in the Gulf of Alaska. Calibration experiments on whisker growth rates and diet/stable isotope ratio changes will be undertaken using captive harbor seals at research facilities in St. John's Newfoundland and at the Mystic Aquarium, Mystic Connecticut. The benefits of this project will be realized throughout the PWS and will be applicable to other areas of the state.

SCHEDULE

A. Measurable Project Tasks for FY 96

1 Oct. 95 - Feb. 1996:	Prepare and analyze isotope ratio samples collected in 1994-1995.
15 Feb. - 31 March 1996:	Synthesis and coordination for sampling in 1996, Annual report on FY 96 (and prior) work.
Apr. 1996 - Aug. 1996:	Field work and sampling, captive animal experiments.
Aug. 1996 - Sep. 1996:	Analysis of samples Post field analysis and planning for 1997 zData synthesis, identification of gaps.

B. Project Milestones and Endpoints

The milestones in this project are a blend of definitive goals and a continuing research process that will extend to the end of the funding period. Specific goals will be attained as follows:

Captive animal studies of vibrissae growth rates and dietary effects on stable isotope ratios — Now underway and completion anticipated in late 1996.

Field collections of prey species over the geographic region, collections of whiskers and tissues from harbor seals — Currently underway. Will continue through FY 97, but will be more directed toward the end of the study as we fill data gaps.

Stable isotope analyses — The laboratory work associated with the preparation of samples and the isotope ratio analyses will continue throughout the duration of this project but will become more focused as the end approaches. The major collection and data base construction will occur during FY 96 and FY 97.

Modeling and synthesis of results will occur over the entire project in an iterative process with the emphasis building in FY 97 and continuing until the conclusion of the project.

Assistance to other investigators — This aspect is now underway and will continue throughout the project. It is anticipated that the maximum interaction will occur during FY 97 and FY 97. Synthesis and interpretation of isotope ratio data will be ongoing.

Project milestones and reporting periods:

Oct. 1996 - Feb. 1997:	Analysis of 1996 field season samples Preparation of journal manuscripts.
Mar. 1997 - Apr. 1997:	Preparation for field, continue analyses Annual Report.
Apr. 1997 - Aug. 1997:	Field work, continued analytical work.
Sep. 1997 - Dec. 1997:	Analytical work, synthesis and completion of captive animal expts.
Jan. 1998 - Mar. 1998:	Final report, synthesis meetings, manuscript preparation.

C. Project Reports

Results of this project will be made available via the following:

Annual Reports:

These reports will detail progress and preliminary findings and notable achievements. These are anticipated for the ends of FY 96 and FY 97.

Final Report:

A final Report will be provided. Technical results in these reports will be shared with EVOS collaborators. Thus they will be apprised of the development of the stable isotope methodology and the interpretation of the results. The PI's will provide expertise in interpretation of isotope results in other projects for which the isotope techniques are only a minor portion of the scientific effort. The final reports of the PI's' will assist others in that they will provide independent means for validation of trophic models and energy flow descriptions of the Prince William Sound ecosystem.

Peer-Reviewed Publications:

Over the course of this study peer-reviewed publications will be generated for the open literature based upon the scientific findings. These publications will generated by the PI's as first author publications where the primary focus is on the findings produced by the isotopic techniques or as second author publications when the isotope work is a minor part of the scientific results.

Papers at Scientific Society Meetings:

We request support for travel to appropriate scientific meetings for dissemination of results and interaction with colleagues. It is anticipated that the Society for Marine Mammalogy or the American Society for Limnology and Oceanography meetings will be attended by the PI and graduate student Amy Hirons.

Public Lectures:

Interaction with the public will arise through formal and informal presentations of results. Synthesis meetings designed to explain the findings of ecosystem studies will be presented at meetings coordinated by the EVOS program and open to the public. Informal presentation of results will occur through interaction with interested members of the public, press and scientific community. Classroom instruction will also involve integration of findings into the presentation of educational material.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

1. Resources and Services — This study focuses on harbor seals, sea birds and the cetaceans of Prince William Sound. Although the major effort is concerned with harbor seals, other marine mammal tissues will be collected in cooperation with those agencies handling or collecting those species. The principal cooperating agency personnel are Kathy Frost and co-workers with the Alaska Department of Fish and Game, with whom a wide variety of sampling efforts have already been undertaken and are continuing in 1995. Dr. Michael Castellini and Brian Fadely have also provided invaluable help by accessing whiskers from seals in their tagging program.

