19.08.01 (3 of 16)

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

Project Number: 00163 A-T

Restoration Category: Research

Proposer: David Cameron Duffy, Project Leader, Paumanok Solutions.

Cooperating Agencies: DOI, ADF&G, NOAA

Alaska SeaLife Center: yes

Duration: First of two years writing up of five-year project

Cost FY 00: $1,765.3 K

Cost FY 01: $500

Cost FY 02: $0.0

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EXXON VALDEZ OIL SPILL
TRUSTEE COUNCIL

Geographic Area: Prince William Sound, Cook Inlet, Northern Gulf of Alaska

Injured Resource/Service: Common Murre, Harbor Seal, Marbled Murrelet, Pacific Herring, Pigeon Guillemot.

ABSTRACT

This study uses seabirds as probes of the trophic (foraging) environment of Prince William Sound and comparing their reproductive and foraging biologies, including diet, with similar measurements from Cook Inlet, an area with apparently a more suitable food environment. These measurements are compared with hydroacoustic, aerial, and net sampling of fish to calibrate seabird performance with fish distribution and abundance. This will allow us to determine the extent to which food limits the recover of seabirds from the Exxon Valdez oil spill. We use historical data from a variety of sources to detect shifts in forage fish abundance and to test hypotheses explaining such shifts.

INTRODUCTION

The spill from the oil tanker Exxon Valdez resulted in significant mortality of several seabirds and in massive acute 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). Other non-oil factors may also 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, Cook Inlet and the Gulf of Alaska in a sustainable manner.

We will continue the study of the distribution and abundance of prey species through acoustic, aerial, and net sampling in relation to environmental conditions. Combined with historical analyses, this will help test hypotheses concerning 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 cormorants (*Phalacrocorax* spp.).

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 provides between-year comparisons within sites and within-year comparisons between sites in Prince William Sound and Lower Cook Inlet, areas that have different food-availability. 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. We are especially interested in comparing 1999 with 1997 and 1998, warm-water years. In addition, we use models to relate oceanographic and spatial features of Prince William Sound and the Gulf of Alaska to changes in seabird diet and population trends.

This proposal should be read in conjunction with the FY 1998 and 1999 Detailed Project Descriptions, especially the appendices which describe the protocols in detail.

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; Oakley and Kuletz 1996). 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 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 productivity has been 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 specialize 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 suwccess when sand lance are available (Pearson 1968; Harris and Hislop 1978; Vermeer 1979, 1980; Monaghan et al. 1993) .

Major oceanographic 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). 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 (Sturtevant 1995), raising the possibility that reductions in the trophic role of one species may 'release' others from competition for food.

B. Rationale/Link to Restoration

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 their recovery several years after 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 former Sound Ecology Assessment and Nearshore Vertebrate Predators projects, ecosystem projects funded by the Exxon Valdez Oil Spill Trustee Council, APEX attempts to 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 helps us to determine when we have finally restored a sustainable and healthy marine environment in the oil spill area.

C. Location

The project will conduct field work in Prince William Sound and Lower Cook Inlet, with historical analyses covering the entire Northern Gulf of Alaska.

COMMUNITY INVOLVEMENT' AND TRADITIONAL ECOLOGICAL KNOWLEDGE

Most community involvement and TEK is at the individual project level. The project maintains a web page <http://www.uaa.alaska.edu/enri/apex/index.html>.

PROJECT DESIGN

A. Objectives

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

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. Examine whether 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.

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.

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.

List of Projects

Project	PI	Short Title
a.	Thedinga/Hulbert	Fish population sampling
b.	Ostrand	Seabird foraging
e.	Irons/Suryan	Kittiwake foraging and reproduction
f.	Golet	Guillemot foraging and reproduction
g.	Roby	Seabird reproduction and energetics
i.	Duffy	Project leader
j.	Roseneau	Barrens nesting study
k.	Roseneau	Predatory Fish Diets
l.	Anderson & Piatt	Historical analysis
m.	Piatt	Cook Inlet studies
o.	McDonald	Statistical support
q.	Ainley, Ford & Schneider	Modeling
r.	Kuletz	Marbled Murrelet

s.	Purcell	Jellyfish
t.	Brown/Norcross	Aerial Survey

Methods by Objective

All activities will involve analysis of data and samples and writing up of the material. Details may be found in the individual FY 00 Detailed Project Descriptions.

C. Cooperating Agencies, ContractS, and other Agency Assistance

Details of the responsibility of each agency and contracts with the private sector and with other government agencies can be found in the appendices describing individual subprojects in the FY 00 Detailed Project Descriptions.

SCHEDULE

A. Measurable Project Tasks for FY 00

These can be found in more detail in the proposals for the individual subprojects.

2000

January	Annual Review
September	Final Report

B. Project Milestones and Endpoints

Annual reports and publications from individual subprojects in the literature will constitute the main milestones. A series of synthesis papers will be produced later in the project.

1999	Symposium on Ten Years of Recovery Following the Exxon Valdez Oil Spill.
2000	Final Reports completed.
2001	Final manuscripts finished. Review volume complete.

C. Completion Date

September 30, 2001

PUBLICATIONS AND REPORTS

Please see the individual subproject annual reports and DPDs.

PROFESSIONAL CONFERENCES

Project-level participation

Presentations are described in the DPDs for the individual subprojects.

NORMAL AGENCY MANAGEMENT

99163 A
Not applicable

99163 B
See explanation under 99163 E

99163 E
The Fish and Wildlife Service is responsible for managing migratory birds. To manage bird populations indices of populations and production of several game bird species and a few non-game bird species are monitored in some parts of Alaska. In Prince William Sound the FWS funded a marine bird survey in 1972 and some seabird colony studies at Hinchinbrook Island in 1976 to 1978 in response to the building of the Alaska pipeline. In 1984-85 the FWS funded their first shoreline sea otter survey, combined with shoreline marine bird survey. Also in 1984 the FWS began annual monitoring black-legged kittiwake populations and productivity in PWS. The only ongoing monitoring of migratory birds in PWS is the kittiwake monitoring. The FWS generally does not fund research studies and when they do the studies are often o game species. The APEX study is only being conducted because there was an oil spill. The need for the APEX study would not exist if the oil spill had not occurred. The FWS has contributed the past data on migratory birds to the EVOS trustees and is continuing to contribute the data collected on kittiwakes to the EVOS trustees.

99163 F
See explanation under 99163 E

99163 G
Not applicable

99163 I
Not applicable

99163 J
This analysis and write-up would not be done if the spill had not occurred and the EVOS Trustees had not funded prior field work.

99163 K

Not applicable

99163 L
This analysis and write-up would not be done, if the spill had not occurred and the EVOS Trustees had not funded prior field work.

99163 M
See explanation under 99163 L.

99163 O
Not applicable

99163 Q
Not applicable

99163 R
See explanation under 99163 E

99163 S
Not applicable

99163 T
Not applicable

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

APEX is in itself a major integrated research effort, spanning 15 subprojects at different institutions, agencies, and private businesses. Details of integration at the individual project level may be found in the appendices for each project.2

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

NA

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PERSONNEL

Approximately 60 persons are involved in APEX. These include 18 Principal Investigators. Their qualifications may be found in the individual detailed project descriptions for 99163 A-T.

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Project Title: Forage Species Studies in Prince William Sound

Project Number:	00163A
Restoration Category:	Research
Proposer:	John Thedinga, Lee Hulbert NMFS Auke Bay Laboratory
ABL Program Manager: NOAA Program Manager:	Dr. Stan Rice Bruce Wright
Lead Trustee Agency:	NOAA
Cooperating Agencies:	ADF&G, USFW, UAF
Duration:	1 year
Cost FY00:	$138 K
Cost FY01:	
Cost FY02:	
Geographic Area:	Prince William Sound, Alaska
Injured Resource:	Forage fish, sea birds

ABSTRACT

Forage fish studies in Prince William Sound (PWS) is a project that estimates the biomass and distribution of forage fish in nearshore habitat of three geographic regions of PWS from 1996 - 1999. Biomass of forage fish is estimated hydroacoustically and species composition and size is verified by capture with purse seines, trawls, and underwater video cameras. Areas of forage fish aggregations are characterized by habitat type and oceanographic features in the three study regions. The overall objective of this phase of the project is to evaluate the inter-annual variability of forage fish distribution, abundance, and availability to apex predators, with habitat and oceanographic features.

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 data analysis and manuscripts that will provide quantitative descriptions of the forage community in PWS .

BACKGROUND

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 constitutents 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).

Macro zooplankton; including euphausiids, shrimp, mysids and 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, Macro zooplankton 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 Macro zooplankton 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 inter-annual 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.

NEED FOR THE PROJECT

A. Statement of Problem

This project is the cornerstone of a larger ecosystem project (APEX) and will provide information leading to a better understanding of the link between prey and predator and of the population dynamics of forage species in PWS. Data from this project needs to be integrated with seabird and aerial forage fish survey data to help better understand the link between predator and prey. An inter-annual summary of forage fish distribution and abundance needs to be addressed in relation to availability to predators, habitat use, and oceanographic features.

B. Rational

An ecosystem approach to describing inter-annual variation in forage fish distribution, abundance, and species composition must integrate habitat and oceanographic considerations in relationship to prey availability. This research is needed to address the working hypotheses that forage fish species differ in their spacial responses to oceanographic processes; and forage fish characteristics limit availability of seabird prey. Therefore, in order to relate variation in forage fish availability to the decline of seabird populations in PWS, concurrently obtained forage fish, seabird, habitat, and oceanographic data needs to be synthesized.

PROJECT DESIGN

Objectives

1. Estimate the distribution and abundance of forage species in three near-shore study areas in Prince William Sound.

2. Describe the species composition of the forage base and size distributions of the most abundant forage fish species in the three study areas.

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

4. Describe the habitat types of areas where forage fish are present.

5. Compare relative abundance of zooplankton in the three near-shore core areas in Prince William Sound.

6. Test APEX hypotheses related to forage fish abundance, distribution, and availability to apex predators.

Cooperating Agencies, Contracts and Other Agency Assistance

This project will coordinate with the other APEX projects so that forage fish biomass and oceanographic data can be integrated with seabird and nearshore vertebrate predator data.

Milestones and Endpoints

1. October - December 1999 - Analyze 1999 hydroacoustic data

2. October - December 1999 - Analyze 1999 zooplankton samples

3. October - December 1999 - Analyze 1999 forage fish length-weight data

4. October - December 1999 - Analyze 1999 forage fish abundance and distribution data

5. October - December 1999 - Analyze 1999 oceanographic data

6. October - December 1999 - Analyze 1999 habitat classification data

7. October - December 1999 - Synthesize 1996 - 1999 forage fish and oceanographic data

8. January - March 2000 - Integrate forage fish data with oceanographic data

9. January - March 2000 - Integrate forage fish data with habitat classification data

10. January - March 2000 - Integrate forage fish data with zooplankton data

11. January - March 2000 - Integrate forage fish data with APEX and SEA data

12. April - September 2000 - Prepare final report

13. April - September 2000 - Prepare two manuscripts (Lead authors)

14. April - September 2000 - Collaborate in preparation of three manuscripts

15. September 2000 - Post summarized results from our inter-annual comparisons of the forage fish assessment project on the APEX web site.

16. October - April 2000 - Prepare one manuscript

Publications and Reports

The Forage Fish Studies project is the cornerstone of the APEX project -- all other predators (birds, marine mammals) are related to the forage base. Most APEX projects rely on this project to provide them with forage fish specimens, estimates of biomass and species composition, and oceanographic data to integrate and calibrate with seabird data and to formulate models of food availability and seabird recovery.

In FY2000, two peer-reviewed manuscripts are planned:

Thedinga, Hulbert, Brown, Halderson. Distribution and abundance of forage fish and availability to predators related to oceanographic and physical conditions in PWS.

This manuscript will compare different species of forage fish and determine how their distribution and abundance determined hydroacoustically and by aerial surveys and availability to predators is related to oceanographic features and physical conditions in PWS such as such as frontal zones, thermoclines, pycnoclines, haloclines, convergences, or major currents.

Hulbert, Thedinga, Ostrand, Halderson, Brown. Distribution and abundance of forage fish related to habitat type.

This manuscript will compare different species and age classes of forage fish and determine how their distribution and abundance are related to habitat type. A habitat typing system used by NVP will be used to classify habitat in the sampling areas.

Thedinga, Brown, Ostrand, Hulbert, Norcross. Relationship between aerial estimates and acoustical estimates of forage fish biomass in PWS.

This manuscript will compare aerial estimates of forage fish abundance with acoustical estimates of forage fish biomass and determine relationships between species and size composition with the two estimates based on net and video samples of forage fish.

Ostrand, Irons, Maniscalco, Thedinga. Availability of forage fish to seabirds.

This manuscript will compare distribution of forage fish (depth, distance from beach, school size, species composition, size distribution) to foraging behavior of seabirds in three study areas of PWS.

Purcell, Hulbert, Brown Hulbert. Dietary overlap of jellyfish and forage fish.

This manuscript will compare the diet of jellyfish and forage fish and describe the role of jellyfish in the PWS ecosystem.

The final report encompassing field work from 1996 -1999 will be submitted in September, 2000. The report will include annual forage fish biomass estimates, oceanographic conditions, habitat descriptions, and will compare inter-annual variations in forage fish abundance, distributions, species composition, and length frequency.

PROFESSIONAL CONFERENCES

We anticipate presenting a poster at the 2000 EVOS Restoration Workshop, one oral presentation at the 2001 EVOS Restoration Workshop, and one oral presentation at a professional meeting.

SEABIRD/FORAGE FISH INTERACTIONS

Project Number:	00163 B
Restoration Category:	Research
Proposed By:	DOI
Duration:	5 years
Cost FY 99:	$120,900
Cost FY 00:	$154,900
Cost FY 01:	$162,000
Geographic Area:	Prince William Sound
Injured Resource/Service:	Piscivorous birds and forage fish

ABSTRACT

The APEX project is investigating the general hypothesis that a shift in the marine trophic structure of spill affected area is preventing the recovery of piscivorous birds. This component contributes to that investigation by examining seabird foraging in relation to schooling forage fish and by examining the ecology of forage fishes within Prince William Sound (PWS). We are proposing to work on 4 objectives: 1) Modeling habitat selection by fish. This effort will focus on Pacific sand lance linkages to bottom type and depth. 2) Modeling habitat selection by seabirds. This effort will take a multivariate approach to describing foraging habitat preferences of both diving and surface feeding birds. 3) Determine if characteristics of forage fish schools limit availability of seabird prey. This effort involves assessing the characteristics of fish schools that are available to seabirds and then determining the proportion and amount of the forage biomass that conforms to those characteristics. 4) Determine if there is a correlation between changes in the distribution of capelin and change in sea surface temperatures of the Gulf of Alaska.

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 3 study sites within Prince William Sound (PWS). Data collected in 1994 and 1995 indicated that seabird activity was concentrated in shallow water near shore. In response to these findings the 1996 study expanded data collection by adding an extensive survey of nearshore habitats.

In 1998 we made initial attempts to model the habitat preferences of forage fish. This pilot effort determined that marine substrates associated with sand lance (*Ammodytes hexapterus*) were significantly different from substrates selected at random. Newly available hydroacoustic bottom typing software was used to identify substrates sampled during the 1997 APEX cruise. Encouraged by our initial results, we preceded to collect substrate samples in 1998 to calibrate our bottom typing. Currently we are bottom typing and will soon be developing bottom type and bathemetry maps of areas sampled in 1997. Next we will a develop resource selection function for sand lance and will develop geographic information system (GIS) coverages that indicate the probability of encountering sand lance at all locations within our study areas.

We have examined foraging habitat preference of seabirds by examining nearshore seabird distribution and forage fish biomass data collected in 1996 and 1997 (Ostrand et al. 1998a). We determined that both birds and fish were associated with shallow water habitats in 1996 but not in 1997. We concluded that seabirds had responded to a shift in the distribution of forage in 1997 and that birds select habitats with the greatest probability of encountering prey. We will complete this work in 2000 by reexamining data from 1996 and 1997 with revised estimates of fish biomass and including data from 1998 and 1999. By examining 4 years of data we should be able to determine if the change in seabird distribution that occurred in 1997 was anomalous, perhaps due to el niño, or a persistent change.

We sought to determine if forage fish characteristics limited availability of prey. From data collected in 1995 we have characterized the forage preferences of Tufted Puffins (*Fratercula cirrhata*) and murrelets (*Brachyramphus* spp.) (Ostrand et al. 1998b). The scope of this approach will be expanded to determine what portion of prey biomass is available to seabirds. This study involves the analysis of hydroacoustic data which has been halted while target strengths of forage fishes were being determined. Data collected in 1996 and 1997 will be re-analyzed and 1998 and 1999 data will receive initial analysis using new target strength values.

Capelin (*Mallotus villosus)* is a pelagic schooling fish which serves as an important source of lipid rich prey for numerous seabird and marine mammal species in northern latitudes (Carscadden and Nakashima 1997; Drinkwater 1997). Fisheries trawl surveys conducted in the western and central Gulf of Alaska reveal that, beginning in 1978, abrupt changes occurred in the species compositions of catches, when a variety of forage fishes such as capelin virtually disappeared (Piatt and Anderson 1996; Anderson et al. 1996). Significant numbers of capelin have yet to reappear in survey trawls following this decline. These changes in the marine fish communities of the northern Gulf of Alaska and adjacent waters (i.e. PWS) are reflected in the diets and population biology of many marine birds and mammals (Piatt and Anderson 1996), several of which are experiencing population declines. Fish and shellfish respond directly to climatic fluctuations. Temperature is one of the primary factors responsible for influencing the large scale distribution patterns observed in fish (e.g. capelin) (Piatt and Anderson 1996), therefore, long term changes in temperature could lead to expansion or contraction of the distribution range of certain fish species (Drinkwater 1997). Hence, we anticipate that we will be able to demonstrate a correlation between changes in sea surface temperature and changes in the distribution of capelin.

NEED FOR THE PROJECT

A. Statement of Problem

The *Exxon Valdez* oil spill resulted in extensive mortality of seabirds and damage to other resources within PWS and the Gulf of Alaska (Piatt et al. 1990). Several of these resources had not recovered 5 years after the spill (Agler et al. 1990a&b, Klosiewski and Laing 1994, Agler and Kendal 1997). The APEX project was initiated in 1994 to determine if a shift in the marine trophic structure had prevented the recovery of injured seabirds. Seabirds interact with the marine system principally through foraging; therefore, a study of seabird/forage fish interactions 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 roll in gaining both an understanding of why populations have not rebounded and identifying any management activities that can aid recovery.

C. Summary of Major Hypotheses

The general hypotheses that have directed this study are:

1. Forage fish characteristics and interactions among seabirds limit availability of seabird prey.

2. Seabird foraging group size and species composition reflect prey patch size.

3. Changes in the distribution of capelin (*Mallotus villosus*) reflect changes in sea surface temperature on an annual scale.

4. Bottom type and depth are predictors of sand lance distribution.

Hypotheses 2 (Maniscalco 1997, Maniscalco et al. 1999) and the interactions among seabirds portion of hypotheses 1 (Maniscalco 1997, Maniscalco et al. 1999, Ostrand in review, Maniscalco et al. in review) have been addressed. Hypotheses 3 and 4 have been added to gain insight into the habitat associations of major seabird forage fishes.

D. Completion Date

We have completed 5 years of field data collection (FY 1995-1999) and anticipate 2 additional years to analyze data and publish the findings of the study in scientific journals. The final report is due on September 2000.

COMMUNITY INVOLVEMENT

A community involvement and traditional knowledge program will be developed by the APEX chief scientist.

FY 99 BUDGET

Personnel	111.7
Travel	2.0
Contractual	10.4
Commodities	0.0
Equipment	10.6
Subtotal	134.7
Gen. Admin.	20.2
Total	154.9

PROJECT DESIGN

Field work will be completed in 1999. Efforts during 2000 will be directed at the analysis of data and writing results for publication.

A. Objectives

Data analysis will be directed at addressing the following objectives which are given in order of their priority:

1. Modeling habitat selection by fish. This effort will focus on Pacific sand lance linkages to bottom type and depth.

2. Modeling habitat selection by seabirds. This effort will utilize a multivariate approach to describe foraging habitat preferences of both diving and surface feeding birds.

3. Determine if characteristics of forage fish schools limit availability of seabird prey. This effort involves assessing the characteristics of fish schools that are available to seabirds and then determining the proportion and amount of the forage biomass that conforms to those characteristics.

4. Determine if there is a correlation between changes in the distribution of capelin and change in sea surface temperatures of the Gulf of Alaska.

B. Methods

Data collection: No field data will be collected during 2000. However data collected by other projects, not previously described, or obtained from outside source will be incorporated.

To model forage fish habitat selection we have developed a set of sand lance locations that were collected by numerous APEX studies in PWS during 1997 and 98. Techniques used to determine the presence of sand lance included cast, dip, and seine nets; fish traps; video cameras; and aerial surveys. To calibrate bottom typing, sediment samples were collected with a Ponar grab at 53 randomly selected locations within the APEX study areas during the summer of 1998. Due to the roughness and/or rockiness of the bottom substrate, successful samples (i.e. ≥ 50 g) were only obtained at 26 of 53 random sites. Samples were frozen and then oven dried (150^0 C for three hours) prior to laboratory analysis. Grain size analysis was performed on sediment samples using a sieve/hydrometer procedure (Day 1965) which determined percentage gravel, sand, silt, and clay for each sample following the USDA scale (Gee and Bauder 1986).

To determine if the distribution of capelin reflects change in sea surface temperatures we will acquire the following data sets:
Capelin:
Biological data exist from historical fisheries research vessel surveys (Anderson) and from recent mid-water trawl and aerial surveys (APEX and Brown). Additional sources of distribution data include: Pahlke (Capelin Thesis; ADF&G - historical distributions throughout Alaska);
Temperature Data:
Coarse scale - Historical temperature data is available in the literature for the Gulf of Alaska from Niebauer (1983) and Royer (1993) - mean temperature per year.
Medium Scale - data is available from numerous hydrological monitoring devices/projects situated in GOA and in PWS. These include:
Gulf of Alaska CTD Time Series (GAK1) - this data may be the most extensive (historically) data available (1972 - 1995).
SEA Weather Data: Sea Surface Temperature (SST) data generated from various buoys and hydrographic stations situated within PWS and NGOA. Data sources include:

- ◊ Middleton Island — 1985-1995 (air temp only)
- ◊ Seal Rocks — January 1995 -June 1997
- ◊ Midsound Buoy — January 1995 -June 1997
- ◊ Bligh Reef — January 1995 -June 1997
- ◊ Potato Point — January 1995 -June 1997
- ◊ Applegate Rocks — realtime data (daily download)
- ◊ CFOS Buoy — January 1991 - December 1996 (multiple year time series soon to be available).

Fine Scale: AVHRR Satellite Imagery. NOAA/NASA Advanced Very High Resolution Radiometer (AVHRR) Oceans Pathfinder Monthly Sea Surface Temperature CD-ROM: contains monthly averaged sea surface temperature data (SST) and browse images derived from the NOAA AVHRR using the Pathfinder Version 3 algorithm.

- Data are available in 18 km and 54 km resolution
- Data are provided in Hierarchical Data Format

- Duration of data: November 1981 - December 1996

Data analysis: To model habitat selection by sand lance we began by performing cluster analysis, Ward's minimum variance method (SAS Institute Inc., 1996), on sediment data with the variables percent gravel, sand, and mud (silt + clay) of each sample. Clusters were assigned a sediment code (gravel, sand, sandy mud, and mud) taken from Folk (1980). We added an unknown substrate type to account for all bottom types that we did not sample. Next, we analyzed hydroacoustic data collected during the 1997 forage fish survey with bottom typing software (VBT Seabed Classifier™, BioSonics, Inc., Seattle, WA). This process produced several variables that describe the characteristics of the bottom signal. We adjusted the software to average the characteristics of the bottom and produce an output at 30-m intervals. We found that the calibration feature of the software to be ineffective and are proceeding to develop our own methods to calibrate and categorize the programs output. First we will import the bottom typing output into GIS. A separate coverage will be developed for each variable of the output to which we will apply a krigging algorithm (surface interpolation function) to create 1-km wide buffers along the survey routes. Next we will catagorize sediments by comparing the characteristics of the bottom signal at locations at which grabs were taken to all locations through the use of compositional analysis (SAS Institute Inc., 1996). Each location within the buffers will be assigned the bottom type to which its bottom signal is most similar. We will also develop a krigged bathymetry coverage from the hydroacoustic data for the buffered survey lines. These coverages will be used to determine the depth, distance from shore, and bottom type at known sand lance and an equal number of randomly selected locations. We will utilize these data to develop a sand lance resource selection function, based upon logistic regression (Manly et al. 1993). Finally the resource selection function will be utilized to develop a GIS coverage that displays the probability of encountering sand lance on the buffered survey routes.

We have previously made a preliminary report on habitat selection by seabirds (Ostrand et al. 1998a). We intend to repeat the presented analysis with updated fish biomass estimates for 1996 and 1997 and to expand the analysis to include 1998 and 1999 data. We will also incorporate analysis of covariance to compare habitat selection among years.

To determine if characteristics of forage fish schools limit availability of seabird prey we will determine a resource selection function for all seabird species for which there is an adequate sample size, for each year (1996 - 1999) via updated methods described by Ostrand et al.(1998b). The Ostrand et al. (1998b) methods will be updated through the use of recently reported target strengths of forage fishes and the use of new software that directly measures the attributes of fish schools. The resource selection functions will be compared among species within years and within species among years. The resource selection functions will then be used to determine which of the fish schools sampled during hydroacoustic surveys were similar to schools associated with foraging birds. We will consider this set of schools to be available to seabirds. Next we will determine the amount and the proportion or the total sampled biomass that is available for each possible combination of seabird species and year.

We intend to compare the distribution and abundance of capelin in the Gulf of Alaska with satellite derived (AVHRR) sea surface temperatures. Capelin data will be compiled into a multi layer GIS. Data layers will be visually examined for spatial and temporal patterns in capelin distribution. If patterns (or changes in patterns) occur in capelin distribution through time and space, these will be compared to monthly composites of SST to determine what correlations exist between the two datasets.

PUBLICATIONS

Publications for fiscal year 2000

Ostrand, W. D., T. A. Gotthardt, K. J. Kuletz, and K. O. Coyle. Murrelet and seabird foraging habitat in William Sound, Alaska.
Data analysis: 2 months
Write up: 2 months
Cooperators: K. J. Kuletz and J. Kern of Western EcoSystems Technology, Inc.

Ostrand, W. D., T. A. Gotthardt, and J. Kern. A method for determining the distribution of potential Sand Lance habitat through the interpretation of hydroacoustic data.
Data analysis: 4 months
Write up: 2 months
Cooperators: J. Kern of Western EcoSystems Technology, Inc.

T. A. Gotthardt, W. D. Ostrand, and J. Kern. Distribution of sand lance and burrowing habitat within Prince William Sound, Alaska.
Data analysis: 5 months
Write up: 2 months
Cooperators: J. Kern of Western EcoSystems Technology, Inc.

T. A. Gotthardt, P. J. Anderson, D. C. Duffy, and W. D. Ostrand. Effects of climate variability on the distribution of capelin (*Mallotus villosus*) in Gulf of Alaska waters.
Data analysis: 4 months
Write up: 3 months
Cooperators: P. J. Anderson of NMFS and D. C. Duffy Univ.of HI.

Publications for fiscal year 2001

Ostrand, W. D., T. A. Gotthardt, and J. Kern. Resource selection by the seabirds of Prince William Sound, Alaska: comparisons of 1996 through 1999.
Data analysis: 8 months
Write up: 3 months
Cooperators: J. Kern of Western EcoSystems Technology, Inc.

Robards, M. D., W. D. Ostrand, and T. A. Gotthardt, and. Comparative analysis of sand lance distribution and habitat preferences in Cook Inlet and Prince William Sound, Alaska.
Data analysis: 4 months
Write up: 3 months
Cooperators: J. F. Piatt and M. D. Robards of BRD, USGS; J. Kern of Western EcoSystems Technology, Inc.

Ostrand, W. D., T. A. Gotthardt, J. F. Piatt, J. Kern, G. S. Drew and D. B. Irons. Comparisons of resources selected by seabirds of Prince William Sound and Cook Inlet, Alaska.
Data analysis: 3 months
Write up: 3 months
Cooperators: J. F. Piatt and G. S. Drew Cooperators: J. F. Piatt and M. D. Robards of BRD, USGS; J. Kern of Western EcoSystems Technology, Inc. of BRD, USGS; J. Kern of Western EcoSystems Technology, Inc.

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Anderson, P. J., J.E. Blackburn, and B. A.Johnson. 1996. Analysis of small-mesh trawl data. *Exxon Valdez* Oil Spill Restoration Project Annual Report, Restoration Project (APEX) 95163L. 14pp.

Carscadden, J., B.S. Nakashima, and K.T. Frank. 1997. Effects of fish length on the timeing of peak spawning in capelin (*Mallotus villosus*). Canadian Journal of Fisheries Aquatic Science 54:781-787.

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KITTIWAKES AS INDICATORS OF CHANGE IN FORAGE FISH

Project Number:	99163E
Restoration Category:	Research
Proposer:	DOI
Duration:	Fifth year of six-year project
Cost FY 00:	$198.6K
Cost FY 01:	$156.6K
Geographic Area:	Prince William Sound
Injured Resource:	Piscivorous birds

ABSTRACT

Black-legged kittiwakes (*Rissa tridactyla*) nest at twenty-seven colonies distributed throughout Prince William Sound (PWS). They are highly mobile predators of surface schooling fishes and collectively forage in all areas of PWS. Marked variation in breeding success has been observed regionally and annually within PWS. This project (163E) was designed to quantify relationships between the reproductive biology, foraging ecology, and population dynamics of kittiwakes and the relative abundance and availability of prey. We are approaching a point of effectively describing causes and mechanisms for observed variation in breeding success and population dynamics of kittiwakes in PWS. By the end of FY 99 we will have completed five field seasons and have submitted for publication nearly half of our proposed manuscripts (see Reports/Publications section). With an additional 2.0 years of analysis and manuscript preparation following our final field season in 1999, we propose to conclude our findings of these predator-prey relationships. These relationships can then be incorporated into a long-term monitoring program to model the effect of environmental perturbations on kittiwake populations in PWS; with applications throughout the range of this species.

INTRODUCTION

Seabirds have 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

Marbled murrelets, pigeon guillemots, common murres, and black-legged kittiwakes were impacted by the oil spill and have not recovered. In Prince William Sound there is evidence that recovery is not occurring because 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. By studying adult survival, recruitment and dispersal rates we can determine if the population is able to maintain itself. Because kittiwakes are piscivorous like other impacted birds, it is likely that they would be affected by lack of food in a similar manner as the other species. Kittiwakes are easier and less expensive to study than other impacted species. By studying kittiwakes, we are learning about factors that may be limiting the recovery of other species too.

After it is determined how food is limiting, we can then begin to answer questions about why food is limiting and what 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 available forage fishes.

4. Kittiwakes select foraging areas based on specific habitat characteristics. (this objective will be done in cooperation with the seabird/forage fish component).

D. Completion Date

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

COMMUNITY INVOLVEMENT

The Shoup Bay kittiwake colony is part of the Alaska State Park system and receives many tourists throughout the summer. The U. S. Fish and Wildlife Service has been granted permission to continue work at this colony while providing visitor use data to the Park Service and natural history interpretation to visitors. We set up remote telemetry equipment on property owned by the Tatitlek and Chenega villages. In obtaining permission for the remote stations we are able to inform these communities of our project findings and answer questions. In addition, we employ local boat operators, barge, fuel, and supply services from the towns of Whittier and Valdez.

BUDGET	FY 2000	FY 2001
Personnel	148.2	128.0
Conferences/Travel	2.0	2.0
Contractual	17.0	5.0
Commodities/Equipment	8.0	2.0
Administration	23.4	19.6
Total	198.6K	156.6K

PROJECT DESIGN

A. Objectives

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

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

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

2. Determine if populations are productive enough to maintain themselves by: Monitoring survival rates of adults and recruitment and dispersal rates of young.

3. Identify habitat characteristics of foraging areas used by kittiwakes (this objective will be done in cooperation with the APEX seabird/forage fish component B).

B. Methods (Field work to be completed in Summer 1999)

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Egg laying dates, clutch size, hatching success, fledgling success and overall productivity data will be collected from the Shoup Bay, Eleanor Island, and North Icy Bay colonies by setting up a series of representative plots throughout the colonies that can be monitored to address these parameters. 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 fledgling 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. Fledgling 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 fledgling divided by the number of nests built.

To determine growth rates, chicks of birds without radios will be weighed to the nearest gram with 300 g and 500 g Pesola scales every five days from hatching to just before fledgling. However, chick growth rates of some radio-tagged birds will be recorded to determine if they are different from chick growth rates of birds without radios. Chicks will be selected from accessible nests in representative plots at Shoup Bay, Eleanor Island, and North Icy Bay. Growth rates will be calculated using non-linear growth curves fitted to the data from individual chicks (Ricklefs 1967).

We will collect diet samples from adults at Shoup Bay, Eleanor 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 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 frozen 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 each Shoup Bay, Eleanor Island and North Icy Bay. The radio packages weigh about 9 grams, which is 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 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 7.3m 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.

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 global positioning system, a bird is considered to be feeding in a different site if it moves more than one km between feeding attempts. Birds are considered 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 RRSs set up at colonies a two element "H" or dipole antenna will be used, for all other locations a more powerful five-element Yagi antenna will be used. Antennae at all sites except at 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 to 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 height 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 a period of one minute.

Chick provisioning rates will be obtained from chicks at Shoup Bay, Eleanor Island, and North Icy Bay colonies. Data will be collected by observing chicks at 30 nests for 20 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, age at first breeding, and survival to breeding age will be determined from marked kittiwakes. Approximately 800 adults and 500 fledglings were individually colored banded at the Shoup Bay colony in 1991. Since 1991, 500 fledglings have been banded annually at Shoup Bay. Additionally, over 150 kittiwakes have been banded at the Eleanor Island and North Icy Bay colonies since 1995. Resighting efforts will be conducted during a three to four week period in May. Cormack Jolly-Seber recapture models will be used to estimate resighting probabilities and survival rates (Clobert et al. 1987).

Analyses

One-way ANOVAs (or nonparametric equivalent tests) 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 the 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, fledgling 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, which will be 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 radio-tagged birds fly on foraging trips 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 $\alpha = 0.10$.

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. Three colonies will be studied intensively, Shoup Bay, Eleanor Island, and North Icy Bay. In 1997, the Shoup Bay colony was the largest in the Sound, with 7100 breeding pairs, Eleanor Island supported 270 breeding pairs, and North Icy Bay had 2100 pairs. These colonies have sufficient numbers of accessible nests to permit obtaining both adults for radio-tagging and chicks for recording growth rates.

SCHEDULE

A. Measurable Project Tasks of FY 00

During FY99 we will complete our final field season. Much of the project data will be analyzed and prepared for synthesis with other APEX components and EVOS projects (e.g. SEA). Manuscripts submitted at the end of FY 99 will be revised for publication. Manuscripts incorporating FY 99 data will be prepared for publication. An annual report will be completed. Presentations of data will be given at the EVOS restoration workshop and the Pacific Seabird Group conference. Posters will be prepared for display at scientific meetings and for public interpretation.

B. Project Milestones and Endpoints

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

C. Project Reports/Publications

Annual reports will be submitted by 15 April of every 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.

Publications

Irons, D.B. 1998. Foraging area fidelity of individual seabirds in relation to tidal cycles and flock feeding. Ecology 79(2):647-655.

Golet, G.H., D.B. Irons and J.A. Estes. 1998. Survival costs of chick rearing in black-legged kittiwakes. J. Anim. Ecol. 67:827-841.

Agler, B.A., S.J. Kendall, D.B. Irons, and S.P. Klosiewski. In press. Declines in marine bird populations in Prince William Sound, Alaska, coincident with a climatic regime shift. Colonial Waterbirds.

Manuscripts submitted

Suryan, R.M. and D.B. Irons. In review. Black-legged Kittiwakes in Prince William Sound, Alaska: population dynamics in a heterogeneous environment. Auk

Suryan, R.M., D.B. Irons, and J. Benson. In review. Inter-annual variation in diet and foraging effort of kittiwakes in relation to prey abundance. Ibis.

Benson, J. and R.M. Suryan. In review. A leg-noose for capturing adult kittiwakes on the nest site. J. Field Ornithology.

Golet, G.H. and D.B. Irons. In review. Raising young reduces body condition and fat stores in Black-legged Kittiwakes. Oecologia.

Manuscripts to be submitted before or during FY 2000

Suryan, R.M., D.D. Roby, D.B. Irons and J.F. Piatt. An evaluation of methods for determining nestling growth.
analysis: 2.0 month (mo.)
write-up: 2.5 mo.

Suryan, R.M., D.B. Irons, J. Benson, D.D. Roby and P. Jodice. Diets, nestling growth, and breeding success of black-legged kittiwakes in Prince William Sound, Alaska.
analysis: 2.5 mo.
write-up: 3.0 mo.

Irons, D.B., R.M. Suryan and J. Benson. Use of feeding flocks by adult kittiwakes during the breeding season.
analysis: 0.5 mo.
write-up: 1.5 mo.

Irons, D.B. Flexible foraging behavior in seabirds: short-term buffer and long-term tradeoff?
analysis: 0.5 mo.
write-up: 0.5 mo.

Irons, D.B. The role of food availability in sibling aggression and brood reduction of the Black-legged Kittiwake.
analysis: 0.5 mo.
write-up: 0.5 mo.

Irons, D.B. Some conceptual ideas concerning marine birds as indicators of changing prey abundance.
analysis: 0 mo.
write-up: 0.5 mo.

Benson, J., R.M. Suryan and J.F. Piatt. A multivariate approach to assessing nestling growth from one-time measurements.
analysis: 0.5 mo.
write-up: 0.5 mo.

Benson, J., R.M. Suryan and D.B. Irons. Limitations of foraging effort of kittiwakes while provisioning nestlings: quantification of a "buffer."
analysis: 2.0 mo.
write-up: 3.5 mo.

Kaufman, M., R.M. Suryan, D.B. Irons and J. Benson. Detecting intra- and inter-annual variation in prey availability using daily foraging trip durations.
analysis: 2.5 mo.
write-up: 3.5 mo.

Golet, G.H., D.B. Irons and D.P. Costa. Energy costs of chick rearing in Black-legged Kittiwakes.
analysis: 0 mo.
write-up: 0 mo.

Golet, G.H., D.B. Irons, J.A. Estes. Variable reproductive costs in a long-lived seabird: a multiyear experimental study of the black-legged kittiwake.
analysis: 0 mo.
write-up: 0 mo.

THERE WILL BE ADDITIONAL COLLABORATIVE MANUSCRIPTS WITH D. ROBY, P. JODICE, G. FORD, D. AINLEY, AND J. PIATT.
analysis: 1-3 mo.
write-up: 1-3 mo.

Manuscripts to be submitted during FY 2001.

Suryan, R.M., D.B. Irons, J. Benson, K. Coyle, J. Thedinga, L. Hulbert, E. Brown and L. Haldorsen, . Kittiwakes as indicators of forage fish availability in Prince William Sound, Alaska.
analysis: 2.0
write-up: 3.0

Suryan, R.M. and D.B. Irons. A long-term monitoring plan for Black-legged Kittiwakes in Prince William Sound, Alaska.
analysis: 1.0
write-up: 2.0

Irons, D.B., G.G. Golet, R.M. Suryan and T.M. Sauer. Survival rates of Black-legged Kittiwakes in relation to prey abundance.
analysis: 4.0
write-up: 3.0

Sauer, T.M., D.B. Irons and J. Gilbert. Natal philopatry within a colony of Black-legged Kittiwakes.
analysis: 1.5
write-up: 2.5

Sauer, T.M., D.B. Irons and J. Gilbert. Dispersal of Black-legged Kittiwakes and the effect of colony success on recruitment.
analysis: 1.5
write-up: 2.5

Irons, D.B., J. Piatt *et al.* and R. Suryan. Response of kittiwakes to changing prey availability: a comparison between two oceanographically distinct regions.
analysis: 3.5
write-up: 3.5

Irons, D.B. et al. The multiple effects of sea otter recolonization, a climatic regime shift, and an oil spill on the marine birds of Prince William Sound, Alaska.

THERE WILL BE ADDITIONAL COLLABORATIVE MANUSCRIPTS WITH D. ROBY, P. JODICE, G. FORD, D. AINLEY, AND J. PIATT.
analysis: 1-3 mo.
write-up: 1-3 mo.

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 and Kevin Stokesbury, (SEA project 96320T) in respect to their data on the distribution, movements, and behavior of young herring in Prince William Sound. We have discussed collaborating with Ted Cooney on a publication combining his data on the river/lake phenomenon and our historical data on kittiwake productivity. We are also collaborating with Tom Kline (SEA project) regarding stable isotope analysis of kittiwake tissues. We routinely share equipment and personnel with the Nearshore Vertebrate Predator Project and other EVOS projects (Black Oystercatchers, Steve Murphy, ABR Inc.) whenever it enhances the overall efficiency of EVOS projects.

The Fish and Wildlife Service, as part of their 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 $80K worth of services and data). In the future, the role of the Service in the APEX project may diminish as funds are cut.

ENVIRONMENTAL COMPLIANCE

We have obtained proper permits for field sites from the U.S. Forest Service and the Alaska State Parks. We also have obtained necessary permits from state and federal agencies for capturing/marking kittiwakes and collection of forage fishes.

