99163A-T (APEX)

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

Project Number:	99163 A-T
Restoration Category:	Research
Proposer:	David Cameron Duffy, Project Leader, Paumanok Solutions.
Cooperating Agencies:	DOI, ADF&G, NOAA
Alaska SeaLife Center:	yes
Duration:	5 th year of five-year project
Cost FY 99:	$1,986.1 K
Cost FY 00:	$1,218.8 K
Cost FY 01:	$250.1
Cost FY 02:	$0.0
Cost FY 03:	$0.0
Geographic Area:	Prince William Sound, Cook Inlet, Northern Gulf of Alaska
Injured Resource/Service:	Common Murre, Harbor Seal, Marbled Murrelet, Pacific Herring, Pigeon Guillemot.

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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 Detailed Project Description, 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 success 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.	Haldorson/Shirley	Fish population sampling
b.	Ostrand	Seabird foraging
e.	Irons/Suryan	Kittiwake foraging and reproduction
f.	Hayes	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.	Piatt, Anderson & Blackburn	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

The lead project with responsibility for coordinating data sharing is given in bold face.

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

   Initial work on archived data strongly suggests major changes in community structure and species abundance over the last several decades. **Project 99163 L** will use existing trawl and net sample data from NMFS and ADF&G to test for changes in forage fish communities over the last three decades.

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

   Projects **99163 A** and **99163 S** will address this. Project **99163 C** has completed its work.

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

   Initial work indicated strong diurnal and depth components to the behavior of different fish species. **Projects 99163 A, B, S, and T** will use acoustic and aerial sampling, net surveys, and oceanographic sampling to determine whether certain fish.species respond predictably to environmental conditions, such as depth, water temperature, distance offshore, or salinity.

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

   The results to date suggest that body condition of fishes changes with size, species, and date. **Projects 99163 A and G** will examine this; A, using fish caught by sampling and G, using fish caught by birds. Most analysis is now complete.

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

   Field work suggested depth of prey, distance offshore and presence of other species affect the species' composition of seabird foraging flocks. **Project 99163 B** will examine foraging in relation to the data collected by Project 99163 A and 99163 T for Objective 3 above.

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

   Project 99163 B will continue to examine foraging in relation to the data collected by Project 99163 T for Objective 3 above.

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

   At a meso-scale level, Cook Inlet and Prince William Sound colonies show a correlation between food availability and seabird reproductive and foraging performance. In 1999, we will continue a joint project involving fish distribution data from 99163 A and 99163 T, foraging data from projects 99163 B, 99163 M, 99163 R and diet data at colonies from projects 99163 E, 99163 F, 99163 G, 99163 J, 99163 M and 99163 R. Data will be examined within Cook Inlet and within PWS, as well as across all study sites.

   b. Determine the "relevant scales".

   Spatial scales will be determined from shipboard transects (Projects 99163 B and M) and radiotracking (Project 99163 E) of seabirds and from repeated sampling of fish (99163 A, 99163 M, and 99163 T); temporal scales will be determined retrospectively from the times over which changes occur in diet and growth of seabirds (Projects 99163 E, F,G, J, M) and in distribution and abundance of fish (Projects 99163 A, 99163 M, and 99163 T). **Project 99163 O.**

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

   This will be a joint project involving fish distribution data from 99163 A and 99163 T, foraging data from projects 99163 B, E, M, and R, and diet data at colonies from projects 99163 E, F, G, J, M. **Projects 99163 Q will coordinate.**

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

   Field data show significant differences in diet quality and growth of seabirds based on differences in forage fish taken. Data on fish-provisioning rates, growth, and diet of wild birds from projects 99163 E, F, J, and M will be provided to **Project 99163 G** and **99163 Q** to test this.

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

   This objective will be examined in Prince William Sound by Project **99163 Q** in conjunction with Projects B, E,F.G. I, L,O, and R, and between three sites in Cook Inlet by Projects **99163 M** and 99163 J . Within species, **Projects 99163 E**, J, and M will examine kittiwake response, and **99163 F** and M will compare pigeon guillemots, **Projects 99163 J** and **M** will compare common murres, and 99163 R will examine Marbled Murrelets. At the foraging level, Project **99163 B** will undertake a similar analysis in conjunction with 99163 O. Data on fish distributions and status will be provided by projects 99163 A, M, S, T.

In addition, **Project 99163 O** will assist with design and analysis of all projects.

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 99 Detailed Project Descriptions.

SCHEDULE

A. Measurable Project Tasks for FY 99

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

1999

May - August	Field work at colonies, aerial fish surveys
July	Acoustic sampling in PWS and LCI

2000

January	Annual Review
April	Annual 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.*
2001 Final Reports completed, except for possible continuation of several projects.

C. Completion Date

September 30, 2001

PUBLICATIONS AND REPORTS

Please see the individual subproject annual reports and DPDs.

PROFESSIONAL CONFERENCES

Project-level participation
In addition to the presentations described in the DPDs for the individual subprojects, APEX will present one or more sessions of integrated presentations at the 1999 *Symposium on Ten Years of Recovery Following the Exxon Valdez Oil Spill.*

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 on 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
The work that will be conducted on seabirds at the Barren Islands by AMNWR for the EVOS APEX project is not something that AMNWR or the FWS is required to do by statute or regulation. Until recently, the Barren Islands were listed as an intermittent monitoring site for tufted puffins and fork-tailed storm-petrels *(Oceanodroma furcata)* in the refuge's seabird monitoring program. In 1994, these islands were also designated as an annual monitoring site for murres and kittiwakes, primarily because EVOS-sponsored restoration studies demonstrated that data could be collected at them that satisfied standard refuge monitoring protocols for these species. Designating the Barren Islands as a annual monitoring site has improved the refuge's chances of obtaining funding for conducting murre and kittiwake studies at them. However, because these islands are not part of the FWS's highest priority ecosystem, the Bering Sea, monetary support for this kind of annual work will not be available until overall FWS priorities change (i.e., from the Bering Sea to other officially designated ecosystems within Alaska). Furthermore, many types of data that will be collected on murres, kittiwakes, puffins, gulls, and cormorants during the Barren Islands component of the APEX project are not obtained during normal AMNWR monitoring studies (e.g., feeding and growth rates of chicks, time-budgets of adults, types and amounts of prey fed to chicks). The proposed project is needed to obtain these and other types of data for a multiyear, multispecies, multicolony analysis of seabird productivity and energetics that will improve understanding of ecological processes and help explain why some species of seabirds are not recovering in the spill area. Results of APEX ecological processes investigations will markedly improve overall management of common murres and other seabird species in the Gulf of Alaska.

99163 K
Not applicable

99163 L
The National Biological Service conducts research in support of the land management missions of state and federal agencies. Internal programs and funds do not exist for routine monitoring or research on ecosystems. This project would not exist if the oil spill had not occurred.

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.

In coordination with 92-97064 (Kathy Frost), 99163 I is completing an analysis comparing harbor seal foraging data with historical data on distribution and changes in forage fish in Prince William Sound and the northern Gulf of Alaska.

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

99163 A
This project will focus on replicating the ongoing series of inshore acoustic measurements of forage fish in the three study areas.

99163 B
This project will be working with Project T to analyze bird distribution and foraging in relation to data from aerial surveys. The project will also focus on modelling sand lance habitat in PWS.

99163 E
No major changes are planned.

99163 F
No major changes are planned.

99163 G
No major changes are planned, although energetic studies planned for 1998 may be moved back a year if there is widespread reproductive failure of kittiakes in 1998.

99163 I
This project will shift host organization but will otherwise continue as planned. Small projects on herring diet, GIS of PWS sensitive areas, and on mitochondria in seabirds may be used to fill gaps between other projects.

99163 J
No major changes are planned.

99163 K
No major changes are planned.

99163 L
No major changes are planned.

99163 M
No major changes are planned.

99163 O
No major changes are planned but there will be increased effort in support of other projects.

99163 Q

The modeling effort will focus on Common Murres in Lower Cook Inlet, examing the role of food limitation in limiting recovery of this species.

99163 R
No manjor changes are planned.

99163 S
No manjor changes are planned.

99163 T
No manjor changes are planned.

PRINCIPAL INVESTIGATORS

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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.

LITERATURE CITED

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A
Forage Fish Assessment

99163 A
Forage Species Studies in Prince William Sound

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NOTE

SINCE THE INVESTIGATORS DID NOT SUBMIT A PROPOSAL, THE PROJECT LEADER EDITED THE 1998 DPD TO REFLECT HIS UNDERSTANDING OF THE PROJECT'S ROLE. IN 1999.

INTRODUCTION

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

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).

Macrozooplankton; 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, macrozooplankton are fed on directly by marine birds (Coyle et al. 1992, Hunt et al 1981, Oji 1980). Swarming behavior by breeding euphausiids (Paul et al. 1990b) and physical factors (Coyle et al. 1992, Coyle and Cooney 1993) may concentrate macrozooplankton and micronekton into aggregations of density suitable for efficient foraging by predators. Unfortunately, there is little information on the abundance, distribution and fluctuations of these key invertebrates in the EVOS impact region. In the GOA zooplankton abundance has varied on a decadal time scale (Brodeur and Ware 1992); and, superimposed on longer cycles, are interannual fluctuations as high as 300% (Frost 1983, Coyle et al. 1990, 1992, Paul et al. 1990a, 1990b, 1991, Paul and Coyle 1993). Such variability in abundance may affect populations of apex predators in PWS.

OBJECTIVES

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

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

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

MILESTONES

1.. August 1999 - complete a 21 day acoustic/net sampling survey of inshore zones in the three APEX core study areas.

2. December 1999 - Complete laboratory analyses of forage species catch compositions and length distributions from 1999 survey sampling.

3. February 2000 - Complete analyses of CTD data collected in 1999.

4. March 2000 - Complete analyses of acoustic data set collected in 1999

ACOUSTIC ASSESSMENTS

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

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

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

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

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

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

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

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

NET AND VIDEO SAMPLING FOR IDENTIFICATION OF ACOUSTIC TARGETS

Hydroacoustic sampling will be the primary method used to quantify the abundance of forage species in Prince William Sound. However, net and video sampling will be needed to identify the species comprising the hydroacoustic signals and to provide biological samples for life history, condition and energetics studies of forage species. For offshore net sampling we will use a research-scale (100 m^2 opening) version of a mid-water commercial trawl and a purse seine. For nearshore net sampling we will use a purse seine, beach seine and cast nets. In both the offshore and nearshore surveys, we will use an underwater video camera to identify acoustic targets. This camera system will operate to depths of 60 meters. The video system has a real-time monitor on the operating vessel, and schools of fish will be recorded with a high resolution video recorder.

Invertebrates.

Macroinvertebrates will be preserved shortly after collection, and sorted by species later. The difficulties of identifying invertebrates to species will preclude working them up in the field. For example, there are likely to be at least five species of euphausiids in PWS. We will fix and preserve macrozooplankton samples from nets and sort and measure them in the laboratory. Large jellyfish will be identified, measured, and returned to the sea. Subsamples of larger zooplankton, particularily eupahusiids, will be frozen in individual containers for later bioenergetic analyses.

Fishes.

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

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

a) written directions as to the number of each species they require, and directions for preserving them.
b) all preservatives, sample and shipping containers
c) arrangements for sample shipping, and payment of all shipping charges.

OCEANOGRAPHIC DATA

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

FIELD STUDY PLAN

The field work will consist of a nearshore survey of the three core study areas in July/August 1999.

We propose to conduct the nearshore survey of the core study areas in a research cruise in July/August 1999 when bird species are at an important stage of their reproductive activity. This survey will be a 21 day cruise beginning as soon as possible after 15 July. The survey will sample three areas intensively (Figure 1): 1) North (Valdez Arm, Port Fidalgo, Port Gravina); 2) Central (Naked Island, northern Knight Island); 3) South (Knight Island Passage, Whale Bay). The survey will be conducted by two vessels - an acoustic vessel that will run pre-selected transects and a catcher vessel that will use a purse seine and video equipment to identify acoustic targets.

Nearshore survey.

Nearshore sampling will follow procedures developed in the 1996 program. In each of the three areas, a series of 8 - 10 study sites will be pre-selected for detailed acoustic and net survey. Each study site will consist of a section of shoreline 12 km in length, and extending from the approximate mean low tide line out to 1 km. This section of shoreline will be surveyed acoustically by a series of 20 zig-zag transects (10 zigs, 10 zags) about 1.2 km in length. A net/video sampling vessel will acompany the acoustic vessel, and will sample acoustic targets as directed by the acoustic vessel. The net/video vessel will also conduct all CTD sampling during the survey.

SURVEY COORDINATION

Surveys will be planned cooperatively with biologists from USFWS, NMFS, and SEA project. At least two weeks prior to each survey, a cruise plan will be circulated to all participants, including all University project participants, agency biologists from USFWS and NMFS, and the SEA project, and the COTR.

BUDGET SUMMARY AND JUSTIFICATION

Vessel Charters.

A major budget item in this study is for vessel charters. The type of research we propose requires relatively large vessels with substantial daily charter rates. We will require:

1) Acoustic vessel - we intend to use the F/V MISS KAYLE and either the F/V CAPE ELRINGTON or the M/V PACIFIC STAR for the acoustic vessels. All were chartered by us in the 1996 field season and have contract extension clauses in those contracts.

2) Net and Video sampling vessel - We intend to use the F/V PAGAN for this purpose. That vessel was chartered by us in the 1996 field season and has a contract extension clause in its contract.

3) Mid-water trawl vessel - We intend to use the ADF&G research vessel R/V PANDALUS to conduct mid-water trawling for approximately 3 days in August.