2. Relations to Other Damage Assessment Work — This study is closely coordinated with the modeling efforts and the pelagic food web studies being undertaken by the Prince William Sound Science Center personnel. Dr. Kline is responsible for most pelagic collections of food base organisms and is sharing these data to help construct the food web models. Dr. Schell is responsible for the marine mammal aspects and will collect additional forage species as required by his project (for example, samples of herring, capelin, sand lance, etc., in regions of high marine mammal density or active feeding). Stable isotope data provide an excellent means for validating models and testing food web linkages. This aspect of the work will be cooperative with many components of the SEA project.

We are very fortunate to be simultaneously involved in an isotope study on marine mammals in the Bering sea. This project, which is supported by the North Pacific Universities Consortium and the Coastal Marine Institute, will provide a valuable amount of complementary data and assist in gathering insight as to the mechanisms involved in the marine mammal population declines.

ENVIRONMENTAL COMPLIANCE

The sampling and use protocols for the sampling and experimentation on vertebrates in the 1995 proposal were reviewed and approved by the University of Alaska institutional Animal Care and Use Committee. This assurance is valid for this proposal and will be reviewed for renewal in FY 97.

96180

Kenai Habitat Restoration & Recreation Enhancement Project

Project Number:	96180
Restoration Category:	General Restoration
Proposer:	ADNR
Lead Trustee Agency:	ADNR
Cooperating Agencies:	ADF&G, DOI
Duration:	Three Years
Cost FY 96:	$560,600
Cost FY 97:	$800,000
Cost FY 98:	$600,000
Geographic Area:	Kenai Peninsula
Injured Resource/Service:	Pink salmon, sockeye salmon, Dolly Varden, commercial fishing, subsistence, recreation & tourism.

ABSTRACT

Adverse impacts to the banks of the Kenai River total approximately 19 miles of the river's 166 mile shoreline. Included in this total are 5.4 river miles of degraded shoreline on public land. Riparian habitats have been impacted by trampling, vegetation loss and structural development. This riparian zone provides important habitat for pink salmon, sockeye salmon and Dolly Varden, species injured by the *Exxon Valdez* oil spill. The project's objectives are to restore injured fish habitat, protect fish and wildlife habitat, enhance and direct recreation and preserve the values and biophysical functions that the riparian habitat contributes to the watershed. Restoration/enhancement techniques will include revegetation, streambank restoration, elevated boardwalks, floating docks, access stairs, fencing, signs, and educational interpretive displays.

INTRODUCTION

The objectives of this project are to:

1. Restore and protect fish habitat on the Kenai River.

2. Improve existing recreational access to the Kenai River watershed in a manner that restores and protects riparian fish and wildlife habitat.

3. Provide information to the public that promotes their understanding of the river's ecology and proper use of its resources.

Public lands on the Kenai Peninsula, including those soon to be acquired with *Exxon Valdez* oil spill joint settlement funds, contain important habitat for several species injured by the spill and provide recreation services for tens of thousands of Alaska residents and tourists. Kenai River fish support a large commercial fishery, a commercial sport fishing industry, a subsistence fishery, and a recreational sport fishery. In the aggregate, revenues generated by sportfishing, commercial fishing and river-based tourism represent a significant and growing proportion of the local economy.

The riparian zone, the transitional area that lies between the river's channel and the uplands, provides important fish and wildlife habitat and plays a major role in the hydrology of the watershed by helping to control floods and erosion. This vegetated area functions as a buffer and filter system between upland development and the river, thereby maintaining water quality by absorbing nutrients, accumulating and stabilizing sediments, and removing heavy metals and pollutants that are a result of urban development and which enter the river from surface runoff. It is also the area where a significant portion of the Kenai River's sportfishing and other recreational activities are concentrated.