PERSONNEL

Co-Project Leader: David Irons received his Ph. D. from the U. of CA, Irvine in 1992. His dissertation was on the foraging ecology and breeding biology of the black-legged kittiwake. The field work for this study was conducted in Prince William Sound. Irons received his M. S. from Oregon State University in 1982 where he studied foraging behavior of glaucous-winged gulls in relation to the presence of sea otters. Irons conducted marine bird and sea otter surveys in PWS in 1984 and 1985. He has been studying kittiwakes in PWS for 12 years and completed the EVOS kittiwake damage assessment study. Irons has overseen several seabird studies in the past few years including marine bird and sea otter surveys in PWS, Cook Inlet, and SE Alaska, a seabird monitoring study on Little Diomede Island, a cost of reproduction study on kittiwakes, a seabird/forage fish interactions study, and various population and reproductive studies on pigeon guillemots and marbled murrelets. Irons has authored and co-authored several reports and publications on seabirds and has made several presentations at scientific conferences on seabirds.

Selected Publications:

Irons, D.B. 1998. Foraging area fidelity of individual seabirds in relation to tidal cycles and flock feeding. Ecology 79(2):647-655.

Golet, G.H., D.B. Irons and J.A. Estes. 1998. Survival costs of chick rearing in black-legged kittiwakes. J. Anim. Ecol. 67:827-841.

Irons, D.B. 1996. Size and productivity of black-legged kittiwake colonies in Prince William Sound, Alaska before and after the T/V *Exxon Valdez* oil spill. Pages 738-747*in* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium..American Fisheries Society Symposium 18.

Hatch, S.A., G.V. Bryd, D.B. Irons, and G.L. Hunt. 1993. Status and ecology of kittiwakes in the North Pacific Ocean. Pages 140-153 *in* editors, K. Vermeer, K.T. Briggs, K.H. Morgan, D. Siegel-Causey, The status, ecology, and conservation of marine birds of the North Pacific. Can. Wildl. Serv. Spec. Publ., Ottawa, Canada.

Irons, D.B. 1992. Aspects of foraging behavior and reproductive biology of the black-legged kittiwake. Unpublished Ph.D. Dissertation.

Vermeer, K., and D.B. Irons. 1991. The Glaucous-winged Gull on the Pacific Coast of North America. Acta Twentieth Congressus Internationalis Ornithologici:2378-2383.

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Co-Project Leader: Rob Suryan received a B.S. degree in wildlife management at Humboldt State University (1989), a M.S. degree in marine science at Moss Landing Marine Laboratories (1995), and has 14 years of experience in field biology. He has conducted studies of terrestrial and marine birds and mammals, involving population estimates, habitat use, foraging ecology, diving behavior, and effects of human disturbance. Rob is a council member of the Pacific Seabird Group representing Alaska and Russia. Rob has been studying the reproductive biology and foraging ecology of Black-legged Kittiwakes in Prince William Sound, Alaska, since May 1995.

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Biological Technician: Jeb Benson received a B. S. in Environmental Science with a minor in Fisheries and Wildlife from Oregon State University in 1995. He has been working with the Black-legged Kittiwake study (APEX component E) for three years (since May 1996) and has conducted field work at all three study colonies in PWS, and Gull Island in Cook Inlet (APEX Component M). Jeb is an integral part of the data compilation, analysis, and paper preparation of this project. He is currently focusing efforts on the completion of several publications.

Selected Reports and Publications
See "Manuscripts submitted" and "Manuscripts to be submitted during FY2000" sections above.

Biological Technician: Max Kaufman received a B.S. in Geology with additional course work in biological sciences at the University of California, Santa Cruz in 1995. He has been with the APEX project for three years (since May 1996) and has focused most of his attention on the remote collection of radio-telemetry data and the analysis of kittiwake foraging data. Max presented preliminary findings at the 1999 Pacific Seabird Group conference. He is working on a foraging trip duration/diets publication (in progress) and will continue analysis of data from remote the remote receiving stations. He is a skilled field technician and was camp leader at the Shoup Bay field site in 1997.

Selected Reports and Publications
See "Manuscripts to be submitted during FY2000" section above.

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March 19, 1999

CONSEQUENCES OF PREY DISTRIBUTION AND ABUNDANCE IN PIGEON GUILLEMOTS AT PRINCE WILLIAM SOUND

Project Number:	00163F
Restoration Category:	Research
Proposed By:	DOI
Lead Trustee Agency:	DOI
Cooperating Agencies:	NOAA and ADFG
Duration:	5 years
Cost FY2000:	156 K
Geographic Area:	Prince William Sound
Injured Resource:	Pigeon Guillemot *Cepphus columba*

ABSTRACT

This project will compare two populations of Pigeon Guillemots at Prince William Sound, Alaska, (Naked Island and Jackpot Island) to determine if the abundance and distribution of high energy density schooling fishes such as Pacific Sand lance, *Ammodytes hexapterus*, and Pacific Herring, *Clupea pallasii*, limit chick growth rates, productivity and ultimately population size. These inquiries are central to understanding what factors may be limiting the recovery of Pigeon Guillemots at Prince William Sound following injury sustained during the *Exxon Valdez* oil spill.

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-dependant factors such as food supply outside the breeding season, whereas 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 foraging 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 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 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, and found a negative correlation between the size of a colony and the number of conspecific colonies within the foraging range of the species (species studied included 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 nonoverlapping foraging zones and that the population of a colony is a function of the size of these zones. In her study of Galapagos Penguins, 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 forage in the nearshore environment within a few kilometers of their colonies, but feed on both demersal and schooling fish. Although differences in the diet of guillemot chicks certainly reflect local differences in the availability or abundance of prey, there are clear indications of adult prey specialization patterns within colonies (Kuletz 1983, Golet et al. 1998). Schooling fish such as sand lance, herring, and capelin 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, Golet et al. 1998).

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 (predominantly herring), the percent of breeding birds in the population appears to be much higher. In most years, nest sites, not food, may be limiting the number of guillemots at this small island. In 1997, however, it appears that food played a role in limiting breeding population size at Jackpot Island. Herring dropped out of the diet in 1997, and many guillemots abandoned their eggs, presumably because the prey base they normally rely upon had nearly disappeared. Only 12 guillemot pairs fledged chicks at Jackpot Island in 1997, when herring was 3.5% of the diet, compared to 25 that were successful fledgling chicks in 1995, when herring comprised 41.3% of the chick diet.

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 a relatively large proportion of the breeding guillemots at Naked Island specialized on sand lance; today there are fewer 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 breeding pairs that preyed mostly upon blennies and sculpins in years when sand lance were readily available (Kuletz 1983). Even in more recent years (1989-1990 & 1994-1997), when high energy density schooling fishes, such as sand lance, were less available, adults that specialized on them had chicks that grew faster and attained higher overall reproductive success than adults that specialized in lower energy demersal fishes or gadids. Thus, the overall productivity of the guillemot population appears to be higher when sand lance and other high energy density fishes are more widely available. The high lipid content of many of the pelagic schooling fishes relative to that of demersal fishes and gadids (D. Roby, personal communication), certainly make these prey fishes a 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 (99163 G), will help assess the relative importance of high energy density schooling fishes such as sand lance and herring 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, however, recent analyses provide a clear demonstration that guillemots populations declined more along oiled- than unoiled-shorelines pre- to post-spill (Irons *unpublished data*). 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, however, populations have increased since 1996.

B. Rationale

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

FY 2000 BUDGET: See attached spreadsheet

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. (Note: this has already been established, see Golet et al. 1998)

4) Differences in the distribution and abundance of forage fishes lead to changes in adult foraging patterns which affect colony productivity and population size.

5) Differences in reproductive performance between oiled and unoiled colonies are not a result of physiological impairment of the adults caused by exposure to residual hydrocarbons.

<u>Foraging study hypotheses</u>

H_A: Pigeon Guillemot breeding population size is, in part, a function of pelagic forage fish abundance.

H_B: Pigeon Guillemots demonstrate stronger long-term foraging site fidelity when foraging on demersal fishes than when foraging on pelagic schooling fishes.

H_C: Guillemots associate with schools of fishes (especially sand lance and herring).

H_D: Guillemots are more clumped (with conspecifics or other seabird species) when feeding on schooling fishes than when feeding on demersal fishes.

H_E: Acts of conspecific aggression are less frequent when feeding on schooling fishes than when feeing on demersal fishes.

H_F: Guillemots travel shorter distances to forage when feeding on schooling vs. demersal fishes.

H_G: Guillemots have higher rates of delivery (shorter foraging trip lengths) when feeding on schooling vs. demersal fishes. (Note: this hypothesis is not supported by Golet et al. 1998).

H_H: Individual guillemots demonstrate foraging site fidelity.

B. METHODS

Below are outlines of field methods used to collect data in past years; details are reported in a separate document entitled "Pigeon Guillemot Field Protocol". No new data will be collected in FY2000. Instead, personnel will work on the data analyses and the preparation of manuscripts.

Population Censusing:
In PWS, guillemots will be censused at Naked, Peak, Storey, Smith, Little Smith, Jackpot, and Pleiades Islands, and Whale and Icy Bays on the mornings of May 28-30 to ascertain population size. Two to three counts of western Naked and Jackpot Islands will be made during this period, while the remaining areas will be surveyed once. These data will be used to determine if the populations at are recovering from injury incurred following the *Exxon Valdez* oil spill. Censuses will be conducted with whalers piloted 100 m offshore. All guillemots sighted onshore and in the water within 200 m of land will be counted, and their locations recorded.

Resighting:
Individually color marked birds are needed to assess differences in delivery patterns and prey specialization among individual adult guillemots. Resighting banded birds and identifying their nest burrows will facilitate such comparisons. As well, resighting will allow estimation of juvenile and adult survival, and sex determination.

Identifying Nest Sites:
Nest sites (in burrows, under tree roots, or in rock crevices) must be identified for studies of productivity, chick growth rates, diets, and meal sizes, adult prey delivery rates, predation, and collection of bio-samples. These sites will be used for capturing adults, thus allowing their banding, measuring and dying, necessary steps for studies of adult body condition, foraging patterns and investigations of individual adult's prey selection preferences.

Chick Diet and Delivery Rates:
Because adult guillemots carry single whole fish in their bills when provisioning their chicks, information on prey species composition can be readily obtained by making direct observations of active guillemot nests during chick-rearing. Observations will be made at selected groups of guillemot nests throughout the nestling period to collect diet and delivery rate data, and to characterize various aspects of adult foraging.

Monitoring Nests:
Nests will be monitored throughout the breeding season to determine reproductive success parameters, chick growth rates, and predation. All accessible burrows should be checked initially in early June (every couple of days if possible) to determine if egg(s) are present. Then, beginning late in incubation, nests will be checked every 5 days. Nest checks will terminate when nestlings fledge or it has been positively determined that the nesting attempt failed.

Productivity Parameters:
The following parameters will be determined from the monitoring of 60 nests at Naked and 40 nests at Jackpot:

Clutch Size[a] (eggs per nest with eggs)	
Lay Date[b]	
Incubation Period[a]	
Hatching Date[b]	
Mean Hatching Success[a] (% of eggs laid that hatch)	
Fledgling Success[a] (% of chicks hatched that fledged)	
Productivity[a] (% of eggs laid that fledged)	[a]mean
Nesting Success[a] (% of nests where at least 1 chick fledged)	[b]median

Chick Growth Rates:
A subset of the nests monitored for productivity will be used to assess chick growth and development. Chick growth rates provide a useful index of food availability. They also can demonstrate differences in the foraging proficiency of adult birds. Collection of these data are critical for comparisons among years, among colonies, and among adults with differing foraging strategies.
All accessible guillemot nests on Naked and Jackpot Islands will be used for collecting growth rate and productivity data. All guillemot chicks that are handled will be banded (one USFWS metal band and three color plastic bands).

Chick Meal Collections:
We will collect chick meals in order to determine the mass, energetic content, and species composition of the prey items being delivered to the guillemot chicks at Naked and Jackpot Islands. The parameter of interest is the total amount of food delivered by the adult.

Capturing Adults:
At least 10 (and preferably many more) adults will be captured to assess body condition, to band and dye individuals for energetics and foraging ecology studies, to intercept meals being delivered to chicks, and to collect bio-samples. All adults captured will be individually marked with colored leg bands, dyes, and streamers. Morphometric variables will be used to derive a condition index for adults during chick-rearing. Adults will be marked in three ways. The individual color bands will allow identification at the colony during meal delivery and adult foraging ecology studies. The dye marks and streamers, in conjunction, will identify individual birds while at sea, when it is often difficult to see the legs. This will permit the identification of foraging locations of individual birds.

Adult Body Condition:
When adults are captured, their weight, wing length, outer primary length, tarsus, and culmen will be measured. Principle components analyses will be used to relate mass to body size for a determination of adult body condition

Food Availability:
In addition to underwater transects completed by divers, information will be collected on species diversity and abundance of benthic and schooling fish through the use of minnow traps and beach seines in several areas near the colonies. Prey items may also be sampled opportunistically, through sand lance stomping and rock turning in the intertidal regions.

-- Minnow traps will be set at 4 sites at Naked, 10 sites at Jackpot, and 2 sites at Kachemak. Traps will be set at these sites three times during the chick rearing period and left for 24 hours. Trapping locations will be chosen from areas where guillemots have been observed feeding. Fish that are not collected for the APEX project will be released. Shrimp and crab will be counted, samples of each fish species will be collected, and the approximate percentage recorded.
-- Five sites at Naked, and 3 sites at Jackpot will be seined five times. Seining of a given site will take place approximately every 7 days. Seining sites were established in 1996. Methods of the seining were detailed by Martin Robards.

Foraging Patterns:
One of the primary objectives of the project is to better understand the effects that differences in diet composition and delivery rates have on the growth and development of chicks. However, the selection of different prey items for the chick may also affect maintenance costs, energetic requirements, body condition, and adult survival. Prey that promote rapid growth in the chicks may be energetically expensive for the adults to obtain. By characterizing the foraging patterns of adult guillemots while simultaneously monitoring the chicks, the costs and benefits of different foraging strategies, and varying prey availabilities can be assessed in a comprehensive manner. Because individual guillemots have been shown to have a high degree of specialization in their prey selection (even within colonies), drawing the link between the foraging patterns of the adults at sea, and the growth and development of the their chicks may be especially fruitful in the present study.

Furthermore, one mechanism that has been proposed for causing the decline of guillemots in PWS is a reduction in high energy density schooling fishes. The current population may be reduced because these high quality prey items are less widely available to breeding birds. A foraging study may help establish if and how foraging options of guillemots are limited when adults are selecting demersal fishes compared to when adults are selecting pelagic schooling fishes.

We will use radio telemetry techniques to monitor individual bird's foraging patterns. The following parameters will be characterized:
-- Foraging locations (site fidelity, distance from colony, association with bathymetric features)
Survey transects will be drawn up for each of the study sites based on identifications that have been made of foraging grounds in years past. These transects will be surveyed 5 times during the chick rearing period.
-- Time budgets on the foraging grounds (surface intervals, dive durations)
-- Schooling fish abundance and distribution. These data will be collected by Evelyn Brown, who will fly over the west side of Naked approximately 5 times during the chick rearing period. By conducting simultaneous surveys for guillemots from a boat, we will be able to determine the level of association that adults have with schooling fishes.
-- Foraging flock dynamics (species composition and inter- and intra-specific behavioral interactions)

Blood Biomarkers:
Finally, because reduced chick growth and productivity may result from either inadequate food supplies or inefficiencies in adult foraging (due to physiological impairment), we will collect and analyze blood samples from 30 guillemots (15 at each study site). It is essential that we determine whether or not there are differences in the physiological health of adult birds at the two sites in order to interpret observed patterns of prey provisioning. A number of blood tests can serve as diagnostic adjuncts in the

development of a presumptive or definitive diagnosis (Duncan et al. 1994; Campbell 1995). Plasma or serum biochemical analyses provide information about internal organs (liver, kidney), electrolytes (sodium, chloride, potassium, calcium, phosphate), proteins (immunoglobulins and albumin) and nutritional or metabolic parameters (cholesterol, triglycerides and glucose) (Franson et al. 1982; Jain 1986; Duncan et al. 1994). Hematological analyses, which include red blood cell counts, white blood cell counts and differential cell counts, provide information about the erythropoietic system and immunological status of an individual. With the establishment of reference range blood parameters for a variety of marine birds impacted by oil contamination (Kocan 1972; Balasch 1974; Bradley and Threlfall 1974; Wolf et al. 1985; Melrose and Nicol 1992; Rosa et al. 1993; Newman 1995; Newman and Zinkl 1996; Newman et al. 1997; Work 1996), it is possible to determine the physiological health of birds from blood sample collections (Newman 1995). These investigations may determine if organ systems required for efficient foraging, and survivorship are impaired.

We will capture 15 adult guillemots each from Naked and Jackpot Islands. Blood samples will be collected from the metatarsal vein through standard methods. Blood will be aliquotted into EDTA Microtainer tubes and serum separator Microtainer tubes for further processing at the field camps. The following hematological tests will be performed at field camps within 24 hours of sample collection. Packed cell volume will be determined by microhematocrit centrifugation (Jain 1986). Total protein measurements will be made using a heat sensitive refractometer while fibrinogen concentrations will be measured by the heat precipitation method (Duncan et al. 1994). White blood cell counts (WBC) will be performed using the modified Natt-Herrick's technique (Zinkl 1986). Blood smears will be made and stored for processing a the laboratory. Blood placed in serum separator tubes will be kept refrigerated and centrifuged for 15 minutes at 3500 rpm using a Triac Centrifuge (Clay Adams, Sparks, MD, USA) within 6 hours of being collected. Disposable polyethylene pipettes will be used to pipette sera from the separator tubes into plastic 1.5 ml micro-cryovials (Out Patient Services, Petaluma, CA, USA) and kept frozen until analyses are performed.

Samples will be analyzed at the Veterinary Medical Teaching Hospital, School of Veterinary Medicine, University of California, Davis to determine enzyme activity and concentrations of the following analytes: alkaline phosphatase (Alk Phos), alanine amino transferase (ALT), aspartate amino transferase (AST), creatine kinase (CK), gamma glutamyltransferase (GGT), albumin, globulin, total protein (TP), total bilirubin (TBili), direct bilirubin (Dbili), creatinine, cholesterol, lactate dehydrogenase (LDH), blood urea nitrogen (BUN), glucose, calcium (Ca), inorganic phosphorus (PO4), bicarbonate (HCO3), chloride (Cl), potassium (K), sodium (Na) and uric acid (UA). An albumin to globulin ratio (A:G ratio) will also determined. Several acute phase protein analyses will be performed. Among those being considered are; serum amyloid A, ceruloplasmin, C-reactive protein, IL1, alpha-2 macroglobulin, and hemopexin. Acute phase protein assays will be selected dependent on sample volume available, and reactivity of reagents with pigeon guillemot blood since (as determined via analyses of samples of guillemot blood collected elsewhere). There are no specific antibodies as yet available for PIGU antigens. Corticosterone concentrations will also be determined by RIA if sample volume allows. Giemsa-stained blood smears will be examined for RBC morphology, the presence of thrombocytes, reticulocytes and RBC parasites, and to perform differential white blood cell counts (heterophils, lymphocytes, monocytes, eosinophils and basophils).

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 performed at Dr. Roby's lab at Oregon State University.

Adult blood analyses will be performed at the Veterinary Medical Teaching Hospital, School of Veterinary Medicine, University of California, Davis under the direction of Dr. Scott Newman. Dr. Newman is also analyzing blood samples collected from chicks fed varying amounts of crude oil.

D. LOCATION

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

E. PUBLICATIONS

<u>Papers to be submitted in FY2000:</u>
Adult prey specialization affects chick growth and reproductive success of Pigeon Guillemots.
Authors: Golet, Kuletz, Roby, Irons
Target Journal: *the Auk*
analysis: 1 mo.
write up: 1 mo.

Factors limiting the recovery of Pigeon Guillemots at Prince William Sound following the *Exxon Valdez Oil Spill*
Authors: Golet, McGuire, Kuletz, Irons, Roby, Seiser, Newman, Fischer, and others
Target Journal: *Ecological Applications*
analysis: 3 mo.
write up: 2 mo.

Foraging site fidelity of Pigeon Guillemots during chick rearing
Authors: Golet, Fischer
Target Journal: *Waterbirds?*
analysis: 2 mo.
write up: 2 mo.

The effect of prey selection on foraging patterns in Pigeon Guillemots during chick rearing.
Authors: Golet, Fischer?, Roby? Irons?
Target Journal: *Animal Behavior?*
analysis: 2 mo.
write up: 2 mo.

Assessment of exposure to oil in a suite of marine predators in Prince William Sound, Alaska; the P450 technique.

Authors: Ballachy, Golet, others from NVP
Target Journal: *Ecological Applications*
analysis: 2 mo.
write up: 1 mo.

Comparison of blood parameters of Pigeon Guillemot chicks from oiled and unoiled areas of Alaska eight years after the *Exxon Valdez* oil spill.
Authors: Seiser, L. Duffy, McGuire, Golet, Litzow.
Target Journal: *Marine Pollution Bulletin*
analysis: 0.5 mo.
write up: 0.5 mo.

The principle investigator of the guillemot project is continuing analysis and writing of the following three kittiwake studies which are directly relevant to the APEX objectives. Little time will be required to complete these manuscripts.

Energy costs of chick rearing in Black-legged Kittiwakes
Authors: Golet, Irons, Costa
Target Journal: *Condor*
analysis: 0.5 mo.
write up: 0.5 mo.

Raising young reduces body condition and fat stores in Black-legged Kittiwakes
Authors: Golet, Irons
Target Journal: *Oecologia*
analysis: 0.5 mo.
write up: 0.5 mo

Variable reproductive costs in a long-lived seabird: a multi-year experimental study of the Black-legged Kittiwake
Authors: Golet, Irons, Estes
Target Journal: *Ecology*
analysis: 0.5 mo.
write up: 1 mo.

<u>Papers to be submitted in FY2001:</u>
Effects of prey delivery rates, energy density, and meal size on chick growth and productivity of Pigeon Guillemots.
Authors: Golet, Litzow, Roby, Jodice, Piatt, Irons?, Fischer?
Target Journal: *Canadian Journal of Zoology?*
analysis: 2 mo.
write up: 2 mo.

The effects of provisioning rates on Pigeon Guillemot chick growth and productivity; a multicolony comparison.
Authors: Jodice, Roby, Golet, Litzow, Irons, Piatt.

Target Journal:
analysis: 1 mo.
write up: 0.5 mo.

Interannual variabliity in the reproductive success of Pigeon Guillemots nesting on Jackpot Island, PWS, AK, 1994-1998.
Authors: Seiser, McGuire, Roby, Golet
Target Journal:?
analysis: 0.5 mo.
write up: 0.5 mo.

Comparison of blood parameters of Pigeon Guillemot adults from oiled and unoiled areas of Alaska a decade after the *Exxon Valdez* oil spill.
Authors: Newman, Golet, Seiser?
Target Journal: ?
analysis: 1 mo.
write up: 1 mo.

PROJECT REPORTS

The final report for this component of APEX will be submitted September 2000.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

The Forage Fish Assessment component (99163A) 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 (99163B) will provide pertinent data on the foraging behavior of guillemots in relation to these schools. The Pigeon Guillemot and Seabird Energetics (Dr. Roby, PI , APEX component 99163G) components are closely tied; virtually all the data collected during each nest visit will be used by both projects.

Dr. Scott Newman, who will be analyzing blood samples collected from adult guillemots in this project, is also being contracted to analyze blood samples taken from chicks fed varying amounts of crude oil at the Seward Sea Life Center. The dosing experiment, which is being directed by Dr. Dan Roby, will be extremely valuable in interpreting results of blood parameters of guillemots collected from oiled and unoiled colonies in the wild.

PERSONNEL

Gregory H. Golet received his M.S. degree in Marine Sciences from the University of California Santa Cruz in 1994, and has advanced to candidacy in the doctoral program of Biology at the same university. He has studied seabird ecology in Alaska since 1989. Field technicians will be carefully selected from the applicant pool as qualified to participate in the proposed research.

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18 March 1998

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Diet Composition, Reproductive Energetics, and Productivity of Seabirds in the *Exxon Valdez* Oil Spill Area (Submitted Under the NOAA BAA)

Project Number:	00163 G (formerly 95118-BAA)
Restoration Category:	Research (continuing)
Proposed By:	Oregon State University (PI - Daniel D. Roby)
Lead Trustee Agency:	NOAA
Duration:	6th year, 7-year project
Cost FY 00:	$96,060
Cost FY 01:	$84,962
Geographic Area:	Prince William Sound (Naked Island, Jackpot Island, Shoup Bay, Eleanor Island) and Lower Cook Inlet (Kachemak Bay, Barren Islands, Gull Island, Chisik Island)
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, meal size, meal delivery rates, adult energy expenditure rates) that constrain the productivity of seabirds in the *Exxon Valdez* Oil Spill 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 of injured populations of piscivorous seabirds and marine mammals.

STUDY HISTORY

This project is similar to the research described in the original proposal submitted under the NOAA BAA (95118- BAA), for which funding was first approved by the Trustee Council in April 1995, the Detailed Project Description (DPD) for FY 96 that was submitted in April 1995, the DPD for FY 97 submitted in March 1996, the DPD for FY 98 submitted in March 1997, and the DPD for FY 99 submitted in March 1998. Funding in FY 00 and FY 01 is designed to support (1) the completion of analyses of samples and data collected during the five field seasons of this research project, (2) the preparation of the Final Synthesis Report for the Alaska Predator Ecosystem Experiment (APEX) Project, and (3) preparation of the remaining manuscripts for publication in the peer-reviewed scientific literature that have resulted from this research.

Research in 1995 for APEX Project 95118-BAA provided the first account of the effects of diet composition on the reproductive energetics and productivity of piscivorous seabirds in the northern Gulf of Alaska. Black-legged kittiwakes, pigeon guillemots, and tufted puffins were studied as bioindicators of the distribution and abundance of forage fishes to further understand the recovery of injured seabird resources. Study sites were at Shoup Bay, and Eleanor, Naked, Jackpot, and Seal islands in Prince William Sound and at Kachemak Bay, Gull, Chisik, and the Barren islands in Lower Cook Inlet. In 1996 and 1997, this research continued without the tufted puffin component and with the shift from Seal Island to North Icy Bay for research on kittiwakes. In 1998, the study sites and study species were as in 1996 and 1997, but additional research on parental energy expenditure rates of kittiwakes was conducted at Middleton Island in the northern Gulf of Alaska, as a reference site. To date, this project has produced new information advancing our knowledge of the comparative biochemical composition and physiological condition of forage fishes available to seabird, marine mammal, and fish predators (Anthony et al., In review); the influence of location, gender, reproductive status, and other factors on intraspecific variation in the nutritional quality of forage fishes; effects of diet quality and provisioning rates on energy intake rates of young seabirds; the consequences of variation in energy provisioning rates on seabird growth and productivity; and the daily energy expenditure of adult kittiwakes raising young at three different colonies (Shoup Bay, North Icy Bay, Middleton Island) where diets, foraging behavior, and reproductive success varied considerably in order to test the hypothesis that breeding adults modify their parental investment in response to changes in food availability.

In 1999, this component of the APEX Project continued to investigate the relationship between diet quality and nesting productivity at the kittiwake and guillemot colonies that were studied in 1996-1998. Results from the 1995-1998 breeding seasons suggested that capelin, sand lance, and herring are key forage fish resources for piscivorous seabirds nesting in the oil spill area, and that certain colonies are more dependent on a particular forage fish species than others. Results from the 1998 breeding season, which followed a strong El Niño and unusually high sea surface temperatures that strongly influenced availability of key forage fish stocks, helped us better understand the adaptive compensation of breeding seabirds to decadal shifts in forage fish stocks. The 1998 breeding season proved to be one of generally poor nesting success for piscivorous seabirds in the northern Gulf of Alaska, with near total breeding failure at several APEX study colonies. Kittiwake reproduction at Chisik Island completely failed and nesting success at the Barren Islands, Gull Island, and Eleanor Island was very low. Reproductive success at Shoup Bay was lower than in any other year since 1992.

1999 will be the fifth and final year of data and sample collection in the field. We will continue to measure diet quantity, diet quality, and energy provisioning rates to nests at three guillemot study sites and six kittiwake study sites. These variables will be compared with chick growth rates, productivity, and overall nesting success at each site. This will provide an interesting and illuminating comparison with 1998, a year of poor nesting success in the aftermath of El Niño. 1999, a La Niña year, promises to be a year of low sea surface temperatures and higher productivity. We will also measure the daily energy expenditure of radio-tagged parent kittiwakes at the Shoup Bay colony in order to assess factors responsible for intra-colony variability in field metabolic rates. By using the doubly labeled water technique on radio-tagged kittiwakes, it would be possible to assess the effects of individual differences in foraging range and habitat preference on energy expenditure rates.

As an integrative component of APEX, this project is linked directly or indirectly to all the other components of APEX. Within APEX, this component interacts most with components E, F, J, M, N, and Q. Among other restoration projects, this study has or still is linked to Sound Ecosystem Assessment (SEA), Nearshore Vertebrate Predators (NVP), Marine Mammal Studies, Marbled Murrelet Productivity, Prince William Sound Marine Bird Surveys, and Status and Ecology of Kittlitz's Murrelet.

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 (Ricklefs 1983, Roby 1991). 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) are limited in the amount of food that they can transport to their brood by the capacity of the foregut and the power requirements for flight (Ricklefs 1983). 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 (see Final Project Report for APEX Component N). This is because (1) the energy density of lipid is approximately twice that of protein and carbohydrate (Schmidt-Nielsen 1991) and (2) the metabolizable energy coefficient for high-lipid diets is higher than for low-lipid diets (Romano, Roby, and Piatt, unpubl. ms.). While breeding adults can afford to consume prey that are low quality (i.e., low-lipid) but abundant, reproductive success may be 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 (Anthony et al., In review). In some seabird prey, such as lanternfishes (Myctophidae) and eulachon (*Thaleichthys pacificus*), lipids may constitute over 50% of dry mass, 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 (Van Pelt et al. 1997; Payne et al., In press; Anthony et al., In review). 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 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 low frequency of chick feeding (Ricklefs 1984; Ricklefs et al. 1985; Lance and Roby, In review).

Lipid content (% dry mass) and energy density (kJ/g wet mass) of forage fishes collected in PrinceWilliam Sound and Lower Cook Inlet during the 1995-1998 breeding seasons have recently been measured in my laboratory. Lipid content varied from as much as 52% in some eulachon to as low as 3% in some juvenile walleye pollock. Average energy density (kJ/g wet mass) of age 1+ herring was 2.5 times greater than that of age 1+ pollock. Consequently, a parent seabird could potentially increase its rate of energy provisioning to its brood by a factor of as much as 2.5 by selecting prey based on quality, given similar availability (Anthony et al. In review).

Among those schooling forage fishes commonly observed in diets of seabirds nesting in the EVOS area, herring (*Clupea pallasi*), sand lance (*Ammodytes hexapterus*), and capelin (*Mallotus villosus*) had the highest average lipid contents and energy densities. Juvenile gadids (pollock, Pacific cod [*Gadus macrocephalus*], Pacific tomcod [*Microgadus proximus*]) and prowfish (*Zaprora silenus*) were generally low in lipids and had the lowest energy densities of the sampled forage fishes. Nearshore demersal fishes (e.g., gunnels, pricklebacks, eelblennies, shannies), important prey of pigeon guillemots, were intermediate between herring and gadids in lipid content and energy density. The lipid content and energy density of herring, sand lance, and capelin, though generally high, were variable depending on age, sex, and reproductive status (pre- or post-spawning) (Anthony et al. In review).

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. B. 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 seabird species are piscivorous and rely to a greater or lesser extent on pelagic schooling fishes during the breeding season.

One prevalent hypothesis for the failure of these seabirds to recover is that changes in the abundance and species composition of forage fish resources within the spill area has resulted in reduced availability and quality of food for breeding seabirds. Concurrent population declines in some marine mammals, particularly harbor seals and Steller sea lions, have also been blamed on food limitation. 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 and Lower Cook Inlet (LCI) 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 00163A-T) 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 the EVOS area affect reproductive success. During the five field seasons of APEX, we have monitored the composition and provisioning rates of food to seabird nestlings, data that can, in association with data on prey availability, be used to assess prey preferences. Measuring provisioning rates was 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/Link to Restoration

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). The latter two species, however, 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 situated high in mature conifers and are very difficult to locate. Most nest visits by parents provisioning young occur during crepuscular periods, 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 major shifts in diet composition of guillemot pairs breeding at Naked Island and Jackpot Island. For example, sand lance were the predominant prey fed to young guillemots at Naked Island in the late 1970s (Kuletz 1983), but currently sand lance is a minor component of the diet (Golet et al. in prep.). In contrast, guillemots breeding in some areas of Kachemak Bay continued to provision their young predominately with sand lance until quite recently, and sand lance was particularly prevalent in the diet at sites that supported high densities of breeding pairs (Prichard 1997). 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 appears to be 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 North Icy Bay in PWS are accessible so that chicks could be weighed regularly. Kittiwake colonies in Lower Cook Inlet (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 was feasible in most years. Diets fed to kittiwake chicks in PWS and Lower Cook Inlet consisted 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.

C. Location

No field work is proposed in FY 2000 or FY 2001. Laboratory analyses of samples and data analyses will be completed at Oregon State University in Corvallis. During 1995-1999, field work focused in PWS (Naked, Jackpot, and Eleanor islands, North Icy Bay, and Shoup Bay) and Lower Cook Inlet (south shore of Kachemak Bay, Gull Island, Chisik Island, and the Barren Islands). These sites were identical to those seabird breeding sites that were used by other components of APEX.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

The APEX study species 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 provide additional knowledge of the study species and colonies and thus assist in identifying longer term trends in populations of seabirds and their diets. In addition, this component of APEX remains committed to taking advantage of whatever opportunities present themselves to inform local residents of our research results and its relevance to the constraints on seabird populations in the EVOS area.

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, reproductive status, region, and year, 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 determine the energy expenditure rates of breeding seabirds and relate differences in parental effort to food availability, diet composition, and foraging behavior of adults feeding young. The doubly labeled water method will be used to measure daily energy expenditure (DEE) as an index to reproductive effort and compared among seabird colonies at different locations, in different years, and under conditions of differing food availability.

5. 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 general hypothesis for the APEX Project (EVOS Projects 99163 A-T) is that a shift in the marine trophic structure of the EVOS area has prevented recovery of injured resources. APEX addresses 10 more specific hypotheses, and three of those specific hypotheses are the focus of this study:

1. Productivity and size of forage species change the energy potentially available for seabirds (APEX Hypothesis 4).

2. Changes in seabird productivity reflect differences in forage fish abundance as measured in adult foraging trips, chick meal size, and chick provisioning rates (APEX Hypothesis 8).

3. Seabird productivity is determined in part by differences in forage fish nutritional quality (APEX Hypothesis 9).

These three hypotheses address three primary determinants of energy provisioning rates to nestling seabirds, namely food delivery rates, diet quality, and meal size. These factors in turn have a direct bearing on the fitness of adults through variation in reproductive output. Another important component of adult fitness, parental investment, can vary among breeding colonies and years. Parental investment is defined as the reduction in future reproductive output as a result of the effort made by parents in their current reproductive attempt. This effort can be expressed in terms of the rate of energy expenditure of parents provisioning their brood. Changes in forage fish availability and quality may be reflected in changes in parental investment.

The overall objective of this 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, parental investment, and productivity of breeding adults. The field research in 1996-99 emphasized pigeon guillemots and black-legged kittiwakes for practical reasons.

The research approach utilized a combination of sample/data collection in the field (in conjunction with other APEX components in PWS and LCI) and laboratory analyses. Sample collection and field data collection were conducted concurrently during the 1995-99 breeding seasons at three sites where pigeon guillemots breed and at six kittiwake breeding colonies, all within the EVOS area. A minimum of 40 active and accessible nests of each species were located and marked prior to hatching at each of the study colonies. These nests were closely-monitored until the young fledged or the nesting attempt failed.

Fresh samples of forage fishes used by guillemots were collected for determination of species composition and proximate analysis using the following three techniques, in order of importance: (1) opportunistically collecting uneaten meal samples found in nest crevices, (2) capturing adults carrying forage fish as they approach or enter the nest and retrieving samples from adults, and (3) retrieving samples from chicks shortly after being fed by parents. Supplemental samples of guillemot forage fishes were 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 consisted of semi-digested food. Kittiwake meal samples were normally collected when chicks regurgitated during routine weighing and measuring. Additional diet samples were collected by capturing adult kittiwakes as they returned to feed their young and inducing them to regurgitate the contents of their esophagus. Fresh specimens of forage fishes used by kittiwakes were provided from net sampling (APEX Component 99163E).

Fresh fish samples and kittiwake regurgitations were weighed (± 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 were maintained at each of the study sites. Samples were shipped frozen to the laboratory of Dr. Alan Springer and Kathy Turco at the Institute of Marine Science, where they were sorted, identified, sexed, aged, and measured in preparation for proximate analysis. Samples were then shipped frozen to the laboratory of the PI at Oregon State University, where proximate analyses were conducted. Forage fish specimens were dried to constant mass in a convection oven at 60°C to determine water content. Lipid content of a subsample of dried forage fish were determined by solvent extraction using a soxhlet apparatus and hexane/isopropyl alcohol 7:2 (v:v) as the solvent system. Lean dry fish samples were then ashed in a muffle furnace at 550°C in order to calculate ash-free lean dry mass by subtraction. Energy content of chick diets were calculated from the composition (water, lipid, ash-free lean dry matter, and ash) of forage fish, along with published energy equivalents of these fractions (Schmidt-Nielsen 1997: 171).

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

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

Parental investment of adults raising broods was assessed by measuring daily energy expenditure (DEE) of breeding adults during the chick-rearing period. DEEs for radio-tagged adult kittiwakes were measured at Shoup Bay, using the doubly-labeled water (DLW) technique (Lifson and McClintock 1966, Nagy 1980, Roby and Ricklefs 1986). Adult kittiwakes that had already been radio-tagged as part of separate study of foraging ecology (99163E) were injected with doubly labeled water in order to simultaneously monitor foraging behavior and energy expenditure rate. Measurements were taken between day 10 and 30 of the nestling period. A sample of 40 radio-tagged, breeding adults from the Shoup Bay colony were captured at the nest site and weighed to the nearest 0.1 gram with an Ohaus balance. Each bird was injected intraperitoneally with a mixture of $H_2{}^{18}O$ (90 atom %) and ^2H_2O (99.8 atom % deuterium) at a dose of 0.4 ml of DLW per kittiwake adults. Both oxygen-18 and deuterium are stable isotopes and thus are not radioactive. Injected adults were then held for one hour in order for isotopes to equilibrate with body water before taking an inititial blood sample. Injected adults were recaptured at the nest site after approximately 10 - 24 h. Once recaptured, injected adults were reweighed, and a blood sample collected by puncturing the brachial vein. Blood was collected in 6-8 microcapillary tubes (ca. 10 ul each), which were subsequently flame sealed. Isotopic enrichments of blood samples were determined at the Centre of Isotope Research, University of Groningen, The Netherlands, by means of mass spectrometry. Carbon dioxide production by each adult during each measurement interval was calculated using the equations of Speakman (1997). DEE was calculated from CO_2 production using an assumed RQ of 0.72 and an energetic equivalent of respired CO_2 of 27.3 kJ per liter (Gessamen and Nagy 1988).

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

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

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/g wet mass, DEE is adult daily energy expenditure in kJ/day, and GFE is adult gross foraging efficiency in kJ consumed/kJ expended. DEE was calculated from field metabolic rates of kittiwakes that were measured at the Shoup Bay and North Icy Bay colonies in PWS using the doubly-labeled water technique. These data were used to test the hypothesis that daily energy expenditure (parental investment) of adults raising young varies among years and among individuals, depending on foraging strategy, diet composition, food availability, and quality of forage fish resources. Comparison of food conversion efficiency of chicks fed different diets (APEX component 98163N) 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 on different diets will be calculated using the equation:

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

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.

Field protocols for the research with live birds described in this DPD were approved by the Institutional Animal Care and Use Committee at Oregon State University.

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. A part-time laboratory technician will be hired to help the PI and post-doctoral research associate perform routine laboratory analyses that are needed to fill in gaps in the data base acquired in previous years of the project.

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.

Isotopic enrichments of blood samples for the doubly labeled water experiments were determined in the laboratory of Dr. Henk Visser (Centre of Isotope research, University of Groningen, The Netherlands) by means of mass spectrometry. Dr. Visser's lab has extensive experience in proper handling and analysis of deuterium and oxygen-18 in blood, and interpretation of results. Dr. Visser will be involved in manuscript preparation for all papers dealing with the doubly-labeled water technique and will be a coauthor on these papers.

SCHEDULE

A. Measurable Project Tasks for FY 00 (May 1, 2000 to April 30, 2001)

September 30: Submission of draft final report on APEX Component G, including three manuscripts for publication in the peer-reviewed scientific literature on field metabolic rates of adult kittiwakes.

December 30: Submission of manuscript on relationship of guillemot diets to reproductive energetics and productivity.

March 15: Submit FY 2001 DPD to Dr. Duffy.

March 31: Submission of manuscript on relationship of kittiwake diets to reproductive energetics and productivity.

B. Project Milestones and Endpoints

Objective 1 has already been largely met and will be completed by April 2001, the end of FY 00. Objective 4 will be completed by September 2000. Objectives 2 and 3 will be completed by April 2001, the end of FY 00. Objective 5 will be completed by April 2002, the end FY 01.

C. Completion Date

The draft final report for this component of APEX will be submitted by 30 September 2000. The anticipated completion of this project with the submission of the last manuscripts for publication in peer-reviewed scientific journals will be the end of FY 01, 30 April 2002. This will allow adequate time to complete data analysis and manuscript preparation with collaborators following the last field season in 1999 and the submission of the draft final report in September 2000.

PUBLICATIONS AND PROJECT REPORTS

The following publications are projected for this research project. These are only the publications that APEX components G and N are taking the lead on. In addition, the PI (D. Roby) and the Postdoctoral Research Associate (P. Jodice) will be coauthors on some papers that other components of APEX are taking the lead on.