BioSonics, Inc. Subcontract

BioSonics Inc. is budgeted for a subcontract to provide technical and consulting support for this project. In the first two years of the APEX program, BioSonics was subcontracted to provide: acoustic equipment, installation and operation of equipment, and data analyses support.

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B
Bird/Fish Interactions

SEABIRD/FORAGE FISH INTERACTIONS

Project Number:	99163 B
Restoration Category:	Research
Proposed By:	DOI
Duration:	5 years
Cost FY 98:	$112,500
Cost FY 99:	$120,900
Cost FY 00:	$124,000
Cost FY 01:	$ 78,000
Geographic Area:	Prince William Sound
Injured Resource/Service:	Piscivorous birds

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 within Prince William Sound (PWS). During 1995 - 1997 we sought to determine if forage fish characteristics and/or interactions among seabirds limit food availability. Progress has been made on this issue; however, further analysis of data will be halted until issues concerning the analysis of hydroacoustic data are resolved. We have examined the habitat preference of seabirds and this will be expanded by participating in multi-component aerial monitoring of the distribution of forage fish and seabirds. Initial progress has been made on determining the characteristics of habitat associated with Pacific sand lance (*Ammodytes hexapterus*). These efforts will be further developed to model potential sand lance habitat throughout PWS.

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. During 1997 we collected data in association with aerial surveys. This effort was expanded in 1998 to include PWS wide monitoring of nearshore schooling fish and birds.

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 intend to validate bottom typing methods in 1998 and map potential sand lance habitat throughout PWS in 1999.

We have examined foraging habitat preference of seabirds by examining nearshore seabird distribution and forage fish biomass data collected in 1996 and 1997. 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. Our boat based evaluation of seabird foraging does have limitations. It produces small sample sizes of surface feeding birds, Larids, due to our inability to determine whether flying birds are in transit to feeding areas or they are searching for forage. These surveys also produce poor sample sizes of mixed species feeding flocks due to their infrequent occurrence (Maniscalco and Ostrand 1997, Ostrand et al. 1998). Initial results obtained from aerial surveys conducted in 1997 indicate foraging behavior of larids can be identified from the air by observing if birds are associated with visible schools. Larger sample sizes of feeding flocks were also obtained due to greater coverage that was achieved by sampling from aircraft. Through participating in multi-component aerial surveys in 1998 and 1999 we will examine phases of seabird foraging that have previously eluded us.

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. 1998). The scope of this approach needs to be expanded to determine what portion of prey biomass is available to seabird. Further progress has been made in this effort; however, this approach involves the analysis of hydroacoustic data. The *Exxon Valdez* Oil Spill Trustee Council's (EVOS TC) Chief Scientist has requested that target strengths of PWS forage fishes be determined prior to publishing results obtained through analysis of hydroacoustic data. Therefore, further work on this question will be curtailed until target strength issues are resolved.

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 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 and Objectives

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.

The second hypothesis has been investigated and the results presented (Maniscalco 1997). The former is the basis of ongoing work. During 1997 an additional objective was added:

3: Determine the habitat preferences of seabirds and forage fish.

This objective was added for both scientific reasons and to provide resource managers with tools to evaluate impacts of expanded use and development of PWS.

D. Completion Date

We anticipate 5 years of field data collection (FY 1995-1999) to quantify seabird/forage fish interactions at both temporal and spacial scales followed by 2 additional years of to analyze data and publish the findings of the study in scientific journals.

COMMUNITY INVOLVEMENT

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

FY 99 BUDGET

Personnel	104.0
Travel	1.0

Contractual	0.0
Commodities	0.2
Equipment	0.0
Subtotal	105.2
Gen. Admin.	15.7
Total	120.9

PROJECT DESIGN

The 1999 field season will be a continuation of on-going research. This study will continue to focus on nearshore shallow habitats. Techniques have been added to address comments expressed by the EVOS TC's Chief Scientist.

A. Objectives

The Seabird/Forage Fish Interactions study will focus sampling efforts on nearshore habitats through both aerial and boat based methods. Data collection 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 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 what proportion of the biomass conforms to those characteristics. Since much of this work involves interpretation of hydroacoustic data and there are unresolved target strength issues for PWS species, this objective has been assigned lower priority.

B. Methods

Data collection: In 1999 we will collect data in association with the aerial and hydroacoustic forage fish surveys of nearshore habitats. For descriptions of study designs, see the Forage Fish Assessment component (99163a) and Modeling (99163q) proposals. Additional data will be collected to support PWS wide sand lance habitat modeling

The sampling design of aerial field studies will be developed through a collaborative effort of components 99163a, 99163b, 99163e (Kittiwake foraging and reproduction), 99163o (statistical support), and 99163q. This group of investigators will also determine data collection and analysis responsibilities.

During 1999 separate field work will be directed at identifying potential sand lance habitat throughout PWS. This will be an extension of field work conducted the previous year. Field work done in 1998 will be directed at identifying marine substrate characteristics that are associated with sand lance, the calibration bottom typing software, and identifying the acoustic return of habitats associated with sand lance. These data collections will be limited to habitat within component's 99163a study areas. In 1999 we will stratify nearshore habitat outside of the 99163a study areas based upon characteristics associated with sand lance and areas of importance to seabirds. Habitats with little potential for sand lance use will not be sampled. Field methods will include hydroacoustic bottom sampling, continued calibration with bottom grabs, and collection of fish samples with dip and cast nets. Sampling will be conducted from a U. S. Fish and Wildlife Service's Boston Whaler to keep expenses low and to minimize travel time between sampling sights. Substrates with acoustic returns similar to those that were associated with sand lance in 1998 will be considered potential habitat.

Data analysis: Multivariate methods will be used to determine habitat selection by seabirds. We intend to quantify a suite of variables that describe habitats that are available to seabirds. We then will determine preference. Variables will be measured both in the field and subsequently through the use of geographic information system (GIS) analysis. We will consult with 98163o on data analysis techniques, prior to the collection of field data, on the best methods of determining preference. Interpretation of results will be accomplished through the use of GIS presentation.

Bottom grab data collected in 1998 will be used to calibrate output from hydroacoustic bottom typing software. Hydroacoustic data collected during earlier years will then be used to type all areas sampled in the APEX study areas. Using GIS we will overlay all known sand lance locations on the APEX survey routes. We then will apply an iterative process to determine the scale at which sand lance habitat are most strongly linked to substrate type (Schneider and Duffy 1985). Component 98163o will be consulted to determine the most appropriate method of determining habitat selection by sand lance (Manly et al. 1993). Hydroacoustic data collected within PWS beyond the APEX study areas will then be bottom typed and locations of available sand lance habitat will be assigned based upon results of the analysis of scale and association. Ultimately, potential sand lance habitat throughout PWS will be displayed through GIS mapping.

Determining if characteristics of forage fish schools limit availability of seabird prey involves the interpretation of hydroacoustic data. The Chief Scientist has issued a proclamation that target strengths of PWS forage fishes must be determined and incorporated into the analysis of hydroacoustic data intended for publication. Therefore, further analysis on this objective is temporarily halted until the target strength issue is resolved.

PUBLICATIONS

Development of papers that involve the interpretation of hydroacoustic fish biomass data have been suspended. The following proposed paper for 1999 will discuss the interpretation of hydroacoustic bottom data.

The distribution of potential sand lance habitat within Prince William Sound, Alaska as determined through the interpretation of hydroacoustic bottom data.

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E
Kittiwake Studies

KITTIWAKES AS INDICATORS OF CHANGE IN FORAGE FISH

Project Number:	98163E
Restoration Category:	Research
Proposer:	DOI
Duration:	Fourth year of six-year project
Cost FY 99:	$183.3K
Cost FY 00:	$115.7K
Cost FY 01:	$73.2K
Geographic Area:	Prince William Sound
Injured Resource:	Piscivorous birds

ABSTRACT

Black-legged kittiwakes (*Rissa tridacyla*) nest at 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 regional and annual variation in breeding success has been observed, however insufficient data were available to determine causes of such variation. This project (163E) was designed to quantify relationships between the reproductive biology and foraging ecology of kittiwakes and the relative abundance and availability of forage fishes. These relationships can then be incorporated with long-term demographic and population trend data (collected by the U.S. Fish and Wildlife Service) to model the effect of environmental perturbations on kittiwake populations.

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 productive enough to maintain itself. Because kittiwakes are piscivorous like other impacted birds, it is likely that they would be affected by a lack of food in a similar manner as the other species. Kittiwakes are easier and less expensive to study than other impacted species. By studying kittiwakes, we are hopefully learning about factors that are 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 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 1999	FY 2000	FY 2001
Personnel	109	98	61
Travel	7.1	3	3
Contractual	18.2	-	-
Commodities/Equipment	31.7	-	-
Administration	17.3	14.7	9.2
Total	183.3	115.7	73.2

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, fledging success, brood size at fledging, 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

Egg laying dates, clutch size, hatching success, fledging 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 fledging will be recorded for all 26 colonies in PWS.

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

To determine growth rates, chicks of birds 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 fledging. 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 for the near-linear portion of the growth curve (i.e., 60 - 300 g) by dividing the weight gain by the number of days. For kittiwakes, this method produces results that are virtually identical to Ricklefs' (1967) maximum instantaneous growth rates (Galbraith 1983).

We will collect diet samples from adults at Shoup Bay, Eleanor Island, 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. Biggs, 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 11 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 8m Boston Whaler during foraging trips. To select a bird to follow, we will wait near the colony until we detect a radio-tagged bird leaving the area; then we will follow it. We will follow only birds with chicks.

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

Data on the foraging trip length and foraging areas of radio-tagged birds will also be collected by using remote receiving stations (RRSs). RRSs are composed of a 164 to 168 MHz Advanced Telemetry Systems receiver connected to an Advanced Telemetry Systems data collection computer. The receiver and computer are powered by an 80 amp/hour lead-acid battery, which is charged by a three amp solar panel. The receiver and computer are housed in a waterproof, plastic "Pelican" case. The type of antenna used depends on the range desired; for the RRS set up at colonies a two element "H" antenna will be used, for all other locations a more powerful five-element Yagi antenna will be used. Antennae at all sites except 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. 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 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, fledging success, nest attendance, brood sizes, brood reduction, and overall productivity. Student's t-test (Zar 1984) will be used to compare growth rates of chicks that are reared by radio-tagged birds and chicks that are reared by birds without radios, and to compare chick provisioning rates. Distances that birds fly, 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 99

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 98 will be revised for publication. Manuscripts incorporating FY 98 and 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 atscientific meetings and for public interpretation.

B. Project Milestones and Endpoints

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

C. Project Reports/Publications

Annual reports will be submitted by 15 March 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 in preparation

Suryan, R. M., D. B. Irons and J. E. Benson. Interannual variability in diet and foraging effort of kittiwakes in relation to prey abundance. Will be submitted to the Auk

Suryan, R. M. and David B. Irons. Population dynamics of kittiwakes in Prince William Sound, Alaska: productivity of individual colonies and popualation trends. Will be submitted to Condor.

Benson, J. E. and R. M. Suryan. A leg noose for capturing nesting birds. Will be submitted to the Journal of Field Ornithology.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

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

The Fish and Wildlife Service, as part of 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. The Service is experiencing unprecedented declines in funding and the trend may continue into the future.

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

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. In press. Foraging site fidelity and tidal rhythms in individual Black-legged Kittiwakes. Ecology.

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.

Irons, D.B., R.G. Anthony, and J.A. Estes. 1986. Foraging strategies of Glaucous-winged Gulls in a rocky intertidal community. Ecology 67:1460-1474.

Hogan, M.E., and D.B. Irons. 1986. Waterbirds and marine mammals. *in* M.J. Hameedi and D.G. Shaw, editors. Environmental management of Port Valdez, Alaska: scientific basis and practical results. Springer-Verlag, New York.

Irons, D.B. In preparation. Flexible foraging behavior in seabirds: short-term buffer and long-term tradeoff?

Irons, D.B. In preparation. The role of food availability in sibling aggression and brood reduction of the Black-legged Kittiwake.

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 13 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.

Reports and Publications

Suryan, R. M. and J. T. Harvey. In press. Tracking harbor seals (*Phoca vitulina richardsi*) to determine dive behavior, foraging activity, and haul-out site use off the northern San Juan Islands, Washington. Mar. Mamm. Sci.

Suryan, R. M. and J. T. Harvey. In review. Variability in reaction to disturbance among Pacific harbor seals *Phoca vitulina richardsi*. Fish. Bull.

Harvey, J.T., K.L. Raum-Suryan, and R.M. Suryan. 1995. Distribution and Abundance of Marine Mammals near Sur Ridge, California, the former proposed site of the Acoustic Thermometry of Ocean Climate (ATOC) sound source. Final report. 37 pp.

Suryan, R.M. 1995. Pupping phenology, disturbance, movements, and dive patterns of the harbor seal off the northern San Juan Islands, Washington. M.S. Thesis, Moss Landing Marine Laboratories. 75 pp.

Harvey, J.T., R.M. Suryan, and K.L. Raum-Suryan. 1994. Seabird surveys during ship shock tests of the U.S.S. John Paul Jones (DDG 53). Report to the Department of the Navy, San Bruno, California 94066. 10 pp.

Harvey, J.T., J.W. Mason, R.M. Suryan, and P.E. Byrnes. 1994. Seabird and Marine Mammal surveys during disposal of dredged material at the ODMDS. Final report to PRC Environmental Management, Inc., San Francisco, California 94105. 44 pp.

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F
Guillemot Studies

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

Project Number:	99163F
Restoration Category:	Research
Proposed By:	DOI
Lead Trustee Agency:	DOI
Cooperating Agencies:	NOAA and ADFG
Duration:	5 years
Cost FY 99:	190 K
Geographic Area:	Prince William Sound
Injured Resource:	Pigeon Guillemot

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. 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, 1997 counts were higher than 1995 or 1996 totals.