Degradation of the river's streambanks, riparian vegetation and fish habitat has the potential of jeopardizing its long term productivity and degrading the quality of the recreational experience. This project proposes revegetation, streambank restoration, and public access improvements that will promote pink and sockeye salmon and Dolly Varden habitat protection and restoration, as well as enhancement of recreational services in the Kenai River watershed. The project also proposes to design and construct educational and interpretive displays that will inform the public of the proper manner in which to access and use the river's resources.

NEED FOR THE PROJECT

A. Statement of Problem

Use of the Kenai River watershed is degrading fish habitat along the riparian zone of the main stream and, to a lesser degree, the tributaries of the river. Streambanks that provide essential fish habitat are being trampled and denuded of vegetation leading to increasing rates of erosion and sedimentation. Both commercial and residential developments are altering shorelines, changing patterns of runoff and creating the potential for the discharge of non-point source pollutants into the river. Federal and state resource agencies have limited ability to manage these problems that have the potential of threatening the productivity and world class recreational value of this river system.

Commercial fishing, subsistence, recreation and tourism (including sport fishing) are services that were reduced or lost because of the spill. Within the Kenai River watershed, the resources that support these services that were injured by the *Exxon Valdez* oil spill include pink and sockeye salmon and Dolly Varden. Chinook and coho salmon also contribute significantly to these services. The *Exxon Valdez* Oil Spill Restoration Plan states that the Kenai River sockeye salmon population is not recovering and that: *With regard to sockeye salmon, the objective of habitat protection is to ensure maintenance of adequate water quality, riparian habitat, and intertidal habitat....*

The restoration strategy articulated in the restoration plan for recreation and tourism focuses on the: *Preservation and improvement of the recreational and tourism values of the spill area.* The Plan goes on to discuss strategies for promoting recovery of commercial fishing, recreation and tourism by: *...increasing the availability, reliability, or quality of the resource on which the service depends.*

What is needed within the Kenai River watershed is an integrated approach that protects resource habitats, restores degraded streambanks and riparian vegetation, maintains productivity and promotes appropriate, sustained human use of the river.

B. Rationale

The work proposed by this project is needed to protect and restore fishery resources. Continuing loss of habitat will exacerbate the injury caused by the spill to both resources and services and lead to diminished productivity. This, in turn, diminishes the value of the commercial, subsistence and sport fisheries and the quality of recreation on the river with significant, adverse implications for the local economy.

Based on a review of historic recreation use patterns and habitat impacts, the project will protect, restore, stabilize, or rehabilitate streambanks where resource damage is occurring; enhance or close existing access points and movement corridors; or re-direct users to other areas of the river on a temporary or long term basis. **These actions will be based on the need to facilitate human use of the river in a way that protects fish habitat and minimizes degradation of other sensitive and/or pristine habitats.**

This project is designed to promote streambank stability, increase vegetative cover, and mitigate accelerated erosion and sedimentation for the benefit of pink salmon, sockeye salmon, Dolly Varden and other fish species that migrate and rear along the river's banks. Techniques used to achieve these goals may include the use of elevated, grated boardwalks, river access stairs, fishing platforms, spruce tree revetments and other riparian habitat improvement and protection techniques. These techniques will, at the same time, restore and enhance sportfishing. One example is elevated, grated boardwalks, constructed to protect revegetating streambanks, that will provide river access to anglers with a minimum of impact to the recovering habitat. Post-construction monitoring will examine the effects of the method and the amount of recreational use that occurs in the area.

The education component of the project will produce user information and interpretive displays at strategically located access points along the river. These displays will provide users with information on the natural history of the river's fish, their habitats, ecology of the river system and the best methods that they can use to maximize their recreational experience with a minimum of impact to the watershed and its resources. Signs placed adjacent to work sites will describe the on-going restoration effort and direct the public away from recovering vegetation.

Each site under consideration for a restoration, enhancement or education project will be evaluated in terms of the condition of its habitats, character of adjacent lands, and historic public use. Improvements to access will reflect patterns of use as well as on-site and adjacent upland environmental sensitivities.