1. Title: Lipid content and energy density of forage fishes from the northern Gulf of Alaska
    - variation in lipid content of forage fishes
    - factors affecting lipid content of forage fishes
    - factors affecting energy density of forage fishes

   Authors: J. Anthony, D. Roby, and K. Turco
   Months of work required: N/A
   Date of submission: October 1998
   Journal: Journal of Experimental Marine Biology and Ecology
   Status: In review
   Costs of analysis, write-up, and publication: $1000
   Priority: high

2. Title: Effects of prey type on growth of piscivorous seabirds in captivity
    - compares growth of kittiwake and puffin nestlings on diets of different forage fishes
    - restricted diets of either capelin, herring, sand lance, or juvenile pollock
    - growth rates of chicks fed high-lipid fishes (capelin, sand lance, herring) markedly higher than chicks fed juvenile pollock

   Authors: M. Romano, J. Piatt, and D. Roby
   Months of work required: 1
   Date of expected submission: June 1999
   Targeted journal: Condor
   Costs of analysis, write-up, and publication: $2000
   Priority: high

3. Title: Effects of diet on growth and body composition of nestling seabirds
    - effect of dietary lipid:protein ratio on growth and development of nestling kittiwakes and puffins
    - effect of dietary lipid content on fat reserves of fledglings
    - effects of dietary lipid content on apparent metabolizable energy coefficients in nestlings

   Authors: M. Romano, D. Roby, J. Piatt, and A. Kitaysky
   Months of work required: 3
   Date of expected submission: September 1999
   Targeted journal: Physiological Zoology
   Costs of analysis, write-up, and publication: $3500
   Priority: high

4. Title: Effect of diet on visceral development of nestling seabirds
    - plasticity of development in GI tract organs in relation to diet in seabird nestlings
    - relative effects of food biomass, energy intake, and lipid content on size of various GI tract organs of seabird nestlings
    - comparison between kittiwake and puffin nestlings in the plasticity of GI tract organ development

   Authors: M. Romano, D. Roby, and J. Piatt
   Months of work required: 3
   Date of expected submission: December 1999
   Targeted journal: Functional Ecology
   Costs of analysis, write-up, and publication: $2000
   Priority: moderate

5. Title: Effects of food availability on parental investment in black-legged kittiwakes: a controlled experiment
    - experiment conducted on Middleton Island at the tower colony in 1998
    - comparison of daily energy expenditure between supplementally fed and control kittiwakes during the chick-rearing period
    - other factors affecting energy expenditure rates (brood size, gender, body condition, previous nesting success) will be examined

   Authors: P. Jodice, D. Roby, K. Turco, V. Gill, S. Hatch, and H. Visser
   Months of work required: 3
   Date of expected submission: March 2000
   Targeted journal: Journal of Experimental Zoology
   Costs of analysis, write-up, and publication: $5500
   Priority: high

6. Title: Parental energy expenditure of black-legged kittiwakes in relation to diet and foraging conditions in Prince William Sound, Alaska
    - comparison of daily energy expenditure in kittiwakes raising chicks at Shoup Bay and North Icy Bay colonies in 1997 and 1998

- factors affecting between-year and between-colony differences in daily energy expenditure
- factors affecting intracolony variability in parental energy expenditure rates
- gross foraging efficiencies of kittiwakes feeding young in PWS

Authors: P. Jodice, D. Roby, K. Turco, D. Irons, R. Suryan, and H. Visser
Months of work required: 3
Date of expected submission: June 2000
Targeted journal: Journal of Animal Ecology
Costs of analysis, write-up, and publication: $5800
Priority: high

7. Title: Energy expenditure of breeding kittiwakes in relation to foraging behavior
    - examination of factors that contribute to the large among-individual and among-day variation in energy expenditure rates of breeding kittiwakes
    - investigation of the relationship between foraging trip distance and duration and energy expenditure rates
    - relationship between prey utilization and energy expenditure rates

    Authors: P. Jodice, D. Roby, K. Turco, R. Suryan, D. Irons, H. Visser
    Months of work required: 4
    Date of expected submission: September 2000
    Targeted journal: Functional Ecology
    Costs of analysis, write-up, and publication: $13,000
    Priority: moderate

8. Title: Relationship of diet and energy provisioning rates in pigeon guillemots nesting in the Northern Gulf of Alaska
    - chick meal delivery rates, meal sizes, meal energy density, and overall energy provisioning rates by guillemots nesting at Naked Island, Jackpot Island, and Kachemak Bay
    - relationship of energy provisioning rates to chick growth rates and overall productivity
    - factors affecting energy provisioning rates to guillemot broods

    Authors: P. Jodice, D. Roby, M. Litzow, G. Golet, J. Piatt, D. Irons, and A. Prichard
    Months of work required: 6
    Date of expected submission: December 2000
    Targeted journal: Auk
    Costs of analysis, write-up, and publication: $9,000
    Priority: high

9. Title: Diet and reproductive energetics in black-legged kittiwakes in the Northern Gulf of Alaska
    - chick meal delivery rates, meal sizes, meal energy density, and overall

energy provisioning rates by kittiwakes nesting at Shoup Bay, North Icy Bay, Eleanor Island, Gull Island, Chisik I., and Barren Islands
- relationship of energy provisioning rates to chick growth rates and overall productivity
- factors affecting energy provisioning rates to kittiwake broods

Authors: P. Jodice, R. Suryan, D. Roby, D. Irons, D. Roseneau, A. Kettle, J. Piatt, and J. Anthony
Months of work required: 6
Date of expected submission: March 2001
Targeted journal: Ecology
Costs of analysis, write-up, and publication: $10,000
Priority: high

10. Title: More lipid contents and energy densities of forage fishes from the northern Gulf of Alaska
    - new data on lipid content of forage fishes
    - annual, seasonal, and regional variation in lipid content of selected forage fishes
    - factors affecting intraspecific variation in energy density of forage fishes

Authors: P. Jodice, K. Turco, and D. Roby
Months of work required: 6
Date of submission: March 2001
Targeted journal: Comparative Biochemistry and Physiology
Costs of analysis, write-up, and publication: $12,000
Priority: moderate

11. Title: Effects of diet quality on reproductive success of piscivorous seabirds in Alaska: testing the junk food hypothesis
    - lipid content of forage fish vs. availability as factors affecting prey selection by kittiwakes and guillemots
    - lipid content vs. availability as factors influencing reproductive success
    - evidence for regime shifts influencing the relative availability of low lipid and high lipid forage fishes

Authors: P. Jodice, D. Roby, J. Piatt, and D. Duffy
Months of work required: 6
Date of expected submission: June 2001
Targeted journal: Ecology
Costs of analysis, write-up, and publication: $8,000
Priority: high

12. Title: Prey exploitation by piscivorous seabirds in Prince William Sound, Alaska: A bioenergetics approach
    - estimates of consumption rates of various forage fishes by seabird species in PWS
    - avian predation rates on fish stocks and relationship with fisheries take

- relative importance of piscivorous seabirds in marine trophic structure of PWS

Authors: P. Jodice, D. Roby, D. Irons, and D. Duffy
Months of work required: 5
Date of expected submission: September 2001
Targeted journal: Canadian Journal of Fisheries and Aquatic Sciences
Costs of analysis, write-up, and publication: $7,000
Priority: high

13. Title: Food as a factor limiting recovery of populations of piscivorous seabirds the aftermath of the Exxon Valdez oil spill
    - evidence for food as the factor preventing recovery of guillemots and constraining recovery in murrelets and murres
    - relationship between diet composition and productivity of seabirds injured by the spill
    - alternative explanations for lack of recovery

Authors: P. Jodice, D. Roby, J. Piatt, D. Irons, and D. Duffy
Months of work required: 5
Date of expected submission: December 2001
Targeted journal: Ecological Applications
Costs of analysis, write-up, and publication: $8,000
Priority: high

14. Title: Food as a constraint on seabird reproduction: Relative importance of availability and quality
    - critique of the theory that food supply limits seabird productivity
    - energy as the currency of fitness for seabirds
    - energy content as the primary factor in selection by seabirds

Authors: D. Roby, P. Jodice, J. Piatt, D. Irons, and D. Duffy
Months of work required: 4
Date of expected submission: March 2002
Targeted journal: American Zoologist
Costs of analysis, write-up, and publication: $6,000
Priority: high

A draft final report for this component of APEX will be submitted by 30 September 2000 for incorporation into a synthesis Final Report for the APEX Project. The final manuscript from this component of APEX will be submitted for publication by 30 April 2002, the end of FY 01.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

The research described in this proposal is a component of the APEX Project (00163 A-T) 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 research approach utilized 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 and LCI.

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 being used as indicators of ecosystem function and health within PWS (APEX Component 00163E), and are the subjects of a similar study on the Barren Islands (APEX Component 00163J) and at Gull Island and Chisik Island in LCI (APEX Component 00163M). 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 and Robert Suryan (PIs on APEX Component 00163E "Kittiwakes as Indicators of Forage Fish Availability), Greg Golet (PI on APEX Component 00163F "Factors Affecting Recovery of PWS Pigeon Guillemot Populations"), David Roseneau, (PI on APEX Component 00163J "Reproductive Success by Murres and Kittiwakes on the Barren Islands"), and John Piatt (PI on APEX Components 00163M "Lower Cook Inlet Forage Fish Studies" and 98163 N "Black-legged Kittiwake Feeding Experiment") in developing protocols for collecting field data so as to minimize project cost and maximize data acquisition. Irons and Golet are both with the Migratory Bird Branch, U.S. Fish and Wildlife Service and Piatt is with the Alaska Biological Science Center, USGS-BRD. 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. Golet was in charge of the field crew working on pigeon guillemots at Naked during the 1997-99 breeding seasons, 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, Golet, Roseneau, and Piatt will be essential for the success of the proposed research.

APEX Components E, F, J, M, 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 was extremely labor intensive and the cooperation of these five components in collecting these data greatly enhanced sample sizes. The six components also require data on chick growth rate, nestling survival, mass and condition of fledglings, and fledging age. Again, cooperation and coordination between these components greatly enhanced sample sizes and the power of statistical tests and inferences.

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

The project has completed data collection in the field to examine potential energetic factors (diet composition, diet quality, meal size, provisioning rates) that constrain the productivity of seabirds in the EVOS area. In FY 00, we will focus on completion of data analyses, preparation of manuscripts for submission to the peer-reviewed scientific literature, and submission of the draft final report. This work in FY 00 will prepare the way for writing the final synthesis manuscripts for publication from this project in FY 01.

PRINCIPAL INVESTIGATOR

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OTHER KEY PERSONNEL

The proposed research will be implemented by the Oregon Cooperative Fish and Wildlife Research Unit, closely coordinated with and in cooperation with U.S. Fish and Wildlife Service and USGS - Biological Resources Division biologists with expertise on the proposed study species in the proposed study areas. The PI (Daniel D. Roby) has extensive experience with studies of the reproductive energetics of high latitude seabirds and the relationship between diet composition and productivity. The PI has assembled in his laboratory the analytical equipment necessary to accomplish the proposed laboratory analyses and is familiar with the relevant analytical procedures. To the PI's knowledge, the expertise and equipment necessary for the proposed research are not available within the federal and state agencies that comprise the Trustees Council. The PI will work closely with Dr. Patrick Jodice, a Postdoctoral Research Associate with previous research experience on seabird foraging ecology at sea and with kittiwake reproductive ecology, in order to achieve the objectives of this research project. The PI and Research Associate will be assisted by Kathy Turco, a Laboratory Technician at the Institute of Marine Science at the University of Alaska Fairbanks with expertise in the identification, aging, and sexing of seabird prey, who also has extensive field research experience on the breeding biology of colonial seabirds. Lab assistants will be carefully selected from the applicant pool as qualified to participate in the proposed research.

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APEX: Project Leader

Project Number:	00163 I
Restoration Category:	Research
Proposed By:	David Cameron Duffy, Project Leader, Paumanok Solutions, AK License 257219 6560 Ilikai Street Kailua HI 96734
Lead Trustee Agency:	NOAA
Duration:	5 years
Cost FY 00:	$86.6 K
Cost FY 01	$45 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 APEX 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/Link to Restoration

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. Location

The APEX project is conducted in Prince William Sound, Lower Cook Inlet and the Northern Gulf of Alaska.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

This project does not directly involve community involvement and traditional ecological knowledge.

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.

   This effort is essentially concluded, but there is the possibility that small scale redirection of funds within or between subprojects may help achieve project goals.

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

   This involves continuing to work with subprojects, especially E, F, G, L, Q, and T, on common approaches to models and exchange of data.

3. Insure publication of APEX project results.

   This involves encouraging and reviewing manuscripts and suggesting appropriate journals.

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

   Although archiving will remain a within agency responsibility, I will work with PIs' to ensure long-term access to their data, for comparison with future monitoring efforts.

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

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

C. Cooperating Agencies, Contracts and Other Agency Assistance

Contracts with NOAA for limited fish stomach analysis, with UAA for GIS services and with an institution to be named for mitochondrial analysis allow this project to provide bridging services that tie several subprojects together.

SCHEDULE

A. Measurable Project Tasks for FY 00

2000
January Review of APEX Project and EVOS Restoration Annual Workshop

September 30 Annual Report

B. Project Milestones and Endpoints

January 2000 Review of Project

September 30 Final Report

C. Completion Date

October 2001 End of Project

PUBLICATIONS AND REPORTS

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

PROFESSIONAL CONFERENCES

I will attend meetings of the Pacific Seabird Group, The Waterbird Society and the Society for Conservation Biology to provide summarized reports on the progress of APEX.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

We will coordinate with other EVOS projects in the production of manuscripts.

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

No further analysis or field work is planned.

PRINCIPAL INVESTIGATOR

David Cameron Duffy
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David Cameron Duffy received his Ph.D. from Princeton University in population biology in 1980. His administrative experience includes acting director of the Darwin Station in the Galapagos Islands, principal investigator in a seabird/forage fish project in the Benguela Current, chairman of the Seabird Specialist Group of the International Union for the Conservation of Nature, executive officer of the International Association of Ecologists, principal investigator of a cooperative agreement with the U. S. Centers for Disease Control, and manager of the Alaska Natural Heritage Program. He has been a visiting professor in Costa Rica and a professor of biology at the University of Alaska Anchorage. Currently, he is Professor of Botany, Pacific Cooperative Studies Unit, Department of Botany, University of Hawaii, Honolulu HI.

Most of his research has been on interactions between seabirds, fisheries and climate perturbations in Peru, Galapagos, Namibia and South Africa. He also studied seabird foraging in relation to fish behavior, including sand lance, in Long Island Sound. He also developed models linking fish school size to marine primary productivity and models attempting to depict spatial and temporal variability in marine ecosystems. He is currently in charge of a cooperative unit providing research and conservation efforts for Hawaii and U.S. possessions in the Pacific Ocean. He has published over 60 refereed papers and 15 book chapters, and co-edited two symposium volumes.

Selected Book Chapters

1997 Duffy. Status and conservation of the seabirds of Atlantic Canada. In. D.N. Nettleship. Conservation of North American Seabirds. Academic Press, New York.

1994 Duffy and Schneider. Seabird-fishery interactions: a manager's guide. In. D. N. Nettleship, J. Burger, and M. Gochfeld (eds). Seabirds on Islands: Threats, Case Studies and Action Plans. Bird Life Tech. Rept., pp. 26-38.

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Selected Journal Articles

1997 Wilson, Duffy, Wilson and Araya. The ecology of species-replacement in Humboldt and Magellanic penguins. Le Gerfaut

1995 Duffy. Why is the Double-crested Cormorant a problem? Insights from cormorant ecology and human sociology. Colonial Waterbirds 18 (Special Publication 1): 25-32.

Duffy. Apparent river otter predation at an Aleutian Tern colony. Colonial Waterbirds 18: 91-92.

1989 Duffy. Seabird foraging aggregations: a comparison of two southern upwellings. Colonial Waterbirds 12: 164-175.

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BARREN ISLANDS SEABIRD STUDIES (PROJECT 00163J)

Project Number:	00163J
Restoration Category:	Research and Monitoring (this study is part of the larger APEX forage fish - seabird ecological processes project; however, it also includes restoration monitoring of common murre nesting chronology and productivity)
Proposer:	DOI-FWS
Lead Trustee Agency:	USFWS
Cooperating Agencies:	USGSBRD
Alaska SeaLife Center:	No
Duration:	2 years (FY 00 - FY 01)
Cost FY 00:	$80.4K
Cost FY 01:	$75.0K
Geographic Area:	Cook Inlet (specifically the Barren Islands)
Injured Resource/Service:	Common murres; other seabird species injured by the T/V *Exxon Valdez* oil spill

ABSTRACT

As part of the Alaska Predator Ecosystem Experiment (APEX), we collected large amounts of information on common murres *(Uria aalge)*, black-legged kittiwakes *(Rissa tridactyla)*, and tufted puffins *(Fratercula cirrhata)* at the Barren Islands East Amatuli Island - Light Rock colony during 1995-1998 (APEX Projects 95163J, 96163J, 97163J, and 98163J), and one more set of data will be obtained during 1999 (APEX Project 99163J). Data types include information on nesting chronology, productivity, time budgets of adults, growth and feeding rates of chicks, and types and amounts of food fed to chicks. This proposed close-out study will analyze and compare the five years of data among years and species and provide information needed to make multiyear comparisons between the Barren Islands and Gull and Chisik islands seabird colonies and test three APEX hypotheses (hypotheses 7, 8, and 9). After analyses are completed, a final report will be written and three manuscripts will be prepared for publication in peer-reviewed scientific journals, one in collaboration with J. Piatt (Project 00163M). We will also help produce a fourth manuscript in collaboration with D. Roby (Project 00163G).

INTRODUCTION

This proposed close-out component of the APEX project (Project 00163) will analyze common murre *(Uria aalge)*, black-legged kittiwake *(Rissa tridactyla)*, and tufted puffin *(Fratercula cirrhata)* data collected during the FY 99 Barren Islands seabird study (Project 99163J). Data types include information on nesting chronology, productivity, time budgets of adults, growth and feeding rates of chicks, and types and amounts of food fed to chicks. Results from analyses of FY 99 data will be compared with corresponding results from previous APEX Barren Islands seabird studies (Projects 95163J, 96163J, 97163J, and 98163J) after the large FY 95 - FY 98 data sets have been rechecked and verified, and compiled in a master data base containing the FY 99 information. The master data base will provide clean, verified multiyear data sets and results for writing reports and manuscripts, and will serve as an important source of information for other APEX investigators (e.g., J. Piatt, Project 00163M; D. Roby, Project 00163G; D. Irons, Project 00163E) preparing manuscripts of 1995-1999 findings.

After all analyses of FY 95 - FY 99 data are complete, final results from the five years of work will be available for multispecies, multicolony, multiyear analyses of seabird productivity and energetics that will help test three APEX hypotheses (hypotheses 7, 8, and 9) and increase understanding of food webs and ecological processes that may be influencing seabird recovery in the spill area. Multiyear results will also be used to write a final report of FY 95 - FY 99 Barren Islands seabird studies for inclusion in the APEX 30 September 2000 final report, prepare three manuscripts for publication in scientific journals, one in collaboration with J. Piatt (Project 00163M), and help produce a fourth manuscript in collaboration with D. Roby (Project 00163G).

NEED FOR THE PROJECT

A. Statement of Problem

Many seabirds were killed during the March 1989 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, 1994b; Klosiewski and Laing 1994), or have only partially recovered from the event (e.g., although the productivity of common murres has been well within normal bounds at the Barren Islands since 1993, little change was apparent in population numbers until 1997—see Roseneau *et al.* 1998a, 1998b). Therefore, information is still needed that can increase understanding of food webs, seabird - forage fish relationships, and ecological processes that may be influencing seabird recovery in the spill area.

B. Rationale/Link to Restoration

This close-out component of the APEX seabird - forage fish project (Project 00163) will analyze and compare five years of seabird data from the Barren Islands, Alaska. Results from the work will provide information for a multispecies, multicolony, multiyear analysis of seabird productivity and energetics that will help test three APEX hypotheses (hypotheses 7, 8, and 9) and improve understanding of food webs and ecological processes that may be influencing seabird recovery in the spill area. Ultimately, results from the work in combination with results from other APEX studies will improve management of common murres and other fish-eating seabirds in the northern Gulf of Alaska.

C. Location

The FY 00 close-out work will be conducted in Homer, Alaska. No communities will be affected by the study.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

A large format, computer-generated color poster summarizing results will be prepared and submitted to the Trustee Council for public display before the final report is written. The poster is transportable 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 posters will also be available on-disk for inclusion in any on-line products that the Trustee Council may develop for public use. Photographs of field work 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 and manuscripts 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 objectives are to analyze FY 99 murre, kittiwake, and puffin data from East Amatuli Island - Light Rock (nesting chronology, productivity, growth and feeding rates of chicks, time budgets of adults, and types and amounts of prey fed to chicks) and use these results and results from the earlier FY 95 - FY 98 studies for an integrated, multispecies, multicolony, multiyear analysis of seabird productivity and energetics that will help describe food webs and identify ecological processes that may be influencing recovery of seabirds in the spill zone.

B. Methods

The study will be conducted in Homer, Alaska. Methods that will used to analyze FY 99 Project 99163J data and compare these results with previous Barren Islands information have been described in earlier APEX annual reports (Roseneau *et al.* 1996b, 1997b, 1998b, 1999); they follow approved APEX protocols and are summarized below.

Data Analysis

Standard methods described in APEX protocols will be used to analyze FY 99 murre, kittiwake, and puffin productivity and chronology data. Nest sites with incomplete records (e.g., data gaps of more than 7 days between pre- and post-event observation dates or insufficient data to indicate chicks fledged) will be eliminated from the data base. The remaining information will then be compiled and analyzed to obtain chronology and productivity indices that will be compared with results from FY 95 - FY 98 Barren Islands studies (e.g., Roseneau *et al.* 1995, 1996a, 1996b, 1997b, 1998b). Statistical tests will be run to check for differences among years and trends, as appropriate (e.g., ANOVA, Tukey HSD multiple comparisons, *t*-tests, linear regressions).

FY 99 data on murre, kittiwake, and puffin chick-feeding rates and amounts of time adults spend away from nests foraging for food will be analyzed to provide chick-feeding frequency and time budget indices for these species (see approved protocols for detailed methods). Results will be compared with information from FY 95 - FY 98 Barren Islands studies; statistical tests will be used to check for differences among years and trends, as appropriate (e.g., ANOVA, Tukey HSD multiple comparisons, *t*-tests, linear regressions).

FY 99 murre chick diets will be analyzed by calculating percentages of numbers of identifiable fish in several basic prey categories (e.g., capelin, sand lance, herring, gadids, flatfish, pricklebacks, other species). Calculations will be made for the entire chick-rearing period and weekly intervals of time. Results will be compared with information from FY 95 - FY 98 Barren Islands studies; statistical tests will be used to check for differences among years and trends, as appropriate (e.g., ANOVA, Tukey HSD multiple comparisons, *t*-tests, linear regressions). Because murres only deliver 1 fish per feeding, combined numbers of identified and unidentified fish will be used to calculate chick feeding rates (see above).

FY 99 data 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 analyzed by weight (in some cases, weights will be estimated from average weights of subsamples of prey). Results will be compared with information from FY 95 - FY 98 Barren Islands studies; statistical tests will be used to check for differences among years and trends, as appropriate (e.g., ANOVA, Tukey HSD multiple comparisons, *t*-tests, linear regressions).

FY 99 kittiwake chick growth rate data will be analyzed by calculating the average daily weight gain of each chick from the most linear section of the growth curve (from 60 to 300 g) by dividing the difference in weight between the first and last measurements by the number of days between measurements. These values will then be used to calculate average growth rates for 'A' chicks (chicks in single-chick nests plus first to hatch chicks in 2-chick nests; n = 33) and 'B' chicks (the second-hatched chicks in 2-chick nests; n = 2). Results will be compared with information from FY 95 - FY 98 Barren Islands studies; statistical tests will be used to check for differences among years and trends, as appropriate (e.g., ANOVA, Tukey HSD multiple comparisons, *t*-tests, linear regressions).

Two variables will be used to describe FY 99 puffin chick growth rates: wing growth reported as cm day^{-1} and body weight reported as gm day^{-1}. Because burrows will not checked until chicks are about 1 week old, actual hatch dates will not be known (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). Median hatch dates, derived from the growth information, will be calculated for each chick; the average of these values will used as the measurement of nesting chronology.

FY 99 growth rate results and other information on puffins (e.g., timing of nesting events, proportion of active vs. inactive burrows, number of chicks per occupied burrow) will be compared with information from FY 95 - FY 98 Barren Islands studies; statistical tests will be used to check for differences among years and trends, as appropriate (e.g., ANOVA, Tukey HSD multiple comparisons, *t*-tests, linear regressions).

FY 99 water temperature data will be reported in degrees C by location, date, and time, and compared with previous information in graphic form. In some cases, data may also be divided into seasonal time blocks (e.g., weeks and months).

C. Cooperating Agencies, Contracts, and Other Agency Assistance

J. Piatt, USGSBRD (Project 00163M), will provide Chisik and Gull island kittiwake data for a manuscript comparing kittiwake productivity and chick growth rates at three colonies in Kachemak Bay - lower Cook Inlet that will be prepared in collaboration with him. In turn, we will supply Barren Islands kittiwake and murre data to J. Piatt (Project 00163M) and D. Roby (Project 00163G) for manuscripts they will be writing. The Alaska Maritime National Wildlife Refuge will supply office space and computers for the work, and donate up to two months of the project manager's time (G.V. Byrd) to the project.

SCHEDULE

A. Measurable Project Tasks for FY 00 (October 1, 1999 - September 30, 2000)

1-31 Oct 1999:	Compile and enter FY 99 Project 99163J data in spreadsheets.
1 Nov - 31 Dec 1999:	Transfer FY 99 and FY 95 - FY 98 data to master data base and check/verify data; analyze FY 99 data, begin comparing results with FY 95 - FY 98 information.
1-31 Jan 2000:	Continue comparing FY 95 - FY 99 results; complete multiyear comparisons and analyses; prepare poster for annual EVOS workshop; attend workshop meetings.
1-28 Feb 2000:	Review results with other APEX investigators; outline manuscripts; coordinate data needs for manuscripts with collaborating APEX investigators; begin supplying data and results to collaborating APEX investigators for manuscripts; begin requesting data and results from collaborating APEX investigators for manuscripts.
1-31 Mar 2000:	Begin preparing manuscripts for publication; continue supplying data and results to collaborating APEX investigators and requesting data and results from them for manuscripts, as needed.
1 Apr - June 2000:	Continue working on manuscripts; continue supplying data and results to collaborating APEX investigators and requesting data and results from them for manuscripts, as needed.
1-31 Jul 2000:	Review draft manuscripts with collaborating APEX investigators and in-house reviewers; make revisions, as needed.
1-31 Aug 2000:	Finalize manuscripts; begin preparing final FY 95 - FY 99 Barren Islands seabird studies report.
1-15 Sep 2000:	Complete final FY 95 - FY 99 Barren Islands seabird studies report; submit to APEX Project Leader for inclusion in final FY 95 - FY 99 APEX report due 30 September 2000.
16-30 Sep 2000:	Check manuscripts and submit to journals for publication.

B. Project Milestones and Endpoints

January 2000	Complete FY 95 - FY 99 multiyear analyses and comparisons.
July 2000	Complete draft manuscripts.
August 2000	Complete revisions to manuscripts
September 2000	Complete FY 95 - FY 99 final report and submit to APEX Project Leader; submit manuscripts to journals for publication.

C. Completion Date

A final FY 95 - FY 99 Barren Islands seabird studies report will be submitted to the APEX project leader by 15 September 2000 for inclusion in the final FY 95 - FY 99 APEX report due 30 September 2000. Collaborative efforts to help produce one paper for publication will be completed by 1 August 2000, and three manuscripts will be prepared and submitted to journals by 30 September 2000.

D. Deliverables and Estimated FY 2000 Project Cost

Data Analysis and Preparation of Final Report: The following estimated costs are for analysis of FY 99 Project 99163J data, rechecking FY 95 - FY 98 data, compiling a master data base of combined FY 95 - FY 99 information, comparing FY 95 - FY 99 results, supplying data to other APEX investigators, preparing a poster of results for the January 2000 EVOS workshop, and preparing a final report of FY 95 - FY 99 findings. The report, prepared by D.G. Roseneau (senior author), A.B. Kettle, and G.V. Byrd, will be submitted to the APEX Project Leader by 15 September 2000. Personnel time and costs for conducting this work are: D.G. Roseneau, 3.0 months at $5.1K/month = $15.3K; A.B. Kettle, 4.5 months at $3.3K/month = $14.9K; G.V. Byrd, 0.5 months at $0/month = $0 (costs for G.V. Byrd's time will be covered by AMNWR); estimated general administration costs calculated on personnel time = $4.5K; estimated poster costs = $0.4K; estimated travel/lodging costs for EVOS meeting = $0.6K; estimated travel/lodging costs for PSG symposium = $1.2K. Total Cost: $36.9K. Priority: High.

Manuscripts: Three manuscripts will be prepared for publication in peer-reviewed scientific journals after data analyses and comparisons are complete (see above), and we will also help produce a fourth paper in collaboration with D. Roby (Project 00163G).

1. A manuscript entitled "Progression of common murre nesting dates at East Amatuli Island, Alaska during the 1990's" will be prepared by A.B. Kettle (senior author), D.G. Roseneau, and G.V. Byrd. The paper will report and discuss the progression toward earlier nesting dates by common murres at the Barren Islands during the 1990's in relation to age and experience of breeders, water temperatures, and variations in timing of nesting at other colonies. It will be submitted to Colonial Waterbirds, Arctic, or the Condor by 30 September 2000. Personnel time and costs for preparing the manuscript, and estimated page and reprint costs are as follows: A.B. Kettle (senior author), 2.0 months at $3.3K/month = $6.6K; D.G. Roseneau, 0.5 month at $5.1K/month = $2.6K; G.V. Byrd, 0.5 months at $0/month = $0 (costs for G.V. Byrd's time will be covered by AMNWR); estimated general administration costs calculated on personnel time = $1.4K; page and reprint costs = $2.0K. Total Cost: $12.6K. Priority: High.

2. A manuscript entitled "Timing of nesting in four species of seabirds at the Barren Islands, Alaska during the 1997-1998 El Niño event" will be prepared by D.G. Roseneau (senior author), A.B. Kettle, and G.V. Byrd. The paper will report multiyear murre, kittiwake, puffin, and storm petrel nesting chronology data from the Barren Islands and discuss late 1998 nesting dates in relation to the 1997-1998 El Niño event. It will be submitted to Colonial Waterbirds by 30 September 2000. Personnel time and costs for preparing the manuscript, and estimated page and reprint costs are as follows: D.G. Roseneau (senior author), 1.5 month at $5.1K/month = $7.7K; A.B. Kettle, 1.0 months at $3.3K/month = $3.3K; G.V. Byrd, 0.3 months at $0/month = $0 (costs for G.V. Byrd's time will be covered by AMNWR); estimated general administration costs calculated on personnel time = $1.7K; page and reprint costs = $1.0K. Total Cost: $13.7K. Priority: High.

3. A manuscript entitled "Black-legged kittiwake productivity and chick growth rates at three colonies in Kachemak Bay - lower Cook Inlet, 1995-1999" will be prepared by D.G. Roseneau (senior author), A.B. Kettle, and G.V. Byrd in collaboration with J. Piatt (Project 00163M). The

paper will report and compare kittiwake productivity and chick growth rates at the Barren Islands and Gull and Chisik islands in 1995-1999. It will be submitted to Colonial Waterbirds or Arctic by 30 September 2000. Personnel time and costs for preparing the manuscript, and estimated page and reprint costs are as follows: D.G. Roseneau (senior author), 1.5 month at $5.1K/month = $7.7K; A.B. Kettle, 1.0 months at $3.3K/month = $3.3K; G.V. Byrd, 0.3 months at $0/month = $0 (costs for G.V. Byrd's time will be covered by AMNWR); estimated general administration costs calculated on personnel time = $1.7K; page and reprint costs = $2.0K. Total Cost: $14.7K. Priority: High. *Note: Personnel costs for J. Piatt are included in his Project 00163M APEX DPD budget.*

4. A manuscript entitled "Diets and energy provisioning in black-legged kittiwakes in the northern Gulf of Alaska" will be prepared by D. Roby (see Project 00163G DPD) in collaboration with us. Personnel time and costs for helping prepare and review the manuscript are as follows: D.G. Roseneau, 0.3 months at $5.1K/month = $1.5K; A.B. Kettle, 0.2 months at $3.3K/month = $0.7K; estimated general administration costs calculated on personnel time = $0.3K. Total Cost: $2.5K. Priority: High. *Note: D. Roby's personnel and page/reprint costs are included in his Project 00163G APEX DPD budget. Also, if funding is provided in FY 01, we will write several more papers that year (see Appendix 1 for list of proposed FY 01 manuscripts).*

PUBLICATIONS AND REPORTS

Project 00163J is part of the multiyear APEX study (Project 00163). If it is funded, FY 99 data will be analyzed and integrated with FY 95 - FY 98 information and the rechecked and verified multiyear data sets will be compiled in a master data base. Results from FY 99 data analyses will be compared with results from FY 95 - FY 98 Barren Islands seabird studies. After these tasks are completed, three manuscripts will be prepared for publication in peer-reviewed scientific journals. One manuscript entitled "Progression of common murre nesting dates at East Amatuli Island, Alaska during the 1990's" will report and discuss the progression toward earlier nesting dates by common murres at the Barren Islands during the 1990's in relation to age and experience of breeders, water temperatures, and variations in timing of nesting at other colonies. It will be written by A.B. Kettle (senior author), D.G. Roseneau, and G.V. Byrd, and will be submitted to Colonial Waterbirds, Arctic, or the Condor by 30 September 2000. A second paper entitled "Timing of nesting in four species of seabirds at the Barren Islands, Alaska during the 1997-1998 El Niño event" will be prepared by D.G. Roseneau (senior author), A.B. Kettle, and G.V. Byrd. It will report multiyear murre, kittiwake, puffin, and storm petrel nesting chronology data from the Barren Islands and discuss late 1998 nesting dates in relation to the 1997-1998 El Niño event; it will be submitted to Colonial Waterbirds by 30 September 2000. A third manuscript entitled "Black-legged kittiwake productivity and chick growth rates at three colonies in Kachemak Bay - lower Cook Inlet, 1995-1999", written by D.G. Roseneau (senior author), A.B. Kettle, and G.V. Byrd in collaboration with J. Piatt (Project 00163M), will report and compare kittiwake productivity and chick growth rates at the Barren Islands and Gull and Chisik islands in 1995-1999; it will be submitted to Colonial Waterbirds or Arctic by 30 September 2000. We will also help produce a fourth paper that will be prepared by D. Roby entitled "Diets and energy provisioning in black-legged kittiwakes in the northern Gulf of Alaska" (see Project 00163G DPD). *Also, if funding is provided in FY 01, we will write several more papers that year (see Appendix 1 for list of proposed FY 01 manuscripts).*

PROFESSIONAL CONFERENCES

Results from the FY 95 - FY 99 studies will be presented at the Pacific Seabird Group meeting in 2000. Travel costs for attending the symposium are included in the FY 00 budget.

NORMAL AGENCY MANAGEMENT

The proposed FY 00 close-out work is needed to analyze the last year of information collected during the five-year APEX Barren Islands seabird study (Project 99163J), compare these results with corresponding FY 95 - FY 98 data, and provide information (clean, verified comprehensive multiyear data sets and multiyear results) to other APEX investigators (e.g., J. Piatt, Project 00163M; D. Roby, Project 00163G; D. Irons, Project 00163E) for multiyear, multicolony analyses of seabird productivity, energetics, and other parameters, and for use in collaborative manuscripts. These tasks are not something that AMNWR or the FWS are required to do by statute or regulation. Furthermore, several types of data collected for the APEX project are not normally obtained during standard refuge monitoring studies (e.g., feeding and growth rates of chicks, amounts of food fed to chicks, time budgets of adults). Final results from the multiyear analysis are needed to provide information for an integrated, coordinated multispecies, multicolony, multiyear analysis of seabird productivity and energetics that will help test 3 APEX hypotheses (hypotheses 7, 8, and 9) and improve understanding food webs and ecological processes that may be influencing seabird recovery in the spill zone. Ultimately, these findings in combination with other APEX results will also improve management of common murres and other fish-eating seabirds in the northern Gulf of Alaska and help identify parameters that can be used for monitoring these birds after FY 2000.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

The proposed FY 00 work is fully coordinated and integrated with other components of the APEX seabird - forage fish project. Results from the analyses, including verified data sets, will be shared with other APEX investigators (e.g., J. Piatt, Project 00163M; D. Roby, Project 00163G, D. Irons, Project 00163E). Data sets and final results will also be incorporated into the Alaska Maritime NWR data base.

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

This is a close-out of a 5-year-long APEX study (Projects 95163J, 96163J, 97163J, 98163J, and 99163J). No changes have been made to basic design or schedules. If any potential changes are identified, they will be discussed with the APEX project leader (D. Duffy); if any are required, they will also be discussed with the EVOS chief scientist and science coordinator.

PROPOSED PRINCIPAL INVESTIGATOR, IF KNOWN

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PRINCIPAL INVESTIGATOR

1. David G. Roseneau (Co-Principal Investigator)

Mr. Roseneau will be responsible for the overall day-to-day operation of the project. He will supervise personnel, review and approve expenditures, and ensure that work stays on schedule and is coordinated with other APEX investigators. He will also be in charge of data analysis and interpretation, preparing posters and presentations for scientific conferences and meetings, and writing final reports and manuscripts for publication. Mr. Roseneau received his B.S. degree in wildlife management and M.S. degree in biology from the University of Alaska - Fairbanks in 1967 and 1972, respectively. His thesis research was on the numbers and distribution of gyrfalcons, *Falco rusticolus* on the Seward Peninsula, Alaska. He joined the U.S. Fish and Wildlife Service in January 1993, and was project leader for EVOS-sponsored common murre restoration studies at the Barren Islands during 1993-1994 (Projects 93049 and 94039). Mr. Roseneau was principal investigator of the APEX Barren Islands seabird and large fish as samplers studies during 1995-1998 (Projects 95163J, 95163K, 96163J, 97163J, 97163K, 98163J, 98163K) and murre population monitoring work at the Barren Islands in 1996-1997 (Projects 96144 and 97144) and Chiswell Islands in 1998 (Projects 96144, 97144 and 98144). Currently, he is co-principal investigator of the FY 99 APEX Barren Islands seabird studies and principal investigator of the FY 99 large fish as samplers studies (Project 99163J and 99163K) and Barren Islands murre population monitoring work (Project 99144). Prior to 1993, Mr. Roseneau worked as a consulting biologist for 20 years, conducting and managing marine bird, raptor, and large mammal projects in Alaska and Canada for government agencies and private-sector clients. He has been involved in several large-scale murre *(Uria* spp.*)* monitoring projects. During 1976-1983, as co-principal investigator of NOAA/OCSEAP Research Unit 460, he conducted monitoring studies of murres and black-legged kittiwakes (Rissa tridactyla) at capes Lisburne, Lewis, and Thompson in the Chukchi Sea, and St. Lawrence, St. Matthew, and Hall islands in the Bering Sea. He also studied auklets *(Aethia* spp.*)* at St. Lawrence and St. Matthew islands, and participated in murre and kittiwake projects at Bluff in Norton Sound. In 1984-1986, he participated in follow-up studies of murres and kittiwakes in the northeastern Chukchi Sea, and during 1987-1988, 1991-1992, and 1995-1997 he helped conduct additional murre and kittiwake work at Chamisso and Puffin islands and capes Thompson and Lisburne. Mr. Roseneau is experienced in collecting and analyzing data on numbers, productivity, and food habits of seabirds; relating trends in numbers and productivity to changes in food webs and environmental parameters (e.g., air and sea temperatures, current patterns); and assessing potential impacts of petroleum exploration and development on nesting and foraging marine birds. He has broad knowledge of rock climbing techniques and has operated inflatable rafts and other outboard-powered boats in the Gulf of Alaska and Bering, Chukchi, and Beaufort seas and various major Alaskan rivers in excess of 3,000 hrs. Mr. Roseneau has also accrued several hundred additional hours operating time in small boats and larger, more powerful vessels (e.g. 25 ft, 300-400 hp HydroSports and Boston Whalers) in Kachemak Bay, Prince William Sound, and Kenai Peninsula and Barren Island waters. During his career, Mr. Roseneau has authored and co-authored over 75 reports and publications, including about 25 on Alaskan seabirds.

<u>Selected Seabird Publications</u>

Murphy, E.C., A.M. Springer, and D.G. Roseneau. 1991. High annual variability in reproductive success of kittiwakes (Rissa tridactyla L.) at a colony in western Alaska. J. Anim. Ecol. 60: 515-534.

Springer, A.M., E.C. Murphy, D.G. Roseneau, C.P. McRoy, and B.A. Cooper. 1987. Paradox of pelagic food webs in the northern Bering Sea - I. Seabird food habits. Cont. Shelf Res. 7: 895-911.

Murphy, E.C., A.M. Springer, and D.G. Roseneau. 1986. Population status of *Uria aalge* at a colony in western Alaska: results and simulations. Ibis 128: 348-363.

Springer, A.M., D.G. Roseneau, D.S. Lloyd, C.P. McRoy, and E.C. Murphy. 1986. Seabird responses to fluctuating prey availability in the eastern Bering Sea. Marine Ecol. Prog. Ser. 32: 1-12.

Springer, A.M. and D.G. Roseneau. 1985. Copepod-based food webs: auklets and oceanography in the Bering Sea. Marine Ecol. Prog. Ser. 21: 229-237.

Murphy, E.C., D.G. Roseneau, and P.J. Bente. 1984. An inland nest record for the Kittlitz's murrelet. Condor 86: 218.

Springer, A.M., D.G. Roseneau, E.C. Murphy, and M.I. Springer. 1984. Environmental controls of marine food webs: food habits of seabirds in the eastern Chukchi Sea. Can. J. Fish Aquat. Sci. 41: 1202-1215.