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 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 99 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.

Foraging study hypotheses

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 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 supported by Golet et al. 1998).

B. METHODS

Below are outlines of our field methods; details are reported in a separate document entitled "Pigeon Guillemot Field Protocol".

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 (40 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. These 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 the survival of the adults. 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)

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.

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.

SCHEDULE

A. Time line

January - May 1999	Planning and preparation for 1996 field season.
March 15 1999	Report results of 1998 field season.
June - August 1999	Accomplishing field objectives.
September 1999	Maintaining, repairing, packing and storing of field season gear for winter.
September 1999-May 2000	Data entry, analyses and manuscript preparation.
December 15 2000	Final report of this component of APEX

B. Publications
The Principle Investigator will contribute to two publications in FY1998 that relate to Pigeon Guillemots:
a) "Adult prey choice affects chick growth and productivity of Pigeon Guillemots," G. Golet, K. Kuletz, D. Roby, and D. Irons; will be submitted to *Ecology* in April 1998.
b) "Diet and reproduction in Pigeon Guillemots from Prince William Sound and Kachemak Bay, Alaska," J. Anthony, G. Golet, D. Roby, and A. Prichard; *Condor*, target submission 1998.
C. Project Reports
The final report for this component of APEX will be submitted 15 December 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. All logistics for field camps at Naked, Eleanor (kittiwakes), and Jackpot Islands will be coordinated (i.e., same barge for transport of equipment, supplies, and fuel) and all transport expenses shared.

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, and currently has a paper in press in the *Journal of Animal Ecology* that focuses on survival costs of chick rearing in Black-legged Kittiwakes. 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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G
Energetics

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

Project Number:	99163 G (formerly 95118-BAA)
Restoration Category:	Research (continuing)
Proposed By:	Oregon State University (PI - Daniel D. Roby)
Lead Trustee Agency:	NOAA
Duration:	5th year, 6-year project
Cost FY 99:	$180,000
Cost FY 00:	$70,000
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, and the DPD for FY 98 submitted in March 1997. Parts of this FY 99 DPD that have been modified from the FY 98 DPD have been printed in bold face below for the convenience of peer reviewers.

Research in 1995 for the Alaska Predator Ecosystem Experiment (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, this research continued without the tufted puffin component and with the shift from Seal Island to North Icy Bay for research on kittiwakes. In 1997, the study sites and study species were the same as in 1996. 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; and the consequences of variation in energy provisioning rates on seabird growth and productivity. In 1997, a pilot study examined the daily energy expenditure of adult kittiwakes raising young at two different colonies with differing diets, foraging behavior, and reproductive success in order to test the hypothesis that breeding adults modify their parental investment in response to changes in food availability.

In 1998, this component of the APEX Project will continue to investigate the relationship between diet quality and nesting productivity at the kittiwake and guillemot colonies that were studied in 1996-1997. In addition, the pilot study of daily energy expenditure in adult kittiwakes will be expanded to assess intercolony differences in parental investment in response to a broader range of food availabilities. Results from the 1995-1997 breeding seasons suggest that capelin, sand lance, and herring are key forage fish resources for piscivorous seabirds nesting in the oil spill area. **Results from the 1998 breeding season, a year when El Niño and unusually high sea surface temperatures promise to strongly influence availability of key forage fish stocks, will allow us to better understand the adaptive compensation of breeding seabirds to decadal shifts in forage fish stocks.**

If 1998 proves to be a season of poor nesting success for piscivorous seabirds in the northern Gulf of Alaska, with widespread breeding failure at the APEX study colonies, it may not be feasible to conduct an extensive study of kittiwake parental investment using the doubly labeled water technique. If few or no nesting pairs are still actively raising nestlings by early in the chick-rearing period, it will not be possible to obtain the required samples. Under these circumstances, it would be prudent to call off the study in 1998 and postpone the field work until the 1999 breeding season, the fifth and final field season for the APEX project. This would require returning that portion of the FY 98 funding that was earmarked for the study of adult daily energy expenditure ($40,000) and a subsequent increase in the FY 99 budget for this component of APEX.

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 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 (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) normally transport meals that are close to the maximum load. Seabirds that transport chick meals as single prey items held in the bill (e.g., guillemots, murres, murrelets) experience additional constraints on meal size if optimal-sized prey are not readily available. Consequently, seabird parents that provision their young with fish high in lipids are able to support faster growing chicks that fledge earlier and with larger fat reserves. This is because the energy density of lipid is approximately twice that of protein and carbohydrate. 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).

Lipid content (% dry mass) and energy density (kJ g wet mass) of forage fishes collected in PrinceWilliam Sound and Lower Cook Inlet during the 1995-1997 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 99163A-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 EVOS area affect reproductive success. By monitoring the composition and provisioning rates of food to seabird nestlings, prey preferences can be assessed. Measuring provisioning rates is crucial because even very poor quality prey may constitute an acceptable diet if it can be supplied at a high rate. Understanding the diet composition, foraging niche, and energetic constraints on seabirds breeding within the spill area will be crucial for designing management initiatives to enhance productivity in species that are failing to recover from EVOS. If forage fish that are high in lipids are an essential resource for successful reproduction, then efforts can be focused on assessing stocks of preferred forage fish and the factors that impinge on the availability of these resources within foraging distance of breeding colonies in the EVOS area. As long as the significance of diet composition is not understood, it will be difficult to interpret shifts in the utilization of forage fishes and develop a management plan for effective recovery of damaged species.

B. Rationale/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 continue to provision their young predominately with sand lance, and sand lance is particularly prevalent in the diet at sites that support high densities of breeding pairs (A. Prichard, unpubl. data). Jackpot Island in southwestern Prince William Sound supports the highest nesting densities of guillemots anywhere in the Sound. The high availability of juvenile herring to guillemots nesting at Jackpot Island may be responsible for this breeding aggregation. Diet at Jackpot Island in 1997 was nearly devoid of herring, however, and nesting productivity declined concurrently. 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 can 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 is feasible. Diets fed to kittiwake chicks in PWS and Lower Cook Inlet consist primarily of high-quality schooling forage fish (i.e., sand lance, herring, capelin), although low-quality forage fishes (e.g., juvenile walleye pollock) are also taken.

C. Location

Field work will be 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) during FY 99. The PWS study sites that were used in 1997 and 1998 will again serve as study sites in 1999. These sites are identical to those seabird breeding sites that are being used by other components of APEX.

Field work on pigeon guillemots will be conducted at breeding colonies on Naked Island, Jackpot Island (both in PWS), and in Kachemak Bay. Approximately 500 guillemots nest along the shores of Naked Island (Sanger and Cody 1993). The Naked Island field camp in Cabin Bay is an excellent base for field studies on guillemots, and Naked Island supports a high proportion of the total breeding population of guillemots in PWS (Sanger and Cody 1993). In addition, Naked Island has been the site of long term studies of guillemot reproductive ecology since 1979 by the Fish and Wildlife Service (Kuletz 1983, Golet et al. In prep.). Jackpot Island supports about 42 breeding pairs of guillemots nesting at the highest densities known in PWS (G. Sanger, D. L. Hayes, pers. comm.). Both Naked Island and Jackpot Island were the site of intensive studies of guillemot nesting success during the 1994-1997 field seasons and have been selected for continued studies (APEX Component 98163 F). Kachemak Bay will serve as a third study site for guillemots. The breeding population of guillemots on the south shore of Kachemak Bay between Mallard Bay and Seldovia was the site of intensive studies in 1994-95 by Alex Prichard, a UAF graduate student, and by Mike Litzow in 1996-97. Results to date indicate that the guillemot prey base in Kachemak Bay is largely sand lance, and is perhaps similar to the prey base at Naked Island 15-20 years ago. Consequently, the Kachemak Bay guillemot study site provides an excellent reference site for guillemot studies in PWS.

Field work on kittiwakes in PWS will be conducted at three breeding colonies, one at Shoup Bay (off Valdez Arm) that supports approximately 1600 breeding pairs of black-legged kittiwakes, another at Eleanor Island (adjacent to Naked Island) that supports about 180 breeding pairs, and the last in North Icy Bay that supports about 500 breeding pairs. The Shoup Bay colony is the site of continuing long-term studies of kittiwake nesting ecology in PWS by the Fish and Wildlife Service and Eleanor Island was selected as a breeding colony within the oiled area of PWS for intensive study for comparison purposes (APEX Component 98163 E). The colony at North Icy Bay was added as a study colony in 1996 because of its proximity to the Jackpot Island guillemot colony and areas where forage fish abundance is being assessed. All colonies include adequate numbers of readily accessible nests. In Lower Cook Inlet, kittiwake breeding colonies at the Barren Islands (offshore), Gull Island (inshore), and Chisik Island (nearshore) will be monitored for diet and reproductive success.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

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

PROJECT DESIGN

A. Objectives

1. To determine the nutritional quality of various forage fish species consumed by seabirds in the EVOS area as a function of size, sex, age class, 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 relationship between diet and parental investment during the brood-rearing period. Daily energy expenditure rates (kJ/day) will be measured as an index to parental investment and compared among colonies of the same species.

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, may 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 research in 1999 will emphasize pigeon guillemots and black-legged kittiwakes for practical reasons.

The proposed research approach utilizes 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 will be conducted concurrently during the 1999 breeding season at three sites where pigeon guillemots breed and at 6 kittiwake breeding colonies, all within the EVOS area. A minimum of 40 active and accessible nests of each species will be located and marked prior to hatching at each of the study colonies. These nests will be closely-monitored until the young fledge or the nesting attempt fails.

Fresh samples of forage fishes used by guillemots will be collected for determination of species composition and proximate analysis using the following three techniques, in order of importance: (1) 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 will be collected using beach seines and minnow traps deployed in guillemot foraging areas and by netting specimens at low tide during spring tide series.

Kittiwakes transport chick meals in the stomach and esophagus, so chick diet samples will consist of semi-digested food. Kittiwake meal samples are normally collected when chicks regurgitate during routine weighing and measuring. Additional diet samples will be collected by capturing adult kittiwakes as they return to feed their young and inducing them to regurgitate the contents of their esophagus. Fresh specimens of forage fishes used by kittiwakes will be provided from net sampling (APEX Component 99163 E).

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

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

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

Parental investment of adults raising broods will be assessed by measuring daily energy expenditure (DEE) of breeding adults during the chick-rearing period. DEEs for adult guillemots will be measured at various colonies in Kachemak Bay, using the doubly-labeled water (DLW) technique (Lifson and McClintock 1966, Nagy 1980, Roby and Ricklefs 1986), pending preliminary results from a pilot study conducted in 1998. Adult guillemots will be measured at Moosehead Point, Halibut Cove, Seldovia Bay, and the Yukon Island area to represent different food availabilities and foraging strategies. Measurements will be taken between day 15 and 30 of the nestling period. A sample of 15 breeding adults from each colony will be captured at the nest site, identified or marked, and weighed to the nearest gram with a Pesola spring scale. Each bird will be injected intraperitoneally with a mixture of $H_2^{18}O$ (90 atom %) and ^2H_2O (99.8 atom % deuterium) at a dose of 2.5 ml/kg body mass (ca. 1 ml of DLW for guillemot adults). Both oxygen-18 and deuterium are stable isotopes and thus are not radioactive. Injected adults will then be released at their nest site without waiting for isotopes to equilibrate with body water or taking an initial blood sample. Injected adults will be recaptured at the nest site after approximately 24 or 48 h. Once recaptured, injected adults will be reweighed, and a blood sample collected by puncturing the brachial vein. Blood will be collected in 6-8 microcapillary tubes (ca. 10 ul each), which will subsequently be flame sealed. Isotopic enrichments of blood samples will be 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 will be calculated using the equations of Lifson and McClintock (1966). DEE will be 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 will be separated by colony for each species, and fit to logistic growth models. Growth constants (K), inflection points (I), and asymptotes (A) of fitted curves will be statistically analyzed for significant differences among years and colonies. Gross foraging efficiency of adults will be calculated from daily energy expenditure by the following equation:

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

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 will be calculated from field metabolic rates of guillemots and kittiwakes that will be measured at study sites in PWS and Lower Cook Inlet using the doubly-labeled water technique. This will test the hypothesis that daily energy expenditure (parental investment) of adults raising young varies among sites and years, depending on species composition, availability, and quality of forage fish resources. Other measurements of daily energy expenditure rates for these two species breeding in other locales are available for comparison in the published literature (Birt-Friesen et al. 1989). Comparison of food conversion efficiency of chicks from different colonies fed different diets will provide an estimate of the relative energetic efficiency of diets composed of various forage fishes. The net production efficiency of the parent/offspring unit will be calculated for each diet and each year for both species using the equation:

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

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

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

Isotopic enrichments of blood samples for the doubly labeled water experiments will be 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.

SCHEDULE

A. Measurable Project Tasks for FY 99 (May 1, 1999 to April 30, 2000)

May 1 - August 31:	Field data collection
September 1 - 30:	Enter field data; begin laboratory analyses.
October 1 - December 31:	Analyze samples in laboratory for FY 99.
January 1 - 14:	Prepare for Restoration Workshop in Anchorage.
January 20 - 23:	Attend Annual Restoration Workshop.
March 15:	Submit Annual Report of 1999 findings Submit FY 2000 DPD to Dr. Duffy.

B. Project Milestones and Endpoints

Objective 1 will have been largely met by April 1998. Objectives 2 and 3 will not be achieved until April 2001, although results from any particular breeding season will be available by the following April. Objective 4 will not be achieved until the completion of this component of APEX in April 2001.