C. Summary of Major Hypotheses and Objectives

The project's major objective is to restore injured fish habitat and to establish public use patterns (i.e., sportfishing, camping, etc.) within the Kenai River watershed that are compatible with habitat protection for injured resources such as intertidal marshes, pink and sockeye salmon and Dolly Varden. The long term goal of the project is to protect fish and wildlife habitat, enhance recreation and preserve the functions and values that the riparian habitat contributes to the watershed.

- Construction of elevated, grated boardwalks; enclosures; floating docks; fencing; signs; and well designed public use facilities will facilitate restoration and protection of riparian vegetation, stabilize streambanks, and maintain/enhance fish habitat by mitigating the effects of human use.

- Recreational enhancements will promote continued use of project sites while allowing riparian habitat to recover.

- Construction of educational and interpretive displays will aid restoration efforts and provide the public with information that will help them to use the river in a manner that protects and sustains its resources.

D. Completion Date

The project is conceived to be a multi-year effort that will build on results determined from the monitoring of the previous year's work. Projected timeline: FY 96 to FY 99.

COMMUNITY INVOLVEMENT

It is intended that the project be fully integrated with on-going agency recreation management, permitting and regional planning activities affecting the Kenai River watershed. This includes coordination with the Kenai Peninsula Borough, City of Kenai, Kenai City Council, City of Soldotna, Soldotna City Council, Kenai Peninsula Borough Assembly, and local interest groups. Whenever feasible, volunteers will be recruited from the local communities to work on the project.

PROJECT DESIGN

A. Objectives

1. Review existing information on:
   a) human impacts to the riparian zone on public lands in the Kenai River watershed in order to select project sites,

   b) recreational use patterns and infrastructure support in the Kenai River watershed, and

   c) appropriate restoration and/or access and use of enhancement technique(s).

2. Select and design the appropriate revegetation, rehabilitation and/or enhancement project for each site.

3. Develop an evaluation process to prioritize project sites and define scope of work.

4. Construct projects using a combination of competitively bid contracts and volunteer help, where feasible.

5. Verify compliance with restoration designs and evaluate construction.

6. Implement a monitoring program to assess restoration and use of project sites.

7. Design and construct educational and interpretive signs and displays.

B. Methods

The present condition of North America's native fish fauna is attributable, in part, to the degradation of aquatic ecosystems and habitat (FEMAT Report, 1993). Loss and degradation of freshwater habitats are the most frequent factors responsible for the decline of anadromous salmonid stocks (Nehlsen, et. al. 1991). Along with habitat modification or loss, changes in water quality and quantity are often cited as causative factors for degradation of aquatic systems and declines in anadromous fish populations.

The *Kenai River Cumulative Impacts Assessment of Development Impacts on Fish Habitat* (Liepitz, 1994) was designed to identify and evaluate the cumulative impacts of development actions including public and private land use impacts on Kenai River fish habitat. The study documented that : *11.1 percent to 12.4 percent (18.4 to 20.6 miles) of the river's 134 miles of upland and 32 miles of island shoreline and nearshore habitats have been impacted by bank trampling, vegetation denuding, and structural development along the river's banks.* Degraded public land along the Kenai River includes 5.4 miles of trampled riparian habitat and 3.5 miles of developed shoreline.

During the first year of the project, we will review information from existing studies of the Kenai River on fish habitat, shoreline characteristics, streambank damage, streambank rehabilitation, land ownership, public use trends, development threats, habitat protection/recreation enhancements, infrastructure and public access. On-going and completed restoration projects on the river will also be inspected. This information will be supplemented with personal observations of ADNR and ADF&G staff who have expert knowledge of the river and its use by the public. These data will be used to document the existing condition of potential sites and used later as a baseline for monitoring project success. The data will also be used to develop an evaluation and ranking system to prioritize projects.