2. Arthur B. Kettle (Co-principal Investigator)

Mr. Kettle will compile and analyze the data, and help prepare final reports and manuscripts for publication. Mr. Kettle received his B.A. degree in Human Ecology from the College of the Atlantic in 1984. Since that time, he has participated in several large-scale seabird projects at remote locations. He joined the U.S. Fish and Wildlife Service in May 1993, and was camp leader for the 1993-1994 EVOS Barren Islands common murre restoration studies (Projects 93049 and 94039). He also served as field team leader during the 1995-1998 APEX Barren Islands seabird studies (Projects 95163J, 96163J, 97163J, and 98163J) and participated in the 1996-1997 Barren Islands murre population monitoring projects (Projects 96144 and 97144). Mr. Kettle is currently co-principal investigator for APEX project 99163J. During Mr. Kettle's 1993-1998 work at the Barren Islands, he was responsible for logistics and data collection at Amatuli Cove camp, and for ensuring that data were obtained according to study design. His broad knowledge of boat-mooring systems and technical rock climbing techniques allowed him to safely collect productivity and chronology data from a series of study plots he established on East Amatuli Island (a difficult technical task not accomplished during any other previous pre- or postspill studies). Mr. Kettle also collected productivity data and censused birds at East Amatuli Island during Exxon-sponsored University of Washington studies in 1990-1992. In addition to this work, he participated in large-scale University of Washington studies of magellanic penguins *(Spheniscus magellanicus)* in Argentina during 1987-1991, and tufted puffins *(Fratercula cirrhata)* and fork-tailed storm-petrels *(Oceanodroma furcata)* at the Barren Islands colonies in 1990-1992. Mr. Kettle has over 18 years experience safely operating small boats in the north Atlantic and Pacific oceans (e.g., Maine and Alaska), including 9 consecutive field seasons running outboard-powered craft in Barren Islands waters.

<u>Selected Seabird Publications</u>

Boersma, P.D., J.K. Parrish, and A.B. Kettle. 1995. Common murre abundance, phenology, and productivity on the Barren Islands, Alaska: The *Exxon Valdez* oil spill and long-term environmental change. Pp. 820-853 *in Exxon Valdez* Oil Spill: Fate and effects in Alaskan waters, ASTM STP 1219, P.G. Wells, J.N. Butler, and J.S. Hughes (eds.), Amer. Soc. for Testing and Materials, Philadelphia, PA.

OTHER KEY PERSONNEL

1. G. Vernon Byrd (Project Manager)

Mr. Byrd will supply overall guidance to the project, including providing advice during data analysis and report writing. He will also review reports and presentations as needed, and help prepare manuscripts for publication. Mr. Byrd received a B.S. degree in wildlife management from the University of Georgia in 1968, did post-graduate studies in wildlife biology at the University of Alaska-Fairbanks in 1975, and completed his M.S. degree in wildlife resources management at the University of Idaho in 1989. His thesis, entitled "Seabirds in the Pribilof Islands, Alaska: Trends and monitoring methods", explored statistical procedures for analyzing kittiwake *(Rissa* spp.) and murre *(Uria* spp.) population data. Mr. Byrd has worked for the U.S. Fish and Wildlife Service for over 20 years, focusing on studies of marine birds in Alaska and Hawaii. His major interests center around monitoring long-term trends in seabird populations, including numbers of birds and reproductive performance at colonies. He has worked at seabird colonies in the Aleutian Islands, Bering and Chukchi seas, and Gulf of Alaska. Mr. Byrd was a co-author of the final T/V *Exxon Valdez* oil spill damage assessment report for murres. Also, he was project manager of the 1993-1994 common murre restoration monitoring studies (Projects 93049 and 94039, projects to remove predators from islands containing seabird colonies (Projects 94041 and 95041), the 1995-1998 APEX and murre monitoring studies (Projects 95163J, 95163K, 96163J, 96144, 97163J, 97163K, 97144, 98163J, 98163K, and 98144). Mr. Byrd is currently serving as project manager for APEX projects 99163J and 99163K, and the Barren Islands murre population monitoring study (Project 99144). He has authored over 55 scientific papers and 65 U.S. Fish and Wildlife Service reports on field studies, and has made about 35 presentations on seabirds at scientific meetings. Mr. Byrd is the supervisory wildlife biologist at the Alaska Maritime National Wildlife Refuge, the premier seabird nesting habitat in the national public land system.

Selected Seabird Publications

Byrd, G.V., E.C. Murphy, G.W. Kaiser, A.J. Kondratyev, and Y.V. Shibaev. 1993. Status and ecology of offshore fish-feeding alcids (murres and puffins) in the North Pacific Ocean. Proceedings of "Symposium on the Status , Ecology, and Conservation of Marine Birds of the Temperate North Pacific". Canadian Wildlife Service, Ottawa.

Byrd, G.V., and J.C. Williams. Whiskered Auklet. 1993. A chapter describing the biology of the species in The birds of North America, No. 76 (A. Poole and F. Gill, eds.). The Academy of Natural Sciences, Philadelphia PA, and the American Ornithologists' Union, Washington, D.C. 12 pp.

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Appendix 1. Proposed APEX manuscripts for fy 2001 (Project 01163J).

We plan to prepare up to four of the manuscripts listed below during FY 2001, if funding is available.

1. Tentative title: "Productivity, nesting chronology, and chick diets and growth rates of tufted puffins at the Barren Islands, Alaska during the 1970's-1990's". This paper will be prepared by A.B. Kettle (senior author) in collaboration with P.D. Boersma, University of Washington. It will report, compare, and discuss Barren Islands tufted puffin productivity, nesting chronology, and chick diets and growth rates during the 1970's-1990's. Priority: High.

2. Tentative title: "Differences among common murres, tufted puffins, and black-legged kittiwakes as samplers of local food webs". This paper will be prepared by D.G. Roseneau (senior author), A.B. Kettle, and G.V. Byrd. It will report and compare the food web segments that these piscivorous diving and surface-feeding species sample and discuss what may or may not be learned from this information. Priority: High.

3. Tentative title: "Within-season changes in tufted puffin chick growth rates at the Barren Islands, Alaska, 1993-1999". This paper will be prepared by A.B. Kettle (senior author), D.G. Roseneau, and G.V. Byrd. It will report and compare tufted puffin chick growth rates incrementally in relation to diets during seven nesting seasons at the Barren Islands. Priority: High.

4. Tentative title: "Common murre, tufted puffin, and black-legged kittiwake productivity and nesting chronology, and chick diets, meal sizes, and feeding rates at the Barren Islands, Alaska during 1995-1999". This paper will be prepared by A.B. Kettle (senior author), D.G. Roseneau, and G.V. Byrd. It will report and compare these parameters in piscivorous diving vs. surface-feeding seabirds (a concordance paper). Priority: High.

5. Tentative title: "Lengths and weights of Pacific cod in Beach seines at East Amatuli Island, Alaska, 1995-1999". This paper will be prepared by A.B. Kettle (senior author), D.G. Roseneau, and G.V. Byrd. It will report and compare changes in sizes of Pacific cod caught in beach seines at East Amatuli Island, Alaska in 1995-1999, Priority: High.

6. Tentative title: "Monitoring population size of common murres using three types of counts". This paper will be prepared by D.G. Roseneau (senior author), A.B. Kettle, and G.V. Byrd. It will report and compare single counts of murres at whole colonies, *vs* replicate counts of birds on a set of monitoring plots containing about 20% of the population *vs* replicate counts on a set of relatively small productivity plots containing only several hundred birds. Priority: High.

7. Tentative title: "Productivity of black-legged kittiwakes at the Barren Islands, Alaska during the 1970's and 1990's". This paper will be prepared by D.G. Roseneau (senior author), A.B. Kettle, and G.V. Byrd. It will report and compare kittiwake productivity at the Barren Islands in the 1970's and 1990's. Priority: Medium.

USING PREDATORY FISH (PACIFIC HALIBUT) TO SAMPLE FORAGE FISH (PROJECT 00163K)

Project Number:	00163K
Restoration Category:	Research and Monitoring (this study is part of the larger APEX forage fish - seabird ecological processes project;)
Proposer:	DOI-FWS
Lead Trustee Agency:	USFWS
Cooperating Agencies:	USGSBRD
Alaska SeaLife Center:	No
Duration:	1 year (FY 00)
Cost FY 00:	$17.0K
Geographic Area:	Kachemak Bay - Cook Inlet (including the Barren Islands)
Injured Resource/Service:	Common murres; other seabird species injured by the T/V *Exxon Valdez* oil spill

ABSTRACT

Evaluating the influence of fluctuating prey populations (e.g., forage fish) is critical to understanding the recovery of seabirds injured by the T/V *Exxon Valdez* oil spill; however, it is expensive to conduct annual hydroacoustic and trawl surveys to assess forage fish stocks over broad regions. As part of the 1995 *Exxon Valdez* Oil Spill Trustee Council-sponsored Alaska Predator Ecosystem Experiment (APEX), we began testing the feasibility and effectiveness of using stomachs from sport-caught Pacific halibut *(Hippoglossus stenolepis)* to obtain spatial and temporal data on capelin *(Mallotus villosus)* and Pacific sand lance *(Ammodytes hexapterus)*, two forage fish important to piscivorous seabirds (Project 95163K; see Roseneau and Byrd 1996, 1997). Additional data were collected during 1996-1998, and one more data set will be obtained in 1999 (Project 99163K). Preliminary results suggest that this relatively simple sampling technique may provide a cost-effective means of monitoring food webs and seabird - forage fish relationships in Kachemak Bay - lower Cook Inlet after FY 2000. This proposed close-out study will analyze FY 95 - FY 99 data and compare them with beach seine, trawl, and seabird chick diet information from the Barren Islands and Gull and Chisik islands, and it will also evaluate the effectiveness of the technique as a monitoring tool. After data are analyzed, a manuscript will be prepared for publication in a peer-reviewed scientific journal. The completed paper and executive summary will also serve as the final project report.

INTRODUCTION

Evaluating the influence of fluctuating prey populations (e.g., forage fish) is critical to understanding the recovery of seabirds injured by the T/V *Exxon Valdez* oil spill; however, it is expensive to conduct annual hydroacoustic and trawl surveys to assess forage fish stocks over broad regions. As part of the 1995 *Exxon Valdez* Oil Spill Trustee Council-sponsored Alaska Predator Ecosystem Experiment (APEX), we began to test the feasibility and effectiveness of using stomachs from sport-caught Pacific halibut *(Hippoglossus stenolepis)* to obtain spatial and temporal data on capelin *(Mallotus villosus)* and Pacific sand lance *(Ammodytes hexapterus)*, two forage fish important to piscivorous seabirds (Project 95163K; see Roseneau and Byrd 1996, 1997). We collected additional data during FY 96 - FY 98 (Projects 97163K and 98163K; see Roseneau and Byrd 1998, 1999) and one more data set will be obtained in FY 99 (Project 99163K).

Preliminary results from the FY 95 - FY 98 studies suggested that sampling forage fish via sport-caught halibut can supply low-cost geographic and relative abundance information that can be utilized to assess seasonal and interannual variations in capelin and sand lance stocks and seabird prey bases. For example, these multiyear data suggested that sand lance stocks increased and populations of capelin declined and then rebounded during 1995-1998 (based on total numbers of fish in all sampling areas, capelin dropped from about 60% in 1995 to 19% in 1997, and then rose to 46% in 1998, while sand lance increased from 23% in 1995 to over 45% in 1997-1998; see Roseneau and Byrd 1999). These data also indicated that one of the sampling areas (Area 6 - Point Adam) supported relatively large stocks of capelin throughout the 4-year interval. Preliminary analysis of 1996-1998 beach seine data collected in Kachemak Bay - lower Cook Inlet by Projects 96163J, 97163J, 98163J, 96163M, 97163M, and 98163M appear to support this observation (M. Robards, pers. comm.). Also, preliminary analysis in conjunction with seabird information showed that Barren Islands black-legged kittiwake chick diet data paralleled the 1995-1998 pattern in capelin and sand lance abundance: nestlings were fed 64%, 28%, 14%, and 32% capelin, and 13%, 53%, 63%, and 50% sand lance by weight during those years (see Roseneau and Byrd 1999 and Roseneau *et al.* 1998b, 1999; in 1998, chick regurgitation's also contained 5% unidentified smelt, most of which were probably capelin).

This close-out component of the APEX project will analyze the FY 95 - FY 99 Kachemak Bay - lower Cook Inlet halibut stomach forage fish data and compare them with beach seine, trawl, and common murre *(Uria aalge)*, black-legged kittiwake *(Rissa tridactyla)*, and tufted puffin (*Fratercula cirrhata)* chick diet data from the Barren Islands and Gull and Chisik islands. After completing these analyses, we will also evaluate the effectiveness of the method for monitoring food webs and seabird - forage fish relationships and interactions after FY 00. After a final report is prepared, a manuscript will be written for publication in a scientific journal.

NEED FOR THE PROJECT

A. Statement of Problem

Many seabirds were killed during the March 1989 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, 1994b; Klosiewski and Laing 1994), or have only partially recovered from the event (e.g., although the productivity of common murres has been well within normal bounds at the Barren Islands since 1993, little change was apparent in population numbers until 1997—see Roseneau *et al.* 1998a, 1998b). Therefore, information is still needed that can increase understanding of food webs and seabird - forage fish relationships that may be influencing seabird recovery in the spill area, and there is also a need to identify low-cost methods that can be used to effectively monitor food webs and seabird - forage fish relationships and interactions after FY 00.

B. Rationale/Link to Restoration

This close-out component of the APEX seabird - forage fish project (Project 00163) will analyze five years of forage fish data from halibut stomachs in conjunction with seabird chick diet, beach seine, and trawl data from other APEX studies (95163J, 96163J, 97163J, 98163J, 99163J, 95163M, 96163M, 97163M, 98163M, 99163M). Results from these analysis will be used to evaluate the effectiveness of using halibut stomach contents to monitor forage fish stocks in Kachemak Bay - lower Cook Inlet after FY 00. Results will also provide information needed for a multispecies, multicolony, multiyear analysis of seabird productivity and energetics that will help test three APEX hypotheses (hypotheses 7, 8, and 9) and improve understanding of food webs and ecological processes that may be influencing seabird recovery in the spill zone. Results from the work in combination with findings from other APEX studies will also improve management of common murres and other fish-eating birds in the northern Gulf of Alaska, and help identify variables that can be used for monitoring the health of seabird populations after FY 2000.

C. Location

The FY 00 close-out work will be conducted in Homer, Alaska. No communities will be affected by the study.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

A large format, computer-generated color poster summarizing annual results will be prepared and submitted to the Trustee Council for public display before the final report is written. The poster is transportable 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 posters will also be available on-disk for inclusion in any on-line products that the Trustee Council may develop for public use. Copies of annual and final reports and manuscripts 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 objective is to test the feasibility of using stomach contents from sport-caught halibut to sample forage fish stocks in the northern Gulf of Alaska and evaluate the effectiveness of the method in obtaining information useful to APEX seabird and forage fish studies in the spill area (e.g., studies of common murres, *Uria aalge*; black-legged kittiwakes, *Rissa tridactyla*; Pacific sand lance, capelin).

B. Methods

The project will be conducted in Homer, Alaska. Methods for analyzing data are briefly summarized below.

Data Analysis

Data collected during FY 95 - FY 99 will be combined and checked to eliminate all potential errors, and then analyzed by first calculating numbers and frequencies of occurrence of fish and invertebrates in different geographic areas and time periods (see Roseneau and Byrd 1996, 1997, 1998, 1999). Statistical tests will then be used to check for temporal trends, differences among years and sampling areas, and correlation's between percentages of prey items in halibut stomachs, seabird diets, and beach seine - trawl catches (e.g., linear regressions, *t*-tests, Tukey HSD multiple comparisons—prior to analyses, statistical methods will be checked with L. McDonald, Project 99163O; seabird diet and beach seine - trawl data will be obtained from Projects 95163J, 96163J, 97163J, 98163J, 99163J, 96163M, 97163M, 98163M, and 99163M for some analyses).

C. Cooperating Agencies, Contracts, and Other Agency Assistance

J. Piatt, USGSBRD (Project 00163M), will provide Chisik and Gull island seabird diet data and Kachemak Bay - lower Cook Inlet beach seine and trawl data for some of the analyses. Statistical methods will be checked with L. McDonald, Project 00163O. A manuscript will be prepared for publication in collaboration with M. Robards and J. Piatt (Project 00163M). The Alaska Maritime National Wildlife Refuge (AMNWR) will provide office space for the project. AMNWR will also provide computers for entering and analyzing data, and donate up to one month of the project manager's time (G.V. Byrd) to the study.

SCHEDULE

A. Measurable Project Tasks for FY 00 (October 1, 1999 - September 30, 2000)

1-30 Oct 1999:	Enter FY 99 Project 99163K data in spreadsheets; sort by date, area, and prey categories in preparation for analysis.
1 Nov - 31 Dec 1999:	Check entered FY 99 Project 99163K data for errors, analyze data.
1-25 Jan 2000:	Prepare poster of FY 99 Project 99163K work for annual EVOS workshop, attend workshop in Anchorage.
26 Jan - 31 Mar 2000:	Combine FY 99 and FY 95 - FY 98 data, recheck resulting multiyear database for errors and inconsistencies; obtain beach seine, trawl, and murre, kittiwake, and puffin chick diet data from other FY 95 - FY 99 Kachemak Bay - lower Cook Inlet APEX studies (e.g., 99163J, 99163M).
1 Apr - 31 May 2000:	Analyze combined FY 95 - FY 98 data set; compare results with FY 95 - FY 99 seabird chick diet, beach seine, and trawl data with statistical advice from L. McDonald (Project 00163O); evaluate sampling technique using these comparisons.
1 Jun - 31 Jul 2000:	Prepare draft manuscript for publication in collaboration with M. Robards and J. Piatt.
1-31 Aug 2000:	Review and revise manuscript as necessary in collaboration with M. Robards and J. Piatt, submit draft manuscript to other researchers for comments.

1-15 Sep 2000:	Finalize manuscript, prepare executive summary, submit completed manuscript and executive summary to APEX Project Leader as final report for combined FY 95 - FY 99 predatory fish as forage fish samplers studies.
16-30 Sep 2000:	Check manuscript and submit to journal (Marine Progress Series or Colonial Waterbirds).

B. Project Milestones and Endpoints

December 1999	Complete FY 99 Project 99163K data analysis.
May 2000	Complete analyses of combined FY 95 - FY 98 data; comparisons with FY 95 - FY 99 seabird chick diet, beach seine, and trawl data; and an evaluation of the sampling technique.
July 2000	Complete draft manuscript of FY 95 - FY 99 results in collaboration with M. Robards and J. Piatt.
August 2000	Complete revisions of manuscript
September 2000	Submit manuscript to journal, and submit manuscript with executive summary to APEX Project Leader for final FY 95 - FY 99 final report.

C. Completion Date

A final FY 95 - FY 99 report will be submitted to the APEX project leader by 15 September 2000 for inclusion in the final FY 95 - FY 99 APEX report due 30 September 2000, and a manuscript reporting results of the FY 95 - FY 99 studies will be submitted to a journal for publication by 30 September 2000.

D. Deliverables and Estimated FY 2000 Costs

Data Analysis and Preparation of Final Report: The following estimated costs are for analysis of FY 99 Project 99163K data; rechecking and analyzing combined FY 95 - FY 99 halibut stomach content information; and comparing these data with seabird chick diet, beach seine, and trawl information in preparation for writing a final APEX report and publishable manuscript of FY 95 - FY 99 findings. Estimated costs for preparing a poster and attending the EVOS workshop in January 2000 are also included in the total amount. The report, consisting of an executive summary and a manuscript for publication in a scientific journal (see below), will be prepared by D.G. Roseneau (senior author) and G.V. Byrd. It will be submitted to the APEX Project Leader by 15 September 2000. Personnel time and costs for analyzing FY 99 data; rechecking and analyzing combined FY 95 - FY 99 information; comparing these data with seabird chick diet, beach seine, and trawl information; and preparing the executive summary are: D.G. Roseneau, 1.75 months at $5.1K/month = $8.9K; G.V. Byrd (co-author), 0.25 months at $0/month = $0 (costs for G.V. Byrd's time will be covered by AMNWR); estimated poster costs = $0.4K; estimated travel/lodging costs for EVOS meeting = $0.6K. Total Cost: $9.9K. Priority: High.

Manuscript: A manuscript entitled "Using Pacific halibut to sample forage fish utilized by piscivorous seabirds nesting in the Kachemak Bay - lower Cook Inlet region of Alaska" will be prepared for publication in a scientific journal after data analyses are complete (see above). The manuscript will compare FY 95 - FY 99 halibut stomach data from Projects 95163K, 97163K, 98163K, and 99163K with FY 95 - FY 99 beach seine, trawl, and common murre *(Uria aalge)*, black-legged kittiwake *(Rissa tridactyla)*, and tufted puffin *(Fratercula cirrhata)* chick diet information from the Barren Islands and Gull and Chisik islands (Projects 95163J & M, 96163J & M, 97163J & M, 98163J & M, and 99163J & M) It will also evaluate the effectiveness of using sport-caught halibut for monitoring seabird food webs and seabird - forage fish interactions in Kachemak Bay - lower Cook Inlet. The paper will be prepared in collaboration with M. Robards and J. Piatt (Project 00163M) with statistical advice from L. McDonald (Project 00163O). It will be submitted to the Marine Progress Series or Colonial Waterbirds by 15 September 2000. Personnel time and costs for preparing the manuscript, and estimated page and reprint costs are as follows: D.G. Roseneau (senior author), 1 month at $5.1K/month = $5.1K; G.V. Byrd (co-author), 0.5 months at $0/month = $0 (costs for G.V. Byrd's time will be covered by AMNWR); page and reprint costs = $2.0K. Total Cost: $7.1K. Priority: High. *Note: Costs for M. Robards and J. Piatt are included in J. Piatt's Project 00163M APEX DPD budget, and L. McDonald's costs have been included in his Project 00163O APEX DPD budget.*

PUBLICATIONS AND REPORTS

Project 00163K is part of the multiyear APEX study (Project 00163). If it is funded, FY 99 data will be analyzed and integrated with FY 95 - FY 98 information, and the resulting 5-year database will be analyzed and compared with FY 95 - FY 99 seabird chick diet, beach seine, and trawl data. A manuscript reporting FY 95 - FY 99 results and evaluating the sampling technique will be written in collaboration with M. Robards and J. Piatt (Project 00163M) for publication in a scientific journal. The manuscript entitled "Using Pacific halibut to sample forage fish utilized by piscivorous seabirds nesting in the Kachemak Bay - lower Cook Inlet region of Alaska" will be submitted the to the Marine Progress Series or Colonial Waterbirds by 30 September 2000. The manuscript and an executive summary will also be submitted to the APEX project leader by 15 September 2000 for inclusion in the final FY 95 - FY 99 APEX report due 30 September 2000. *Note: One paper, based on FY 95 data, has already published in the Lowell Wakefield Fisheries Symposium series (see Roseneau and Byrd 1997).*

PROFESSIONAL CONFERENCES

Results from the FY 95 - FY 99 studies will be presented at the Pacific Seabird Group meeting in 2000. Travel costs for attending the symposium are included in the FY 00 budget. *Note: The FY 95 - FY 99 results may also be presented at a Lowell Wakefield Fisheries Symposium in 2000, if this does not conflict with publishing the study in the Marine Progress Series or Colonial Waterbirds.*

NORMAL AGENCY MANAGEMENT

The proposed work is required to finish evaluating the effectiveness of using stomach contents from sport-caught halibut to sample forage fish stocks in the northern Gulf of Alaska. This task is not something that the AMNWR or the FWS are required to do by statute or regulation. Also, the types of data analyzed by the project are not part of standard AMNWR seabird monitoring protocols. Final FY 00 results will be used to determine the effectiveness of the method for monitoring forage fish stocks in Kachemak Bay - lower Cook Inlet after FY 00. Results from the work will also provide information for a multispecies, multicolony, multiyear analysis of seabird productivity and energetics that will help test three APEX hypotheses (hypotheses 7, 8, and 9) and improve understanding of food webs and ecological processes that may be influencing seabird recovery in the spill area. Ultimately, these findings in combination with other APEX results will also improve management of common murres and other fish-eating seabirds in the northern Gulf of Alaska and help identify parameters that can be used for monitoring these birds after FY 2000.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

The proposed FY 00 work is fully coordinated and integrated with other components of the APEX seabird - forage fish project. Results from the work will be shared other APEX investigators (e.g., Projects 00163E, 00163G, 00163L, 00163M, 00163Q). Results will also be shared with FWS biologists who may be able to use the technique for monitoring presence/absence for key forage fish species in other regions where seabird foraging areas and sport fishing charter boat fleets overlap (e.g., southeastern Alaska). The project is also coordinated with ADF&G fisheries personnel in Homer. Both raw and analyzed information from the FY 95 - FY 99 field seasons will be shared with the ADF&G fisheries biologists because these data may provide new information on Cook Inlet halibut diets that may be useful for management purposes.

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

This is a close-out of a 5-year-long APEX study (Projects 95163K, 97163K, 98163K, and 99163K). No changes have been made to basic design or schedules. If any potential changes are identified, they will be discussed with the APEX project leader (D. Duffy); if any are required, they will also be discussed with the EVOS chief scientist and science coordinator.

PROPOSED PRINCIPAL INVESTIGATOR, IF KNOWN

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PRINCIPAL INVESTIGATOR

1. David G. Roseneau (Co-Principal Investigator)

Mr. Roseneau will be responsible for the overall day-to-day operation of the project. He will supervise personnel, review and approve expenditures, and ensure that work stays on schedule and is coordinated with other APEX investigators. He will also be in charge of data analysis and interpretation, preparing posters and presentations for scientific conferences and meetings, and writing final reports and manuscripts for publication. Mr. Roseneau received his B.S. degree in wildlife management and M.S. degree in biology from the University of Alaska - Fairbanks in 1967 and 1972, respectively. His thesis research was on the numbers and distribution of gyrfalcons, *Falco rusticolus* on the Seward Peninsula, Alaska. He joined the U.S. Fish and Wildlife Service in January 1993, and was project leader for EVOS-sponsored common murre restoration studies at the Barren Islands during 1993-1994 (Projects 93049 and 94039). Mr. Roseneau was also principal investigator of the APEX Barren Islands seabird and large fish as samplers studies during 1995-1998 (Projects 95163J, 95163K, 96163J, 97163J, 97163K, 98163J, and 98163K), murre population monitoring work at the Barren Islands in 1996-1997 (Projects 96144 and 97144), and murre population studies at the Chiswell Islands in 1998 (Project

98144). Currently, he is co-principal investigator for APEX Project 99163J and principal investigator of APEX Project 99163K and the Barren Islands murre population monitoring study (Project 99144). Prior to 1993, Mr. Roseneau worked as a consulting biologist for 20 years, conducting and managing marine bird, raptor, and large mammal projects in Alaska and Canada for government agencies and private-sector clients. He has been involved in several large-scale murre (*Uria* spp.) monitoring projects. During 1976-1983, as co-principal investigator of NOAA/OCSEAP Research Unit 460, he conducted monitoring studies of murres and black-legged kittiwakes (Rissa tridactyla) at capes Lisburne, Lewis, and Thompson in the Chukchi Sea, and St. Lawrence, St. Matthew, and Hall islands in the Bering Sea. He also studied auklets (*Aethia* spp.) at St. Lawrence and St. Matthew islands, and participated in murre and kittiwake projects at Bluff in Norton Sound. In 1984-1986, he participated in follow-up studies of murres and kittiwakes in the northeastern Chukchi Sea, and during 1987-1988, 1991-1992, and 1995-1997 he helped conduct additional murre and kittiwake work at Chamisso and Puffin islands and capes Thompson and Lisburne. Mr. Roseneau is experienced in collecting and analyzing data on numbers, productivity, and food habits of seabirds; relating trends in numbers and productivity to changes in food webs and environmental parameters (e.g., air and sea temperatures, current patterns); and assessing potential impacts of petroleum exploration and development on nesting and foraging marine birds. He has broad knowledge of rock climbing techniques and has operated inflatable rafts and other outboard-powered boats in the Bering, Chukchi, and Beaufort seas and on various Alaskan rivers in excess of 2,900 hrs. Mr. Roseneau has also accrued several hundred additional hours operating time in small boats and larger, more powerful vessels (e.g. 25 ft, 300-400 hp HydroSports and Boston Whalers) in Kachemak Bay, Prince William Sound, and Kenai Peninsula and Barren Island waters. During his career, Mr. Roseneau has authored and co-authored over 75 reports and publications, including about 25 on Alaskan seabirds.

Selected Publications

Roseneau, D.G. and G.V. Byrd. 1997. Using Pacific halibut to sample the availability of forage fishes to seabirds. Pp. 231-241 *in* Forage Fishes in Marine Ecosystems, Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems, University of Alaska Sea Grant College Program Report No. 97-01, University of Alaska-Fairbanks, Fairbanks, AK.

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Springer, A.M., D.G. Roseneau, D.S. Lloyd, C.P. McRoy, and E.C. Murphy. 1986. Seabird responses to fluctuating prey availability in the eastern Bering Sea. Marine Ecol. Prog. Ser. 32: 1-12.

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OTHER KEY PERSONNEL

1. G. Vernon Byrd (Project Manager)

Mr. Byrd will supply overall guidance to the project, including providing advice during data analysis and report writing. He will also review reports and presentations as needed, and help prepare manuscripts for publication. Mr. Byrd received a B.S. degree in wildlife management from the University of Georgia in 1968, did post-graduate studies in wildlife biology at the University of Alaska-Fairbanks in 1975, and completed his M.S. degree in wildlife resources management at the University of Idaho in 1989. His thesis, entitled "Seabirds in the Pribilof Islands, Alaska: Trends and monitoring methods", explored statistical procedures for analyzing kittiwake (*Rissa* spp.) and murre (*Uria* spp.) population data. Mr. Byrd has worked for the U.S. Fish and Wildlife Service for over 20 years, focusing on studies of marine birds in Alaska and Hawaii. His major interests center around monitoring long-term trends in seabird populations, including numbers of birds and reproductive performance at colonies. He has worked at murre colonies in the Aleutian Islands, the Bering and Chukchi seas, and western Gulf of Alaska. Mr. Byrd was a co-author of the final T/V *Exxon Valdez* oil spill damage assessment report for murres. Also, he was project manager of the 1993-1994 common murre restoration monitoring studies (Projects 93049 and 94039, projects to remove predators from islands containing seabird colonies (Projects 94041 and 95041), and the 1995-1997 APEX and murre monitoring studies (Projects 95163J, 95163K, 96163J, 96144, 97163J, 97163K, 97144, 98163J, 98163K, and 98144). Mr. Byrd is currently serving as project manager for APEX projects 99163J and 99163K, and the Barren Islands murre population monitoring study (Project 99144). He has authored over 50 scientific papers and 60 U.S. Fish and Wildlife Service reports on field studies, and has made about 30 presentations on seabirds at scientific meetings. Mr. Byrd is the supervisory wildlife biologist at the Alaska Maritime National Wildlife Refuge, the premier seabird nesting area in the national public land system.

Selected Publications

Roseneau, D.G. and G.V. Byrd. 1997. Using Pacific halibut to sample the availability of forage fishes to seabirds. Pp. 231-241 *in* Forage Fishes in Marine Ecosystems, Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems, University of Alaska Sea Grant College Program Report No. 97-01, University of Alaska-Fairbanks, Fairbanks, AK.

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Piatt, J.F., C.J. Lensink, W. Butler, M. Kendziorek, and D.R. Nysewander. 1990. Immediate impact of the "*Exxon Valdez*" oil spill on marine birds. Auk 107:387-397.

Roseneau, D.G, and G.V. Byrd. 1996. Using predatory fish to sample forage fishes, 1995. Appendix K (13 pp.) *in* APEX: Alaska Predator Ecosystem Experiment (D.C. Duffy, Compiler), *Exxon Valdez* Oil Spill Restoration Proj. Annual rept. (Restoration Proj. 95163), Alaska Natural Heritage Program, Univ. of Alaska - Anchorage, Anchorage, AK.

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Synthesis and Analysis of Data Collected From Small-Mesh Trawl Surveys in the Gulf of Alaska 1953-1996.

Project Number:	00163L
Restoration Category:	Research-Forage Species Assessment
Proposer:	Paul Anderson and John Piatt
Lead Trustee Agency:	DOI/NOAA
Cooperating Agencies:	ADFG, DOI(USGS), NOAA
Duration:	1 year for research - Forage Species Assessment (FSA)
Cost FY 00:	$75,600 (Research Completion and close out)
Cost FY 01:	$0
Cost FY 02:	$0
Geographic Area:	Prince William Sound, Kenai Peninsula, Lower Cook Inlet, Kodiak Island Group, and Alaska Peninsula to Unimak Pass. Entire spill affected area
Injured Resource:	Forage species food base for a large variety of seabirds and marine mammals. Commercial Fisheries.

ABSTRACT

Large declines of apex predator populations (murres, kittiwakes, harbor seals, and Steller sea lion) have occurred in the Gulf of Alaska since the 1970s. This project encompasses a unique approach in understanding the dynamics of the forage species base in the Gulf of Alaska (GOA). This project will analyze the only known long-term data series that has shown, after preliminary analysis, that the GOA marine benthic and epi-benthic community has undergone dramatic changes during the past two decades. This project quantifies the spatial and temporal changes that have taken place and will ultimately test some hypothesis to determine the likely mechanisms that have driven these changes.

INTRODUCTION

In FY 96-99 the project continued refinement of the large small-mesh database for detailed analysis. Much of FY96 and FY97 was devoted to creating ARCINFO coverages of the existing geocoded data sets. These coverages were used to identify areas consistently sampled over long time periods. After delineating the area sampled over time, ARCINFO was then used to define these areas, the database was then modified with ADFG codes representing the sampled areas. Subsequent analysis was conducted for these defined areas without the need of mapping software. FY97 was the first year a preliminary analysis was conducted on the icthyplankton database for the Gulf of Alaska. The database was compiled and edited for errors and ARCINFO coverages were created to identify sampled locations on map backgrounds. These geocoded coverages were linked to size data collected from each sample. These data sets were converted to ARCVIEW format so subsequent analysis could take place in a PC work environment. The remainder of FY99 will largely be devoted to analysis of this dataset. In FY99 and FY00 we will be refining the design of electronic data atlas formats as a major product, supplying the data needs for other researchers is an important project output. This part of the project will be completed and closed out in FY00. In FY96-99 five presentations and manuscripts were produced on project data. FY00 will be devoted to finishing the data analysis and additional manuscript preparation.

NEED FOR PROJECT

A. Statement of Problem

Since the late 1970's there has been a total reorganization of the marine ecosystem in the Gulf of Alaska (Piatt and Anderson 1996). Abruptly, the ecosystem transformed from crustacean dominated to a fish dominated regime in a period of about one year. In assessing the recovery of injured resources it is necessary to know what factors occurring naturally in the environment may be responsible for failure of some species to re-build or chronic low post-spill population levels. This project has found a link between pre-spill population declines and a Gulf of Alaska wide regime shift in the marine ecosystem. Assessment of the important food base will need to continue to properly judged the success or failure of injured species and commercial fisheries to recover subsequent to the oil spill.

B. Rationale

This project has been responsible for providing an important marine ecosystem index to judge the recovery of injured species and some commercial and subsistence fisheries activities. The index provided by the small-mesh data set gives researchers and managers the background they need to assess why population changes have occurred prior to the spill and what effect the relative abundance of the forage base may have on population recovery after the spill. The data from this project also help separate changes in commercial or subsistence resources were induced by the spill and those that can be explained by a Gulf of Alaska wide regime shift in the marine ecosystem.

We are in danger of loosing the continuity of the long-term small- mesh data set. Declines in commercially important shrimps have lessened the perceived need of resource agencies such as ours (NMFS and ADFG) to fund small-mesh trawl survey work. This study shows the value of a consistently collected data series in addressing some of the major concerns relating to food limitation on marine bird and mammal populations. Without support this data series will be increasingly under attack and probably reduced to a point where it will be of little use by future natural resource investigators in dealing with contemporary problems. Its important to point out that shifts in the components of the marine ecosystem can occur rapidly as presented in the annual report and enclosed manuscripts. By reducing survey frequency to once every three years (as is the situation now) the timing resolution of regime shifts is lost and correlations with bird and marine mammal populations will be degraded. In view of the above, we are requesting our first year of assessment funds for FY00 to augment agency survey frequency in the Kodiak Island, survey area in an attempt to sustain the usability of this data series for the future. This is not a replacement of ADFG duties or authority, but rather augments what ADFG can reasonably survey given the resources available. This assessment funding will be used judiciously to survey important key areas where ongoing studies need continuous data on changes in the marine forage base. For details on assessment funding see separate funding request.

C. Location

The project has been centered and most analysis activities conducted in Homer and Kodiak Alaska. Additional areas that are important in the project area are: Cordova, Kenai Peninsula, Barren Islands, Shelikof Strait and associated villages, Chignik, Akhiok, Old Harbor, Trinity Islands, Afognak, Lower Cook Inlet, Kachemak Bay, and Prince William Sound.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

Community evolvement would help in identifying species changes that should be investigated in the formal database. These include a historical review of commercial fishery landings for major species to confirm the regime shift in marine species detected in scientific surveys. Observations and data gathering should concentrate on decline of spawning capelin runs, the decline of subsistence take on crustacean resources especially shrimp and crabs, and changes in marine bird and mammal populations. Further analysis of the available commercial fishery data will help identify changes in trophic level groups not sampled in the small-mesh surveys. Observations of the type outlined above would be helpful in verifying and validating results obtained from the survey databases.

PROJECT DESIGN

A. Objectives

The project's research and assessment objectives for FY99 and out years are outlined below:

1. Determine if and when changes in the forage base occurred in the Gulf of Alaska small-mesh survey database. What species were affected.

2. Investigate possible mechanisms for the observed changes in the species complex and develop and test hypothesis concerning these.

3. Investigate the early life history and dynamics of Pacific sand lance from Shelikof Strait icthyoplankton surveys 1972-92.

4. Refine electronic format database server that is on the Internet: www.fakr.noaa.gov/trawl

5. Compile historic commercial fisheries catch information that provide information on other trophic groups that are not sampled by the surveys.

6. Collaborate with other investigators to provide data into modeling exercises.

B. Methods

Small-mesh Trawl Survey
See cited manuscripts to FY98 annual report

C. Cooperating Agencies, Contract, and Other Agency Assistance

Overall coordination for this project is provide through the DOI and the Biological Resources Division (USGS). The ADFG is represented by both the Homer and Kodiak office staff, their cooperation is imperative since they contribute all fishery data statistics and have collected about one-half of the small-mesh trawl survey data. The NMFS in Kodiak is responsible for overseeing most of the analysis of the data and provides a UNIX workstation and software to assist in handling the large combined data sets. NMFS Kodiak was instrumental in designing the initial small-mesh trawl surveys and has collected about one-half of the total historic data set. Since there are differences in the temporal scale of sampling, combining the two sets gives the most complete picture of the changes to the marine ecosystem over a longer time span than if treated separately. Assessment planning in interim (2 out of 3) years will be a coordinated effort by all participants.

In FY98 ADFG Homer was responsible for completing the addition of their portion of the data to the combined database, this part of the project is now completed. ADFG Homer will research the commercial catch data available and produce summaries used in the completion of project goals. ADFG Homer will also be evolved in any assessment charter and survey that is conducted in the Lower Cook Inlet area.

In FY00 ADFG Kodiak will assist in the cleanup of database issues and assist with the design criteria for the electronic database. ADFG Kodiak will be involved in any potential assessment effort and survey design.

NMFS Kodiak will continue overseeing data analysis, take lead role in manuscript preparation, coordinate forage species survey assessment (if funded), and database electronic design.

SCHEDULE

A. Measurable Project Tasks for FY00 (October 1, 1999 - September 30, 2000)

Oct 1 - September 30:	Analyze data from data sources; maintain database
Jan 1 - Jul 31:	Enhance design of Electronic Database and Web products (PI supervise)

Jan 15 - 24: Attend Annual Restoration Workshop
Feb 15 - Mar 31: Prepare Annual Report and Attachments
Apr 1 - Sep 30 Prepare Manuscripts for Publication

B. Project Milestones and Endpoints

Presentation of project results at the 2nd International Pandalid Shrimp Symposium Sept 8 - 10, 1999.

Publication of initial project results, in a major journal. During FY99 or FY00. One manuscript submitted.

Continue upgrade of electronic format project database design (FY99) and publishing to the Internet (FY99-00)

Publication of benthic community structure changes and hypothesis of mechanisms responsible for abrupt regime shifts

C. Completion Date

All portions of the research component for this project should be completed by the end of FY00 (September 30, 2000). Monitoring funding should continue (but is not requested in this DPD) until full recovery of all injured resources and services has occurred or agency funds are restored to continue annual small-mesh data collection in the spill-affected area.

PUBLICATIONS AND REPORTS

1. Pandalid Shrimp Declines in the Gulf of Alaska, A case of Forage Species Regime Shift, Paper for presentation and inclusion in the proceedings of the Second International Pandalid Shrimp Symposium to be published in a special addition of NAFO Journal.

2. Long-term Changes in the Gulf of Alaska Marine Ecosystem;
Major journal article submitted to Marine Ecology Progress Studies (in review).

3. Long-term Shifts in Benthic Commercial Fishery Species; A Case Study in the Gulf of Alaska with John Piatt, first as a presentation for North pacific Salmon conference, then manuscript--Journal Article for Marine Ecology Progress Series.

PROFESSIONAL CONFERENCES

Anticipate attendance and presentation of project research at the Second International Pandalid Shrimp Symposium, September 8 -10, 1999 in Halifax, Nova Scotia.