C. Completion Date

The anticipated completion of this project will be early in FY 01, early in calendar year 2001. This will allow adequate time to complete data analysis and manuscript preparation following the last field season in 1999.

PUBLICATIONS AND PROJECT REPORTS

The following publications are projected for this research project (this is a rough projection and by no means complete):

a) "Lipid content and energy density of forage fishes from the northern Gulf of Alaska," J.A. Anthony, D. D. Roby, and K.R. Turco Can. J. Fish. Aquat. Sci. submitted April of 1998.

b) "Diet and reproductive energetics in pigeon guillemots from Prince William Sound and Kachemak Bay, Alaska," M. Litzow, G. Golet, K Kuletz, D. D. Roby, and A.K. Prichard; Condor, target submission in 1999.

c) "Diet and reproductive energetics in black-legged kittiwakes from Prince William Sound, Alaska," D. B. Irons, R. Suryan, J. A. Anthony, & D. D. Roby; Auk, target submission in 1999.

d) "Effects of prey type on postnatal growth and development of piscivorous seabirds: a captive feeding experiment," M. Romano, D. D. Roby, and J. Piatt; Condor, target submission in 1998.

e) "Effect of dietary lipid content on postnatal growth and development piscivorous seabirds: captive feeding trials," M. Romano, D. D. Roby, and J. Piatt; Physiol. Zool., target submission in 1998.

f) "Parental energy expenditure of black-legged kittiwakes in relation to diet and foraging conditions," D. D. Roby, D. B. Irons, R. Suryan, K.R. Turco; J. Anim. Ecol., target submission in 1999.
g) "Parental energy expenditure of pigeon guillemots in relation to diet and foraging conditions," M. Litzow, D. D. Roby, and K.R. Turco; J. Anim. Ecol., target submission in 2000
h) "Effects of diet quality on reproductive success of piscivorous seabirds in Alaska," D. D. Roby, J. Piatt, & D. C. Duffy; Ecology, target submission in 1999.
i) "Prey exploitation by piscivorous seabirds in Prince William Sound, Alaska: A bioenergetics approach," D. D. Roby, D. B. Irons, & D. C. Duffy; Can. J. Zool., target submission in 1999.
j) "Food as a constraint on seabird reproduction: Relative importance of quantity and quality," D. D. Roby, J. Piatt, D. C. Duffy; Amer. Zool., target submission in 2000.

A draft annual report for this component of APEX will be submitted by 15 March 2000 for incorporation into a synthesis Annual Report for the APEX Project by 15 April 2000. This schedule of annual report preparation will apply to 1996-98 field seasons. The final report for this component of APEX will be submitted 15 March 2001.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

The research described in this proposal is a component of the APEX Project (99163 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 proposed research approach utilizes prey composition, reproduction rates, and energetics models to help identify and quantify the present level of forage fish availability within the PWS and Lower Cook Inlet ecosystems. This approach is necessary because evaluation of the stocks of various forage fishes is extremely complex due to temporal and spatial variability and unpredictability in the distribution of forage fishes in PWS 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 currently being used as indicators of ecosystem function and health within PWS (APEX Component 98163 E), and are the subjects of a similar study on the Barren Islands (APEX Component 98163 J) and at Gull Island and Chisik Island in LCI (APEX Component 98163 M). 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 99163 E "Kittiwakes as Indicators of Forage Fish Availability), Greg Golet (PI on APEX Component 99163 F "Factors Affecting Recovery of PWS Pigeon Guillemot Populations"), David Roseneau, (PI on APEX Component 99163 J "Reproductive Success by Murres and

Kittiwakes on the Barren Islands"), and John Piatt (PI on APEX Components 99163 M "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 and 1998 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 is extremely labor intensive and the cooperation of these five components in collecting these data will greatly enhance sample sizes. The six components also require data on chick growth performance (body mass in relation to wing and flight feather development), nestling survival, mass and condition of fledglings, and fledging age. Again, cooperation and coordination between these components will greatly enhance sample sizes and the power of statistical tests and inferences. The field crews for the five components will work together to insure that data collection methods and procedures are consistent.

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

The project continues to collect data to examine potential energetic factors (diet composition, diet quality, meal size, provisioning rates) that constrain the productivity of seabirds in the EVOS area. In 1999, we plan to expand the investigation of adult daily energy expenditure using the doubly labeled water technique to include pigeon guillemots in Kachemak Bay. These data will enable us to compare parental investment and adult foraging efficiency among guillemot colonies that rely on different forage fishes (e.g., schooling fishes vs. nearshore demersal fishes) as their primary food supply. Together with the data on daily energy expenditure of kittiwakes, the guilemot data will provide a unique data set on the relationship of parental investment in seabirds as a function of food availability.

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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 U.S.G.S.-B.R.D. 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 be assisted by a Postdoctoral Research Associate, K.R. Turco at Institute of Marine Science at the University of Alaska Fairbanks, Field Technicians, Lab Technicians, and undergraduate field assistants who will be carefully selected from the applicant pool as qualified to participate in the proposed research.

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I
Project Leader

APEX Project Leader

Project Number:	99163 I
Restoration Category:	Research
Proposed By:	David Cameron Duffy, Project Leader, Paumanok Solutions, AK License 257219 2397 E 47 Anchorage AK 99507
Lead Trustee Agency:	NOAA
Duration:	5 years
Cost FY 99:	$92.3 K
Cost FY 00:	$95 K
Cost FY 01	$95 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

See cover proposal. 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 99

1999
January Review of APEX Project and EVOS Restoration Annual Workshop

April 15 Annual Report

B. Project Milestones and Endpoints

January 1999 Review of Project, Approval of APEX by Trustee Council

April 15 1999 Annual Report

C. Completion Date

October 2001 End of Project

PUBLICATIONS AND REPORTS

A first annual report was presented in April 1996. Subsequent reports will 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 continue, as part of APEX, the SEA herring project. We are also continuing, as part of the Pigeon Guillemot work, the Jackpot Island component of the Nearshore Vertebrate Project.

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

Professor Duffy agreed to stay on and lead APEX after his move from the University of Alaska to

Hawaii, running the project through a private firm. It was felt that a change in project leader at this late date would lead to unnecessary problems in the project's final year.

PRINCIPAL INVESTIGATOR

David Cameron Duffy
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Tel 907-561-0169

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, Cooperative Resources Research 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

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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.

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J
Barren Islands Study

BARREN ISLANDS SEABIRD STUDIES (PROJECT 99163J)

Project Number:	99163J
Restoration Category:	Research and Restoration (this study is part of the 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, NMFS, ADF&G
Duration:	2 years (FY 99 - FY 00)
Cost FY 99:	$115.0K
Cost FY 00	$100.7K
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 a variety of coordinated 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 mid-June - early September 1995-1997 (APEX Projects 95163J, 96163J, and 97163J). Additional data will be collected on these species in 1998 (APEX Project 98163). The presence of large stocks of capelin *(Mallotus villosus)* and other forage fishes (e.g., Pacific sand lance, *Ammodytes hexapterus*; walleye pollock, *Theragra chalcogramma*; Pacific cod, *Gadus macrocephalus*) that are utilized by seabirds breeding at the Barren Islands has provided opportunities to study seabird - forage fish relationships and natural ecological processes that may help explain why populations of seabirds have not increased in the T/V *Exxon Valdez* oil spill area since the spill. Data collected on murres, kittiwakes, and puffins during FY 95-97 included information on nesting chronology, productivity, time budgets of adults, growth and feeding rates of chicks, and types and amounts of food fed to chicks. These data and additional information obtained during FY 98 and FY 99 will be used to test 3 important APEX project hypotheses: (a) composition and amounts of prey in seabird diets reflect changes in relative abundance and distribution of forage fish near the nesting colonies; (b) changes in seabird productivity reflect differences in forage fish abundance as measured by amounts of time adult birds spend foraging for food, amounts of food fed to chicks, and provisioning rates of chicks; and (c) seabird productivity is determined by differences in forage fish nutritional quality.

INTRODUCTION

The proposed FY 99 APEX Barren Islands seabird study (Project 99163J) is designed to provide 1 additional year of data on 3 key species of fish-eating birds: common murres *(Uria aalge)*, black-legged kittiwakes *(Rissa tridactyla)*, and tufted puffins *(Fratercula cirrhata)* at the Barren Islands colonies. Results from the 5 years of work (FY 95 - FY 99) will be used in a multispecies, multicolony, multiyear analysis of seabird productivity and energetics that will help identify and define ecological processes that may be influencing seabird recovery within the T/V *Exxon Valdez* oil spill area. The data will help test 3 key APEX project hypotheses: (a) composition and amounts of prey in seabird diets reflect changes in relative abundance and distribution of forage fish near the nesting colonies; (b) changes in seabird productivity reflect differences in forage fish abundance as measured by amounts of time adult birds spend foraging for food, amounts of food fed to chicks, and provisioning rates of chicks; and (c) seabird productivity is determined by differences in forage fish nutritional quality. As in past years, field work will be conducted at the East Amatuli Island - Light Rock colony during about 10 June - 10 September. Information collected on the 3 seabird species during the study will include data on nesting chronology, productivity, time budgets of adults, feeding and growth rates of chicks, and types and amounts of food fed to chicks (data types will vary slightly between species-see below). Fish and invertebrates brought to chicks will also be collected for stable isotope and nutrient analysis.

The Barren Islands seabird studies were integrated into the APEX seabird - forage fish ecological processes project because capelin *(Mallotus villosus)*, an important forage fish species scarce in the northern Gulf of Alaska since the late 1970's (see Piatt and Anderson 1995; P. Anderson, unpubl. data), were abundant in Barren Islands waters during FY 93 - FY 94 (Roseneau *et al.* 1995, 1996a). The presence of large concentrations of capelin near the islands during these years and, their reoccurrence in FY 95 (D.G. Roseneau, unpubl. data), suggested that stocks of these important forage fish were beginning to rebound in the northwestern Gulf of Alaska. However, comparisons of 1995-1997 Barren Islands murre and kittiwake chick diets (see Roseneau *et al.* 1996b, 1997b. 1998b) and forage fish data from Pacific halibut *(Hippoglossus stenolepis)* caught in nearby waters (Projects 95163K and 97163K; see Roseneau and Byrd 1996, 1997, 1998) indicated that capelin were less available and Pacific sand lance *(Ammodytes hexapterus)* more available to surface feeding kittiwakes during these years [capelin = 64%, 28%, and 14%, and sand lance = 13%, 53%, and 63% by weight in kittiwake chick diets in 1995, 1996, and 1997, respectively; capelin = 82%, 64%, and 28%, and sand lance = 0%, 0%, and 33% by number in halibut stomachs in 1995, 1996, and 1997, respectively]. During this same time, murres continued to feed large quantities of capelin (the preferred prey species) and small amounts of sand lance to their chicks annually (capelin = 86%, 91%, and 91%, and sand lance = 1%, 2%, and 4% by number in 1995, 1996, and 1997, respectively). Although, murre productivity remained high and similar over the 1995-1997 interval, kittiwake productivity dropped sharply in 1997, when sand lance dominated chick diets (murres = 0.73, 0.74, and 0.81 fledglings per egg, and kittiwakes = 0.81, 0,71, and 0.30 fledglings per nest start in 1995, 1996, and 1997, respectively).

These and other differences that are now becoming apparent in the multiyear Barren Islands data sets, including seabird utilization of other forage fish species (e.g., walleye pollock, *Theragra chalcogramma*; Pacific cod, *Gadus macrocephalus*; see Roseneau *et al.* 1996b, 1997b, 1998b), are continuing to provide new information on seabird - forage fish relationships that will be used in conjunction with other lower Cook Inlet and Prince William Sound APEX studies (e.g., APEX components E, G, H, K, L, M, Q) for a multispecies, multicolony, multiyear analysis of seabird productivity and energetics that will test 3 APEX hypotheses (hypotheses 7, 8, and 9; also, see below) and increase understanding of ecological processes that may be influencing seabird recovery in the spill zone.

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, there is still a need to collect information that can increase understanding of seabird - forage fish relationships and ecological processes that may be influencing seabird recovery within the spill area.

B. Rationale/Link to Restoration

The study is a component of the larger APEX seabird - forage fish project (99163) that was designed to collect 5 years of data. The work was integrated into the APEX project because data on common murre, black-legged kittiwake, and tufted puffin productivity, nesting chronology, feeding and growth rates of chicks, time budgets of adults, and types and amounts of fish fed to chicks were needed from the Barren Islands colonies for use in a multispecies, multicolony, multiyear analysis of seabird productivity and energetics designed to help identify and define ecological processes that may be influencing the recovery of seabirds in the spill area.

C. Location

The FY 99 study will be conducted at the Barren Islands East Amatuli Island - Light Rock colony about 100 km south of Homer in the northwestern Gulf of Alaska. No communities will be affected by the study.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

Large format, computer-generated color posters summarizing annual results will be prepared and submitted to the Trustee Council for public display each year after data have been analyzed (as in past years). The posters are easily transported 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. Field activities will be photographed and a file of 35 mm color slides will be compiled for Trustee Council use at community meetings and in public newsletters, displays, and on-line information services. Copies of annual and final reports will be available to the public in Homer and Anchorage. Study results will also be presented at public Trustee Council-sponsored meetings and workshops, and published in scientific journals. Any vessels/aircraft needed for travel to/from the Barren Islands during the project will be chartered locally. Also, most supplies will be purchased locally (i.e., in Homer), and an attempt will be made to find local volunteers for the study. At present, there do not appear to be any sources of traditional ecological knowledge about the Barren Islands seabird colony that can be incorporated into the FY 99 studies.