Although these data are useful for a broad, area-wide approach, they are not adequate for specific site design. Consequently, once a preliminary list of sites is selected, on-site verification/assessment will be carried out. The final list of project sites will reflect the results of these assessments. Site specific project designs will reflect site characteristics including: topography, hydrologic variables, vegetation, soils, extent and type of degradation and historic use patterns. Designs may include elements that restore or enhance specific habitat values. For example, instream structures may be used to enhance fish habitat and/or angler access. Plant propagation and streambank restoration techniques will be selected on the basis of site characteristics, constraints and cost. Revegetation designs will attempt to re-establish the native, riparian plant communities. Grasses that have been successfully used for riparian and saltmarsh revegetation in Alaska include: bluejoint reedgrass (*Calamagrostis canadensis*), Bering hairgrass (*Deschamsia beringensa*), sloughgrass (*Beckmannia syzigachne*), sedges (*Carex spp.*) and beach wildrye (*Elymus mollis*).

Successful revegetation requires control of site impacts. Consequently, fences and/or signed closures may be required to protect undamaged sites from human impact or to prevent additional damage to recovering sites. Project areas will either be closed and posted during the course of revegetation, or environmental engineering techniques will be used that allow public access but protect the recovering habitat from additional adverse impacts. Habitat improvement and protection techniques to be considered include:

On-site Revegetation/Restoration
Enclosures
Spruce Tree Revetments
Access Trails
Signage
Elevated Grating/Boardwalks
Access Stairs Ladder
Floating Docks

The number of sites selected for revegetation or enhancement in a given year will be dependent upon the time necessary for completion, i.e., permitting, construction and installation, and the availability of funding. The project intends to utilize volunteers to assist with construction and installation. The ADNR Parks and Outdoor Recreation Division has an established network of contacts with volunteer organizations on the Kenai Peninsula. ADNR has successfully used volunteers in trail construction and park maintenance efforts. Each site plan will include a maintenance element. Maintenance may include watering, fixing fences, replacing signs and/or repair of habitat enhancements.

Educational/interpretive displays will be designed, constructed and placed in strategic locations along the river. Signs will also be designed and located to prevent bank trampling in areas where revegetation efforts are occurring.

A monitoring program will be used to evaluate the success or failure of each project. Monitoring parameters will be chosen that reflect site-specific restoration/enhancement objectives and may include habitat, vegetation and public use measurements. The assessment of the existing condition of each site will serve as the baseline for monitoring. Monitoring measurements will be obtained frequently early in the project and could be used to amend the design if necessary. Once it is determined that restoration/enhancement is proceeding on an acceptable course and rate, monitoring measurements will be taken less frequently. Habitat and population monitoring parameters may include: vegetation diversity and cover, fish utilization and stream stability. Public use of the sites and impacts to adjacent areas will also be monitored. Site visitation shall be based on counts of individual people by field staff and project personnel.

C. Contracts and Other Agency Assistance

All components of the project will be carried out by personnel from ADF&G and ADNR. Construction work will be carried out by contractors on an "as-needed" basis depending on the project design. Volunteers supervised by agency staff will assist in the installation of prefabricated structures and in routine maintenance.

D. Location

All construction, maintenance and monitoring components of the project will be located within the Kenai River watershed. Planning and coordination will be based in Anchorage. Primary ecological benefits from the project will be realized by the natural systems within the watershed. Secondary benefits will affect the economy of the communities of the Kenai Peninsula and the commercial fishing industry. Improved and enhanced recreation benefits will affect users from southcentral Alaska as well as tourists from outside of the state. Communities that may be affected by the project include: Kenai, Soldotna, Homer, Sterling, Cooper Landing, Anchorage and the unincorporated communities on the Kenai Peninsula.

SCHEDULE

A. Measurable Project Tasks for FY 96

Startup to April 15:

- Acquire and review existing data on Kenai River,
- Develop implementation strategy, i.e., applicability of techniques to different site conditions,
- Review planned, on-going and completed restoration projects in the Kenai River watershed,
- Develop site evaluation, ranking and prioritization system,
- Conduct pre-construction site surveys, assessments and data collection,
- Develop design plans for restoration, enhancement and education components,
- Apply for Title 16, Parks and COE permits for first priority sites,

	Conduct public scoping meetings and resource agency meetings and prepare environmental compliance documents, Harvest and store plant materials, and Organize volunteer support.
April 16 to May 15:	Review comments and revise environmental compliance documents, Respond to permitting issues and secure construction permits, and Conduct construction work, e.g., floating docks, needed below the OHW elevation on first priority sites.
May 16 to July 15:	Construct bank stabilization and revegetation projects, construct boardwalks, fencing, signage, etc. Design and put up signs and information displays.
July 16 to August 15:	Inspect all project sites to check for compliance with design parameters, Monitor revegetation sites, and Monitor public use of completed project and proposed sites for next year.
August 16 to September 30:	Continue monitoring. Prepare annual report.