Attendance at the: Beyond El Niño, Conference on Pacific Climate Variability and Marine Ecosystem Impacts...... La Jolla, CA March 23 -26, 2000

NORMAL AGENCY MANAGEMENT

This project coordinates and assists in acquisition of data bases from other agencies and defines procedures to aid in the quantification and analysis of spatio-temporal trends in abundances forage fishes and invertebrates. These activities are critical to on-going analyses and population assessment modeling for marine birds and mammals and for judging the effects of the EVOS on them. Without support for this project our ability to conduct and support analysis of this unique and standardized 25 year data series will be severely impaired. These analyses are essential for the understanding of how forage fish abundance may have affected the dynamics of marine birds and mammals. It is against this background of ecological change that effects of the EVOS must be objectively considered. This project combines the frame work for agencies to cooperate in solving problems together, with each contributing unique and necessary assets to solve these larger problems.

COORDINATION AND INTEGRATION

This study addresses a number of issues related to other components of the APEX project. Direct project coordination with Cook Inlet Seabird and Forage Fish Study, and Ecology and Demographics of Pacific Sandlance (Both projects under direction of Biological Resources Division (BRD) of U.S. Geological Survey (USGS)). Project database component for PWS has been provided to Tracey Gotthardt , a graduate student under Dr. Kathy Frost studying dietary changes in Harbor seals. In FY98 the project data was provided to Dr. Jennifer Purcell in order to analyze the changes in jellyfish over time.

EXPLANATION OF CHANGES

Changes in the duration of funding were necessitated to to delays in manuscript preparation and approval from agency. More manuscripts are being prepared this year under this project.

PRINCIPLE INVESTIGATORS
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OTHER KEY PERSONNEL

Dr. James E. Blackburn, ADF&G Kodiak, is a database design expert and has worked extensively in fishery research in the Gulf of Alaska for over 20 years.

Dr. William Bechtol, ADF&G Homer, is fishery research biologist for the region covering Lower-Cook Inlet and the Kenai outer coast and Prince William Sound.

Sharon Loy, NMFS Kodiak, is staff GIS technician at the Alaska Fisheries Science Center and has extensive experience in GIS analysis and statistical procedures, and electronic database design.

LITERATURE CITED

See FY97- 99 annual reports for this project for a complete listing of cited literature.

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

Project Number:	00163 M
Restoration Category:	Research
Proposed By:	U.S. Geological Survey (PI- John F. Piatt)
Lead Trustee Agency:	DOI
Cooperating Agencies:	ADFG, USFWS
Duration:	2 years
Cost FY 00:	$239,500 (data analysis, reporting)
Cost FY 01:	$239,500 (data analysis, reporting)
Geographic Area:	Cook Inlet, Gulf of Alaska
Injured Resource:	Multiple resources

ABSTRACT

Cook Inlet Seabird and Forage Fish Studies (CISeaFFS) was established in 1995 with EVOSTC (APEX) and USGS funding to measure the foraging (functional) and population (numerical) responses of seabirds to fluctuating forage fish densities around three seabird colonies in lower Cook Inlet. This involved at-sea surveys for forage fish (hydroacoustics, trawling, seining) and seabirds (line transects), and some characterization of oceanography (AVHRR satellite imagery, CTD profiles, moored thermographs), while measuring aspects of seabird breeding biology (egg and chick production, chick growth, population trends) and foraging behavior (diets, feeding rates, foraging time) at adjacent colonies. Field work will be completed in summer, 1999, and FY00 and FY01 will be devoted to analyzing data and reporting of results.

INTRODUCTION

Some seabird populations in the Gulf of Alaska declined markedly during the past few decades. Whereas human impacts such as those from the *Exxon Valdez* oil spill can account for some proportion of these declines, natural changes in the abundance and species composition of forage fish stocks have also affected seabird populations. Marine fish communities in the Gulf of Alaska changed dramatically during the past 20 years. 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. Seabirds and marine mammals exhibited several signs of food stress (population declines, reduced productivity, die-offs) throughout the 1980's and early 1990's. Factors that regulate seabird populations are poorly understood, but food supply is clearly important. In many cases, anthropogenic impacts on seabird populations cannot be distinguished from the consequences of natural variability in food supplies. Thus, 'management' of seabird populations remains an uncertain exercise. For example, how can we enhance or predict recovery of seabird populations lost to the *Exxon Valdez* oil spill if food supplies in the Gulf of Alaska limit reproduction?

To address these questions, the EVOSTC initiated APEX (Apex Predator Ecosystem Experiment) in 1995. In Cook Inlet, pilot studies were initiated with USGS and MMS support in 1995, and expanded in 1996 with substantial APEX support. 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 (research there conducted and reported by the Alaska Maritime National Wildlife Refuge). 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.

In 1997 and 1998, this research program was refined and expanded where appropriate. For example, we have included benthic trawling nearshore since 1997, increased study effort on pigeon guillemots, added nearshore sampling for zooplankton, phytoplankton and nutrients (in collaboration with Peter McRoy, UAF), studied physiological responses of adult and chick seabirds to food stress, begun to measure adult survival of murres and kittiwakes on Gull and Chisik islands, and increased coordination of seabird studies at the three colonies using protocols developed in collaboration with other principal investigators in the EVOS/APEX program. The basic components of this study have not changed, however, and we measured the same fundamental parameters of forage fish and seabird biology for the duration of the study (1995-1999).

SUMMARY OF FINDINGS TO DATE

Populations, productivity, diets and foraging behavior of Common Murres and Black-legged Kittiwakes were studied at three seabird colonies in lower Cook Inlet (Chisik, Gull and Barren islands). Ancillary data were also collected on Tufted and Horned Puffins, Cormorants (spp.) and Glaucous-winged Gulls. Pigeon Guillemots were studies in Kachemak Bay only. Oceanographic measurements, seabird and hydroacoustic surveys, trawls, and beach seines were conducted in waters around (<45 km) each colony. In all years, offshore and southern waters of Cook Inlet were dominated by juvenile walleye pollock, important prey for murres and puffins. Nearshore waters of Cook Inlet were dominated by sandlance, which were consumed by seabirds (e.g., kittiwakes, guillemots, murres) in proportion to their local abundance. The CPUE of forage fish in either mid-water trawls or beach seines around Chisik Island is typically 1-2 orders of magnitude less than around the Barren Islands; with Kachemak Bay yielding intermediate CPUE's. Acoustically-measured forage fish biomass is also lowest around Chisik Island, moderate in Kachemak Bay, and highest around the Barren Islands. Water temperatures throughout the summers of 1995-1997 were similar and near the long-term average, but temperatures in winter of 1997/98 were about 1-2 C higher than in previous years owing to warming from El Niño.

The breeding biology of seabirds differs markedly among colonies owing to differences in food supply, but within each colony, breeding and behavioral parameters were similar in 1995-1997. Breeding success in all species was lower in 1998 than in previous years. Murres on Chisik Island had a complete reproductive failure-- the first time we have observed a murre failure at any colony since studies began in 1995. Measures of baseline corticosteroid levels suggest that murres on Chisik were highly stressed even before they attempted to lay eggs in July. A large die-off of murres was observed in Cook Inlet in April and May, and although most birds affected were subadults, this die-off foreshadowed the poor breeding season for murres during summer of 1998. Murres at Gull Island in Kachemak Bay appeared to do quite well, however, as evidenced from moderate breeding success and time-budgets. Breeding success of kittiwakes at Gull, Barren and Chisik islands was lower in 1998 than previous years, and kittiwakes failed at both Chisik and the Barrens. Population censusing revealed that seabirds at Chisik Island continue in a long-term decline, whereas populations at Gull and Barren islands are stable or increasing. Behavioral studies reveal that seabirds work harder (longer foraging trips, less "free" time) at colonies where nearby fish densities are lower (Chisik). Preliminary results of survival studies suggest that the survival rate of adult kittiwakes on Chisik Island is substantially higher on Chisik than Gull Island, while survival of murres appears similar between the islands.

Overall, the results show that seabird parameters (breeding success, foraging effort, diets, etc.) vary most between islands, and least between years. We attribute this regional stability in biological responses to distinct oceanographic regimes around each colony that tend to strongly influence the biology of birds within those areas. Thus, all measured seabird parameters varied some between years, but, for example, murres at Gull Island always fared better than those at Chisik. While each colony responded differently to the ENSO perturbation of 1997/98, responses were commensurate with the underlying physical and biological regime observed in each area. As predicted, the numerical and functional responses of seabirds to food density is non-linear. Based on response curves of breeding success, foraging effort, attendance, etc., to prey density, it appears that food supplies at Gull and Barren islands— but not at Chisik— are presently adequate to support recovery of losses from the Exxon Valdez oil spill.

OBJECTIVES FOR FY00

The objective in FY00 is to analyze and report a substantial portion of our research findings from 1995-1999. The first priority will be to compile a comprehensive report which includes all significant findings and will provide a preliminary synthesis and interpretation of results. This report will constitute a final repository for raw and summarized data, provide documentation of methods for the entire project, and serve as a useful reference for researchers who may wish to conduct research in lower Cook Inlet in the future.

In addition to this final report, papers will be submitted for publication in peer-reviewed journals. In FY00, most of these papers will be syntheses of particular aspects of the project (e.g., oceanography, fish, murres, etc.), and in FY01, we will prepare papers which synthesize all aspects of the project in Cook Inlet. Following these, we can begin to collaborate with investigators in Prince William Sound to prepare papers that compare findings from both regions.

The following lists indicate priority products for FY00 and FY01, as well as products completed to date.

Cook Inlet related manuscripts for analysis and write-up in FY00:

"Cook Inlet Seabird and Forage Fish Studies" (Final Report to EVOS Trustee Council, detailed compilation of observations on oceanography, fish, and seabirds; interpretation emphasizing overall findings, distribution maps, appendices of data, to serve as archive for EVOSTC, USGS, MMS, and Alaska Maritime NWR) {Piatt, Drew, Abookire, Robards, Van Pelt, Litzow, Shultz, Harding, Kitaysky, Speckman} [12 person months]

"The numerical response of seabirds to variation in food density" (per title, a note showing response of murres and kittiwakes) {Piatt, Roseneau, Irons, Duffy et al.} Nature [1 pm]

"Characterization of fish schools in relation to the marine environment in Lower Cook Inlet, Alaska" (Examination of how oceanographic factors such as temperature, salinity, location of the thermocline and bottom depth, as well as biological factors such as primary production and zooplankton abundance, affect the characteristics of forage fish schools) {Speckman, Swartzman, Piatt, et al.). ICES Journal of Marine Science [4 pm]

"Remotely-sensed measurements of sea-surface temperature and the detection of environmental gradients in Cook Inlet, Alaska" (description of basic oceanography in Cook Inlet, vertical and horizontal gradients from AVHRR and CTD profiles) {Drew, Piatt, et al.}Estuarine, Coastal and Shelf Science [3 pm]

"Marine habitats, productivity and spatial variability in abundance of forage fish in lower Cook Inlet" (analyses of 5 years of acoustic surveys, trawl and beach seine catches at Chisik, Gull, Barrens) { Drew, Piatt, Abookire, Robards, Speckman, Kettle} Fisheries Oceanography [6 pm]

"Dynamic structure and composition of marine fish communities in a large estuarine ecosystem" (use non-parametric MDS to analyse fish community structure in lower Cook Inlet relative to spatial and interannual variability in environment) {Abookire, Piatt, Speckman, et al.} Canadian Journal of Fisheries and Aquatic Sciences [4 pm]

“Spatial associations of seabirds and their prey around three colony sites in Lower Cook Inlet, Alaska” (Will measure and compare degrees of aggregation of birds and prey at varying scales to examine how seabird foraging patterns and strategies vary with changes in prey abundance, distribution, and species composition) {Speckman, Piatt, Swartzman, et al.} Marine Ecology Progress Series. [4 pm]

“Using Pacific halibut to sample forage fish used by piscivorous seabirds in lower Cook Inlet, Alaska” {Roseneau, Robards, et al.} Marine Ecology Progress Series [0.7 pm]

“Chick feeding rates, foraging time budgets, and nest site attendance of Common Murres at three colonies with differing food regimes” (synthesis and summary of 5 years of study at Chisk, Gull, and Barren islands) {Shultz, Piatt, Kettle, Roseneau et al.} [4 pm]

“Chick feeding rates, foraging time budgets, and nest site attendance of Black-legged Kittiwakes at three colonies with differing food regimes” (synthesis and summary of 5 years of study at Chisk, Gull, and Barren islands) {Kettle, Piatt, Harding, et al.} [2 pm]

“Consequences of variability in prey abundance and prey energy content for breeding Pigeon Guillemots” (relating PIGU chick diet composition, provisioning rates, and chick growth rates to prey availability) {Litzow, Piatt, Roby, Abookire, et al.} Journal of Animal Ecology [2 pm]

“Foraging behavior and time-budgets of breeding pigeon guillemots feeding on dispersed and aggregated prey” (contrasting time-budgets and foraging areas of PIGU’s using different prey) {Litzow, Piatt, Croll, Estes, et al.} Behavioural Ecology [4 pm]

“Effects of food supply on breeding phenology of Common Murres and Black-legged Kittiwakes at two contrasting colonies in Alaska” (relate phenology to environment and food availability) {Shultz, Piatt, Abookire, Harding, Kitaysky}Auk [3 pm]

“Attendance patterns and monitoring of Horned Puffins in Cook Inlet, Alaska” (per title, mostly a methods paper) {Harding, Piatt, et al.). Condor. [3 pm]

“Breeding biology and feeding ecology of horned puffins at Chisik Island, Alaska” (self-explanatory, details of 5 years of research) {Harding, Piatt, et al.} Auk [4 pm]

“Begging behavior and feeding rates of common murre chicks artificially stressed with corticosteroid implants” (self-explanatory) {Kitaysky, Wingfield, et al.}Behavioral Ecology and Sociobiology [2 pm]

“Corticosteroids and stress response in common murres at colonies with scarce and abundant food supplies” (showing response of murres to food stress, relation to body condition, food supply) {Kitaysky, Piatt, et al.} Functional Ecology [2 pm]

“Corticosteroid levels and stress in growing tufted puffin chicks fed on diets of differing quality”(showing that puffins do not exhibit stress levels observed in kittiwakes raised under similar circumstances, and why not) {Kitaysky, Romano, et al.} Auk [2 pm]

"Diets of seabirds in lower Cook Inlet". (overall summary of dietary information obtained on murres, kittwakes, murrelets, puffins, cormorants, gulls, etc.; comparison with other areas of Alaska) {Van Pelt, Piatt, Springer, et al.} Canadian Journal of Zoology [2 pm]

"Long-term monitoring of nearshore fish in Cook Inlet" (summary and published archive of beach seine data){Robards, Piatt, Abookire, Kettle} Alaska Fisheries Journal [2 pm]

"Abundance and distribution of smelts (Osmeridae) in lower Cook Inlet" {Abookire, Piatt, Robards, et al.} Transactions American Fishery Society [1.2 pm]

"Spatial segregation and habitat use by Marbled and Kittlitz's Murrelet in lower Cook Inlet, Alaska" (self-explanatory) {Speckman, Piatt, et al.} Oecologia [1.5 pm]

"Persistent foraging areas and vulnerability of seabirds to oil pollution in lower Cook Inlet" (species distributions and vulnerability) {Drew, Speckman, Piatt, et al.} Marine Pollution Bulletin [2 pm]

Trophic levels and carbon sources for seabirds in Cook Inlet (examination of stable isotope variability in seabirds and prey in Cook Inlet, relation to diet and oceanography) {Hobson, Piatt, et al.} Marine Ecology Progress Series [1 pm]

"Comparison of blood parameters of Pigeon Guillemot chicks from oiled and unoiled areas of Alaska eight years after the Exxon Valdez oil spill" (self-explanatory) {Seiser, Duffy, McGuire, Golet, Litzow} Marine Pollution Bulletin [0.1 pm]

Cook Inlet related manuscripts partially or mostly completed in FY99, but most will require additional work in early FY00 (especially since field season is soon upon us, and work on manuscripts will not resume until October in most cases):

Benson, J., R.M. Suryan, and J.F. Piatt. A multivariate approach to assessing growth of seabird nestlings from one-time measurements. Mss under final revision for submission to Condor.

Robards, M.D., J. Anthony, J.F. Piatt, G. Rose, and J.F. Piatt. 1999. Seasonal and regional variation in proximate composition of Pacific sand lance (*Ammodytes hexapterus*) in lower Cook Inlet, Alaska. Mss. submitted to Journal of Experimental Marine Ecology.

Piatt, J.F., G. Drew, T.Van Pelt, A. Abookire, A. Nielsen, M. Shultz, and A. Kitaysky. 1999. Biological effects of the 1997/1998 ENSO event in lower Cook Inlet, Alaska. Mss. under revision for submission to Canadian Journal of Fisheries and Aquatic Sciences

Zador, S.G., J.F. Piatt, A. Kettle, A. Abookire, and Alan Springer. 1999. Can the diet of Common Murres be used to assess forage fish stocks? Submitted to Marine Ecology Progress Series.

Norcross, B.L., A.A. Abookire, and S.C. Dressel. 1999. Essential fish habitat requirements of juvenile groundfishes in southcentral Alaska. Submitted to Bulletin of Marine Science.

Robards, M.D., G.A. Rose, and J.F. Piatt. 1999. Somatic growth and otolith development of Pacific sand lance (*Ammodytes hexapterus*) under different oceanographic regimes. Mss. under final revision for submission to Fisheries Oceanography.

Kitaysky, A.S., J.F. Piatt, J.C. Wingfield, and M. Romano. 1999. Stress-response of Black-legged Kittiwake chicks in relation to dietary restrictions. Mss. under final revision for submission to Journal of Animal Ecology.

Romano, M.D., D.D. Roby, J.F. Piatt and A. Kitaysky. 1999. Effect of diet on visceral development of nestling seabirds. Mss. under final revisions for MS thesis, and journal publication.

Romano, M.D., J.F. Piatt and D.D. Roby. 1999. Effects of prey type on the growth of piscivorous seabirds in captivity. Mss. under final revisions for MS thesis, and journal publication.

Romano, M.D., D.D. Roby, and J.F. Piatt. 1999. Effects of diet on growth and body composition of nestling seabirds. Mss. under final revisions for MS thesis, and journal publication.

Abookire, A.A., J.F. Piatt and M. Robards. 1999. Stratification and small-scale thermohaline differences influence nearshore fish distributions in an Alaskan estuary. Mss. under final revision for submission to Estuarine, Coastal and Shelf Science.

Kitaysky, A., J. Wingfield, and J. Piatt. 1999. Parent-offspring feeding interactions in food-stressed Black-legged Kittiwakes. Mss. under final revision for submission to Behavioural Ecology.

Harding, A., J.F. Piatt, T. Van Pelt and A. Kitaysky. 1999. Parental Flexibility: An experimental reduction of provisioning effort in response to chick nutritional status in the Horned Puffin (*Fratercula corniculata*). Mss. under revision for submission to Behavioural Ecology and Sociobiology.

Zador, S., A. Nielsen, J.F. Piatt, A. Kettle, and Tom van Pelt. 1999. Diets of Black-legged Kittiwakes in relation to prey availability in Cook Inlet, Alaska. Mss. under revision for submission to Polar Biology.

Litzow, M.A., J.F. Piatt, A.A. Abookire, A.K. Prichard and M.D. Robards. 1999. Pigeon Guillemot Nestling Diets as Monitors of Nearshore Fish Communities. Mss. Under final review for submission to Marine Ecology Progress Series.

Zador, S., J.F. Piatt, and A.S. Kitaysky. 1999. Prey selectivity in breeding common murres. Mss. under revision for submission to Journal of Avian Biology

A tentative list of Cook Inlet related manuscripts that will be initiated or drafted in FY01 (and beyond):

"The role of food supply and environmental variability in the regulation of seabird populations" (synthesis of major findings on Cook Inlet environment, fish, and seabird biology and behavior) {Piatt, Roseneau, et al.} Ecological Monographs

"Can seabirds recover from effects of the Exxon Valdez oil spill?" (consideration of ecological factors limiting recovery, current status of colonies in Cook Inlet, and forecast of future) {Piatt, Roseneau, Duffy, Byrd, Anderson et al.} Biological Conservation

"Survivorship of adult common murres and black-legged kittiwakes at colonies under different food regimes" (comparison of annual adult survival at Gull and Chisik, 1997-99) {Piatt, Van Pelt, Shultz et al.} Journal of Animal Ecology

"Ecological and evolutionary consequences of diet specialization in a generalist, Pigeon Guillemots" (short and long-term success of pigeon guillemots depends on prey type, also consider predation) {Litzow, Piatt, et al} Ecology.

"Spatial relationships between seabirds and their forage fish prey in Lower Cook Inlet, Alaska" (Ph.D. dissertation, University of Washington, School of Fisheries. Will consist of 3-5 chapters, each addressing a different aspect of the general hypothesis that oceanographic factors influence the distribution, abundance, and availability of forage fish to seabirds) {Speckman}

"Characterization of fish schools in relation to their use by seabirds in Lower Cook Inlet, Alaska" (Examination of how school characteristics such as distance from the water surface, distance from shore, fish size and species, and density of fish within a school affect the selection of prey schools by different seabird species) {Speckman, Piatt, Swartzman, et al.}. Fisheries Oceanography.

"Common Murre productivity and population trends at three colonies with markedly different food supplies" (synthesis and summary of 5 years of study at Chisk, Gull, and Barren islands) {Piatt, Roseneau, Byrd, et al.}

"Black-legged Kittiwake productivity and population trends at three colonies with markedly different food supplies" (synthesis and summary of 5 years of study at Chisk, Gull, and Barren islands) {Roseneau, Piatt, et al.}

"Costs of egg production in common murres" (results of manipulative experiment to assess reproductive costs of egg production at a food stressed colony) {Van Pelt, Monaghan, Piatt et al.} Oecologia

"Oceanographic factors as predictors of marbled murrelet distribution, phenology, and productivity in southcentral Alaska" (self -explanatory) {Kuletz, Piatt, et al.). Marine Ecology Progress Series.

"Use of satellite-derived measurements to predict seabird and forage fish distributions in Lower Cook Inlet, Alaska" (Examine relationships between satellite-derived measurements of sea surface temperature and fluorescence (a proxy for primary production) with the distributions of seabirds and forage fish) {Speckman, Drew, Swartzman, Piatt} Journal Unknown

"Temporal and Spatial Patterns in Water Properties of Lower Cook Inlet: Local Stability in a Variable Environment" (use AVHRR, CTD and ONSET data, focus on variability among and between days, tidal effects, and seasonal changes) {Drew, Piatt....} Journal Unknown

"Timing and magnitude of phytoplankton blooms in Kachemak Bay, Alaska" (showing annual and seasonal variability in nutrients and production in Kachemak Bay) {Drew, Piatt, Abookire, McRoy, et al.} Limnology and Oceanography

"Abundance and distribution of juvenile gadids in lower Cook Inlet" {Robards, Piatt, Abookire et al.} Fishery Bulletin

"Nutrients and phytoplankton biomass across a cold-water plume in Lower Cook Inlet, Alaska" (focus on cross-section of upwelling plume and how this influences productivity in Kachemak Bay) {Drew, Piatt, McRoy, et al.} Journal of Marine Research

"Annual Variability is Sea-surface Temperatures in Cook Inlet: A Barometer of Climate Change in the Gulf of Alaska" (use AVHRR to examine long-term changes in SST's, especially with regard to ENSO events) {Drew, Piatt....} Journal Unkown

"A comparative analysis of sand lance distribution and habitat preferences in Cook Inlet and Prince William Sound, Alaska" {Robards, Ostrand, et al.} Journal Unknown

"Growth and allocation of dietary nitrogen and carbon in tufted puffin and black-legged kittiwake chicks fed on known diets" (from analyses of stable isotopes in birds raised for growth experiments) {Hobson, Romano, Piatt, van Pelt} Journal Unknown

"An evaluation of methods for determining nestling growth" {Suryan, Roby, Irons, and Piatt} Journal Unknown

Cook Inlet APEX related papers published prior to FY00:

Anderson, P.J., and J.F. Piatt. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series. *Accepted.*

Piatt, J.F., G. Drew, T.Van Pelt, A. Abookire, A. Nielsen, M. Shultz, and A. Kitaysky. 1999. Biological effects of the 1997/1998 ENSO event in lower Cook Inlet, Alaska. PICES Scientific Report No. 10. *In press.*

Zador, S., and J.F. Piatt. 1998. Time-budgets of Common Murres at a declining and increasing colony in Alaska. Condor 101:149-152.

Robards, M.R., and J.F. Piatt. 1999. Biology of the Genus *Ammodytes* - The Sand Lances. U.S. Forest Service Technical Report Series. *In Press.*

Willson, M.F., R.H. Armstrong, M.D. Robards, and J.F. Piatt. 1999. Sand lance as cornerstone species for predator populations. U.S. Forest Service Technical Report Series. *In Press.*

Kitaysky, A.S., J.C. Wingfield, and J.F. Piatt. 1998. Dynamics of food availability, body condition and physiological stress response in breeding Black-legged kittiwakes. Functional Ecology. *Accepted.*

Robards, M.D., J.F. Piatt, and G.A. Rose. 1999. Maturation, fecundity and intertidal spawning of Pacific Sand Lance (*Ammodytes hexapterus*) in the northern Gulf of Alaska. Journal of Fish Biology. *In press.*

Robards, M., J.F. Piatt, A. Kettle, and A. Abookire. 1999. Temporal and geographic variation in fish populations in nearshore and shelf areas of lower Cook Inlet, Alaska. Fishery Bulletin. *In Press.*

Kuletz, K. and J.F. Piatt. 1998. Juvenile Marbled Murrelet nurseries and the productivity index. Wilson Bulletin. *In press.*

Piatt, J.F., N.L. Naslund, and T.I. van Pelt. 1998. Nesting habitat selection and nest-site fidelity in the Kittlitz's Murrelet (*Brachyramphus brevirostris*). Northwestern Naturalist *In Press.*

Litzow, M.A., J.F. Piatt, and J.D. Figurski. 1998. Hermit crabs in the diet of Pigeon Guillemots at Kachemak Bay, Alaska. Colonial Waterbirds. 21:242-244.

Abookire, A.A. and B.L. Norcross. 1998. Depth and substrate as determinants of distribution of juvenile flathead sole (*Hippoglossoides elassodon*) and rock sole (*Pleuronectes bilineatus*) in southcentral Alaska. Journal Sea Research 39:113-123.

Piatt, J.F. 1998. Marbled Murrelets *have* declined in Alaska. Northwest Science 72:310-314.

Van Pelt, T.I., J.F. Piatt, and G.B. van Vliet. 1998. Vocalizations of the Kittlitz's Murrelet. Condor. *In press.*

Piatt, J.F., D.D. Roby, L. Henkel, and K. Neuman. 1998. Habitat use, diet, and breeding biology of Tufted Puffins in Prince William Sound, Alaska. Northwestern Naturalist 78:102-109.

Piatt, J.F., and T.I. van Pelt. 1997. Mass-mortality of guillemots (*Uria aalge*) in the Gulf of Alaska in 1993. Marine Pollution Bulletin 34:656-662.

Van Pelt, T., J.F. Piatt, B.K. Lance, and D.D. Roby. 1997. Proximate composition and energy density of some North Pacific forage fishes. Comparative Biochemistry and Physiology 118(A): 1393-1398.

Piatt, J.F. 1997. Alternative interpretations of oil spill data. Bioscience 47:202-203.

Kuletz, K.J., D.B. Irons, B.A. Agler, J.F. Piatt and D.C. Duffy. 1997. Long-term changes in diets and populations of piscivorous birds and mammals in Prince William Sound, Alaska. Pp. 703-706 *in*: Forage Fishes in Marine Ecosystems. Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems. Alaska Sea Grant College Program Report No. 97-01. University of Alaska Fairbanks.

Hobson, K.A., J.L. Sease, R.L. Merrick, and J.F. Piatt. 1997. Investigating trophic relationships of pinnipeds in Alaska and Washington using stable isotope ratios of nitrogen and carbon. Marine Mammal Science 13:114-132.

Piatt, J.F., and P. J. Anderson. 1996. Response of Common Murres to the *Exxon Valdez* oil spill and long-term changes in the Gulf of Alaska marine ecosystem. Pp. 720-737 in: Exxon Valdez Oil Spill Symposium Proceedings. Rice, S. D., R. B. Spies, D. A. Wolfe and B. A. Wright (Eds). American Fisheries Society Symposium 18, Bethesda, Maryland.

Piatt, J.F., and R. G. Ford. 1996. How many seabirds were killed by the *Exxon Valdez* oil spill? Pp. 712-719 in: Exxon Valdez Oil Spill Symposium Proceedings. Rice, S. D., R. B. Spies, D. A. Wolfe and B. A. Wright, (Eds). American Fisheries Society Symposium 18, Bethesda, Maryland.

Piatt, J. 1995. Water over the bridge. American Scientist 83:396-398.

Van Pelt, T.I., and J.F. Piatt. 1995. Deposition and persistence of beachcast seabird carcasses. Marine Pollution Bulletin 30:794-802.

FY 00 BUDGET

The FY00 budget includes only requests for salary support for staff needed to compete the above reports and manuscripts. We estimate that the 25 products for FY00 outlined above would require 72 person-months of effort to complete. Funding would support 8 different staff members for one year (5) or for part of the year (3), of which 3 would be paid through contracts and university agreements, and the rest would be maintained as USGS employees.

Summary EVOS Budget FY00:

	$1000's
Personnel	145.0

Travel	0.0
Contractual	68.0
Commodities	0.0
Equipment	0.0
Subtotal	213.0
Gen. Admin.	26.5
Total	239.5

Statistical Review submitted under the Broad Agency Announcement (BAA) by the National Oceanic and Atmospheric Administration (NOAA).

Project Number:	00163 O
Restoration Category:	
Proposer:	Dr. Lyman L. McDonald, Western EcoSystems Technology, 2003 Central Avenue, Cheyenne, Wyoming 82001
Lead Trustee Agency:	NOAA
Cooperating Agencies:	USFWS
Duration:	6 Years
Cost FY 96:	$21,400
Cost FY 97:	$21,400
Cost FY 98:	$21,400
Cost FY 99:	$32,100
Cost FY 00:	$32,100
Cost FY 01:	$32,100
Geographic Area:	Prince William Sound, Cook Inlet and Gulf of Alaska
Injured Resource/Service:	Statistical Review of Study Design and Analysis

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 resource selection functions. During the FY 2000, we propose to contribute as co-authors on three papers with William Ostrand and T. A. Gotthardt. In addition, other APEX Principal Investigators have identified a need for us to cooperate on 10 proposed papers. This proposed work will involve consultation on statistical analysis procedures or review of statistical methods used in draft manuscripts. We will participate in preparation of the APEX Final Report due in September, 2000. During FY 2001, five manuscripts have been identified on which we will cooperate. We anticipate that additional manuscripts will be proposed for completion in FY 2001.

Statement of Problem and Rationale

Constraints on sampling designs for acoustic survey of nearshore forage fish, analysis of fish diets, ocular observations of foraging sea birds, and collection of extensive data at seabird colonies continue to call for non-standard statistical analyses. During the FY 2000, we propose to co-author three manuscripts with William Ostrand and T. A. Gotthardt:

1) Ostrand, W. D., T. A. Gotthardt, and J. Kern. Resource selection by the seabirds of Prince William Sound, Alaska: comparisons of 1996 through 1999.
Cooperator: J. Kern of Western EcoSystems Technology, Inc.

2) Ostrand, W. D., T. A. Gotthardt, and J. Kern. A method for determining the distribution of potential Sand Lance habitat through the interpretation of hydroacoustic data.
Cooperator: J. Kern of Western EcoSystems Technology, Inc.

3) T. A. Gotthardt, W. D. Ostrand, and J. Kern. Distribution of sand lance and burrowing habitat within Prince William Sound, Alaska.
Cooperator: J. Kern of Western EcoSystems Technology, Inc.

In addition, APEX Principal Investigators have identified 10 manuscripts to be submitted before or during FY 2000 on which WEST, Inc. will cooperate. This proposed work will involve consultation on statistical analysis procedures or review of statistical methods used in draft manuscripts. At this time we do not anticipate that the level of effort required of WEST, Inc. on these manuscripts will be sufficient to warrant joint authorship. However, if unique methodology is required in the analyses or other significant contributions are made to the manuscripts then joint authorship is anticipated. The manuscripts identified are:

1) Foraging Dynamics of Pigeon Guillemots During Chick Rearing Authors: Golet, Roby? Irons?, Kuletz?, Fischer?
Estimated submission date: 15 May 2000 Target Journal: Animal Behavior?
Cooperators: Lyman McDonald and other employees of WEST, Inc.

2) Effects of Prey Delivery Rates, Energy Density, and Meal Size on Chick Growth and Productivity of Pigeon Guillemots
Authors: Golet, Litzow, Roby, Jodice, Piatt, Irons?, Fischer? Estimated submission date: 15 May 2000
Target Journal: Canadian Journal of Zoology?
Cooperators: Lyman McDonald and other employees of WEST, Inc.

3) Ostrand, W. D., T. A. Gotthardt, K. J. Kuletz, and K. O. Coyle. Murrelet and seabird foraging habitat in Prince William Sound, Alaska.
Cooperators: K. J. Kuletz and J. Kern of WEST, Inc.

4) M. D. Robards, W. D. Ostrand, and T. A. Gotthardt, and. Comparative analysis of sand lance distribution and habitat preferences in Cook Inlet and Prince William Sound, Alaska.

Cooperators: J. F. Piatt and M. D. Robards of BRD, USGS; J. Kern of WEST, Inc.

5) Benson, J., R.M. Suryan and J.F. Piatt. A multivariate approach to assessing nestling growth from one-time measurements.
Cooperators: Lyman McDonald and other employees of WEST, Inc.

6) Benson, J., R.M. Suryan and D.B. Irons. Limitations of foraging effort of kittiwakes while provisioning nestlings: quantification of a "buffer."
Cooperators: Lyman McDonald and other employees of WEST, Inc

7) Kaufman, M., R.M. Suryan, D.B. Irons and J. Benson. Detecting intra- and inter-annual variation in prey availability using daily foraging trip durations.
Cooperators: Lyman McDonald and other employees of WEST, Inc

8) Kuletz, K.J., R. Burns, L. Prestash, D. Marks, D. Nigro. Foraging ranges and habitats used by radio-tagged marbled murrelets in Prince William Sound, Alaska. Condor. (Most analyses is done. The paper needs to be written, and submitted for peer review.)
Cooperators: Lyman McDonald and other employees of WEST, Inc

9) Kuletz, K.J., E. Brown, L. Haldorson (?). Effects of prey type, abundance, and distribution on the breeding and productivity of marbled murrelets in Prince William Sound, Alaska. Auk.
Cooperators: Lyman McDonald and other employees of WEST, Inc

10) Kuletz, K.J., E. Brown, B. Ostrand. Functional response thresholds of adult and juvenile marbled murrelets to schools of fish during the breeding season. Waterbirds.
Cooperators: Lyman McDonald and other employees of WEST, Inc

During FY 2001, we propose to cooperate in preparation of manuscripts including:

1) Suryan, R.M., D.B. Irons, J. Benson, L. Halsorsen, J. Thedinga, L. Hulbert and E. Brown. Kittiwakes as indicators of forage fish availability in Prince William Sound, Alaska.

2) Suryan, R.M. and D.B. Irons. A long-term monitoring plan for Black-legged Kittiwakes in Prince William Sound, Alaska.

3) Irons, D.B., G.G. Golet, R.M. Suryan and T.M. Sauer. Survival rates of Black-legged Kittiwakes in relation to prey abundance.

4) Kuletz, K.J., J. Piatt, and [oceanography person]. Oceanographic factors as predictors of marbled murrelet distribution, chronology, and productivity in southcentral Alaska. Marine Ecology Progress Series.

5) Kuletz, K.J. and R. DeVelice. Marine and terrestrial factors determining the distribution and productivity of marbled murrelets: management implications for a widely dispersed seabird. Conservation Biology.

Additional work proposed for FY2001.

WEST has interacted with principal investigators on studies in Prince William sound which have generated data on a variety of trophic levels in the PWS ecosystem. To date, these data have not been adequately integrated or synthesized at the regional PWS scale. Currently there are estimates of biomass density at 25 near shore study areas, aerial identification of individual fish schools in those areas and surveys of sea bird use areas associated with the acoustic transects and based on long term monitoring of seabirds in PWS. We propose to assess the compatibility of these data for synthesis by statistical procedures and to investigate relationships between biota endpoints including resource selection studies. Additionally, existing seabird monitoring data collected by the US Fish and Wildlife Service could also be used to validate seabird resource selection models developed from APEX data. These investigations would require collaborative efforts from WEST, Kenneth Coyle, William Ostrand, David Irons, John Thedinga (?) and Lee Hulbert (?) and should result in one or two jointly authored papers.

Summary of Major Hypotheses and Objectives

We will continue to interact with the Principal Investigators and authors of the various manuscripts to help develop testable hypotheses and to insure that appropriate statistical procedures are used in the analyses. In particular, our specialty includes analysis and modeling of resource selection by animals and we will be working closely with investigators to quantify and model habitat and food selection by sea birds.

COMMUNITY INVOLVEMENT

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

Proposed FY 2000 Budget :

Position		Months	Cost per Month		Subtotal
Senior Biometrician		0.75	$14,400		$10,800
Biometrician II		1.5	$10,400		$15,600
Travel:			No. Trips	Cost/ticket	
DIA to Anchorage		2	trips @	$900	1800
Meal Per Diem		10	days @	35	350
Hotel Per Diem Winter		4	days @	60	240
Hotel Per Diem Summer		4	days @	90	360
Car Rental		10	days @	40	400
Commodities:					
Long Distance Telephone					300
Shipping, Postage					100
Supplies					50
=============	=====	====	=====	=====	=====
FY00 Project Budget					$30,000
FY00 Budget Total					$32,100

PROJECT DESIGN

Not Applicable

SCHEDULE

A. Measurable Project Tasks for FY 00:

1 October 1999 to 30 September 2000: Submit three jointly authored manuscripts with APEX Principal Investigators. Contribute to other manuscripts as outlined above.

B. Project Milestones and Endpoints

Journal publications are primarily the responsibility of the individual Principal Investigators. We will provide consultation and assistance on development of unique statistical analyses. We will review manuscripts as requested.

C. Project Reports

Project reports are primarily the responsibility of the individual Principal Investigators. We will provide consultation and assistance in data analysis and review of statistical analyses. Significant new or unique applications of statistical methods will result in joint authorship on papers.

I. Deliverable Date for the APEX Final Report

September 30, 2000.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

Dr. McDonald is a member of the Nearshore Vertebrate Predator (NVP) Project and will help to coordinate research activities between APEX and NVP.

ENVIRONMENTAL COMPLIANCE

Not Applicable

PERSONNEL

Dr. Lyman L. McDonald, Senior Biometrician
Dr. John Kern, Biometrician II
Dr. Trent L. McDonald, Biometrician II
Western EcoSystems Technology, Inc.
2003 Central Avenue
Cheyenne, WY 82001

THE FACTORS THAT LIMIT SEABIRD RECOVERY IN THE EVOS STUDY AREA: A MODELING APPROACH SUBMITTED UNDER THE BAA

Project Number:	20163Q
Restoration Category:	Research
Proposer:	H.T. Harvey & Associates
Lead Trustee Agency:	NOAA
Cooperating Agencies:	DOI, USGS, UA, OSU
Alaska SeaLife Center:	No
Duration:	4th year
Cost FY 99:	$67,500
Geographic Area:	No field work anticipated
Injured Resource/Service:	All seabird species being considered by APEX

ABSTRACT

We propose to use models to assess ways in which food supply could be affecting recovery of seabirds in the EVOS study area. We will continue to develop models of foraging effort and success as it relates to breeding productivity and population growth. In the first year of effort, we integrated oceanographic and forage-fish data to explain foraging strategies as they affect breeding productivity in the Black-legged Kittiwakes of Prince William Sound, especially 1995 and 1996. In the second and third year of effort we incorporated 1997 and 1998 data, when fish and kittiwake data were collected more synoptically, worked with Pigeon Guillemot data, and worked directly with field researchers to integrate bird with fish data. We also analyzed kittiwake foraging behavior in relation to physical and biological factors and developed an initial foraging model. In the proposed, fourth year of effort we will adapt models to the Pigeon Guillemot in both Prince William Sound and Lower Cook Inlet. We will also attempt to work with data gathered for Marbled Murrelets. Results will test the degree to which food limitation is affecting recovery, indicate the mechanisms by which this could come about, and identify the scale at which interactions are occurring between food availability and the colonies being studied by APEX.

INTRODUCTION

The APEX Project in Prince William Sound is based on the hypothesis that reduced food supply during the chick-provisioning period of seabird reproduction is slowing the recovery of seabird populations from mortality incurred during the *Exxon Valdez* oil spill (EVOS). This hypothesis has precedent, in that it was argued to be the case for similar species at the same latitude nesting around the British Isles (Furness & Birkhead 1984, Cairns 1989; see below). However, the hypothesis has not been tested among the Prince William Sound and Lower Cook Inlet colonies and, as shown by Furness & Birkhead (1984) and Ainley et al. (1995), geographic scale figures importantly in the way that the effect could come about.

We propose here to use models to assess the ways in which food supply could be affecting recovery. For seabirds nesting in the EVOS study area, we have been developing models of foraging effort and success as it relates to breeding productivity. Results not only will test the degree to which the hypothesis of food limitation is valid, but will indicate the scale at which researchers should be assessing interactions between food availability and the colonies being studied. Moreover, results thus far have served to integrate the APEX research effort by bringing together the data from several APEX components. Our results also help to "aim" field work so that sufficient data are collected to provide input into the overriding APEX objective: to understand the ways in which food supply is limiting recovery of seabirds in the EVOS study area. Our work will be based on existing data (e.g. the Alaska Seabird Colony Register) and certain results of ongoing APEX studies (e.g. foraging range of affected species in the region, search effort of foraging birds, and forage fish availability). We have been and will continue to work closely with APEX PIs, soliciting their input in all phases of our effort.