PROJECT DESIGN

A. Objectives

The project objective is to collect data on the same murre, kittiwake, and puffin variables targeted in FY 95-98 (nesting chronology, productivity, growth and feeding rates of chicks, time budgets of adults, and types and amounts of prey fed to chicks) at the East Amatuli Island - Light Rock colony for use in a multispecies, multicolony multiyear analysis of seabird productivity and energetics that will help identify and define ecological processes that may be influencing recovery of seabirds in the spill zone.

B. Methods

The study will be conducted at the Barren Islands East Amatuli Island - Light Rock colony near the entrance to Cook Inlet. As demonstrated during the FY 95 Barren Islands pilot project (95163J), limiting work to this location conserves funds and maximizes data collection opportunities (i.e., compared to study designs that include Nord Island). Methods for collecting and analyzing data will follow approved protocols and be consistent with those used in FY 95 - FY 98.

Data Collection

Data will be collected by 4 personnel stationed at the FWS Amatuli Cove camp during about 10 June - 10 September (the camp leader has 8 years experience working at the East Amatuli Island - Light Rock colony). Personnel will commute to study plots by hiking and boating. Murre and kittiwake productivity and nesting chronology data will be collected from the same sets of plots used to obtain this information during the FY 93 - FY 94 restoration monitoring studies (93049 and 94039; see Roseneau *et al.* 1995,1996a) and the FY 95 - FY 98 projects (95163J, 96163J, 97163J, and 98163J). These plots contain about 340 murre and 370 kittiwake nest sites and they sample a wide range of nesting habitats. Eleven murre plots (COMU/LPP1-11) and 12 kittiwake plots (BLKI/LPP1-12) will be checked every 2-3 days, weather permitting. Information on any factors that might adversely affect the reproductive success of murres and kittiwakes will also be collected during the productivity-chronology work (e.g., avian predation events, disturbance by humans, adverse weather conditions). During predation events or other episodes causing adults to flush from the nesting cliffs, efforts will be made to record losses of eggs or chicks.

Data will be collected on feeding rates of murre and kittiwake chicks and time budgets of adults by monitoring at least 20 murre and 10 kittiwake nest sites in plots established for these purposes. During these intensive nest site watches, records will be kept on all food deliveries to chicks and lengths of time adults spend away from nest sites. Data will be used to calculate weekly and seasonal chick feeding rates and time budget indices for adults of both species.

Fish brought to murre chicks will be identified as often as possible during the study to obtain basic information on availability of prey. Blocks of time averaging about 8-10 hrs wk-1 will be set aside to specifically watch for birds returning to nest sites with fish in their bills. Fish will be observed with the aid of spotting scopes and binoculars and identified to species or basic prey groups (e.g., capelin, sand lance, herring, gadids, flatfishes, pricklebacks, other fishes, unidentified fishes) using field characteristics (e.g., colors, tail and fin shapes; observers conducting this part of the study have experience identifying fish hanging from murre bills). Because kittiwakes do not carry fish in their bills, chicks will be gently captured and encouraged to regurgitate food (kittiwake chicks readily regurgitate prey when they are handled and the procedure does not harm the nestlings). About 10-15 regurgitated meals will be collected each week during the nestling period, providing a total of 50-70 samples, which will be sufficient to quantify prey types fed to chicks and detect seasonal changes in diets. Regurgitated food will be weighed to provide information on meal sizes. Samples will be analyzed by A.M. Springer, Fairbanks, using previously published techniques (e.g., see Springer *et al.* 1984, 1986).

Data collected on tufted puffins will include information on nesting chronology, burrow densities, numbers of active burrows, numbers of occupied burrows producing chicks, chick growth and feeding rates, and types of prey fed to chicks. These data will be obtained from 5 previously established study plots on East Amatuli Island in August after chicks are about 1 week old (disturbing burrows earlier in the nesting season often results in abandonment). Hatch dates will be initially estimated by observing percentages of adults returning to the island during 1000-1300 hrs that have prey in their bills (in previous years, chicks were about 1 week old on these plots when about 20% of the adults were returning with bill-loads of food). To supplement this information, small samples of 5-10 burrows will be checked each week in other sections of the colony to help refine hatch dates. Active burrows will be marked with survey flags and 30 chicks will be carefully removed and weighed and measured about every 5 days until they reach fledging age (wing chord will be the primary measurement). An additional 20 chicks on 2 other plots will be weighed and measured 3 times during the chick-rearing period to test effects of disturbance at the more frequently visited plots. A separate plot of about 25 nests will be used to evaluate hatching success. Just before fledging begins, data on burrow densities, occupancy rates, and numbers and sizes of chicks will be collected from 4 3-m wide transects totaling 270 m^2 that have been monitored every year since 1986. Information on feeding rates will be collected by setting up a blind and recording the number of times adults deliver food to nestlings in about 10 active burrows during 3 day-long watches. Prey items brought to chicks will be obtained from about 150 active burrows outside of the study plots about twice per week during the nestling period by temporarily blocking burrow entrances for 3-hr periods with wire-mesh screens (adults usually drop their bill-loads in front of blocked burrow entrances; e.g., Hatch and Sanger 1992). Fish and invertebrates collected in this manner will be weighed, measured, and frozen, or preserved in 5-10% buffered formaldehyde for 24 hrs and then transferred to 50% ethanol for later identification in the lab (see Hatch and Sanger 1992). Frozen specimens will be sent to D. Roby (99163G) and J. Piatt (USGSBRD) for nutrient and stable isotope analysis.

Some information will also be collected on glaucous-winged gulls *(Larus glaucescens)* and cormorants *(Phalacrocorax* spp.*)* during the project. Data will include counts of birds, nests and their contents, and timing of nesting events. This information will be shared with J. Piatt, USGSBRD. Because water temperatures are an important factor influencing both seabirds and their prey (see Springer *et al.* 1984), water temperature data will be collected near the East Amatuli Island -Light Rock colony at regular intervals throughout the study. A data logger - probe or comparable digital unit will be set up near the colony to provide hourly and daily records of sea surface temperatures (SST). SST will also be measured with calibrated hand-held thermometers around East Amatuli Island on a weekly basis during late June - early September. Special attention will be paid to the late July - mid-August period, because during FY 94 - FY 95, these types of on-site data detected a positive 2^0 C late summer shift in SST that J. Piatt, USGSBRD, confirmed via analysis of satellite imagery.

Data Analysis

Standard methods specified in approved protocols will be used to analyze murre, kittiwake, and puffin productivity-chronology data. Nest sites with incomplete observation records (e.g., data gaps of more than 7 days between pre- and post-event observation dates; insufficient data to indicate chicks fledged) will be eliminated from the database. The remaining data will then be analyzed to obtain chronology and productivity information.

Because productivity is an important measurement being used to help assess the recovery status of common murres (see Proceedings of the Science for the Restoration Process Workshop, April 13-15, 1994), murre productivity data will be compared with FY 95 - FY 98 information (see

Roseneau *et al.* 1996b, 1997b, 1998b) and data from the FY 89 - FY 94 damage assessment and restoration monitoring studies (see Roseneau *et al.* 1995, 1996a). ANOVA and Tukey HSD multiple comparisons tests will used to check for significant differences among years, and Kendall's Tau test will be run to check for trends.

Data on murre, kittiwake, and puffin chick-feeding rates and amounts of time adults spend away from nests foraging for food will be analyzed in a manner that will provide chick-feeding frequency and time budget indices for these species (see approved protocols for detailed methods).

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

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

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

Growth rate data and other information obtained on puffins during FY 99 (e.g., timing of nesting events, proportion of active vs. inactive burrows, number of chicks per occupied burrow) will be compared with FY 95 - FY 98 results and results from previous years, as they become available (e.g., mid-1970's - early 1980's and 1990-1993; these data are being prepared for publication by A.B. Kettle and P.D. Boersma).

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

C. Cooperating Agencies, Contracts, and Other Agency Assistance

The Student Conservation Association (SCA) will be contracted to provide 2 volunteers for the project, as in past years (the volunteers are needed to help the field crew collect data). The SCA program is a cost-effective source of volunteers; it can also be used to obtain both local and nonlocal assistants. The volunteer positions are part of the project design; they provide important training opportunities for high school and college students seeking jobs in resource-related fields.

Food samples collected from kittiwake chicks will be analyzed by a private firm using a Purchase Order, as in past years. Because the work will cost less than $2.5K, a formal contact is not required. The private sector is being tapped to perform this work because analysis requires specialized lab equipment, expertise in identification of fish otoliths, and knowledge of up-to-date age/length/weight equations for several fish species (the work will be performed by the same people used in past years to ensure that results are directly comparable to FY 95 - FY 98 data).

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

Also, opportunities exist to share logistical costs with other studies, including an ongoing Minerals Management Service - U.S. Geological Survey Biological Resources Division (MMS-USGSBRD) and APEX seabird ecosystem study in Kachemak Bay - lower Cook Inlet (Project 98163M) lead by J. Piatt, and an intermittent National Marine Fisheries Service -Alaska Dept. of Fish and Game (NMFS-ADFG) sea lion study at the Barren Islands (e.g., in 1996-1997, we supported J. Piatt's researchers at our camp for several days and in return received 2 free supply deliveries; we also provided water for the NMFS-ADF&G Sugarloaf Island camp, and in return, received 2 free helicopter flights).

SCHEDULE

A. Measurable Project Tasks for FY 99 (October 1, 1998 - September 30, 1999) and FY 00 (October 1, 1999 - September 30, 2000)

1 Oct - 31 Dec 1998:	Compile, enter, and analyze data from 1998 field season, prepare posters of 1998 results for meetings.
1 Jan - 15 Mar 1999:	Prepare draft annual report of 1998 results and submit to APEX Project Leader (D. Duffy) for review, prepare for EVOS work shop (10th anniversary meeting in March).
16 Mar - 15 Apr 1999:	Submit final draft of annual report to APEX Project Leader, attend EVOS work shop (10th anniversary meeting in March).
16-30 Apr 1999:	Review study plan, coordinate protocols with other APEX investigators, arrange hiring of temporary employees, contract for SCA volunteers and transportation, begin purchasing equipment/supplies.
1 May - 9 Jun 1999:	Finalize logistical needs, purchase/pack equipment/supplies, train volunteers.
10-11 Jun 1999:	Load vessel, depart Homer, travel to study area.
12-15 Jun 1999:	Set up camp at East Amatuli Island.
16 Jun - 10 Sep 1999:	Collect data.

11-13 Sep 1999:	Pack equipment/supplies, load vessel, return to Homer.
14-15 Sep 1999:	Unload vessel.
16-20 Sep 1999:	Unpack equipment/supplies, clean equipment, store gear.
21-30 Sep 1999:	Begin analyzing 1999 field data.
1 Oct - 31 Dec 1999:	Continue analyzing 1999 data, prepare poster of 1999 results.
1 Jan - 15 Mar 2000:	Complete data analyses, prepare draft annual report of 1999 results, attend EVOS workshop, submit draft report to APEX Project Leader (D. Duffy) for review.
16 Mar - 15 Apr 2000:	Submit final draft of annual report to APEX Project Leader.
16 Apr - 30 May 2000:	Begin reanalzying 1995-1999 data in combination with data from other APEX study sites, prepare draft final report of combined 1995-1999 results discussing data from other APEX study sites.
1 Jun - 15 May 2000:	Complete analyses, prepare draft final report of combined FY 95 - 99 results discussing data from other APEX study sites.
16 May - 30 Sep 2000:	Complete final report and begin preparing manuscripts for publication.

B. Project Milestones and Endpoints

March 1999	Final draft of FY 98 results submitted to APEX Project Leader (D. Duffy).
September 1999	FY 99 Field work completed at East Amatuli Island.
March 2000	Final draft of FY 99 results submitted to APEX Project Leader(D. Duffy).
May 2000	First draft of FY 95 - FY 99 final report submitted to APEX Project Leader (D. Duffy).
September 2000	Final draft of FY 95 - FY 99 final report submitted to APEX Project Leader (D. Duffy).

C. Completion Date

The annual report for the FY 98 field season will be submitted to the APEX project leader (D. Duffy) by 15 March 1999, and it will be submitted to the Trustee Council as part of the APEX package by 15 April 1999. Field work will be completed in FY 99, and the annual report summarizing these data will be submitted to the APEX project leader by 15 March 2000. A final report summarizing and discussing FY 95 - FY 99 results in context with data from other APEX studies will be completed by 30 September 2000.

PUBLICATIONS AND REPORTS

Project 98163J is part of the multiyear APEX study (Project 98163). If it is funded, an annual report will be completed by 15 March 2000, and a more comprehensive final report summarizing and discussing FY 95 - FY 99 results in context with information from other APEX studies will be completed by 30 September 2000 (see above). Currently, we are supplying data to J. Piatt (98163M) for 2 papers in preparation on murre and kittiwake chick diets that will report and discuss differences among the Barren Islands and Gull and Chisik island colonies. We also provided data to M. Robards for a paper he is preparing on sand lance. Data from the FY 95 - FY 97 Barren Islands seabird studies are also being used in a manuscript we are preparing on changes in murre population numbers at the Barren Islands colonies. We have also started working on a manuscript that will report and discuss changes in murre nesting chronology at the Barren Islands colonies [tentative title: Changes in nesting chronology of common murres *(Uria aalge)* at the Barren Islands, Alaska during 1993-1998). Tentatively, we plan to submit the paper to The Auk or Condor, but may submit it to another journal (e.g., Marine Progress Series, Arctic).

PROFESSIONAL CONFERENCES

Results from the FY 99 field season and comparative information from previous Barren Islands seabird studies (e.g., FY 95 - FY 98) will be presented at the Pacific Seabird Conference during fall, 1999. Travel costs for attending the meeting are included in the budget. Also, results from FY 99 will be presented at other conferences that may be scheduled for 1999-2000, if the conferences are appropriate forums.