B. Project Milestones and Endpoints

Startup to November 1, 1995

Review existing information on:

a) human impacts to the riparian zone on public lands in the Kenai River watershed in order to select project sites,

b) recreational use patterns and infrastructure support in the Kenai River watershed, and

c) appropriate restoration and/or access and use enhancement technique(s).

November 1, 1995 to April 15, 1995

Select and design the appropriate revegetation, rehabilitation and/or enhancement project for each site.

Develop an evaluation process to prioritize project sites and define scope of work.

April 16, 1995 to July 15, 1995

Construct projects using a combination of competitively bid contracts and volunteer help, where feasible.

Verify compliance with restoration designs and evaluate construction.

<u>July 16, 1995 to August 15, 1995</u>

Implement a monitoring program to assess restoration and use of project sites.

Design and construct educational and interpretive signs and displays.

<u>August 16, 1995 to September 30, 1995</u>

Continue monitoring.

Prepare annual report.

<u>FY 96 and Beyond</u>

Continuing work will include primarily permitting, construction and monitoring. Environmental compliance and public coordination efforts will also continue.

C. Project Reports

An annual report will be prepared detailing results of the previous year's efforts including monitoring. This report will be submitted to the Chief Scientist in the Fall of each year.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

Coordination will occur with agency staffs in ADNR, ADF&G and the Kenai National Wildlife Refuge. Their expertise will be used in defining management objectives, developing criteria, evaluating and ranking potential project sites, conducting archaeological and historical reviews and clearances, performing design to include preparing plans and specifications, bidding construction projects, oversight of project construction, permitting, monitoring public use, and enforcing site restrictions.

The project will build upon pilot efforts that have been implemented or are being developed for the river. In 1994, boardwalks were installed near the Soldotna airport and on numerous private parcels; enclosures have been used with a high degree of success along portions of the Russian River and in units of the state park system. State permitting procedures have also resulted in numerous bank stabilization projects that maintain or enhance fish habitat by using spruce tree revetments, root wads, live willow cuttings, and other protective measures.

The state and federal governments have already committed funds to accomplish several of the objectives identified by this project. Fish and Game *Exxon Valdez* criminal settlement funds ($3 million) have been dedicated for the construction of habitat protection demonstration projects and land acquisition on the Kenai River. The U.S. Fish and Wildlife Service has provided challenge grant funding to assist the ADF&G demonstration projects. The National Marine Fisheries Service will provide the ADF&G with an additional one million dollars for streambank improvements under an appropriation requested by

Senator Stevens. ADNR restitution funds ($7 million) will be used, in part, to construct boardwalks and access platforms that protect streambanks at heavily used state park units at Morgan's Landing, Bing's Landing, and Slikok Creek. Dingle-Johnson funds are being used to provide recreational access, streambank revegetation, and streambank protection structures at The Pillars project site.

The intense public use pressures and development activities on the Kenai River threaten to overwhelm the limited budgets available to resource agencies attempting to manage the river for resource protection and sustained recreational use. That is why supplementary funding is so important. The proposed project, along with those utilizing other available funds, provides a cost-effective method to protect streambanks and minimize further habitat degradation.

ENVIRONMENTAL COMPLIANCE

The revegetation and education elements of the project are categorically exempt from formal documentation in an Environmental Assessment or Environmental Impact Statement according to NEPA guidelines. In-stream construction of floating docks, boardwalks, access stairs or other in-stream structures will require an Environmental Assessment and a Title 16 permit. All permits will be obtained prior to commencement of on-site improvements.