NEED FOR THE PROJECT

A. Statement of Problem

The factors that affect the size or growth of seabird populations are complex and more than one mechanism may be involved. It has been theorized, in general, that the <u>size</u> (and therefore the growth, too) of a seabird population in a region is affected by food supply during breeding and/or nesting space; influencing population growth, as well, are the contributions of density-dependent mortality during the non-breeding season (a function also of food supply) and social factors related to colonial nesting (Birkhead & Furness 1985; Cairns 1989, 1992). In some cases nesting space appears to be the more important ultimate factor (e.g., Duffy 1983; Ainley & Boekelheide 1990) and in others it is argued that food is the more important, especially during the chick provisioning period (e.g., Ashmole 1963, 1971; Furness & Birkhead 1984, Cairns 1989).

The geographic structure or distribution of a seabird population in a region (i.e., the size and spacing of colonies) is also affected by availability of nesting habitat and food (Furness & Birkhead 1984, Cairns 1989). In Prince William Sound, predation by aerial species likely is important. These factors are allocated by an interplay of forces, both "positive" (favoring coloniality) and "negative" (favoring solitary living) (Ainley et al. 1995). As summarized by Wittenberger & Hunt (1985) and Burger & Gochfeld (1990), negative forces, such as interference and exploitative competition, counter the positive ones, such as group defense against predators and facility in gaining mates. If the size distribution of colonies is stable, this implies both sets of forces to be at work. Negative forces, mediated proximally through emigration to colonies with more favorable conditions or establishment of new colonies, act on colony size through a negative feedback loop: the greater the colony size, the greater the impact of negative forces, thus, encouraging a reduction in colony size. Positive factors, in contrast, result in positive feedback: to new recruits, high density areas are the most attractive. If positive forces are sufficiently strong relative to negative ones, new colonies would not be established.

The factors that affect total population size come to bear when new colonies are formed or depleted ones re-established. Many studies of seabirds have found that when breeding density at large colonies is high, prospectors are more likely to settle at smaller colonies nearby, thus, increasing the emigration rate from the central colony and increasing growth rate of small colonies (e.g. Potts 1969, Potts et al. 1980, Birkhead & Hudson 1977, Coulson et al. 1982). Conversely, small colonies decrease more rapidly than larger colonies, as demonstrated in studies of kittiwakes *Rissa* sp. (Coulson 1983) and murres *Uria* sp. (Takekawa et al. 1990). Additionally, inverse relationships between colony size and breeding success and chick growth also provide indirect evidence for food limitation (studies of murres: Hunt et al. 1986, Gaston et al. 1983).

B. Rationale/Link to Restoration

The APEX project should provide much insight about the ecological processes that affect the well being, growth, and size of seabird populations in Prince William Sound and Cooke Inlet (EVOS study area). However, the project's underlying assumptions need to be fully tested so that the mechanisms by which food limitation is affecting population growth can be fully appreciated and to insure that sufficient data on pertinent aspects of seabird life history are being collected so that, in the end, an integrated explanation of population limitation and colony distribution is available. A meaningful way by which to carry out this test is to use models, both foraging and demographic.

To date, we have formatted and integrated data from several APEX components: 1) Component A: forage fish availability; 2) Component E: Kittiwake foraging ecology and breeding success; 3) Component F: Guillemot foraging ecology and breeding success; and 4) Component G: Seabird energetics. We also have made extensive use of data gathered by the SEA component of the EVOS restoration effort. We have defined and ranked seabird foraging areas (especially kittiwakes and, to a growing degree, guillemots); quantified foraging effort; related foraging effort to forage fish availability; and begun to relate the latter to demographic processes. Results indicate that the recovery of Prince William Sound seabirds, indeed, is linked to the availability of forage fish.

C. Location

The data used in the modeling will come from Prince William Sound and Cooke Inlet as a result of the APEX project and other efforts such as the Alaska Seabird Colony Register. Our effort will be conducted on computers at our home offices. The benefits of the project will be realized in the EVOS area, as results will help to direct restoration of seabird colonies there.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

All communities affected by the APEX project will be involved indirectly in the proposed work.

PROJECT DESIGN

A. Objectives

Hypotheses to be evaluated by modeling using existing data: Under the null hypothesis,

1. Annual survivorship, age of first breeding, foraging range, feeding frequency of chicks, and reproductive success are not related to the availability of forage fish.

2. Exploitation of the fish resource by seabird species is not related to the previous experience, hence the foraging strategy, of individual birds.

B. Methods

We will be keying analyses on APEX species and those identified as not recovering (kittiwake, murrelets, pigeon guillemots).

To test Hypothesis 1, we will be constructing models of demography and foraging energetics as related to breeding success, as follows.

Demographic Analysis. Demographic and reproductive data from colonies that are not recovering will be used to determine those aspects of colony performance that are having the most significant effect in delaying or preventing recovery. Where data are available, we will construct simple life table models of pre- and post-spill colonies to determine which demographic factors contribute the most to declining (or not growing) colony sizes. This analysis will help to determine when and on what age-class the effects of food limitation would be most significant, and help to provide further insight into the mechanism(s) underlying poor colony performance.

Foraging Energetics and Breeding Success. Understanding the linkage between food availability and breeding success is critical to formulating a model that can predict the effect of perturbations of food supply on seabird populations. These relationships were modeled in detail by Ford et al. (1982) for oil spill-induced perturbations of murre and kittiwake populations on the Pribilof Islands. This model concluded that the effects of direct adult mortality during an oil spill were of greater significance than the concurrent reduction in food supply, but did not address the effects of long-term decreases in food availability.

Food availability, and how it affects prospects for recovery from catastrophic events (such as oil spills) were considered in a more recent model constructed by Nur et al. (1992). This model was directed toward recovery of the populations of three seabird species, including the common murre. It was found, indeed, that food availability has importance influences on recovery, as it affects many of the demographic parameters that cause a seabird population to grow (e.g., chick production, survivorship, age of first breeding, and breeding probability). Most of these parameters concern aspects of seabird life history that bear on adults and subadults. The modeling was based on empirical data on seabird populations at the Farallon Islands, California.

We are taking an empirical approach for the present study, as well, relying on data from ongoing and future studies in Prince William Sound and Lower Cook Inlet (APEX). Emphasis has been placed on describing the relationship between the quantity and quality of food delivered to the chicks and subsequent reproductive success, and the relationship between food availability, foraging strategy and delivery rates. This analysis has already revealed APEX data gaps relating to the linkage between food availability, breeding success and population growth, and that these findings have provided guidance for subsequent field studies. Our work in Prince William Sound to date has showed, too, that the population growth of seabirds (kittiwakes) is linked directly to forage fish availability.

C. Cooperating Agencies, Contracts, and Other Agency Assistance

The proposed analysis will be conducted by individuals from private institutions. However, PI's will consult frequently with the biologists from Trustee agencies who are collecting the data in the APEX project. Agency personnel will likely be co-authors of the reports or publications prepared. The other institutions and agencies involved include Department of the Interior, U.S. Geologic Survey, University of Alaska, and Oregon State University.

SCHEDULE

A. Measurable Project Tasks for FY 2000 (October 1, 1999 - September 30, 2000)

Jan. 1- :	Assemble data resulting from APEX during FY 99
March 23-26:	Attend annual Restoration Workshop (10-yr synthesis).
May 1 - 30 June:	Continue to assemble data; adapt models derived in year 1
1 July - 31 August:	Refine models of seabird foraging effort/breeding
1 - 30 September:	Finish final report for review.
Winter 1999-2000:	Revise final report.

B. Project Milestones and Endpoints

30 September 1999:	Annual report, with foraging/energetic model.
January 2000:	Present papers at annual meeting of Pacific Seabird Group:
15 April 1999:	Submit final version of annual report.
Spring 2000:	Submit papers for publication in either *Condor* or *Auk*

C. Completion Date

A draft final report will be available by 15 January 2000.

PUBLICATIONS AND REPORTS

Besides an annual report, we anticipate the following publications:

1. Physical and biological factors affecting the occurrence patterns of foraging Black-legged Kittiwakes in Prince William Sound, Alaska.

   Authors: Ainley (0.25 mo), Brown, Ford (0.25), Spear; this is wrap up of writing that began in FY 99. Results initially presented at 23-27 March 1999 Symposium

2. Physical and biological factors affecting the distribution and size of Black-legged Kittiwake colonies in Prince William Sound, Alaska. Analysis begun in FY99.

   Authors: Ainley (0.5 mo), Ford (0.75 mo), Spear (0.25 mo)

3. A model of foraging strategies of Black-legged Kittiwakes in Prince William Sound, Alaska.

   Authors: Ford (2.0 mo), Brown (0.25 mo), Irons (0.25 mo), Suryan (0.25 mo), Ainley (0.5 mo).

PROFESSIONAL CONFERENCES

We anticipate presenting two papers, among those identified above, at the annual meeting of the Pacific Seabird Group in winter 1999-2000.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

This project depends fully on integration with almost all studies in the APEX project.

PROPOSED PRINCIPAL INVESTIGATORS

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PERSONNEL

David G. Ainley, PhD, has investigated the ecology of seabirds for 25 years, having conducted studies in Alaska, California, Mexico, Hawaii and Antarctica. Much of his research has involved the species of seabirds affected by EVOS, especially guillemots and murres. He has published over 125 scientific papers and has authored three books and 2 monographs. With Glen Ford, he participated in development of demographic models to assess impacts of catastrophic events on seabird populations in California (for NOAA, Gulf of the Farallones National Marine Sanctuary).

Selected Ainley Publications

Ainley, D.G. & R.J. Boekelheide (eds.). 1990. Seabirds of the Farallon Islands: Ecology, Structure and Dynamics of an Upwelling System Community. Stanford University Press, Palo Alto. 425 pp.

Ainley, D.G. N. Nur & E. J. Woehler. 1995. Factors affecting the size and distribution of pygoscelid penguin colonies in the Antarctic. Auk 112: 171-182.

Ainley, D.G., L.B. Spear & S.G. Allen. 1997. Temporal and spatial variation in the diet of the Common Murre in California. Condor.

Ainley, D.G., W. J. Sydeman, S. A. Hatch & U. W. Wilson. 1994. Seabird population trends along the west coast of North America: causes and the extent of regional concordance. Studies Avian Biol. 15: 119-133.

Ainley, D.G., W. J. Sydeman, R. H. Parrish & W. R. Lenarz. 1993. Oceanic factors influencing distribution of young rockfish (*Sebastes*) in central California: a predator's perspective. Calif. Coop. Ocean. Fish. Investig., Repts. 34: 133-139

R.Glenn Ford, PhD, was trained in mathematical ecology at University of California, Berkeley, and has been investigating the quantitative ecology of seabirds for the past 20 years, especially in regard to species of the eastern North Pacific, Gulf of Alaska and Bering Sea. He is well versed in GIS applications, having developed software that has been used widely by marine ornithologists, including those studying marbled murrelets in Alaska. He has modeled impacts of oil spills to marine bird populations and conducted computer simulations of the response of seabirds to perturbations in their food supply. Dr. Ford has authored 23 scientific papers (and 28 reports), including 11 on marine birds.

<u>Selected Ford Publications</u>

Ford, R.G., J.A. Wiens, D. Heinemann & G.L. Hunt, Jr. 1982. Modeling the sensitivity of colonially breeding marine birds to oil perturbation. J. Appl. Ecol. 19:1-31.

Ford, R.G., M.L. Bonnell, D.H. Varoujean, G.W. Page, H.R. Carter, B.E. Sharpe, D. Heinemann & J.L. Casey. 1996. Total direct mortality of seabirds from the *Exxon Valdez* oil spill. In: B. Wright, J. Rice, R. Spies & D. Wolfe (eds.) Am. Fish. Soc. Symposium, Vol. 18 (in press).

Nur, N., R.G. Ford & D.G. Ainley. 1993. Computer model of Farallon seabird populations. Natl. Ocean. Atmosph. Admin., Gulf Farallones Natl. Mar. Sanct., Contract CX-8140-1-0019. San Francisco CA.

Piatt, J.F. & R.G. Ford. 1993. Distribution and abundance of Marbled Murrelets in Alaska. Condor 95:662-669.

Wiens, J.A., R.G. Ford, D. Heinemann & C. Fieber. 1978. Simulation of marine bird population energetics, food consumption, and sensitivity to perturbation: Pribilof Islands. In: Environmental Assessment of the Alaskan Continental Shelf. Annual Reports 2: 1-83.

David C. Schneider, PhD, has been involved in a number of studies on the distribution of seabirds in relationship to marine features and has constructed bioenergetic and carbon models to assess the role of seabirds in nutrient cycling in the Bering Sea, Benguela Current, and elsewhere. He has authored over 50 publications, including the recently published book: *Quantitative Ecology: Spatial and Temporal Scaling.* Currently, he holds a position at the Institute of Cold Ocean Science, Memorial University, Newfoundland.

<u>Selected Schneider Publications</u>

Schneider, D.C. 1995. Spatial and temporal scaling of energy flux through populations of marine nekton. Pp. 419-428 in (E. Runde & K.J. Erikstad, eds.) Ecology of Fjords and Coastal Waters. Elsevier, Amsterdam.

Schneider, D.C. 1994. Scale-dependent spatial dynamics: marine birds in the Bering Sea. Biol. Reviews 68:579-598.

Schneider, D.C. & V.P. Shuntov. 1993. The trophic organization of marine birds in the Bering Sea. Rev. Fish. Sci. 1:311-335.

Schneider, D.C. 1992. The thinning and clearing of prey by predators. Amer. Natur. 139:148-160.

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Birkhead, T.R. & R.W. Furness. 1985. The regulation of seabird populations, pp. 145-167 in (R.M. Sibly & R.H. Smith, eds.) Behavioural Ecology. Blackwell, Oxford.

Birkhead, T.R. & P.J. Hudson. 1977. Population parameters for the Common Guillemot *Uria aalge*. Ornis Scand. 8:145-154.

Burger, J. & M. Gochfeld. 1990. The Black Skimmer: Social Dynamics of a Colonial Species. Columbia Univer. Press, New York.

Cairns, D.K. 1989. The regulation of seabird colony size: a hinterland model. Amer. Nat. 134:141-146.

Cairns, D.K. 1992. Population regulation of seabird colonies, pp. 37-61 in (D.M. Power, ed.) Current Ornithology, Vol. 9. Plenum Press, NY.

Coulson, J.C. 1983. The changing status of the Kittiwake *Rissa tridactyla* in the British Isles, 1969-1979. Bird Study 30:9-16.

Coulson, J.C., N. Duncan & C. Thomas. 1982. Changes in the breeding biology of the Herring Gull *Larus argentatus* induced by reduction in the size and density of the colony. J. Animal Ecol. 51:739-756.

Duffy, D.C. 1983. Competition for nesting space among Peruvian guano birds. Auk 100:680-688.

Ford, R.G, J. A. Wiens, D. Heinemann & G.L. Hunt, Jr. 1982. Modeling the sensitivity of colonially breeding marine birds to oil spills: guillemot and kittiwake populations on the Pribilof Islands, Bering Sea. J. Appl. Ecol. 19:1-31.

Furness, R.W. & T.R. Birkhead. 1984. Seabird colony distributions suggest competition for food supplies during the breeding season. Nature 311:655-656.

Gaston, A.J., G. Chapdelaine & D.G. Noble. 1983. The growth of Thick-billed Murre chicks at colonies in Hudson Strait: inter- and intra-colony variation. Can. J. Zool. 61:2465-2475.

Hunt, G.L., Jr., Z.A. Eppley & D.C. Schneider. 1986. Reproductive performance of seabirds: the importance of population and colony size. Auk 103:306-317.

Lack, D. 1954. The Natural Regulation of Animal Numbers. Clarenden, Oxford, UK.

Nur, N., R.G. Ford & D.G. Ainley. 1993. Computer model of Farallon seabird populations. Natl. Ocean. Atmosph. Admin., Gulf Farallones Natl. Mar. Sanct., Contract CX-8140-1-0019. San Francisco CA.

Potts, G.R. 1969. The influence of eruptive movements, age, population size and other factors on the survival of the Shag (*Phalacrocorax aristotelis* L.). J. Anim. Ecol. 38:53-102.

Potts, G.R., J.C. Coulson & I.R. Deans. 1980. Population dynamics and breeding success of the Shag *Phalacrocorax aristotelis*, on the Farne Islands, Northumberland. J. Anim. Ecol. 49:465-484.

Takekawa, J., H.C. Carter & T.E. Harvey. 1990. Decline of the Common Murre in Central California, 1980-1986, pp. 149-163 in (S.G. Sealy, ed.) Auks at Sea. Studies in Avian Biology, Cooper Ornithol. Soc., Berkeley, CA.

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PURCELL et al., 1994a). Other estimates, based on laboratory experiments, of predation effects by pelagic cnidarians on fish eggs were low (0.1 to 3.8% d^{-1}; FANCETT and JENKINS, 1988).

At high jellyfish densities, as can occur especially in semi-enclosed bodies of water (PURCELL, 1990), such as Prince William Sound (PWS), predation on copepods may limit copepod populations and cause competition for food with zooplanktivorous fish species and fish larvae . Predation by jellyfish on fish eggs and larvae can be very severe. Medusae have potentially great effects on fish populations because of their often great abundances and feeding that increases directly with prey density without saturation.

Research to date on jellyfish in Prince William Sound. In July, 1996, I was invited to participate in the SEA sampling in PWS by Dr. Gary Thomas. During the field work, I observed the great abundance of jellyfish in northern PWS from aerial surveys and from trawls and acoustic surveys. Massive aggregations of *Aurelia* 1/4 to 2 km long were seen commonly from the air and by acoustics. *Cyanea* and *Aequorea* were distributed throughout PWS, but had higher densities in some areas (e.g. Irish Cove). The plane and acoustics boat would notify the seiner where to set his net on a fish school, but often more jellyfish than fish were in the net. I also compiled existing data from the Alaska Dept. of Fish and Game collected during SEA cruises that showed in drift seines, which were not set specifically on fish schools, jellyfish biomass often exceeded fish biomass in PWS.

In anticipation of EVOS funding starting in October, 1997, APEX investigators invited me to participate in the July-August cruise. The jellyfish populations were somewhat different from 1996, being generally less abundant and with *Aequorea* in low numbers. Specimens of four species (*Cyanea, Aurelia, Aequorea, Pleurobrachia*) were collected for gut content analysis. *Cyanea* and *Aequorea* ate mainly larvaceans and some copepods, while *Aurelia* and *Pleurobrachia* ctenophores ate mainly copepods (Fig. 1). Comparison of jellyfish diets with the diets of forage fish (juvenile pink salmon, walleye pollock, herring, and sandlance) showed that the fish diets also contained mainly copepods and larvaceans (Fish dietary data provided by Dr. Molly Sturdevant, Fig. 1). There was substantial dietary overlap between the jellyfish and fish species (Table 1). During the APEX cruise in July, 1998, specimens were individually collected and preserved for gut content analyses, which are in progress.

Figure 1. Gut contents of jellyfish and forage fish from PWS. Cope = copepods. (Data of Purcell and Sturdevant).

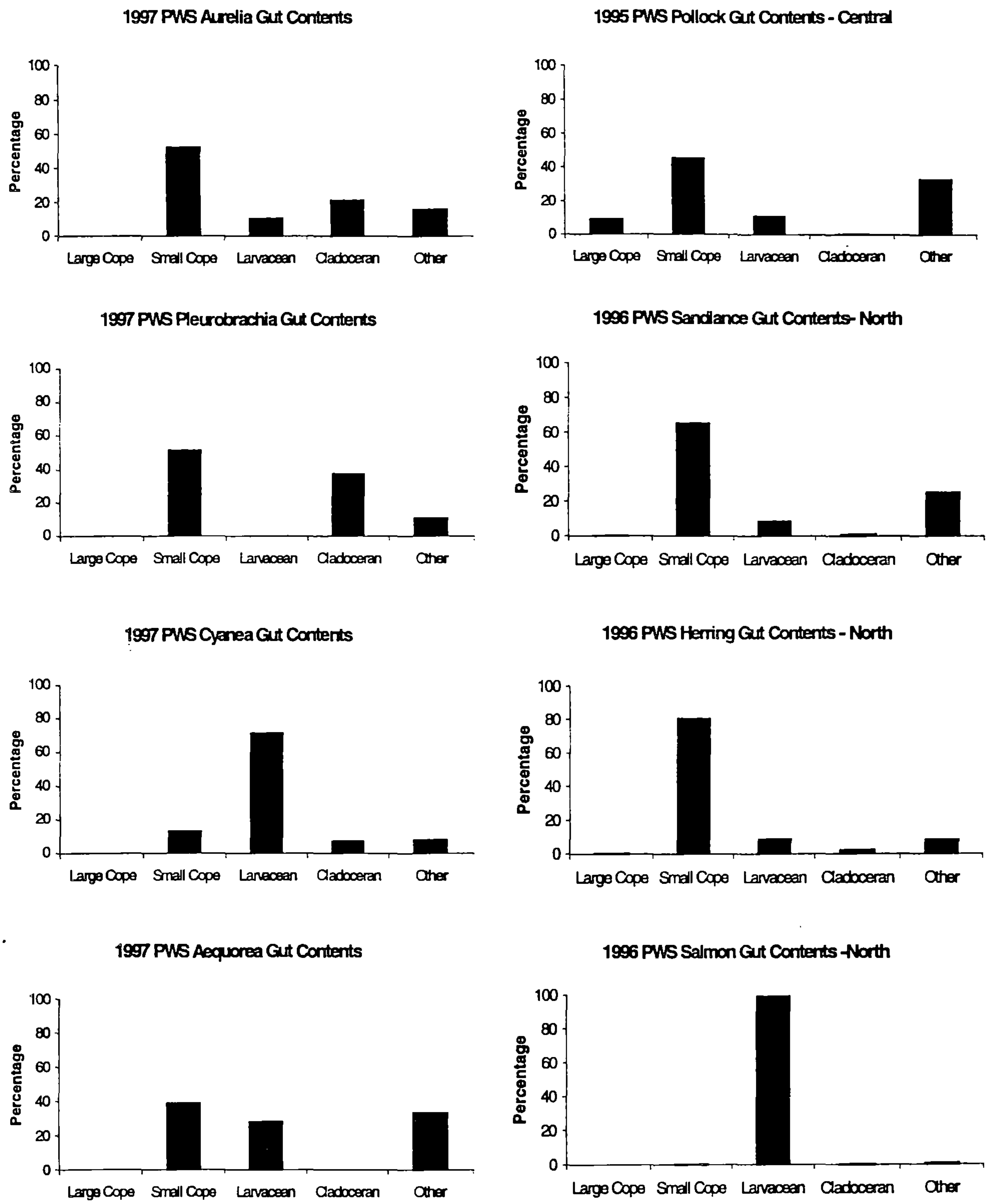


Table 1. Percent diet similarities (SCHOENER, 1974) among species of jellyfish and forage fish in PWS. The % similarities among mainly crustacean-eating species (top left) and among mainly larvacean-eating species (bottom right) are highlighted. (Data of Purcell and Sturdevant).

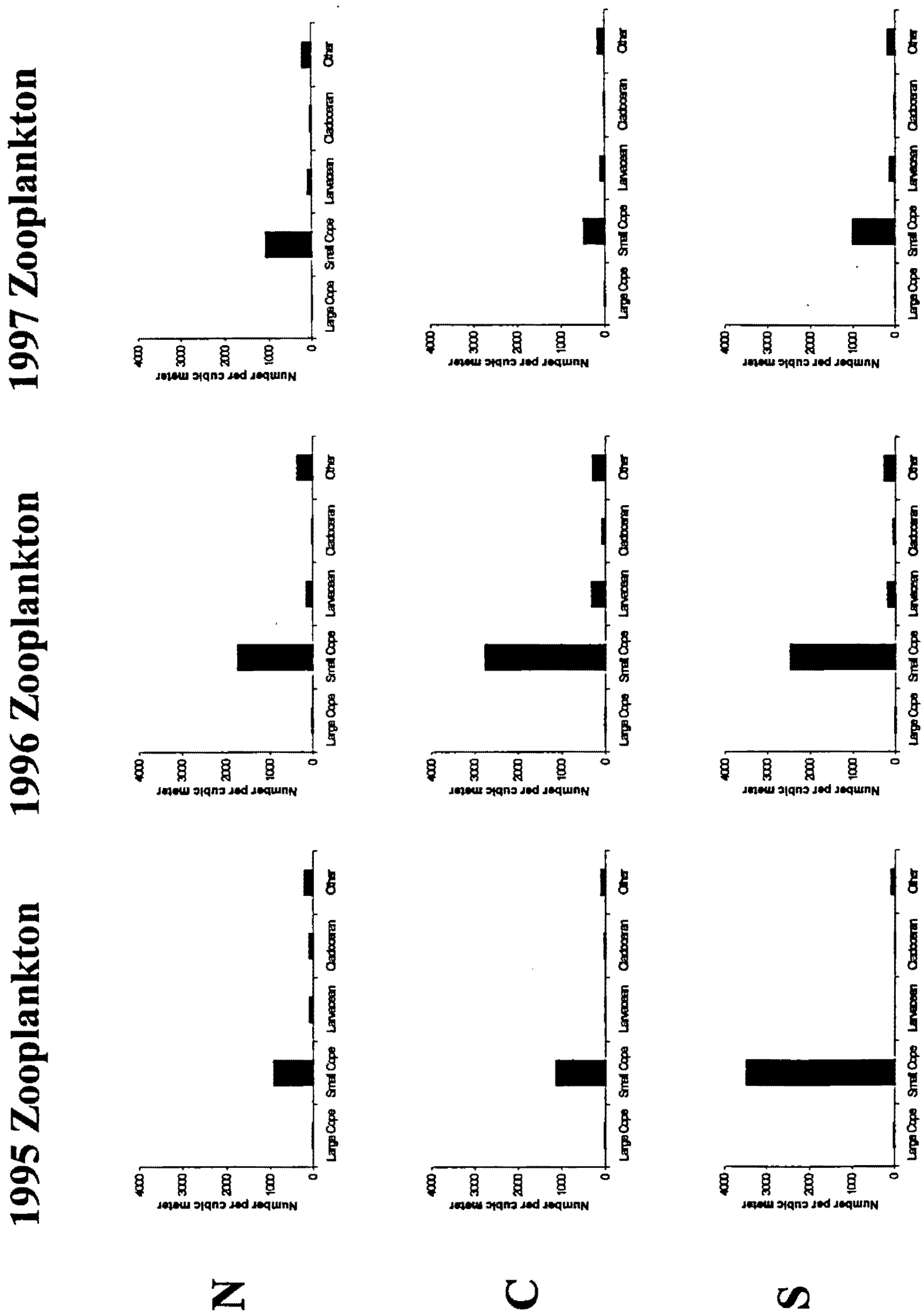
Percent Diet Similarity (%)

	Pollock	Sandlance	Herring	Salmon
Aurelia	67.2	61.6	67.4	18.7
Pleurobrachia	41.1	47.8	45.2	5.3
Cyanea	34.8	29.6	42.5	78.1
Aequorea	55.2	43.4	56.0	59.0

In order to estimate the feeding rates of jellyfish on zooplankton, digestion rates of the various prey taxa must be determined in addition to gut content analysis. Digestion experiments were conducted during the APEX cruise in July, 1998, and sample processing is underway. My preliminary results on *Aurelia* and *Cyanea* eating copepods and larvaceans are comparable to those of MARTINUSSEN and BAMSTEDT (1999), whose experiments were at a different temperature than typical for PWS in July, and did not include larvacean prey.

I have analyzed zooplankton samples from APEX cruises in July 1997 and 1998 (in progress), and compiled zooplankton data from APEX cruises in July 1995 and 1996 (Data provided by Dr. Molly Sturdevant). Those samples also provided data on small hydromedusae and ctenophores from PWS. There was high similarity in the percentages of the various zooplankton groups among years (mean 88%), thereby allowing valid comparisons between jellyfish and fish diets (above). The zooplankton and hydromedusae densities in 1996 were generally higher than in either 1995 and 1997 (Fig 2)

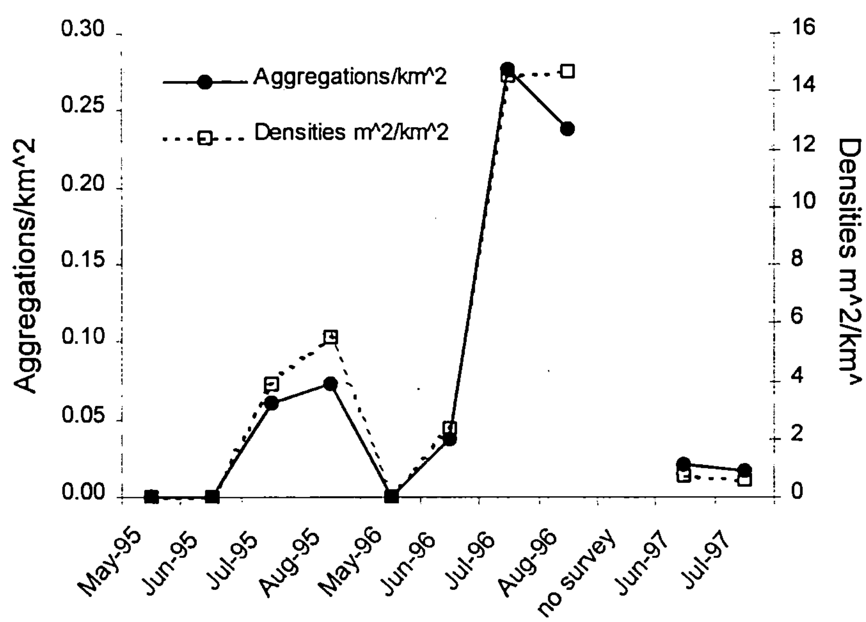
Figure 2. Zooplankton (numbers per m^3) in North, Central and South regions of PWS. Cope = copepods, N = northern region, C = central region, S = southern region. (Data of Sturdevant and Purcell).



A herring seine was set at each APEX station in July, 1998, and we measured the live volumes and numbers of each large jellyfish species (*Aurelia, Cyanea, Aequorea*). These data are extremely important because they will be used to calculate the predation effects of jellyfish on zooplankton populations, and because good biomass and abundance data are lacking for large jellyfish in PWS. Preliminary estimates indicate that jellyfish consumed an average of 4% d^{-1} of the copepods and larvaceans in PWS (range 2 - 13% d^{-1}). Such estimates will be made for 1997 - 1999. Preliminary comparisons of jellyfish biomass (adjusted for high water content) and forage fish biomass (data provided by Dr. Lew Haldorson) suggests that jellyfish have equal or higher biomasses in PWS than forage fish. We (Haldorson, Thedinga, Brown, Purcell) plan to refine our biomass estimates for careful comparisons between jellyfish and fish in 1998 and 1999.

The jellyfish *Aurelia* occurs in large aggregations that have provided extremely interesting data (PURCELL et al., submitted). In collaboration with Evelyn Brown, we analyzed aerial data on the distribution and abundance of aggregations of *Aurelia* in PWS from 1995, 1996, and 1997. 1996 showed significantly higher numbers of aggregations than 1995 or 1997 (Fig. 3). Data contributed by Dr. Kevin Stokesbury showed that whenever juvenile walleye pollock were captured in seine sets, *Aurelia* medusae also were numerous. Underwater videotapes provided by Dr. Lew Haldorson showed a school of juvenile walleye pollock underneath an *Aurelia* aggregation. We believe the apparent association of juvenile walleye pollock with *Aurelia* aggregations may provide the fish with protection from their many vertebrate predators, such as diving birds. Further analysis of the videotapes showed that jellyfish swimming was strongly directional (up or down) within the aggregations, suggesting that they were orienting to vertical flow or shear in the water column. I plan to continue collaboration with E. Brown to estimate *Aurelia* aggregation numbers and densities in 1998 and 1999 for interannual comparisons.

Figure 3. Seasonal and interannual variation in densities and surface areas of *Aurelia aurita* aggregations in PWS estimated from aerial surveys (PURCELL et al., submitted).



I also analyzed historical data on jellyfish abundance in the Gulf of Alaska provided by APEX investigator Dr. Paul Anderson, which showed a dramatic peak in abundance in 1980, during the faunal transition observed (ANDERSON et al. 1997) from mainly shrimp to predominantly groundfish. Preliminary data have been incorporated into the EcoPath model of PWS in collaboration with Drs. Thomas Okey and Daniel Pauly.

NEED FOR THE PROJECT

A. Statement of Problem

The project will address two of the main causes of natural mortality in fish populations, namely food limitation (through competition) and predation. It will specifically target forage fish species such as Pacific herring, sand lance, and juvenile pollock that are major prey of sea birds (e.g. pigeon guillemots) and other vertebrates (i.e. harbor seals) that have not recovered from the Exxon Valdez Oil Spill. This project addresses the APEX hypothesis that sea bird recovery has been hampered by changes in their food base, specifically forage fishes.

B. Rationale/Link to Restoration

Many natural factors that cannot be controlled by human efforts affect mortality in fish populations. It is important to estimate the magnitude of the various sources of mortality in order to evaluate those that are most important. This research will contribute to understanding the dynamics of forage fish populations, by determining the magnitude of jellyfish predation on their zooplankton foods. The forage fish populations continue to be reduced relative to pre-EVOS levels, and that would contribute to the lack of recovery of vertebrate species that depend on forage fish for food.

C. Location

Prince William Sound

COMMUNITY INVOLVEMENT

This project will use local personnel associated with the boat charters. During my visit to Cordova in July 1996, I gave a public presentation on the importance of jellyfish as predators and competitors of fishes and an interview with Sound Waves, which was broadcast locally and in Anchorage. Similar efforts at public education will be made throughout this project.

PROJECT DESIGN

A. Objectives

1. Determine annual variation in species composition, biomass, and abundances of jellyfish, ctenophores, and zooplankton in Prince William Sound, and evaluate interannual differences in environmental conditions (e.g. temperature, stratification) that could contribute to differences in plankton production in 1995 - 1999.

2. Evaluate interannual variation in prey consumption by key jellyfish species (*Aurelia, Cyanea, Aequorea* and other hydromedusae, *Pleurobrachia* ctenophores).

3. Determine the gut passage (digestion) times for key predator species eating key prey taxa (i.e. copepods, larvaceans).

4. Calculate size-specific feeding rates for each key predator species based on gut contents and gut passage times, and correlate feeding rates with medusa size and prey densities in order to be able to estimate feeding impacts in other years from jellyfish size distributions and jellyfish and zooplankton densities.

5. Calculate predation impacts (percentages of standing stocks consumed daily) on key prey taxa (copepods and larvaceans) based on feeding rates and densities of jellyfish and zooplankton prey species.

6. Compare the biomasses and predation effects of jellyfish and forage fishes in order to determine their relative importance as zooplanktivores in the PWS food web.

7. Contribute these results to the APEX, SEA and overall EVOS modeling efforts.

Hypotheses

This project will test the following null hypotheses:

1. Distributions and abundances of jellyfish are independent of zooplankton and forage fish distributions and abundances.

2. Abundances of key jellyfish species are similar among years (specifically addressing environmental factors that differ among years, such as temperature and stratification).

3. Jellyfish and forage fish have similar impacts on zooplankton populations, because they have similar organic biomasses in PWS and similar food demands.

B. Methods

The work proposed for FY 00 includes analysis of field samples collected in July, 1999, as well as data analysis and manuscript preparation of results from 1995 to 1999.

Distribution and abundance. Analysis of zooplankton samples collected in July, 1999 will be completed, and the data stored in the APEX data base. Zooplankton will be identified, counted, and measured from subsamples with the aid of a CUE-2 image analysis system available at HPL. Small gelatinous species (hydromedusae and ctenophores) will be identified and counted from whole samples using a dissecting microscope. CTD data will be made available to me from APEX for all appropriate cruises.

Semi-quantitative seine samples will be taken in July, 1999 at the same times and locations as the zooplankton samples to determine abundances of large medusae (*Cyanea, Aurelia, Aequorea*). The samples will be processed on board ship; the medusae will be identified, counted, biovolumes of each species measured, and the swimming bell diameter measured for a subset of specimens.

Gut contents. In July, 1999, medusae and ctenophores (*Cyanea, Aurelia, Aequorea,* small hydromedusae and ctenophores) will be dipped from the surface at sampling locations and immediately preserved in 5% Formalin. Prey taxa in the guts will be identified, counted, and measured in J. Purcell's laboratory using a dissecting microscope (available at HPL). The gut content method minimizes laboratory artifacts, and it reveals the true diets of the predators. Feeding rates estimated from gut contents in the field always have been higher when compared with rates measured for jellyfish feeding in containers (SULLIVAN and REEVE, 1982; PURCELL, 1982, 1992).

Gut passage times. During the APEX cruises in July, 1999, individual medusae will be collected by dip nets and immediately placed in large coolers (90 liters) with 32 μm filtered sea water. Individual medusae will be preserved at 30 min intervals and their gut contents analyzed for partly digested prey (as done in PURCELL, 1982). Analysis of the gut contents of these jellyfish, which reveals the disappearance rates of consumed prey, will be completed in the laboratory during FY 00. The maximum time when prey are unrecognizable in the gut contents will be used as the digestion time in calculations of feeding rates. This method was used successfully in July, 1998 because of unsuccessful attempts to measure digestion times in laboratory experiments, which had proven useful previously (PURCELL, 1983; PURCELL, 1992; PURCELL et al., 1994a).

Accurate determination of gut passage times is laborious because the times may depend on prey size or type, temperature (most important), and numbers of prey in the gut (PURCELL, 1992; MARTINUSSEN AND BAMSTEDT, 1999). Medusa size did not significantly affect gut clearance times (PURCELL, 1992; PURCELL et al., 1994a; MARTINUSSEN AND BAMSTEDT, 1999). Generally digestion of copepods requires about 2 to 4 h for a variety of pelagic cnidarian species occurring at greatly different temperatures (e.g. LARSON, 1987a,b; PURCELL, 1982, 1992). My preliminary results suggest that copepods were digested in about 4 hr by *Aurelia*, and larvaceans were digested in 1-2 hr by *Cyanea*. While MARTINUSSEN AND BAMSTEDT (1999) measured digestion by these two species on copepods, no digestion data besides my own are at the appropriate temperature, or use larvaceans as prey.

Calculations of feeding rates and impacts. Data on the numbers of prey in the guts will be divided by digestion times to calculate feeding rate (No. of prey eaten h^{-1} medusa^{-1}). Multiple regression analyses will be conducted for each key predator species and each key prey species where the independent variables are water temperature, prey density, and medusa diameter, and the dependent variable is feeding rate (see PURCELL, 1992; PURCELL et al., 1994a). These multiple regressions can then be used to calculate feeding rates for medusae from other years and locations given population density data. The individual feeding rates will be multiplied by medusa densities and divided by prey densities to determine the daily impacts of the medusae on the various prey populations. Preliminary estimates for 1997 suggest that medusae consumed an average of 4% of the copepods and larvaceans in PWS. This estimate will be refined, and careful estimates made for 1998 and 1999.

Comparisons between jellyfish and forage fish. Data on gelatinous zooplankton distributions and abundances will be compared with those for zooplankton, and forage fish species, with the collaboration of other APEX investigators for fish data (Drs. Lew Haldorson, Evelyn Brown, John Thedinga, and Lee Hulbert). With their collaboration, I will compare the biomasses of jellyfish and forage fish. My preliminary comparisons suggest that jellyfish (biomass corrected for high water content) have comparable or higher biomass than forage fish in PWS.

I will collaborate with Drs. Molly Sturdevant, Lew Haldorson, Evelyn Brown, John Thedinga, and Lee Hulbert in order to compare the predation effects of forage fish and jellyfish on zooplankton populations. Preliminary estimates suggest that jellyfish and forage fish have similar metabolic needs and consumption when compared on an organic biomass basis (carbon or nitrogen).

Interannual comparisons. Data compiled from SEA and APEX projects in 1995, 1996, and 1997 show markedly greater zooplankton, hydromedusae, and *Aurelia* populations in 1996 as compared with 1995 and 1997 (collaborators Drs. Sturdevant, Coyle, Brown). I will collaborate with Drs. Haldorson, Brown, Thedinga, and Hulbert in order to determine if forage fish show the same pattern. I will extend the comparisons of jellyfish and fish to 1998 and 1999 as the data become available. I will collaborate with Dr. Shari Vaughan in order to evaluate the environmental conditions that differed among years and could affect plankton abundances. Preliminary evaluation indicates that 1996 had greater vertical mixing in the water column than the other two years, which could have enhanced plankton production.

C. Cooperating Agencies, Contracts, and Other Agency Assistance

SCHEDULE

A. Measurable Project Tasks for FY 00 (October 1, 1999 - September 30, 2000)

Oct. 1 - Sept. 30:	Analyze field samples from summer 1998, data analysis, manuscript preparation
January 18-28:	Attend Annual Restoration Workshop
April 15:	Submit annual report (FY 99 findings)
September 30:	Submit final report

B. Project Milestones and Endpoints

1999. Complete analysis of July, 1998 zooplankton, jellyfish gut analysis, and digestion experiment samples. Collect field data in PWS during July-August. Intensive gut clearance rate experiments. Begin analysis of 1999 field samples. Continue calculations of dietary overlap and feeding rates and impacts. Continue compilation of all EVOS jellyfish population data, begin multi-year data analyses, and submit jellyfish data to modeling efforts. Preparation of manuscripts.

2000. Complete analysis of 1999 zooplankton, jellyfish gut analysis, and digestion experiment samples. Continue calculations of feeding rates and impacts. Complete compilation of EVOS jellyfish population data and continue multi-year data analyses, and submit jellyfish data to modeling efforts. Preparation of additional manuscripts.

2001. Complete multi-year data analyses and calculations of feeding rates and impacts for 1997-1999. Preparation of manuscripts.

C. Completion Date

The field work will be completed in 1999. Because of the time-consuming sample analysis of jellyfish gut contents and digestion experiments, and because 1999 includes field work, all of the objectives will not be met until FY 2001.

PUBLICATIONS AND REPORTS

I anticipate submission of two manuscripts for publication in 1999. One manuscript, which is ready to submit, covers aggregations of the jellyfish *Aurelia* and the association of juvenile pollock. The second manuscript will evaluate feeding, prey selection and dietary overlap of jellyfish and forage fish. Several other manuscripts are anticipated in 2000-2001.