NORMAL AGENCY MANAGEMENT

The proposed Barren Islands seabird study that will be conducted by AMNWR for the EVOS APEX project is not something that AMNWR or the FWS are required to do by statute or regulation. Although the Barren Islands are now listed as an annual monitoring site under the refuge's seabird monitoring program, the islands are not part of the FWS's highest priority ecosystem, the Bering Sea, and as a result, monetary support for monitoring work will not be available until overall FWS priorities change (i.e., from the Bering Sea to other officially designated ecosystems within Alaska). Furthermore, many types of data collected specifically 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). The proposed project is needed to collect these and other types of data 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 of ecological processes that may be influencing seabird recovery in the spill zone. Results of the APEX ecological processes investigations will ultimately help management of common murres and other seabirds in the Gulf of Alaska.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

The FY 99 Barren Islands seabird studies are fully coordinated and integrated with other components of the APEX seabird - forage fish project. Information on murre, kittiwake, and puffin productivity; feeding and growth rates of chicks; amounts of food fed to chicks; and time budgets of adults will be transmitted to D. Roby for use in his energetics study (98163G). Roby will also receive data on prey species fed to chicks and specimens of prey for nutrient analysis. D. Irons (98163E) will be sent a variety of information on kittiwakes, including timing of nesting events, and several measurements of productivity (e.g., fledglings nest-1, fledglings single and double chick nests-1) and growth rates of chicks (e.g., all chicks combined, and "a" and "b" nestlings). During the field work, J. Piatt, USGSBRD (98163M), will be given information on observations of feeding concentrations of birds to help him locate schools of forage fish during his hydroacoustic and trawl surveys. Data obtained on all of the murre, kittiwake, puffin, gull, and cormorant variables will also be shared with and analyzed in cooperation with Piatt. Piatt will also be sent specimens of fish for stable isotope analysis.

The Barren Islands seabird study is closely coordinated with an ongoing joint NMFS-ADFG sea lion study that is conducted intermittently at the Barren Islands; this may allow sharing of some logistics costs, as in past years (e.g., in 1997, we were able to have supplies delivered to the field camp, and fly out and return 1 volunteer in a family emergency situation, at no extra cost to the project). Also, because the project is coordinated with other AMNWR monitoring studies in Alaska, extra equipment is usually available at no extra cost to the project (e.g., backup outboard motors, radios, emergency gear).

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

No changes have been made to the project design or schedules for the FY 99 Barren Islands seabird study (i.e., project objectives and design, including methods and schedules, are the same as those proposed in the approved 98163J DPD). If any changes are identified, they will be discussed with the APEX project leader (D. Duffy) and other APEX investigators, and if changes are necessary, they will be cleared 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 in both the field and the office. He will supervise project personnel, review and approve logistics plans and expenditures, and ensure that work stays on schedule and is coordinated with other APEX investigators. He will also be in charge of overall data analysis and interpretation, preparing posters and presentations for scientific conferences and meetings, and writing annual and 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 1995-1997 (Projects 95163J, 95163K, 96163J, 97163J, and 97163K), and the murre population monitoring work at the Barren Islands in 1996-1997 (Projects 96144 and 97144). Currently, he is co-principal investigator for APEX project 98163J and principal investigator of APEX project

98163K and the Chiswell Islands murre population monitoring study (Project 98144). 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 Seabird Publications

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 be in charge of the Amatuli field camp operations, as in past years. He will purchase and organize field supplies and equipment, supervise and lead the field team in the absence of Mr. Roseneau, and ensure data are collected according to study guideline and protocols. He will also help compile and analyze the data, and assist in the preparation of draft and 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 1995-1997 APEX Barren Islands seabird studies (Projects 95163J, 96163J, 97163J) 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 98163J. During Mr. Kettle's 1993-1997 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 previous pre- or postspill study). 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 17 years experience safely operating small boats in the north Atlantic and Pacific oceans (e.g., Maine and Alaska), including 8 consecutive field seasons running outboard-powered craft at the Barren Islands.

Selected Seabird Publications

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 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, and 97144). Mr. Byrd is currently serving as project manager for APEX projects 98163J and 98163K, and the Chiswell Islands murre population monitoring study (Project 98144). 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 Seabird Publications

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K
Fish as Samplers Study

USING PREDATORY FISH (PACIFIC HALIBUT) TO SAMPLE FORAGE FISH (PROJECT 99163K)

Project Number:	99163K
Restoration Category:	Research and Restoration (this study is part of the APEX forage fish - seabird ecological processes project;)
Proposer:	DOI-FWS
Lead Trustee Agency:	USFWS
Cooperating Agencies:	USGSBRD, ADF&G
Duration:	2 years (FY 99 - FY 00)
Cost FY 99:	$12.0K
Cost FY 00	$16.0K
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 a study 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). Because our initial efforts demonstrated that valuable target species information could be obtained by this method, additional data were collected in 1996 with support from the Alaska Maritime National Wildlife Refuge (AMNWR). In 1997, we collected and analyzed over 1,400 halibut stomachs from the Kachemak Bay - lower Cook Inlet study area for the ongoing APEX ecosystems study. Results from the third year of study provided additional evidence that the sampling technique can supply low-cost geographic and relative abundance information that can help assess seasonal and interannual variations in forage fish stocks and seabird prey bases.

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. This component of the *Exxon Valdez* Oil Spill Trustee Council-sponsored Alaska Predator Ecosystem Experiment (APEX) is designed to continue collecting low-cost temporal, spatial, and relative abundance information on forage fish stocks in the northern Gulf of Alaska by obtaining and analyzing stomach contents from sport-caught Pacific halibut *(Hippoglossus stenolepis)*.

As part of the 1995 APEX project, we began a study to test the feasibility and effectiveness of using stomachs from sport-caught halibut 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). Because our initial efforts demonstrated that valuable information on target species could be obtained by this method, additional data were collected in 1996 with support from the Alaska Maritime National Wildlife Refuge (AMNWR). In 1997, we collected and analyzed over 1,400 halibut stomachs from the Kachemak Bay - lower Cook Inlet study area for the ongoing APEX ecosystems study.

Results from the third year of study provided additional evidence that using halibut to sample forage fish populations can supply low-cost geographic and relative abundance information that can be used to help assess seasonal and interannual variations in capelin and sand lance stocks and seabird prey bases. For example, differences apparent in the multiyear data set suggested that capelin stocks declined in the study area while populations of sand lance increased over the 1995-1997 interval (based on total numbers of fish, capelin dropped from about 60% in 1995 to 19% in 1997, and sand lance rose from 23% in 1995 to 49% in 1997; see Roseneau and Byrd 1998). These data also indicated that 1 of the sampling areas (Area 6 - Point Adam) continued to support relatively large stocks of capelin during this same period. Preliminary analysis of 1996-1997 beach seine data collected in Kachemak Bay - lower Cook Inlet by Projects 96163J, 97163J, 96163M, and 97163M appeared to support these observations (M. Robards, pers. comm.). Also, data obtained from Barren Islands waters (Area 10) that suggested declines in capelin populations and increases in sand lance stocks during 1995-1997 matched changes observed in Barren Islands kittiwake chick diets [capelin = 64%, 28%, and 14%, and sand lance = 13%, 53%, and 63% by weight in 1995, 1996, and 1997, respectively; see Roseneau *et al.* 1998a).

These observations and data collected in FY 99 will provide information on capelin and sand lance stocks in Kachemak Bay - lower Cook Inlet that can be used in conjunction with other APEX studies (e.g., 99163J, 99163M, 99163Q) for a multispecies, multicolony, multiyear analysis of seabird productivity and energetics that will test 3 APEX hypotheses (hypotheses 7, 8, and 9; also, see below) and increase understanding of ecological processes that may be influencing seabird recovery in the spill zone.

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, there is still a need to collect information that can increase understanding of seabird - forage fish relationships and ecological processes that may be influencing seabird recovery within the spill area.

B. Rationale/Link to Restoration

This study component of the APEX seabird - forage fish project (Project 99163) was designed to collect 5 years of data. It was integrated into the APEX project in FY 95 because data on availability of forage fish are critical to identifying and understanding food webs and ecological processes that may be influencing recovery of seabirds in the spill area.

C. Location

The FY 99 work will be conducted in Homer, Alaska, and data will be collected from the same Kachemak Bay - lower Cook Inlet study area used during FY 95 - FY 98 (Projects 95163K, 97163K, and 97163K). No communities will be affected by the study.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

Large format, computer-generated color posters summarizing annual results will be prepared and submitted to the Trustee Council for public display each year after data have been analyzed, as in past years (several small versions of the poster will also be produced that can be used as hand-outs at community meetings). The posters are easily transported 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 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. Supplies will be purchased locally (i.e., in Homer), and at least one local volunteer will participate in the study. As in past years, local knowledge of the charter boat fishing fleet and observations made by local boat operators will be incorporated into the work.

PROJECT DESIGN

A. Objectives

The project objective is to continue testing 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, and data will be collected from the same Kachemak Bay - lower Cook Inlet study area used during the FY 95 - FY 98 studies (Projects 95163K, 97163K, and 97163K; see Roseneau and Byrd 1996, 1997, 1998). Methods for collecting and analyzing data are briefly summarized below; they remain the same as those used during FY 95 - FY 98 (see Roseneau and Byrd 1996, 1997, 1998)

Data Collection

Halibut were chosen as potential samplers of forage fish populations because they opportunistically feed on a wide range of fish and invertebrate prey, including sand lance and capelin (see Yang 1990). They were also selected as sampling tools because a large 100-150 vessel charter boat fleet sport fishes for them in Kachemak Bay - lower Cook Inlet throughout May-August in several of same general areas frequented by foraging seabirds from the Barren Islands and Gull and Chisik islands breeding colonies (see Roseneau and Byrd 1996, 1997, 1998).

As in past years, most halibut stomachs will be collected from participating charter boat operators when they fillet fish for customers at public and private fish-cleaning facilities on the Homer Spit during late May - early September. Cooperating Alaska Department of Fish and Game (ADF&G) biologists will also collect stomachs for the project when they obtain age-sex data from sport-caught halibut in the Deep Creek and Ninilchik vicinities during June-August.

Stomachs will either be processed when they are collected, or frozen and processed in larger batches a few weeks later. Contents, identified with the aid of taxonomic keys, photographs, and voucher specimens, will be sorted into several categories, including capelin, sand lance, flatfish, sculpin, cod, crabs, shrimp, squid, octopus, mollusks, and other fish and invertebrate species (see Roseneau and Byrd 1996, 1997, 1998). Empty stomachs will be weighed to provide information on content weight, and undigested capelin and sand lance will also weighed and measured to obtain size information for other studies (e.g. J. Piatt, Project 99163M). Samples of whole capelin and sand lance will also be frozen or preserved in 10% buffered formaldehyde and 75% ethanol - 2% glycerin solutions for use by other investigators. Data, including information on catch dates and locations, will be entered stomach-by-stomach into computer spreadsheets that can be easily sorted by dates, areas, and species.

Data Analysis

Data will be analyzed by first eliminating all potential bait items from the data base (e.g., cod and salmon heads; Pacific herring, *Clupea harengus pallasi*), and then calculating numbers and frequencies of occurrence of fish and invertebrates in different geographic areas and time periods (see Roseneau and Byrd 1996, 1997, 1998). Statistical tests may also be used to check for differences among years and sampling areas (e.g., *t*-tests, Tukey HSD multiple comparisons).

C. Cooperating Agencies, Contracts, and Other Agency Assistance

Homer based ADF&G fisheries biologists (S. Meyer and W. Dunn) will collect halibut stomachs for the project when they collect age-sex data from sport-caught halibut in the Deep Creek and Ninilchik vicinities during June-August. Also, J. Piatt, USGSBRD (Project 99163M), will provide some assistance during identification of prey items. The Alaska Maritime National Wildlife Refuge (AMNWR) will provide all office, warehouse, and freezer space needed for the project. AMNWR will also provide computers for entering and analyzing data, and donate up to 1 month of the project manager's time (G.V. Byrd) to the study.

SCHEDULE

A. Measurable Project Tasks for FY 99 (October 1, 1998 - September 30, 1999) and FY 00 (October 1, 1999 - September 30, 2000)

1 Oct - 31 Dec 1998: Analyze data from 1998 field season, prepare posters for meetings.

1 Jan - 15 Mar 1999:	Prepare draft annual report of 1998 results and submit to APEX Project Leader (D. Duffy) for review, prepare for EVOS work shop (10th anniversary meeting in March).
16 Mar - 15 Apr 1999:	Submit final draft of annual report to APEX Project Leader, attend EVOS work shop (10th anniversary meeting in March).
16-30 Apr 1999:	Review study plan, arrange for volunteer help, coordinate plans with charter boat operators and ADF&G fisheries biologists.
1-20 May 1999:	Train volunteers, purchase supplies.
20 May - 31 Aug 1999:	Collect data.
1-30 Sep 1999:	Begin analyzing 1999 data.
1 Oct - 31 Dec 1999:	Continue analyzing 1999 data, prepare poster of 1999 results for meetings.
1 Jan - 15 Mar 2000:	Complete analysis of 1999 data, prepare draft annual report of 1999 results, attend EVOS workshop, submit draft report to APEX Project Leader (D. Duffy) for review.
16 Mar - 15 Apr 2000:	Submit final draft of annual report to APEX Project Leader (D. Duffy).
16 Apr - 30 May 2000:	Begin reanalyzing 1995-1999 data in combination with information on murre, kittiwake, and puffin chick diets, and beach seine and other fisheries information from the Barren Islands and Gull and Chisik islands APEX study sites.
16 May - 31 Jul 2000:	Prepare draft final APEX report and begin preparing manuscripts for publication.
1 Aug - 30 Sep 2000:	Complete final report and submit to APEX project leader.