Manuscript ready for submission in FY 99:

PURCELL J.E., BROWN E., STOKESBURY K.D.E., HALDORSON L.H., SHIRLEY T.C., -- Aggregations of the scyphomedusan *Aurelia aurita*: Abundance, distribution, association

with age-0 walleye pollock, and behavior of the jellyfish in Prince William Sound, Alaska. Mar. Ecol. Prog. Ser. April 1999.

Manuscripts planned for FY 99 and FY 00

PURCELL J.E., STURDEVANT M.V., HALDORSON L.H., BROWN E.D., -- Dietary overlap and the potential for competition among zooplanktivorous jellyfish and forage fish in Prince William Sound, Alaska. Mar. Ecol. Prog. Ser. September 1999.

PURCELL J.E., ANDERSON P.J., -- Trends in scyphomedusae abundance in 1972 - 1996 during a faunal transition in the Gulf of Alaska. Mar. Biol. December 1999.

PURCELL J.E., COYLE K.O., FOY R., -- Distribution, abundance, and interannual variation in hydromedusan populations in Prince William Sound, Alaska. Mar. Ecol. Prog. Ser. May 2000.

PURCELL J.E., -- Predation effects of scyphomedusae on zooplankton populations in Prince William Sound, Alaska. Mar. Ecol. Prog. Ser. September 2000.

PURCELL J.E., HALDORSON L.H., BROWN E.D., THEDINGA J., HULBERT L., -- Biomass comparisons among forage fishes and jellyfish in Prince William Sound, Alaska, and the implications for potential competition for zooplankton prey.

PROFESSIONAL CONFERENCES

I will present results from this research at one meeting in 2000, The American Society of Limnology and Oceanography, or another meeting if more appropriate. I will also present results at the Exxon Valdez Oil Spill Restoration Workshop in January 2000.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

This project will coordinate with the APEX project data analysis. My project has utilized their ship time and their zooplankton and forage fish collections, thus maximizing the return on those sampling efforts. The work proposed involves extensive collaboration with the APEX and SEA research teams. I plan to produce a comprehensive picture of the importance of jellyfish in PWS, which will be best achieved with the cooperation of both groups. Data from previous years, sent to me from Anderson, Brown, Coyle, Haldorson, and Sturdevant, have been analyzed. I anticipate continued collaborations with those investigators, and from Robert Foy and Brenda Norcross in 1999-2000.

PROPOSED PRINCIPAL INVESTIGATOR

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PRINCIPAL INVESTIGATOR

Jennifer E. Purcell, Principal Investigator

Education:

B.S., Stanford University, Stanford, California, 1976
M.S., Stanford University, Stanford, California, 1976
Ph.D., University of California, Santa Barbara, California, 1981

Professional Experience:

Postdoctoral Scholar and Investigator, Woods Hole Oceanographic Institution, Woods Hole, MA, 1981-1983.
NATO Postdoctoral Fellow, University of Victoria, Canada, 1983-1984.
Assistant Professor, College of Oceanography, Oregon State University, 1984-1986.
Visiting Assistant Professor, Friday Harbor Laboratories, University of Washington, 1986-1987.
Assistant, Associate, Full Professor, Horn Point Laboratory, University of Maryland Center for Environmental Science, 1987-present.
Visiting Assistant Professor, The Whitney Laboratory, University of Florida, 1990-1991.
Chesapeake Research Consortium, Faculty Fellow, September 1997 - June 1998, sabbatical

Research Interests:

Trophic ecology, population dynamics, and physiology of gelatinous zooplankton. Predation on ichthyoplankton and gelatinous zooplankton. Selective predation.

Background Relevant to the Proposed Research:

I have had extensive experience studying predation by jellyfish on zooplankton and ichthyoplankton. I have 26 peer-reviewed publications (of 48 total) specifically on that topic, many of which are in the following Literature Cited section. All but 7 (which are on anemones, corals, and salps) of the remaining publications are on various aspects of jellyfish feeding, physiology, and population dynamics. I also have considerable experience in the waters of the northeast Pacific from Oregon to Alaska. I spent all or part of nine years working in those waters, including nearshore and offshore operations. My experience with sampling includes the special techniques for gelatinous zooplankton, including dry-suit diving; MOCNESS, Tucker Trawl, and plankton net sampling for jellyfish, zooplankton and ichthyoplankton; and Mid-water Trawl and seine collection of jellyfish and fish.

My responsibilities will be to supervise analysis of July, 1999 samples, and to direct data analysis. I will oversee all aspects of this research, closely supervise my assistant, have primary responsibility for data analysis and, and sole responsibility for preparation of reports and manuscripts.

OTHER KEY PERSONNEL

Mrs. Margaret Leonard began training for this project in March, 1999, to replace Ms. Kimberly Black, who had to move out of the area. Ms. Leonard will be responsible for data base management and sample analysis (zooplankton, gut contents, digestion experiments). Her additional responsibilities will include analyses and graphic presentation of the data with my direction. Her efforts will be devoted solely to this project.

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Ecological Factors Affecting the Distribution and Abundance of Forage Fish in Prince William Sound, Alaska; An APEX Synthesis Product

Project Number:	00163-Ta
Restoration Category:	Research
Proposer:	University of Alaska Fairbanks
Lead Trustee Agency:	ADFG
Cooperating Agencies:	UAF
Alaska SeaLife Center:	no
Duration:	1st year, 2-year project
Cost FY 00:	$100,941 + ADFG Overhead $7,064 = $107,978
Cost FY 01:	$37,723 + ADFG Overhead $2,641 = $40,364
Cost FY 02:	$ 0
Geographic Area:	Prince William Sound (PWS)
Injured Resource/Service:	Pacific herring, Sea birds (Marbled murrelet, Pigeon guillemot, Black-legged kittiwake)

ABSTRACT

The main goal for this project is to improve our understanding of ecological factors that affect the distribution and abundance of juvenile Pacific herring, sandlance, capelin and eulachon in the surface waters of Prince William Sound. The availability of these prey species impacts the foraging success of several species of sea birds; however, the mechanisms are poorly understood. This project will synthesize a large body of information collected in recent years by various ecosystem projects in order to address the goal. Geostatistical analyses and general additive models will be used to report and model significant findings.

INTRODUCTION

This project includes an important synthesis of information collected by a variety of research projects funded by the *Exxon Valdez* Oil Spill (EVOS) Trustee Council (TC). This project addresses core hypotheses of the Alaska Predator Ecosystem Experiment (APEX) project concerning the effects of availability of forage fish prey on sea bird energetics and reproduction (see Hypotheses 3, 5, and 6, Duffy 1998). The testable specific hypotheses that will be addressed within this project is:

Foraging patterns of sea birds is dependent on the occurrence and availability of forage fish in surface waters;

The occurrence and availability of forage fish in surface waters is dependent on ocean conditions and zooplankton distribution and abundance.

A primary objective of this project is to frame the distribution and abundance of juvenile Pacific herring (*Clupea pallasi*) and other forage species (including sandlance or *Ammodytes hexapterus*, capelin or *Mallotus villosus*, and eulachon or *Thaleichthys pacificus*) in an ecological context. We would like to better define ecological mechanisms affecting the availability of these schooling fish in the surface waters of Prince William Sound (PWS).

Little was known about the distribution and relative abundance of juvenile Pacific herring, *Clupea pallasi*, and other forage fish in Prince William Sound (PWS), Alaska, prior to the *Exxon Valdez* oil spill in 1989. Herring, capelin and pollock composed three of the top five species in number caught as larvae in PWS in 1989 (Norcross and Frandesen 1996). That study documented that larval abundance of herring, capelin, pollock and sand lance peaked in June (Figure 1) and fell off in July in offshore waters (over 1 km from shore) (B.L. Norcross, University of Alaska, unpublished data). During the summers of 1996 and 1997, pre-metamorphic larval herring were captured at the entrances to and within documented herring nursery areas within PWS (Stokesbury et al. 1997; Figure 1). Peak capture rates occurred in July. During the same month, peak numbers of age 0 juvenile herring were observed via aerial surveys within the same nursery bays (Stokesbury et. al. in press; Figure 2). Peak numbers of age 0 sand lance were also observed at nearshore beaches in PWS (Figure 3). This represents the first documentation of the process of larval recruitment into the nearshore nursery areas. From 1995–1997, there was considerable variability in abundance of forage fishes (Brown 1998; Table 1). This variability has implications on availability of these species as prey to sea birds and other mammals.

We now have an extensive amount of marine ecological data available in PWS from EVOS-funded ecosystem research conducted from 1995 to 1997. This information can be used to vastly improve our understanding of factors affecting the distribution and abundance of forage fish and their availability as prey to apex predators. From 1995 to 1997, both the Sound Ecosystem Assessment (SEA) project and the APEX project were collecting data in Prince William Sound.

Data collected and models developed within the SEA project (Cooney, 1996–1998) included: 1) broadscale distribution of surface schooling pelagic forage fish and a foraging pattern of sea birds from May through August from aerial surveys; 2) acoustic measurements of subsurface fish distribution (including forage fish) at discrete sites within PWS; 3) broadscale measurements at discrete sites of ocean conditions and zooplankton (species composition and biomass); 4) broadscale acoustic (continuous) data on zooplankton distribution and abundance; 5) broadscale continuous estimates of ocean conditions and circulation from SEA model efforts; and 6) discrete samples of larval fish distribution and abundance from tucker trawl hauls. Data available from the APEX project (Haldorson, Shirley, Coyle, UAF, per. comm.) is mainly from the summer period (July and August) and includes: 1) broadscale acoustic (continuous) measurements on subsurface fish distribution within the APEX study regions and 2) zooplankton and ocean condition measurements from discrete sites within the APEX study regions.

In order to build upon this limited knowledge of forage species, we will include an analysis of oceanographic conditions (including zooplankton) synoptic with the time frame of the fish distribution data. There is evidence from trophic phasing of biological events in PWS that the occurrence of surface schools is related to the timing of the zooplankton bloom (Figure 4; Brown et al. 1999). The phytoplankton bloom occurs just as the surface waters in PWS begin to warm (Cooney 1998). Shortly thereafter, the zooplankton bloom initiates. The bloom in nearshore waters (mainly bays) has a similar timing but appears to result in a higher concentration of prey; not ironically, the highest concentrations of surface schools of juvenile herring and sand lance appear to occur in nearshore areas, particularly bays. The timing of surface schools of juvenile herring and to a lesser extent sand lance is coherent with the peak in zooplankton production offshore and inshore. Finally, the number of foraging kittiwakes observed from the air peaks in coherence with the appearance of surface schools of forage prey.(Brown et al. in press). There is also a considerable amount of overlap between locations of foraging kittiwakes and forage fish schools (Figure 5). In this project, we will continue to explore this link between ocean conditions and zooplankton and forage fish availability by examining each year separately. We will also look for commonalties in habitat conditions where forage fish repeatedly occur that may represent habitat requirements for these species. This analysis will, therefore, add considerably to our understanding of forage fish ecology.

NEED FOR THE PROJECT

A. Statement of Problem

Factors limiting the recovery of sea birds include insufficient prey or poor prey quality. Several of these sea bird species were listed as injured by the spill. This project will assist in uncovering ecological factors that may not only limit forage fish production, but also that affect the availability of prey to seabirds. This project is a synthesis for the ongoing APEX investigations as well as SEA data from 1995–1997. It also includes the study of Pacific herring (*Clupea pallasi)* which were injured, but now recovering from the spill. Our findings will increase our understanding of juvenile herring nursery processes and population structure. Finally, this project will provide the only baseline information available on population trends of sand lance, capelin and eulachon in PWS and the adjacent Gulf of Alaska waters.

Table 1. Summary of estimated annual biomass and density of forage fish in Prince William Sound, Alaska.

	Year					
	Biomass (kg)			Density (kg/km^2)		
Species/Age	1995	1996	1997	1995	1996	1997
Herring Age 1	2,406,855	6,402,581	1,011,460	1,664.1	9,603.2	537.2
Herring Age 0	3,223,190	2,922,611	34,121,049	1,692.7	1,454.4	18,967.8
Sandlance (All juveniles)	0	394,075	2,860,096	0.0	196.1	1,589.9
Capelin (all adults)	235,820	352,589	0	163.1	528.8	0.0
Eulachon (age unknown)	0	0	6,293,788	0.0	0.0	3,342.5

B. Rationale/Link to Restoration

The research completed under this project using existing data from both the SEA and APEX projects will help us refine our understanding of ecological factors affecting forage fish distribution and abundance. This project addresses core hypotheses 3, 5 and 6 of the APEX project (Duffy 1998).

C. Location

The data for the work included in the proposal is primarily from PWS, although some data from the Outer Kenai and the Gulf of Alaska bordering PWS will be included. Communities within the region include Cordova, Valdez, Whittier, Tatitlek, Chenega Bay, and Seward.

Figure 1. Locations of larval forage fish species in June 1989 (Norcross et al. 1996) and age 0 larval herring prior to metamorphosis in July 1996 in the context of June residuals ocean currents (SEA ocean model, J. Wang, unpublished output).

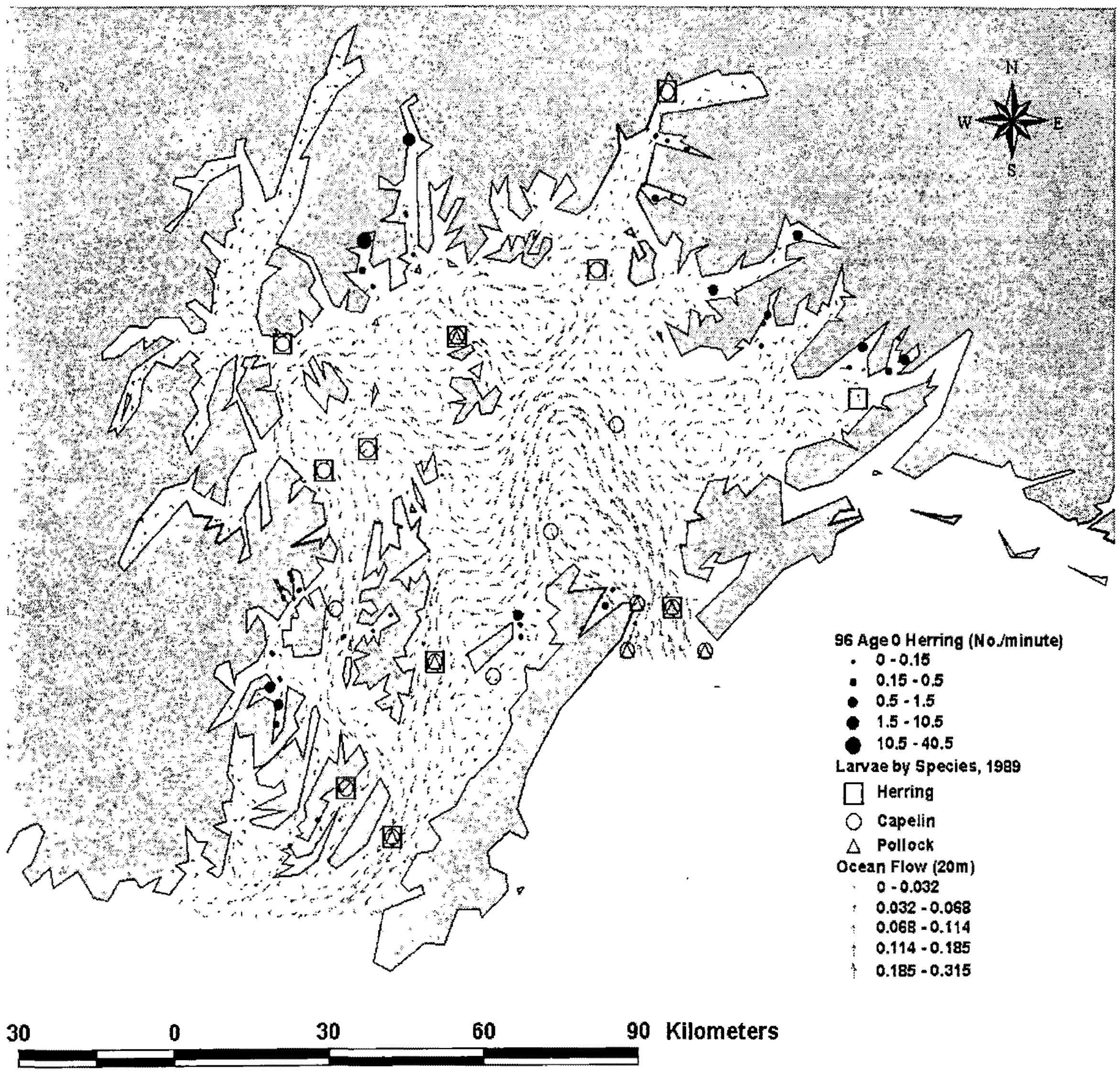


Figure 2. Interannual variability in the occurrence of Pacific herring surface schools, 1995–1997.

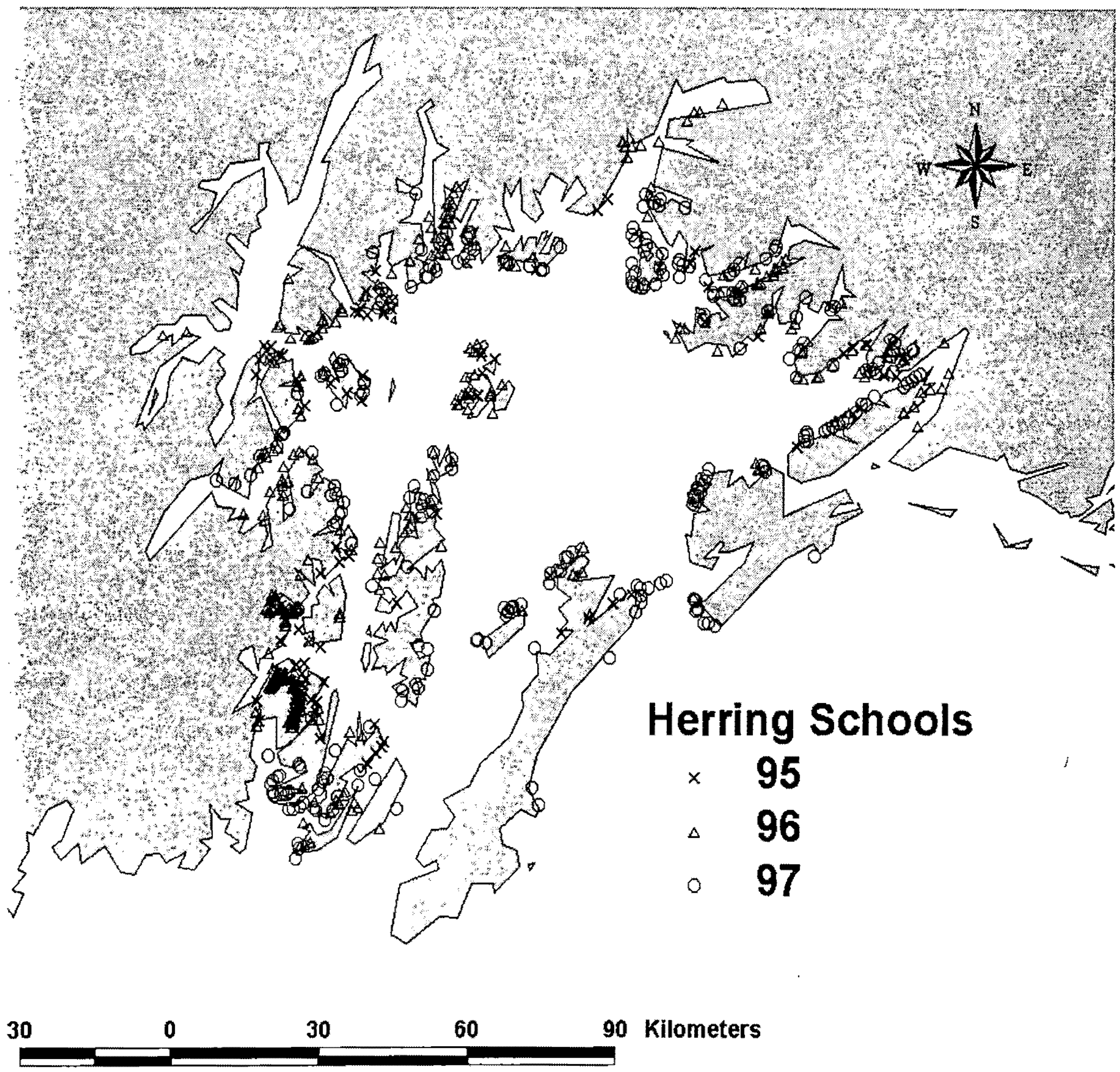


Figure 3. Interannual variability in the occurrence of Pacific sand lance surface schools, 1995–1997

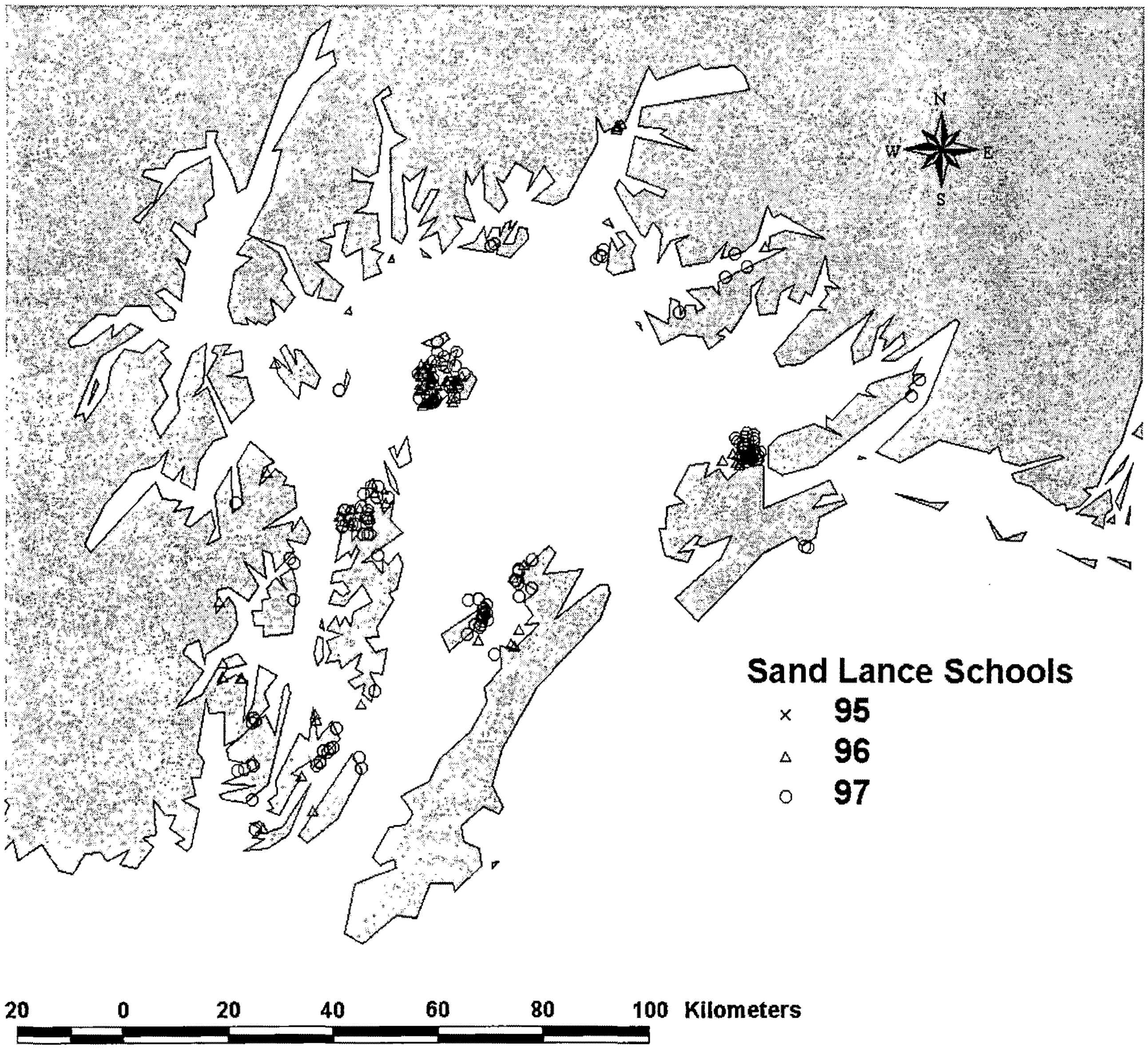


Figure 4. The timing of key ecological events in Prince William Sound, Alaska, including: the formation of the stratified layer (depth in m left axis) and ocean temperatures at 20 m depth (C, right axis); primary and secondary production (mg/m^2 or mg/m^3); herring spawning (cumulative miles of spawn, right axis) and larval fish (no. larvae/m^3, left axis); surface schooling forage fish (total m^2 school surface areas; capelin on right axis, sandlance and herring on the left); and apex predators (total no. of individuals, kittiwakes on gulls on left axis, sea lions and seals on the right).

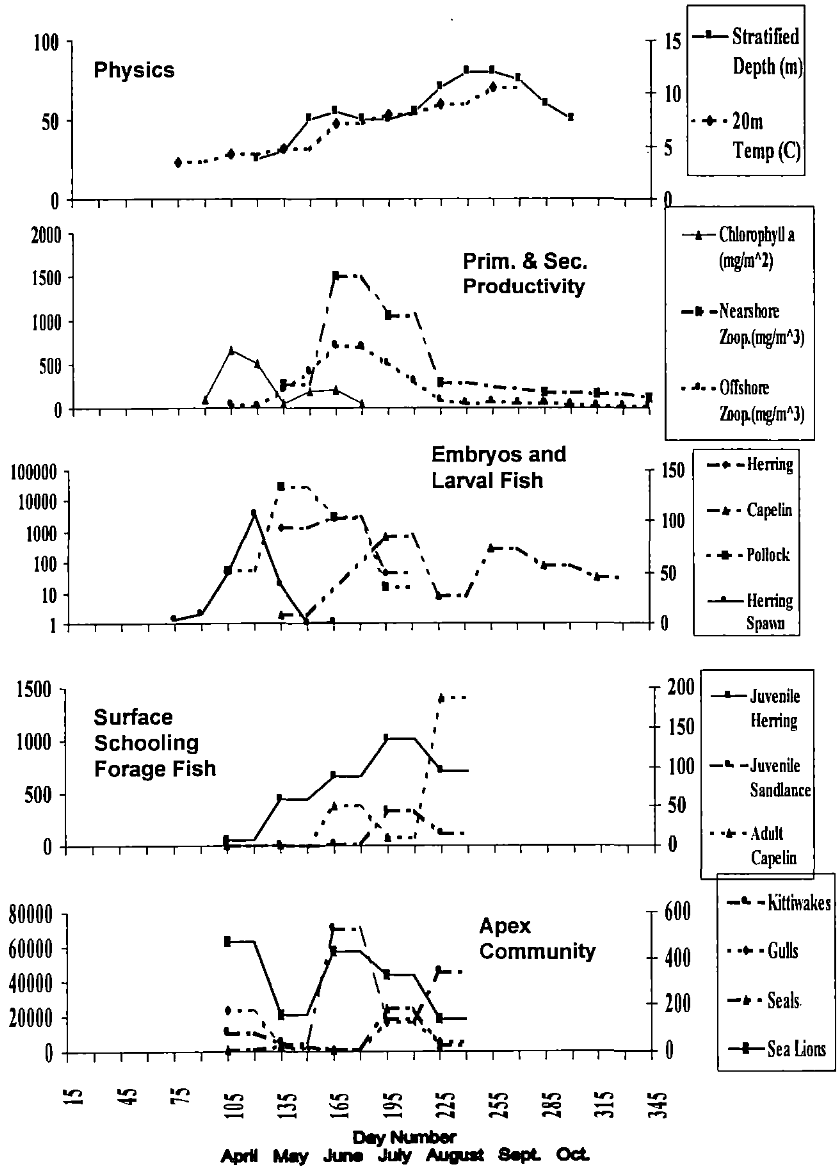
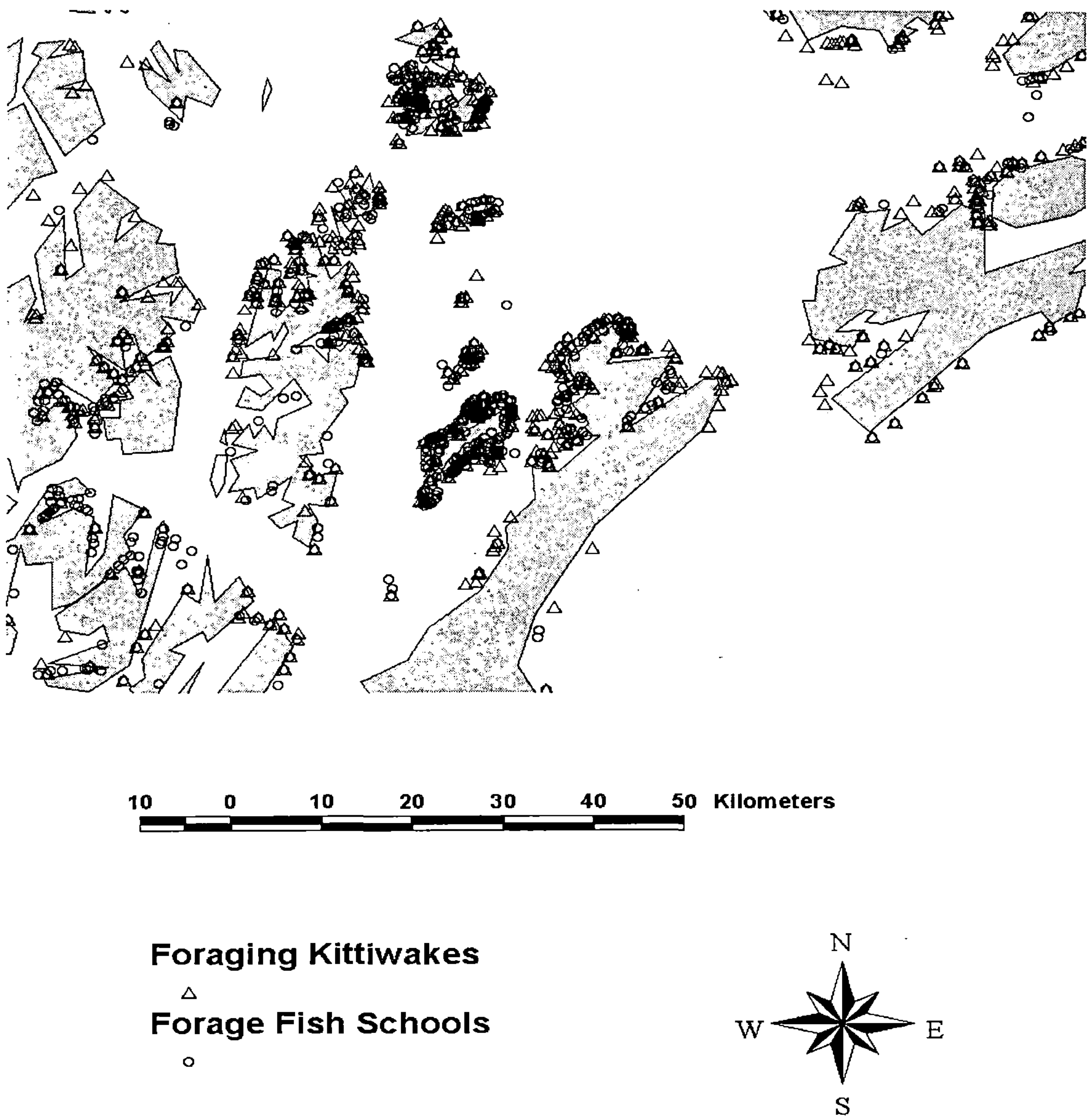


Figure 5. Overlap between Black-legged kittiwakes in active foraging behavior (milling, plunging, or in a tight aggregation on the water) and forage fish schools in 1998 in the central portion of Prince William Sound.



COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

We will compare our distribution descriptions with the results of TEK project 99320T supplement entitled, "Documenting Forage Fish Natural History through Local and Traditional Ecological Knowledge." Consistency may indicate some long-term stability in locations where the forage fish are found given the interannual variability in abundance. The principal investigator, Evelyn D. Brown, is directly involved with that TEK project and will be assisting with closeout and publication preparation. The findings of this study will be shared with interested participants in the herring TEK project and the APEX program.

PROJECT DESIGN

A. Objectives

The hypotheses restated are:

Foraging patterns of sea birds are dependent on the occurrence and availability of forage fish in surface waters; and

The occurrence and availability of forage fish in surface waters are dependent on ocean conditions and zooplankton distribution and abundance.

The research objectives designed to test these hypotheses are:

1. Determine and compare the annual spatial coherence between foraging kittiwakes and surface schools of forage fish.

2. Determine how distributions of forage fish in the surface waters co-vary with oceanographic structure and zooplankton concentration.

3. Compare the depth distribution of forage fish for the three years and determine how it is affected by and related to ocean conditions and zooplankton concentrations.

4. Analyze and publish all significant findings.

B. Methods

In order to meet the objectives of this project, data must be obtained from a variety of sources. We will use broadscale aerial survey results (from this principal investigator) to describe temporal and spatial patterns in foraging kittiwakes and schooling fish in surface waters. We will use discrete acoustic data collected by the SEA project and the APEX project to compare subsurface distributions of fish. We will use discrete zooplankton and physical oceanography data collected and made available by the SEA project as well as results from a broadscale acoustic survey of zooplankton (continuous data). Finally, we will output from the SEA ocean model for the three years of the study to provide continuous spatial variables on oceanography and zooplankton production.

Aerial and Acoustic Survey Data

Aerial surveys were conducted in PWS, a small adjacent portion of the Gulf of Alaska, and the Outer Kenai from 1995 to 1997 (Brown and Norcross, in prep.). Methodology for this project was developed in those years. In all three years surveys were flown during the months of June and July; in 1995 and 1996 surveys were also flown during May and August. Seasonal, regional, and interannual variability in distribution and abundance was observed within and between species of forage fish (herring, sandlance, capelin, and eulachon)(Stokesbury et al. In prep.; Appendix I).

Data from aerial surveys must be converted to densities for comparisons in time and space with other features since the area surveyed varied seasonally and annually. For estimating total school or sea bird density and forage fish abundance available at the surface (not including subsurface fish), the appropriate model is outlined by Quang and Lanctot (1991):

$$\hat{D} = \frac{n\hat{f}(d)}{L}, \; \hat{N} = 2A\hat{D} \text{ or } \hat{N} = \frac{n}{\hat{p}}, \; C = \frac{1}{\hat{p}}$$

where D is density, n is the observed schools or birds, $f(d)$ is the maximum height of the probability density function ($f(x)$) of distances (x) at distance d from the center of the transect, L is the length of the transect, N is the total number of animals estimated in the area, A is the area sampled, p is the probability of detection and C is the visibility coefficient. Estimates of variance should include estimates of variance for p and surveyor bias (calculated via double counting, Brown and Norcross., 1997). For this study, only one parameters needed to be estimated ($f(d)$). The estimate of p (0.83) was obtained in an earlier study using independent sampling techniques and is described in a publication in preparation that will appear in the EVOS final report for SEA project 99320T (Brown et al., in prep; also in Brown and Borstad 1998). In order to estimate $f(d)$, we collected angles on a subset of sightings. This was accomplished by marking the strut of the aircraft with a series of graduated marks indicating angle off the wing and collecting the angles by flattening the aircraft (using the gyroscope) and taking a measurement. The angles were converted to distance from transect centerline using simple geometry and the frequency distribution of the distances (x) were plotted (i.e. the $f(x)$). In this model, a beta curve best represents the probability density function of x and $f(d)$ is obtained from the plot of x).

In order to expand the estimate to include subsurface distributions, acoustics must be incorporated. Distributions of forage fish were obtained by acoustics in four herring nursery bays from October 1995 through October of 1997 (Stokesbury et al. 1997). In addition, a single broadscale survey was conducted by SEA in the summer of 1996 (Stokesbury et al. in press) along with an annual broadscale survey conducted by APEX during July and early August. The species-specific acoustic data will be binned in 1-m depth strata. Schools are represented by a number of filled bins surrounded by empty (no targets) bins. The mean depth and depth distribution of each group of filled bins represents the subsurface distribution pattern by species which can than be compared to other variables.

Oceanographic and Model Output Data

Much of the physical and biological oceanographic data collected by the SEA project has been or is in the process of being published; therefore, methodology will have been well established. We will create three zooplankton variables for use in temporal and spatial analysis: total biomass, species diversity, and dominant species density. Many of the physical oceanographic variables to be used will have been compiled already for an EVOS project currently underway (EVOS Restoration project 99375). For that project, we are in the process of compiling the following list of soundwide and regional oceanographic variables that could be applied in the analysis for this project:

Soundwide
Summer inflow/outflow of PWS waters at Hinchinbrook Entrance
Wind velocity (direction and strength)
Variability in wind velocity over the period of interest
Bakun Upwelling Index (avail. through 1948; but possibly less meaningful than wind alone)
Precipitation and variability of precip.
Hydrological Data (freshwater input via terrain)

Regional
Temperature (to 20m)
Salinity (to 20m)
T/S anomalies over the period
T/S time plots (variability of time)*
Initiation date of summer bloom**
Initiation and length of stratification

In order to provide continuous variables over space and time that are amenable to spatial analyses, we will use output from a revised SEA ocean model. The revised model will be specific by month and year but needs the annual hydrography and wind field data. We will coordinate with a project headed by Dr. Jia Wang (from this University) to obtain that output and we will subcontract with the Prince William Sound Science Center to provide the input needed to tune the model. We will also rely on both Dr. Wang and the Science Center staff to aid with the interpretation and analysis of the physical variables.

Statistical Analysis

A variety of graphic and statistical methods will be applied for this analysis. The distribution data varies in time and space. Sampling is discrete over time, with a month as a unit of time; we therefore do not expect temporal autocorrelation problems. The spatial data however is very likely autocorrelated, and we propose three separate approaches to different aspects of the study robust to autocorrelation problems. We will include the participation of Dr. Ron Barry, Professor of Statistics, to guide and review the spatial analysis for this project.

For the comparison of sea bird and surface school distribution, we propose two approaches. The first uses a Cramér-von Mises test described by Syrjala (1996). This test is non-parametric and is appropriate for testing the difference between the spatial distribution of two populations (in this case birds and fish). The aerial data set will be sub-sampled randomly within an area encompassing the larval study area. Envision that the total area resembles a rectangle. Once both data sets are compiled within a single defined rectangular region, the data must be normalized to account for the difference in scale and population size within a Cartesian coordinate system. A cumulative distribution function (the sum of the normalized densities along a line within the rectangle) is calculated for each population and the square of the distance between the two is calculated resulting in the test statistic. Multiple iterations of the test statistic should be run from at least each of the four corners of the rectangle, and the values averaged. The null hypothesis is that the distribution between birds and fish is identical. The second approach uses spatial statistics methodology to determine how fish and birds co-vary in space and time. Variograms of each group will be compared by month and year. We predict that the coherence in variance will occur with peaks in surface school abundance.

Once the preceding step has been accomplished, the rigorous analysis of ecological effects on fish distribution can be performed. This will include the relationship between forage fish schools in the surface waters, subsurface distribution of forage fish (from acoustics) and the ecological variables of ocean conditions and zooplankton. There are many possible approaches for this type of analysis. The Mantel test can be applied to test for specific habitat components (from the oceanographic variables) affecting fish distribution (Legendre and Fortin 1989). This test will be useful in hypothesis testing. We can also apply a general additive model (GAM) approach (Swartzman and Huang, 1992; Wright and Begg, 1997). An important step in this analysis will be the examination of the residuals of any continuous variable within each region. If there are serious departures from uniform variance, transformations may have to be performed. Assumptions of linearity and normality are not critical in this analysis.

The GAM approach involves several steps. The first step involves compartmentalizing all the variables, biological and physical, within the regions identified. If the relationships between the predictor and response variables are largely linear (or can be linearized via transformations), we can perform a simple analysis of variance (ANOVA) and multiple regression to identify the important parameters. However, it is anticipated that many of the relationships will be non-linear and that oceanographic variables will be non-normal. The choice for GAM is therefore clear. The general model takes the form:

$$\ln(R) = \alpha + \sum_{j=1}^{p} f(E_j) + \varepsilon$$

where R is the temporal and spatially-specific density of forage fish, α is an intercept parameter, p is the number of environmental predictor variables, $f(E_j)$ are function of the environment predictor variables (continuous or class; linear or non-linear forms), and ε is an error term (modified from Hastie and Tibshirani 1990; Jacobson and MacCall 1995; Swartzman et al. 1992). Multiple iterations of this model will be run with some variables falling out and others emphasized. The significant findings of the procedure will be reported.

C. Cooperating Agencies, Contracts, and Other Agency Assistance

The Institute of Marine Science at UAF is the main agency included in this proposal. We will also contract personnel from PWSSC to assist in the compilation of oceanographic data and inputs for the ocean model. PWSSC will also provide assistance in interpretation.

SCHEDULE

A. Measurable Project Tasks for FY 00 (October 1, 1999 – September 30, 2000)

In FY 00, we will address the objectives with the following tasks:

December 31, 1999:	Produce monthly plots of bird and fish school distributions Test for statistically significant differences in fish and bird distributions
February 23, 2000:	Participate in Herring 2000 conference
February 28, 2000:	Compile physical and biological oceanographic discrete variables Obtain input for revision of SEA ocean model
March 1, 2000:	Prepare for and attend the EVOS annual review
March 15, 2000:	Obtain revised output of SEA ocean model
May 15, 2000:	Review spatial data and appropriate statistical treatment; check for violations in assumptions in models Complete statistical analysis of ecological variables
June 15, 2000:	Complete and submit the publication

In FY 01, we address the objectives with the following tasks:

December 15, 2000:	Revise and finalize publication
April 15, 2001:	Submit final report and reprint

B. Project Milestones and Endpoints

FY 00

December 31, 1999:	Determine the coherence between bird and fish distributions
February 23, 2000:	Prepare extended abstract for Herring 2000
June 15, 2000:	Submit the project publication

FY 01

December 15, 2000:	Finalize the publication
April 15, 2001:	Submit final report

C. Completion Date

December 15, 2001 for publication
April 15, 2001 for final report

PUBLICATIONS AND REPORTS

An annual report will be prepared for the April 2000 deadline, but our final report will be in the form of a publication reprint. The draft title for the FY 01 publication is:

Ecological factors affecting the distribution and abundance of surface schooling forage fishes in Prince William Sound, Alaska.