B. Project Milestones and Endpoints

March 1999	Draft annual report of FY 98 results submitted to APEX Project Leader (D. Duffy).
April 1999	Annual report of FY 98 results submitted to APEX Project Leader (D. Duffy).
May 1999	Begin FY 99 field work.
August 1999	FY 99 field work completed.
March 2000	Final draft of FY 99 results submitted to APEX Project Leader(D. Duffy).
July 2000	First draft of FY 95 - FY 99 final report submitted to APEX Project Leader (D. Duffy).

September 2000 — Final draft of FY 95 - FY 99 final report submitted to APEX Project Leader (D. Duffy).

C. Completion Date

The annual report of FY 98 field season activities will be submitted to the APEX project leader (D. Duffy) by 15 March 1999, and it will be submitted to the Trustee Council as part of the APEX package by 15 April 1999. Field work will be completed in FY 99, and the annual report summarizing these data will be submitted to the APEX project leader by 15 March 2000. A final report summarizing and discussing FY 95 - FY 99 results in combination with data from other APEX studies will be completed by 30 September 2000.

PUBLICATIONS AND REPORTS

Project 98163K is part of the multiyear APEX study (Project 98163). If it is funded, an annual report will be completed by 15 March 2000, and a more comprehensive final report summarizing and discussing FY 95 - FY 99 results in combination with information from other APEX studies will be completed by 30 September 2000 (see above). One paper, based on FY 95 data, has already published in the Lowell Wakefield Fisheries Symposium series (see Roseneau and Byrd 1997). Another manuscript reporting and discussing combined FY 95 - FY 99 data will be prepared for publication after FY 99 data have been collected and analyzed. Tentatively, we plan to submit the manuscript to the Lowell Wakefield Fisheries Symposium series, or to an appropriate fisheries journal (e.g., Marine Progress Series, Canadian Journal of Fisheries; depending on the outcome of the 5 year study, the manuscript may also be appropriate for an ornithological journal—e.g., Auk, Condor, Ibis). We have also provided data to M. Robards for a paper he is preparing on sand lance. Data from the combined FY 95 - FY 99 studies may also be used in manuscripts written in cooperation with J. Piatt (Project 99163M).

PROFESSIONAL CONFERENCES

Results from the FY 99 field season and data from the FY 95 - FY 98 studies will be presented at a Lowell Wakefield Fisheries Symposium in 2000. Travel costs for attending the symposium are included in the FY 00 budget. Also, depending on results, information from the FY 95 - FY 99 studies may also be presented at the Pacific Seabird Group meeting in 2000.

NORMAL AGENCY MANAGEMENT

The proposed study that will be conducted by AMNWR for the EVOS APEX project is not something that AMNWR or the FWS are required to do by statute or regulation. Furthermore, the types of data collected by the study are not part of standard AMNWR seabird monitoring protocols. The project is needed to finish testing the use of stomach contents from sport-caught halibut to sample forage fish stocks in the northern Gulf of Alaska. Test results will be used to evaluate and describe the effectiveness of this technique in obtaining information useful to 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). The project is also needed because data on key forage fish species are scarce, and are an integral part of conducting a 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 of ecological processes that may be influencing seabird recovery in the spill zone. Ultimately, results from the proposed project in conjunction with other APEX studies should help improve management of common murres and other fish-eating seabirds in the Gulf of Alaska.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

The FY 99 large fish as samplers study is fully coordinated and integrated with other components of the APEX seabird - forage fish project. Results from the work will be provided to other APEX investigators (e.g., Projects 99163E, 99163L, 99163M, 99163Q). 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. ADF&G biologists are participating in the study by collecting stomachs for the project in the Ninilchik and Deep Creek vicinities (as they did in 1996-1998). Both raw and analyzed information from the FY 95 - FY 99 studies will be shared with the ADF&G fisheries biologists because these data provide new information on Cook Inlet halibut diets that may be useful for management purposes.

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

No changes have been made to project design or schedules (i.e., project objectives and design, including methods and schedules, remain the same as proposed in the approved 98163K DPD). If any changes are identified, they will be discussed with the APEX project leader (D. Duffy) and other APEX investigators, and if changes are necessary, they will be cleared with the EVOS chief scientist and science coordinator.

PROPOSED PRINCIPAL INVESTIGATOR, IF KNOWN

Name: David G. Roseneau
Affiliation: Alaska Maritime National Wildlife Refuge
Mailing address: 2355 Kachemak Bay Drive (Suite 101), Homer, Alaska 99603-8021
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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 in both the field and the office. He will supervise project 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 overall data analysis and interpretation, preparing posters and presentations for scientific conferences and meetings, and writing annual and 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 1995-1997 (Projects 95163J, 95163K, 96163J, 97163J, and 97163K), and the murre population monitoring work at the Barren Islands in 1996-1997 (Projects 96144 and 97144). Currently, he is co-principal investigator for APEX project 98163J and principal investigator of APEX project 98163K and the Chiswell Islands murre population monitoring study (Project 98144). 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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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, and 97144). Mr. Byrd is currently serving as project manager for APEX projects 98163J and 98163K, and the Chiswell Islands murre population monitoring study (Project 98144). 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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L
Historical Date Review

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

Project Number: 99163L

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 99: $90,000 (Research Completion and close out)

Cost FY 00: $0

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 marine birds and 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 96-98 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 FY98 will largely be devoted to analysis of this dataset. In FY98 we will be designing the electronic data atlas 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 FY99. In FY96-98 three presentations and manuscripts were produced on project data. FY99 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 FY98 to augment agency survey frequency in the Kodiak Island, Shelikof Strait, and Kachemak Bay survey areas in an attempt to sustain the useability 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. The assessment funding requested here only will allow a small but important effort, and will leverage agency assets such as survey gear, deck sampling equipment, and personnel.

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. Design electronic format database server that can be Internet deployed to serve information to interested researchers and others.
5. Compile historic commercial fisheries catch information that provides information on other trophic groups that are not sampled by the surveys.
6. Collaborate with other investigators to provide data into modeling excercises.

B. Methods

Small-mesh Trawl Survey
See cited manuscripts to FY97 annual report

Icthyoplankton
See annual report for FY97.

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 FY98 ADFG Kodiak will assist in the cleanup of database issues and assist with the design criteria for the electronic database. ADFG Kodiak will be envolved 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. A contract will be negotiated with a research associate (Ph.D. or equivalent) to assist in data analysis and manuscript preparation.

SCHEDULE

A. Measurable Project Tasks for FY99 (October 1, 1998 - September 30, 1999)

Oct 1 - November 31:	Prepare Presentation and Attend the 2nd International Pandalid Shrimp Symposium (tentative)
Oct 1 - September 30:	Analyze data from data sources
Jan 1 - Jul 31:	Outsource design of Electronic Database (PI supervise)
Jan 15 - 24:	Attend Annual Restoration Workshop
Feb 15 - Mar 31:	Prepare Annual Report and Attachments
Apr 1 - Jun31	Prepare Manuscripts for Publication
Aug 15 - Oct 30:	Conduct Assessment Survey During 15 day Period in this Time Window ADFG - Kodaik.

B. Project Milestones and Endpoints

Presentation of project results at the 2nd International Pandalid Shrimp Symposium (tentatively planned for early FY98)

Publication of initial project results, in a major journal. During FY98

Completion of the electronic format project database design (FY99) and publishing to the Internet (FY98-99)

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 FY99 (September 30, 1999). 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.

2. Long-term Changes in the Gulf of Alaska Marine Ecosystem;
Major journal article for Science or Nature.

3. Early life history and dynamics of Pacific Sand Lance in the Lower Cook Inlet and Shelikof Strait Region of Alaska. Journal Article for Fisheries Oceanography or Marine Ecology Progress Series.

4. Long-term Shifts in Benthic Commercial Fishery Species; A Case Study in the Gulf of Alaska -- Journal Article for Marine Ecology Progress Series.

PROFESSIONAL CONFERENCES

Anticipate attendance and presentation of project research at the Second International Pandalid Shrimp Symposium, being tentatively planned for late 1999 in Halifax, Nova Scotia.

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 analize the changes in jellyfish over time.

EXPLANATION OF CHANGES

No changes from last year.

PRINCIPLE INVESTIGATORS

John F. Piatt, PhD., Research Biologist (GS-13)
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Paul J. Anderson, Fisheries Biologist (Research GS-12)
National Marine Fisheries Service, Alaska Fisheries Science Center
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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.

B. Alan Johnson, NMFS Kodiak, is staff senior biometrician at the Alaska Fisheries Science Center and has extensive experience in large data set analysis and statistical procedures.

LITERATURE CITED

See FY97 annual report for this project for a complete listing of cited literature.

M
Lower Cook Inlet

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

Project Number:	99163 M
Restoration Category:	Research
Proposed By:	U.S. Geological Survey (PI- John F. Piatt)
Lead Trustee Agency:	DOI
Cooperating Agencies:	ADFG, USFWS
Duration:	3 years
Cost FY 99:	$267,700
Cost FY 00:	$180,000 (data analysis, reporting)
Cost FY 01:	$125,000 (data analysis, reporting)
Geographic Area:	Cook Inlet, Gulf of Alaska
Injured Resource:	Multiple resources

ABSTRACT

Cook Inlet Seabird and Forage Fish Studies (CISeaFFS) is a long-term study designed to measure the foraging (functional) and population (numerical) responses of six seabird species to fluctuating forage fish densities around three seabird colonies in lower Cook Inlet. This involves at-sea surveys for forage fish (hydroacoustics, trawling, seining) and seabirds (line transects), and some characterization of oceanography (AVHRR and SeaWIFS 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.

INTRODUCTION

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

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

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

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

In 1996, this research program was refined and expanded where appropriate. For example, we increased hydroacoustic sampling of nearshore habitats, tried some new fishing techniques (pair trawls, cast-nets), increased study effort on some species of seabirds (pigeon guillemots, puffins, cormorants) and forage fish (sandlance), and increased coordination of seabird studies at the three colonies (for example, we synchronized feeding watches and census counts with respect to breeding phenology).

In 1997, we added two components to the study of birds at colonies: 1) We initiated banding of adult murres and kittiwakes in order to measure annual adult survival; and, 2) We conducted studies of foraging stress by measuring blood concentrations of corticosteroids in murres and kittiwakes at Gull and Duck islands. Both projects were successful. Proposals were submitted to the EVOS Trustees to continue these pilot projects. Funding was received to continue and expand the banding work. Stress studies were not funded and will not be continued. In 1997, we also initiated a small study of primary and secondary productivity (nutrient, phytoplankton and zooplankton sampling). We attempted to secure funding (from NOAA, BRD/MMS, EVOS Trustees) to maintain and expand this effort slightly in 1998 because of the anticipated effects of the 97/98 ENSO. However, no support is forthcoming, and we will not continue this work.

In 1998 and 1999, the field program will entail a similar effort with respect to seabirds at their colonies. We now have well-established methods and protocols at Gull, Chisik and Duck islands, and do not anticipate making any changes in either the types of data collected, or the effort required. On the at-sea side of the project, forage fish sampling by trawling, seining, and hydroacoustics will continue at a similar level. In summary, the basic components of this study have not changed since 1995, and we will measure the same fundamental parameters of forage fish and seabird biology for the duration of the study.

NEED FOR THE PROJECT

A. Statement of the Problem

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

B. Rationale

Functional relationships between seabird predators and their prey are poorly known because the vast majority of seabird research has been conducted on colonies without benefit of concurrent studies at sea on prey availability and seabird foraging behavior (Hunt et al. 1991). The response of seabirds to environmental change can vary widely among species, and is influenced by a host of physical and biological factors. Differential adaptations of seabirds for exploiting plankton and fish, widely-varying foraging abilities and breeding strategies, and complex relationships between oceanography and prey dispersion, abundance, and behavior all serve to complicate our interpretation of changes in seabird population biology. Therefore, in order to assess the potential for recovery of seabirds affected by the *Exxon Valdez* oil spill, a concurrent, multi-disciplinary study of oceanography, forage fish, and seabirds is required.

C. Summary of Major Hypotheses and Objectives

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

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

D. Completion Date

Marine ecosystems can vary markedly over time and between geographic areas, so our approach of studying three different colony areas simultaneously during several breeding seasons is an appropriate and cost-effective research strategy. We anticipate that it will take a minimum of five summers (FY 1995-1999) of field research to quantify the functional and numerical responses of seabirds to fluctuations in forage fish density. It will require a minimum of two additional years (FY 2000-2001) to analyze data and publish the findings of the study in scientific journals.

COMMUNITY INVOLVEMENT

Gull Island in Kachemak Bay is owned by the Seldovia Native Association (SNA). Limited subsistence use occurs during summer, with occasional egging and harvesting of juvenile birds (Fred Elvsaas, pers. comm.). It is also a major tourist attraction for visitors to Homer. Permission to work on and around the island was obtained in 1995 under the provision that annual reports of findings be made available to the SNA. In 1998, we plan to visit the SNA in Seldovia to discuss our work, and present an overview of our research in lower Cook Inlet at the next Kachemak Bay Science Symposium in Homer (May 1998). We have informed local tour boat operators about our activities so that our presence at the island can be explained to visiting tourists. Chisik Island and the Barren Islands are managed by the Alaska Maritime National Wildlife Refuge. We have employed tourist charter vessels from Homer to support field camps at these colonies. Chisik Island supports a small, seasonal fishing community and we have chartered small vessels for research there, and informed most of the summer residents about the purpose of our activities.