Authors: E.D. Brown, R. Barry, K. Coyle, R. Foy, L. Haldorson, J. Kirsch, B.L. Norcross, T. Shirley, and S. Vaughn.

PROFESSIONAL CONFERENCES

During FY 00, we will attend the EVOS symposium to review and present initial results at the 18th Annual Lowell Wakefield Symposium entitled Herring 2000, February 23–26, 2000.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

This project represents a synthesis of current information resulting from EVOS restoration research. Data from the SEA and APEX project will be married in this analysis. We will coordinate with Prince William Sound Science Center for oceanographic data and zooplankton distribution data from acoustic surveys. We will coordinate with Drs. Lewis Haldorson and Thomas Shirley, UAF Juneau campus, for net catch and zooplankton data.

PROPOSED PRINCIPAL INVESTIGATORS

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PRINCIPAL CO-INVESTIGATORS

Evelyn D. Brown (formerly Biggs)

E. Brown is responsible for all project tasks and objectives.

Education:

B.S. Zoology and Chemistry, University of Utah, Salt Lake City, 1977.

M.S. Fisheries Biology and Aquacultural Engineering, Oregon State University, Corvallis, OR, 1980.

Current Ph.D. candidate in Fisheries at University of Alaska, Fairbanks.

Experience:

Research Associate, University of Alaska, Fairbanks, 1995 to the present.

Herring and Fisheries Research Biologist, Alaska Department of Fish and Game, Cordova, Alaska from 1985 to 1995.

Principal Investigator, Injury to Prince William Sound Herring from the *Exxon Valdez* Oil Spill, NRDA FS 11, 1989–1992.

Fisheries Biologist, Florida Department of Natural Resources, St. Petersberg, Florida, 1987–1988; hydroacoustics.

Fisheries Management Biologist, Metlakatla Indian Community, Annette Island, Alaska, 1980–1982.

Field Experience:

Aerial surveys; P.I. and primary surveyor, single engine aircraft; 1988–present.

U.W. Dive Surveys; P.I. and dive officer for ADFG dive program; 1988–1995.

Shipboard surveys; small vessels (30–60 ft); P.I. on 2, participated in over 12; last decade.

Large shipboard surveys; over 100 ft; participant; 1983 GOA and 1998 SE Alaska.

Skiff work; participated annually in solo and team operations of marine research from skiffs from 1979 to the present.

Familiarity with a variety of marine electronics from acoustics, side-scan sonars, GPS, and computerized navigation to a Compact Airborne Spectrographic Imager (CASI).

Selected Publications:

Brown, E.D., G.A. Borstad, K.D.E. Stokesbury, and B.L. Norcross. Accepted, manuscript in prep. Calibrating and improving the utility of aerial surveys via the use of CASI, videography, and acoustics in American Fisheries Society Symposium 00:00 (1998 in Hartford, Connecticut).

Brown, E. D., G.A. Borstad, and B.L. Norcross. In prep. Assessment of forage fish distribution and abundance using aerial surveys: survey design and methodology. (To be submitted to Ecological Applications).

Brown, E.D. , S. Vaughan, and B.L. Norcross. In press. Annual and seasonal spatial variability of herring, other forage fish, and seabirds in relation to oceanographic regimes in Prince William Sound, Alaska *in* Ecosystem Considerations in Fisheries Management, AFS/Lowell-Wakefield Symposium 00:00 (1998 in Anchorage, Alaska).

Stokesbury, K. D. E., J. Kirsch, E. D. Brown, G. L. Thomas, B. L. Norcross. Accepted. Seasonal variability in Pacific herring (*Clupea pallasi*) and walleye pollock (*Theragra chalcogramma*) spatial distributions in Prince William Sound, Alaska. Fisheries Research 00:00.

Brown, E.D., T.T. Baker, J.E. Hose, R.M. Kocan, G.D. Marty, M.D. McGurk, B.L. Norcross, and J. Short. 1996. Injury to the early life history stages of Pacific herring in Prince William Sound after the *Exxon Valdez* oil spill. Am. Fish. Soc. Symp. 18. pp. 448–462.

Brown, E.D., B.L Norcross, and J.W. Short. 1996. An introduction to studies on the effects of the *Exxon Valdez* oil spill on early life history stages of Pacific herring, *Clupea pallasi*, in Prince William Sound, Alaska. *Can J. Fish. Aq. Sci.* 53: 2337–2342

Brown, E.D. and E. M. Debeves. In press. Effects of the *Exxon Valdez* oil spill on in situ survival of Pacific herring (*Clupea pallasi*) eggs. *Can J. Fish. Aq. Sci.*

Brenda L. Norcross

B. Norcross will review survey design, data, and analysis; review reports and publications.

Education:

A.B., Biology, MacMurray College, Jacksonville, Illinois, 1971.

M.S., Biology, St. Louis University, St. Louis, Missouri, 1976.

Ph.D., Marine Science, Virginia Institute of Marine Science, School of Marine Science, College of William and Mary, Gloucester Point, Virginia, 1983.

Experience:

Associate Professor, Institute of Marine Science, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 1996–present.

Assistant Professor, Institute of Marine Science, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 1989–1996.

Assistant Professor, Division of Biological Oceanography and Fisheries Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, 1984–1988.

Field Experience:

One fisheries vessel, Principal Investigator, Pelagic fish, zooplankton, hydroacoustics, oceanography, underwater camera (Prince William Sound, 7 days), 1998.

One – five fisheries vessels, Principal Investigator, Pelagic fish, zooplankton, hydroacoustics, oceanography, underwater camera, aerial surveys (Prince William Sound, 34 days), 1997.

Five fisheries vessels, Principal Investigator, Pelagic fish, zooplankton, hydroacoustics, oceanography, aerial surveys (Prince William Sound, 60 days), 1996.

Six fisheries vessels, Principal Investigator, Pelagic fish, hydroacoustics, oceanography, aerial surveys (Prince William Sound, 22 days), 1995.

Selected Publications:

Norcross, B.L. and F.J. Mueter. 1999. The use of an ROV in the study of juvenile flatfishes. *Fish. Res.* In press.

Foy, R.J. and B.L. Norcross. 1999. Spatial and temporal differences in the diet of juvenile Pacific herring (*Clupea pallasi*) in Prince William Sound, Alaska. *Can. J. Zoolog.* In press.

Norcross, B.L., J.E. Hose, M. Frandsen and E. Brown. 1996. Distribution, abundance, morphological condition and cytogenetic abnormalities of larval herring in Prince William Sound, Alaska, following the *Exxon Valdez* oil spill. *Can. J. Fish. Aquat. Sci.* 53:2376–2387.

Brown, E.D., B.L. Norcross and J.W. Short. 1996. Conditions affecting the distribution of oil from the *Exxon Valdez* spill and exposure of Pacific herring, *Clupea pallasi*, in Prince William Sound, Alaska. *Can. J. Fish. Aquat. Sci.* 53:2337–2342.

Norcross, B.L. and M. Frandsen. 1996. Distribution and abundance of larval fishes in Prince William Sound, Alaska, during 1989 after the *Exxon Valdez* oil spill. *In* S.D. Rice, R.B. Spies, D.A. Wolfe and B.A. Wright (eds.). *Exxon Valdez* Oil Spill Symposium Proceedings. *Am. Fish. Soc. Symp.* 18:463–486.

OTHER KEY PERSONNEL

Kenneth O. Coyle
Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775-7220

Education:

Ph.D., Oceanography, University of Alaska, 1997.
M.S., Oceanography, University of Alaska, 1974.
B.S., Oceanography, University of Washington, 1972.

Positions Held:

Research Associate, Institute of Marine Science, University of Alaska Fairbanks, 1988–present.

Oceanographic Technician, University of Alaska, 1974–1988.

Graduate Research Assistant, Institute of Marine Science, University of Alaska, January 1972–June 1973.

Graduate Teaching Assistant, Microbiology, University of Alaska, September 1971–December 1971.

Experience:

Scientific Exchange: Murmansk Marine Biological Institute, November 1989; Marine Biological Institute, Vladivostok, June–July 1990; Marine Biological Institute, Vladivostok, August 1994

Amphipos energetics, sample collection and processing, data processing, publications, APPRISE project, 1985–1991

Bering Sea Ice Edge Ecosystem, sample collection, sample processing, data processing, publications, 1976–1978 (BLM, NOAA, OCS), 1981–1982 (Polar Programs)

Zooplankton and microplankton studies in the Bering, Chukchi and Beaufort Seas (BLM/NOAA, OCS), 1975–1977

Phytoplankton studies, sea ice and marginal ice zone, Beaufort and Chukchi Seas, 1972–1974

Recent Publications:

Coyle, K.O. and R.C. Highsmith. 1994. Benthic amphipod community in the northern Bering Sea: Analysis of potential structuring mechanisms. *Mar. Ecol. Prog. Ser.* 107:233–244.

Highsmith, R.C. and K.O. Coyle. 1992. Productivity of arctic amphipods relative to potential gray whale predation. *Mar. Ecol. Prog. Ser.*83:141–150.

Highsmith, R.C. and K.O. Coyle. 1991. Amphipod life histories: Community structure, impact of temperature on decoupled growth and maturation rates, productivity and P:B ratios. *Amer. Zool.* 31:861–873.

Highsmith, R.C. and K.O. Coyle. 1990. High productivity of northern Bering Sea benthic amphipods. *Nature* 344(6269):862–864.

Coyle, K.O. and R.C. Highsmith. 1989. Arctic ampeliscid amphipods: Three new species. *J. Crust. Biol.* 9(1):157–175.

Relevant Publications:

Coyle, K.O., T.J. Weingartner and G.L. Hunt. 1998. The distribution of acoustically determined biomass and major zooplankton taxa in the upper mixed layer relative to water masses in the western Aleutian Islands. *Mar. Ecol. Prog. Ser.* 165:95–108.

Coyle, K.O. 1998. Acoustic assessment of *Neocalanus* scattering layers near the western Aleutian Islands. *J. Plank. Res.* 20:1189–1202.

Coyle, K.O. and R.T. Cooney. 1993. Water column sound scattering and hydrography around the Pribilof Islands, Bering Sea. *Cont. Shelf Res.* 137:803–827.

Coyle, K.O., G.L. Hunt, M.B. Decker, and T.J. Weingartner. 1992. Murre foraging, epibenthic sound scattering and tidal advection over a shoal near St. George Island, Bering Sea. *Mar. Ecol. Prog. Sr.* 831–14.

Coyle, K.O., A.J. Paul, and D.A. Ziemann. 1990. Copepod populations during the spring bloom in an Alaskan subarctic embayment. *J. Plank. Res.* 12(4):759–797.

Collaborators During Past 48 Months:

George L. Hunt, Jr., Department of Ecology and Evolutionary Biology, University of California Irvine, Irvine, CA 92717.

R.T. Cooney, Institute of Marine Science, University of Alaska Fairbanks, Fairbanks, AK 99775-7220.

Ronald P. Barry
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Specialties: Time series and spacial statistics.

Meibing Jin

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Educational History:
B.Sc., July 1989, in engineering physics, Qinghua University, Beijing, China.
M.Sc., July 1992, in oceanography, First Institute of Oceanography, SOA, Qingdao.
Ph.D., April, 1998, in oceanography, Chinese Academy of Sciences, Qingdao, China.

Employment History and Experience:
First Institute of Oceanography, SOA, China: Research Scientist, July 1992–October 1998.
IMS, University of Alaska Fairbanks: Assistant Research Professor, November 1998–Present.

Publications
Jin Meibing, Wang Zongshan and Xu Bochang, 1993, Three-dimensional numerical prediction of vertical temperature structure of the Huanghai and the Bohai Seas. Acta Oceanological Sinica 12(4):511–520.
Jin Meibing and Jiang Tailiang, 1997, A numerical model of the three-dimensional barotropic tidal-current field in the East China Sea. Oceanography in China 8:1–13.
Jin Meibing, Jiang Tailiang and She Jun,1997, Three-dimensional numerical research of nonlinear interaction between surge and tide in the East China Sea. Oceanography in China 8:21–30.
Jiang Tailiang and Jin Meibing, 1997, Environmenatal impact prediction of suspended sands caused by the Lingdingyang bridge construction of Zhuhai. Oceanography in China 8:47–57.
Jin Meibing and Jiang Tailiang, 1997, An implicit difference method of three-dimensional baroclinic current field. Oceanography in China 8:14–20.

Jiang Tailiang and Jin Meibing, 1997, Numerical modeling of oil spill of the East China Sea. Oceanography in China 8:31–37.
Wang Zongshan, Jin Meibing Zou Emei and Xu Bochang, 1997, The inversion of the Equatorial Undercurrent in the western tropical Pacific during 1986/1987 EI Nino event. Acta Oceanological Sinica 12(4) 487–498.
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Effects of Forage Fish School Density and Species Composition on Foraging Patterns of Sea Birds: An APEX Synthesis Product

Project Number:	00163-Tb
Restoration Category:	Research
Proposer:	University of Alaska Fairbanks
Lead Trustee Agency:	ADFG
Cooperating Agencies:	UAF
Alaska SeaLife Center:	
Duration:	1st year of 2 years
Cost FY 00:	$55,755 + ADFG Overhead $3,903 = $59,658
Cost FY 01:	$24,600
Cost FY 02:	$ 0
Geographic Area:	Prince William Sound (PWS)
Injured Resource/Service:	Pacific herring, Sea birds (Marbled murrelet, Pigeon guillemot, Black-legged kittiwake)

ABSTRACT

The main goal for this project is to improve our understanding of finer scale foraging processes. Using existing digital imagery and underwater photography, we will examine how school spacing, density, and species composition of forage fish in shallow regions and surface waters affect the foraging pattern of sea birds (mainly kittiwakes). We intend to use multivariate statistics to detect significant differences. We will also determine if there is a species preference and estimate thresholds of fish abundance for commencement of observed foraging. Area specific trends can be compared to bird diet data for coherence in observations by other APEX researchers.

INTRODUCTION

This project uses existing data to address core hypotheses of the Alaska Predator Ecosystem Experiment (APEX) project concerning forage fish characteristics and interactions among seabirds (see Hypotheses 5, and 6, Duffy 1998). The dynamics and limiting factors between forage fish assemblage characteristics and foraging success of sea birds are poorly understood. The findings of this study are therefore important in gaining a better understanding of those dynamics. The specific hypotheses that will be tested within this project are:

1. Numbers and patterns of sea birds foraging on surface fish school assemblages are dependent on fish species, age of the fish, school size, and school density

2. There is a region-specific threshold of fish school size and number below which foraging by seabirds is unlikely.

A primary objective of this project is to interpret, on the order of a few hundred meters, finer scale processes that affect sea bird foraging success. We will focus on three species of forage fish including Pacific herring (*Clupea pallasi*), sand lance (*Ammodytes hexapterus*), and capelin (*Mallotus villosus*). Our findings will provide information on an unknown aspect of feeding behavior and will be useful in the interpretation of sea bird diets and reproductive success (particularly in the context of other APEX studies).

We have three types of data that will be used in this investigation. We have a 5-year database including distribution and abundance of surface schooling forage fish and sea birds (example of output in Figure 1). We will have collected over 400 digital aerial images of forage fish schools and the associated sea birds (1998 coverage is in Figure 2; examples in Figure 3). Finally, we will have a collection of over 200 underwater images (associated with the aerial sightings and images) of forage fish schools. The investigator in this project has used digital images in the past to estimate parameters for modeling aerial survey data (Brown and Borstad, 1998). This takes the utility of those images one step further. Therefore, this project is cost-effective since it entails only the processing of existing data and images.

There is evidence from past analyses that seabirds exhibit a prey species preference. Certainly the energetic characteristics, and therefore diet quality, of different species and ages of forage fish vary (Duffy, 1998). This investigator found that there was a significant difference in the numbers of herring versus sand lance schools associated with birds. In 1996 and 1997, 35.7% and 43.6% of juvenile herring schools, respectively, had foraging birds associated with them. This compares with 18.3% (1996) and 11.1% (1997) of sand lance schools. The frequency distribution of school sizes associated with the sea birds was not different between the two fish Figure 1. Locations of foraging kittiwakes, sand lance and herring schools in a blown-up region in central Prince

William Sound (Knight Island group and Smith Island).

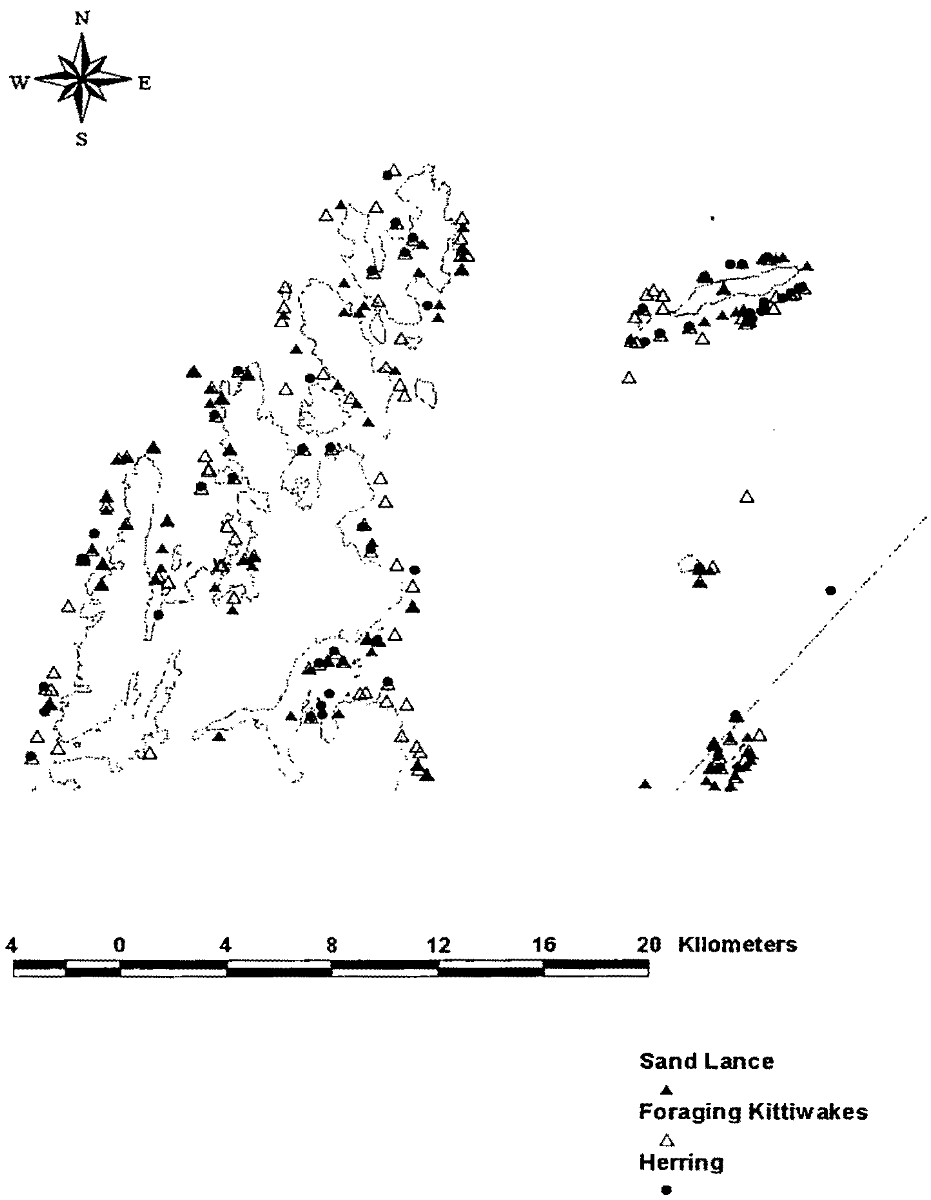


Figure 2. Locations of digital images collected in 1998 in Prince William Sound.

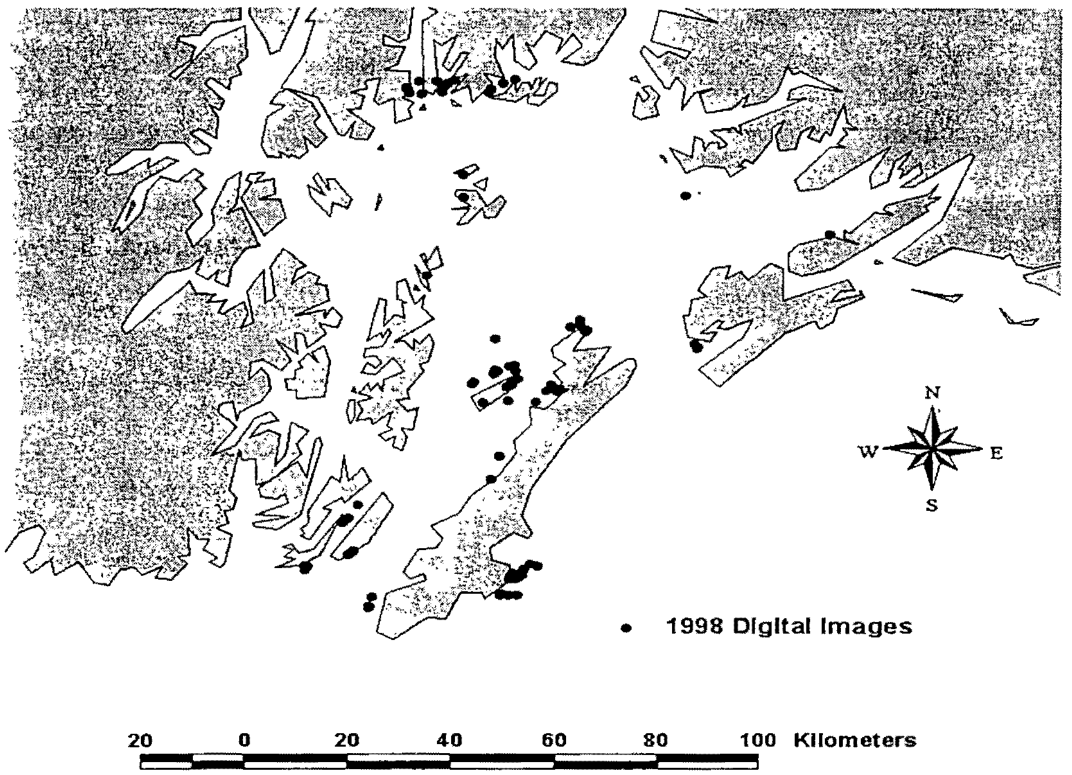
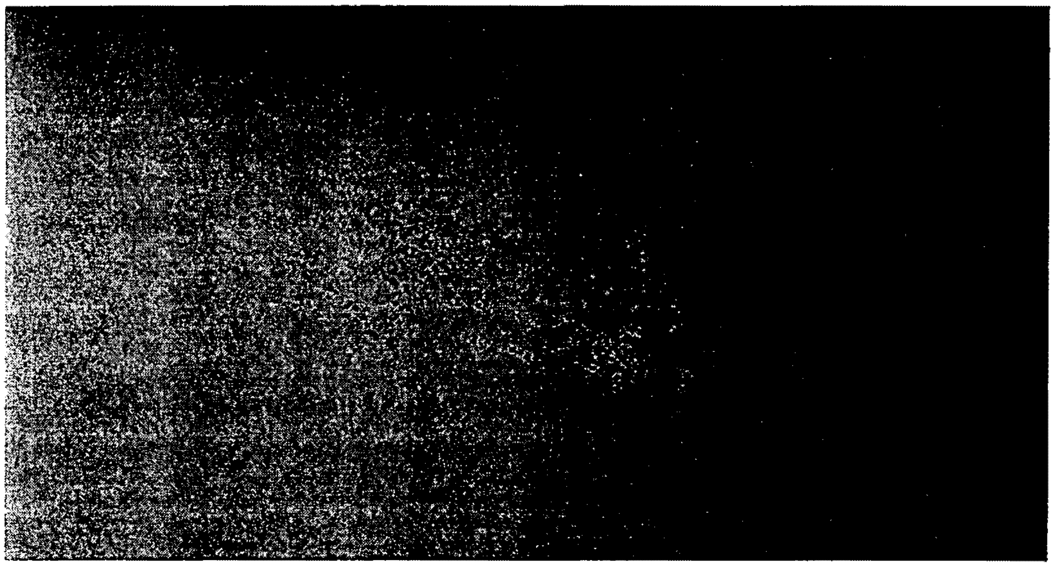
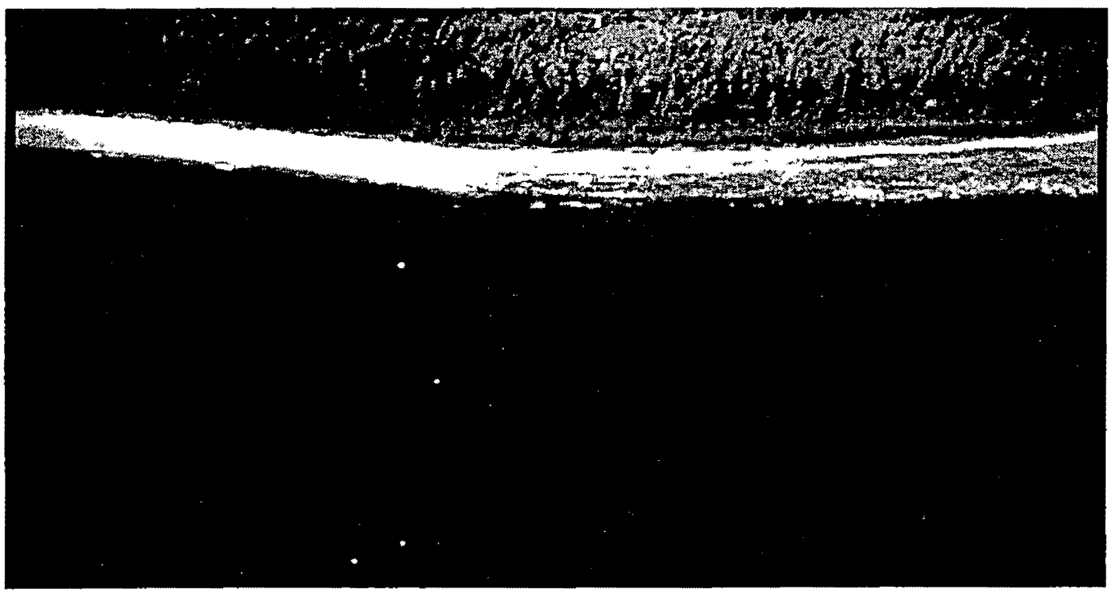


Figure 3. Examples of digital images from 1998.



a. Enhanced photo of resting bird pattern.



b. Age-0 sand lance, kittiwakes and alcids.

species. However, total numbers of schools within an area (or shoal size), biomass, and density was different for each of the two species and could have been a confounding factor. We intend to address that question within the context of this study.

NEED FOR THE PROJECT

A. Statement of Problem

Factors limiting the recovery of sea birds include insufficient prey or poor prey quality. Several seabird species were listed as injured by the spill. However, little is known of the factors influencing foraging by seabirds or whether characteristics of forage fish assemblages (e.g. school size and density) may be important. This project will assess forage fish assemblage characteristics that may affect the dynamics of foraging by sea birds to determine whether changes in assemblage characteristics can serve to limit seabird recovery. This project will serve as a synthesis for ongoing APEX investigations. It includes the study of Pacific herring (*Clupea pallasi*) which were injured but now recovering from the spill. Our findings will increase our understanding of the partitioning of juvenile herring nurseries and population structure.

B. Rationale/Link to Restoration

The research completed under this project using existing data from both the SEA and APEX projects will help us refine our understanding of foraging dynamics between sea birds and forage. This project will address core hypotheses 5 and 6 of the APEX project (Duffy 1998).

C. Location

The data for this project was collected mainly in July and August from 1996–1998 in Prince William Sound. We will also use new data collected in the summer of 1999 in the same region.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

Although we have no direct involvement of the public, the images produced by this project can be used for public education purposes. As part of our deliverables, we will provide a GIS CD with the geocoded images for public viewing and use.

PROJECT DESIGN

A. Objectives

The primary objective of this project is to address the two key hypotheses:

1. Numbers and patterns of sea birds foraging on surface fish school assemblages are dependent on fish species, age of the fish, school size, and school density.

2. There is a region-specific threshold of fish school size and number below which foraging by seabirds is unlikely.

We intend to provide critical information concerning the relationship of forage fish assemblages to seabird foraging. This information will be placed in the context of other APEX investigations as well as in the context of limitations of seabird recovery from oil spill. The research tasks designed to test these hypotheses are:

1. Group the images by region, species, and by shoal size (number of schools in each image quadrat) and assign continuous or categorical variables (these are the predictor variables).

2. For each image processed, determine the total number of kittiwakes and the nearest neighbor statistics of the birds (response variables).

3. Use multivariate statistics to determine statistical correlations and relationships between the predictor and response variables. Use parametric and non-parametric tests for level of significance.

4. Determine if thresholding is occurring (no response values below defined levels of the predictor variables) and define it. Develop a probability associated with the threshold.

B. Methods

Aerial surveys were conducted in PWS, a small adjacent portion of the Gulf of Alaska, and the Outer Kenai from 1995 to 1997 (Brown and Norcorss, 1997). Methodology for the surveys was developed in those years. In 1998 repeat surveys were conducted over a more restricted temporal and spatial scale. In addition, the digital video camera was added to the survey plane.

Each image is assigned a name or number, is associated to a particular latitude and longitude, and is linked to aerial and validation data that provides fish species and age. It is also given a region code. The validation data comes from net catches linked via time and space codes to the images or from underwater video images that were taken synoptic with the aerial images.

Each image can be scaled using altitude since the focal point and settings on the camera were static. The image is imported into ArcView Geographic Information System (GIS) software and gridded according to the predetermined scale (dimensions of the image in meters; see Verbyla and Chang, 1997). Bird locations and school perimeters are digitized on the image. The statistics for school area and bird counts are then automatically determined within the software. Nearest neighbor statistics can also be calculated. All the output can be dumped to a spreadsheet or directly to S-plus statistical package (Spector 1994).

The data linked to each image is then sorted by region and other characteristics to determine if clumping of variables is occurring. We expect, due to the clumping of images in particular locations, that we may have to deal with spatial autocorrelation. If we find this to be a problem, we will group images and analyze image groups instead (i.e., analyze means of image groups) which will affect the overall sample size and may affect our choice of test to use.

We will use a multivariate approach for the analysis of the data. Applicable multivariate methods include canonical correlation analysis and multi-dimensional scaling. Expected statistical tests for significance of the results includes Bartlett's and the Mantel test (Manly 1986). The choice for tests will depend on the realized sample size, the difficulty in interpretation of the correlation coefficients, and the level of significance realized.

Significant results will be summarized in a publication. We will also deliver the data set for public use in the form of a CD containing the GIS database, the images, and ancillary data.

C. Cooperating Agencies, Contracts, and Other Agency Assistance

The Institute of Marine Science at UAF is the main agency included in this proposal. We will contract with Top Cover Inc., an Alaskan company, for delivery and processing of the digital images.

SCHEDULE

A. Measurable Project Tasks for FY 00 (October 1, 1999 – September 30, 2000)

In FY 00, we will address the objectives with the following tasks:

December 31, 1999;	Acquire and organize all digital images and associated data needed to create the variables.
February 28, 2000	Scale images and digitize parameters from each image.
March 1, 2000:	Participate in annual EVOS review.
March 15, 2000:	Complete nearest neighbor statistics for birds and schools.
May 15, 2000:	Complete multivariate analysis.
June 15, 2000:	Complete and submit the publication.

In FY 01, we address the objectives with the following tasks:

December 15, 2000:	Revise and finalize publication.
April 15, 2001:	Submit final report and reprint.

B. Project Milestones and Endpoints

FY 00

May 15, 2000:	Analysis complete.
June 15, 2000:	Publication submitted.

FY 01

December 15, 2000:	Publication finalized.
April 15, 2001:	Submit final report and CD.

C. Completion Date

December 15, 2001 for publication
April 15, 2001 for final report.

PUBLICATIONS AND REPORTS

An annual report will be prepared for the April 2000 deadline, but the final report will be in the form of a publication reprint. The draft title for the FY 01 publication is:

Effects of forage fish school density and species composition on foraging patterns of sea birds. Blanchard A., E. Brown, T. Veenstra, and S. Moreland.

PROFESSIONAL CONFERENCES

During FY 00, we will attend the EVOS symposium and review. At this time, we do not have plans to present the results at a scientific meeting.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

This project represents a synthesis of current information resulting from EVOS restoration research. Data from the SEA and APEX project will incorporated in this analysis.

PROPOSED PRINCIPAL INVESTIGATORS

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PRINCIPAL INVESTIGATORS

Evelyn D. Brown (formerly Biggs)

Responsible for meeting project objectives and tasks; formulation of publication.

Education:
B.S. Zoology and Chemistry, University of Utah, Salt Lake City, 1977
M.S. Fisheries Biology and Aquacultural Engineering, Oregon State University, Corvallis, OR, 1980
Current PhD candidate in Fisheries at University of Alaska, Fairbanks

Experience:
Research Associate, University of Alaska, Fairbanks, 1995 to the present.
Herring and Fisheries Research Biologist, Alaska Department of Fish and Game, Cordova, Alaska from 1985 to 1995.
Principal Investigator, Injury to Prince William Sound Herring from the *Exxon Valdez* Oil Spill, NRDA FS 11, 1989–1992.
Fisheries Biologist, Florida Department of Natural Resources, St. Petersberg, Florida, 1987–1988; hydroacoustics.
Fisheries Management Biologist, Metlakatla Indian Community, Annette Island, Alaska, 1980–1982.

Field Experience:
Aerial surveys; P.I. and primary surveyor, single engine aircraft; 1988–present.
U.W. Dive Surveys; P.I. and dive officer for ADFG dive program; 1988–1995.
Shipboard surveys; small vessels (30–60 ft); P.I. on 2, participated in over 12; last decade.
Large shipboard surveys; over 100 ft; participant; 1983 GOA and 1998 SE Alaska.
Skiff work; participated annually in solo and team operations of marine research from skiffs from 1979 to the present.
Familiarity with a variety of marine electronics from acoustics, side-scan sonars, GPS, and computerized navigation to a Compact Airborne Spectrographic Imager (CASI).

Selected Publications:
Brown, E.D., G.A. Borstad, K.D.E. Stokesbury, and B.L. Norcross. Accepted, manuscript in prep. Calibrating and improving the utility of aerial surveys via the use of CASI, videography, and acoustics in American Fisheries Society Symposium 00:00 (1998 in Hartford, Connecticut).
Brown, E. D., G.A. Borstad, and B.L. Norcross. In prep. Assessment of forage fish distribution and abundance using aerial surveys: survey design and methodology. (To be submitted to Ecological Applications).
Brown, E.D. , S. Vaughan, and B.L. Norcross. In press. Annual and seasonal spatial variability of herring, other forage fish, and seabirds in relation to oceanographic regimes in Prince

William Sound, Alaska *in* Ecosystem Considerations in Fisheries Management, AFS/Lowell-Wakefield Symposium 00:00 (1998 in Anchorage, Alaska).
Stokesbury, K. D. E., J. Kirsch, E. D. Brown, G. L. Thomas, B. L. Norcross. Accepted. Seasonal variability in Pacific herring (*Clupea pallasi*) and walleye pollock (*Theragra chalcogramma*) spatial distributions in Prince William Sound, Alaska. Fisheries Research 00:00.
Brown, E.D., T.T. Baker, J.E. Hose, R.M. Kocan, G.D. Marty, M.D. McGurk, B.L. Norcross, and J. Short. 1996. Injury to the early life history stages of Pacific herring in Prince William Sound after the *Exxon Valdez* oil spill. Am. Fish. Soc. Symp. 18. pp. 448–462.
Brown, E.D., B.L Norcross, and J.W. Short. 1996. An introduction to studies on the effects of the *Exxon Valdez* oil spill on early life history stages of Pacific herring, Clupea pallasi, in Prince William Sound, Alaska. *Can J. Fish. Aq. Sci.* 53: 2337–2342
Brown, E.D. and E. M. Debeves. In press. Effects of the *Exxon Valdez* oil spill on in situ survival of Pacific herring (*Clupea pallasi*) eggs. *Can J. Fish. Aq. Sci.*

Brenda L. Norcross

Advisory capacity on project.

Education:
A.B., Biology, MacMurray College, Jacksonville, Illinois, 1971.
M.S., Biology, St. Louis University, St. Louis, Missouri, 1976.
Ph.D., Marine Science, Virginia Institute of Marine Science, School of Marine Science, College of William and Mary, Gloucester Point, Virginia, 1983.

Experience:
Associate Professor, Institute of Marine Science, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 1996–present.
Assistant Professor, Institute of Marine Science, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 1989–1996.
Assistant Professor, Division of Biological Oceanography and Fisheries Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, 1984–1988.

Field Experience:
One fisheries vessel, Principal Investigator, Pelagic fish, zooplankton, hydroacoustics, oceanography, underwater camera (Prince William Sound, 7 days), 1998.
One – five fisheries vessels, Principal Investigator, Pelagic fish, zooplankton, hydroacoustics, oceanography, underwater camera, aerial surveys (Prince William Sound, 34 days), 1997.
Five fisheries vessels, Principal Investigator, Pelagic fish, zooplankton, hydroacoustics, oceanography, aerial surveys (Prince William Sound, 60 days), 1996.
Six fisheries vessels, Principal Investigator, Pelagic fish, hydroacoustics, oceanography, aerial surveys (Prince William Sound, 22 days), 1995.

Selected Publications:

Norcross, B.L. and F.J. Mueter. 1999. The use of an ROV in the study of juvenile flatfishes. *Fish. Res.* In press.

Foy, R.J. and B.L. Norcross. 1999. Spatial and temporal differences in the diet of juvenile Pacific herring (*Clupea pallasi*) in Prince William Sound, Alaska. *Can. J. Zoolog.* In press.

Norcross, B.L., J.E. Hose, M. Frandsen and E. Brown. 1996. Distribution, abundance, morphological condition and cytogenetic abnormalities of larval herring in Prince William Sound, Alaska, following the *Exxon Valdez* oil spill. *Can. J. Fish. Aquat. Sci.* 53:2376–2387.

Brown, E.D., B.L. Norcross and J.W. Short. 1996. Conditions affecting the distribution of oil from the *Exxon Valdez* spill and exposure of Pacific herring, *Clupea pallasi*, in Prince William Sound, Alaska. *Can. J. Fish. Aquat. Sci.* 53:2337–2342.

Norcross, B.L. and M. Frandsen. 1996. Distribution and abundance of larval fishes in Prince William Sound, Alaska during 1989 after the *Exxon Valdez* oil spill. *In* S.D. Rice, R.B. Spies, D.A. Wolfe and B.A. Wright (eds.). *Exxon Valdez* Oil Spill Symposium Proceedings. *Am. Fish. Soc. Symp.* 18:463–486.

OTHER KEY PERSONNEL

Arny L. Blanchard

Conduct the multivariate analysis of foraging dynamics; formulation of publication

Education:
B.S. Biological Sciences, University of Alaska Fairbanks. 1989.
M.S. Statistics, University of Alaska Fairbanks. Expected graduation date May 1999.

Positions Held:
Research Associate, University of Alaska Fairbanks, Nov. 1996 to present.
Laboratory Technician, University of Alaska Fairbanks, 1990 to present.
Laboratory Assistant, University of Alaska Fairbanks, 1989 to 1990.
Student Assistant, University of Alaska Fairbanks, 1986 to 1989.

Research Experience:
Provide statistical consulting services to principal investigators (1995 to present). Projects included assessment of habitat utilization by juvenile flatfish, trends in heavy metal concentrations from the Chukchi Sea, and assessment of disturbance in benthic communities due to dredging, gold mining, and disposal of treated ballast waters from oil tankers.

Coordinate environmental monitoring projects throughout Alaska to assess stress on benthic communities (1990 to present). Research experience includes investigations of intertidal mussels and limpets, intertidal community recruitment and succession, taxonomy of Alaskan marine invertebrates, and assessment of the effects of physical disturbance (dredging and gold mining), long-term waste disposal, and the *Exxon Valdez* oil spill.

Selected Published Papers:

Blanchard, A. and H. M. Feder. 1997. Reproductive timing and nutritional storage cycles of *Mytilus trossulus* Gould, 1850, in Port Valdez, Alaska, site of a marine oil terminal. Veliger, 40:121–130.

Blanchard, A. and H. M. Feder. In Press. Shell Growth of *Mytilus trossulus* Gould, 1850, in Port Valdez, Alaska. Veliger.

S.C. Jewett, T. A. Dean, R. 0. Smith, and A. Blanchard. In Press. The *Exxon Valdez* oil spill: impacts and recovery in the soft-bottom benthic community in and adjacent to eelgrass beds. Marine Ecology Progress Series.

Feder, H. M. and A. Blanchard. 1998. The deep benthos of Prince William Sound, Alaska, sixteen months after the *Exxon Valdez* Oil Spill. Marine Pollution Bulletin, 36:118–130.

Norcross, B. L., A. Blanchard, and B. A. Holladay. 1998. Comparison of models for defining nearshore flatfish nursery areas in Alaskan waters. Fisheries Oceanography. 8:50–67.

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Manly, B.F.J. 1986. Multivariate Statistical Methods A Primer. Chapman and Hall, London, England 213 pp.

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Verbyla, D.L. and K. Chang. 1997. Processing digital images in GIS. Onword Press, Santa Fe, N.M. 295 pp.