FY 99 BUDGET

Summary EVOS Budget FY 1998:

	$1000's
Personnel	51.8
Travel	0.0
Contractual	130.0
Commodities	69.0
Equipment	0.0
Subtotal	250.8
Gen. Admin.	16.9
Total	267.7

Funding for the project is anticipated from three major sources: EVOS Trustees ($268 K), Minerals Management Service ($150 K), and U.S. Geological Survey ($120 K). A detailed budget for EVOS funds is attached. The following table shows how other funds will be allocated.

Detailed MMS and BRD BUDGET FY 1998:

	$1000's
PERSONNEL	
Piatt, GS-13 10 months	66.1
Drew, GS-11 8 months	40.2
van Pelt, GS-7 10 months	26.4
Abookire, GS-7 12 months	31.7

Speckman, GS-7 10 months	26.4
Snegden, WG-4 9 months (+OT)	28.0
Biotech (GS-5) 3X4 months	23.8
Subtotal	242.6
TRAVEL	
Volunteers (6) per diem	7.2
Volunteers (6) RT airfare Anchorage	5.4
Biologists (7) per diem	3.2
RT airfare ANC-HOM (15)	2.7
Subtotal	18.5
COMMODITIES & EQUIPMENT	
Satellite imagery	3.0
Computers/supplies	2.0
Digital bathythermograph (4)	0.9
Misc. scientific equipment	2.5
Communications	0.5
Subtotal	8.9
TOTAL MMS and NBS BUDGET	270.0

PROJECT DESIGN

A. Background

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

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

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

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

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

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

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

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

B. Objectives

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

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

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

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

C. Methods

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

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

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

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

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

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

Study Design: The approach used in this study will be to quantify the numerical and functional responses of seabirds at spatial scales ranging from fine (m to km, Gull Island in Kachemak Bay) to moderate (1-100's km, lower Cook Inlet). Similarly, and where possible, variability in response parameters will be measured at small (daily, seasonal) and moderate (annual) temporal scales. At fine and moderate spatial scales, six species of seabirds will be studied simultaneously at three different colonies in lower Cook Inlet. Species to be studied include two surface-feeding seabirds (kittiwake and glaucous-winged gull), two pelagic-diving seabirds (common murre and puffin), and two benthic-diving seabirds (cormorant and guillemot). Some of these species forage mostly near shore (<5 km) whereas others feed more offshore (± 60 km; Piatt 1994).

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

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

The distribution and abundance of prey species will be measured hydroacoustically (using a BIOSONICS DT4000 digital echosounder) and with trawls (bottom, midwater) over an area extending at least 45 km away from the colonies. Trawling with be conducted from a different vessel (ADF&G "Pandalus") during the time that hydroacoustic surveys are conducted from the "Tiglax". Shoreline habitat (<100 m from shore) within the core study areas will also be hydroacoustically surveyed in a small vessel (11 m) at the same time. Prey specimens collected from trawls and seabird chicks will be examined to assess species composition, sex-ratios, body condition, and energetic content. In addition to trawling, we will sample nearshore fish schools using beach seines, gill-nets and cast-nets.

It would be desirable to measure as many response parameters (Table 1) as possible at Gull, Chisik and Barren islands. Based on our prior experience, and using protocols developed in 1995-1997 by APEX researchers, efforts will concentrate on measuring those parameters that are most important and logistically feasible. For the numerical response, basic data will be gathered (where possible) on clutch size, brood size, hatching success, and/or fledging success to obtain some measure of overall breeding success for all six seabird species. Chick growth rates and fledging weights will be measured for a few species (e.g., kittiwakes, murres, puffins). To obtain these data, field camps will be established on Chisk and Barren islands, and Gull Island will be visited frequently by boat.

To measure functional response parameters, we will focus our efforts on Gull and Chisik islands and coordinate with the AMNWR to collect similar data at the Barren Islands. Seasonal variability in activity budgets and chick feeding rates will be assessed through a combination of direct observations at the colonies (blind watches), use of video cameras, and radio telemetry to monitor colony attendance and foraging activity (e.g., Wanless et al. 1988, 1991; Monaghan et al. 1994; Uttley et al. 1994). Aggregation behavior and foraging ranges will be assessed from the pelagic surveys and radio telemetry. Diet information will be obtained by collecting adults at sea and chick meals at the colonies. Only 15 adults of the common species (murres, kittiwakes, puffins; populations greater than 10,000's in study area) will be collected at each colony, under Federal and State collecting permits. Traditional dietary analyses will be supplemented with studies using stable isotope ratio analyses (Hobson et al. 1994). Whole prey obtained from seabirds and by net-sampling will be analyzed for proximate lipid content (Montevecchi and Piatt 1984).

In addition to the above, field work in 1999 will include studies on Pigeon Guillemots in Kachemak Bay. Guillemots breed along the south shore of Kachemak Bay in about 20 different areas, but are concentrated in 4 sites. As with kittiwakes and murre, we will measure breeding parameters (hatching, fledging, chick growth) and feeding behavior (meal composition, delivery rates), and census populations, using methods previously established by Prichard (1997) and Roby et al. (1996) in Kachemak Bay and Hayes (1995) in Prince William Sound.

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

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

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

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

The remaining hypotheses can be tested by special studies. Prey species will be collected from trawls and chick meals, and analyzed for proximate composition (Montevecchi and Piatt 1984, 1987) to determine if they differ significantly in quality (hypothesis 12). Such analyses have already been completed for 10 forage fish species from the Gulf of Alaska (van Pelt et al. 1997). Effects of differing prey quality on chick growth, foraging effort, and breeding success (hypotheses 13-15) require directed studies at colonies. Such a study was initiated in 1996 at Kachemak Bay (Romano, APEX project 96163 N) and will be completed in 1998. Finally, the hypothesis (16) that different forage fish have different schooling characteristics can be tested by detailed hydroacoustic and trawl surveys of forage fish in Kachemak Bay. Whether prey schooling characteristics affect prey capture rates (hypothesis 17) could perhaps be determined in a laboratory or aquarium study. Such a study is not currently planned as part of this program.

D. Contracts and Other Agency Assistance

An Interagency Agreement as been established with the Alaska Department of Fish and Game, and 30K will be transferred in 1998 to charter the R/V "Pandalus", a 20 m research vessel based in Homer. As in 1995/96, the charter provides a vessel with mid-water trawl capabilities, accomodations for 4 researchers, a crew of 3 including Captain, deckhand and cook, and food while at sea. This vessel will be used to trawl for fish schools located on hydroacoustic surveys in June-August.

A Research Work Order has been established with the University of Washington. In 1999, we will transfer funds which will be used to support a post-doctoral student (Alexander Kitaisky), working under supervision of Dr. John Wingfield, to be involved with field work and analyses of data collected in 1995-1998. We plan to continue collaboration with Wingfield and Kitaisky for the duration of this project (1997-1999). This research work order is also supporting a Ph.D. student (Suzann Speckman) in studies on hydroacoustics (abundance, distribution, density of different fish species). Speckman is currently working under the supervision of Dr. Gordie Swartzman at the Applied Physics Lab, Department of Oceanography.

E. Location

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

SCHEDULE

A. Measurable Project Tasks for FY 99

Jan. 99-April 99:	Preparations for field work, equipment acquisition, hiring personnel, establish contracts and work orders
May 99:	Initiate seabird and hydroacoustic surveys in Kachemak Bay. Trawl sampling in mid-May. Set up field camps and/or study plots and gather data on seabird populations and productivity on Chisik, Gull, and Barren Islands.
June 99:	Continue pelagic surveys, and colony observations. Trawling in Kachemak Bay on mid-June. Test other fishing methods (pair-trawl, gill-nets, etc.). Colony censusing and plot monitoring.
July 99:	Continue pelagic surveys, and colony observations. Initiate pilot studies using radio telemetry. Trawling and hydroacoustic surveys in lower Cook Inlet, in July using R/V "Pandalus". Initiate colony observations on chick feeding activity and adult attendance.
August 99:	Continue pelagic surveys, colony observations, telemetry studies, feeding rate and attendance observations, and fish sampling.
September 99:	Field work ends in mid- September. Field camps removed from Chisik and Barren Islands. Hydroacoustic surveys and nearshore fish sampling continue to end of September.
October 99-Sept. 01:	Data analysis and compilation of results.
February 2000:	Annual Report on FY 99 research.

B. Project Milestones and Endpoints

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

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

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

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

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

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

C. Project Reports

February 15, 2000: Annual Report and Summary of work accomplished in summer 1999, and preliminary findings.

March 15, 2000: Interim Report to summarize research findings from work in summers, 1995-1999. To include more extensive analyses of results and conclusions, especially from 1995-1997 work.

April 15, 2001: Draft Final Report of field research, 1995-1999.

September 1, 2001: Final Report.

In addition to the above, results will be published in conference proceedings and scientific journals as analysis and synthesis take place.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

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

In FY 99, additional funding from Minerals Management Service is anticipated to equal $150,000 (budget pending). Base funds from BRD to support the principal investigator in FY 98 are anticipated to equal $120,000 (budget pending), and most of this will be directed to the Cook Inlet study. Logistic support from the AMNWR in FY 98, including use of a Boston Whaler, zodiacs, vehicles, etc., is valued at approximately $30,000.

ENVIRONMENTAL COMPLIANCE

Permits for fish collections are required from the State of Alaska (ADF&G). Permits for collection of seabirds are required from the U.S. Fish and Wildlife Service and the State of Alaska (ADF&G). No other permits or environmental evaluations are required to carry out the proposed research.

PERSONNEL

Project Leader- Dr. John F. Piatt, Research Biologist (GS-13) with the Alaska Science Center, Biological Resources Division, USGS, in Anchorage. Obtained a Ph.D. in Marine Biology from Memorial University of Newfoundland in 1987 (dissertation on seabird-forage fish interactions). Since 1987, studied seabirds at colonies and at sea in Gulf of Alaska, Aleutians, Bering and Chukchi seas. Author on 55 peer-reviewed scientific publications about seabirds, fish, marine mammals, and effects of oil pollution on marine birds. Other BRD staff are listed in the budget.

Post-doctoral Fellow- Dr. Alexander Kitaysky, University of Washington. Masters research in the Sea of Okhotsk on seabird feeding ecology, chick growth and physiology. Ph.D. with Dr. George Hunt, Jr., on comparative ecology and physiology of puffins and auklets in the Sea of Okhotsk and Gulf of Alaska.

<u>Cooperators</u>: Following are anticipated collaborations for field and laboratory research in 1999 to accomplish goals for EVOS Trustee and MMS funded research in lower Cook Inlet.

Vernon Byrd, Leslie Slater, Dave Roseneau, Art Kettle (Alaska Maritime National Wildlife Refuge, Homer). Including financial and logistic support for colony work in lower

Cook Inlet and for research cruises on the M/V Tiglax.

Paul Desjardins, James Brady (Alaska Department of Fish and Game, Homer and Anchorage). Including boat charter and logistic support for trawl sampling with the M/V Pandalus.

Richard Merrick (National Marine Mammal Lab, Seattle). Collaboration on hydroacoustic and trawl data collection around Barren islands, stable isotope studies of food-webs.

Marc Romano, Dan Roby (Cooperative Research Unit, Oregon State University). Graduate student research on effects of diet quality of kittiwake and puffin chick growth.

George Rose (Memorial University of Newfoundland, St. John's, Newfoundland). Laboratory support and consultation for analysis of hydroacoustic data.

signed: John Piatt

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

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

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

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

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

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

O
Statistical review

Statistical Review

Project Number:	99163 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:	4 Years
Cost FY 96:	$21,400
Cost FY 97:	$21,400
Cost FY 98:	$21,400
Cost FT 99:	$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. Our responsibility as biometricians is to provide review of and advice for any required modifications in study protocols for the 1999 field season in order to help insure that appropriate statistical inferences can be made during the analysis phase of the studies. We will also provide advice and assistance during statistical analysis of data, final report preparation, and preparation of journal papers based on data collected through the 1998 field season.

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 study designs and statistical analyses. We will continue to work with the APEX Principal Investigators in modification of future data collection methods. Data collection methods will call for close coordination of sampling efforts in the SEA and NVP projects. Dr. McDonald is working in a similar capacity on the EVOS Trustee's Nearshore Vertebrate Predator (NVP) project and can help provide continuity between sampling methods to yield comparable data of mutual interest to these two projects.

Collection of data during the 1998 field season will follow the same basic sampling protocols as used in 1997 (summarized in the 1998 DPD). Analyses for abundance, distribution, and life history parameters of forage fish and foraging sea birds are following statistical procedures specifically developed for data collected under these protocols.

Summary of Major Hypotheses and Objectives

We will continue to interact with the Principal Investigators of the various segments of the APEX 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 David Irons, William Ostrand, Art Kettle, and Dave Roseneau of the USFWS, and John Piatt of the NBS to quantify and model habitat and food selection by sea birds. We will continue to work with Lew Haldorson and Ken Coyle in estimation of abundance and distribution of forage fish based on the spatially correlated data collected through 1998. Interaction with other PI's will be as requested within the budgeted time.

Completion Date

Sampling protocols, standard operating procedures, draft reports, and final reports will be issued as appropriate with individual Principal Investigators.

COMMUNITY INVOLVEMENT

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

Proposed FY 99 Budget :

Position	Month	Cost per Month		Subtotal
Senior Biometrician	1	$14,400		$14,400
Biometrician II	1.1	10400		11440
Travel:		No. Trips	Cost/ticket	
DIA to Anchorage	2	trips @	$950	1900
Meal Per Diem	10	days @	45	450
Hotel Per Diem Winter	4	days @	75	300
Hotel Per Diem Summer	4	days @	110	440
Car Rental	10	days @	45	450
Commodities:				
Long Distance Telephone				400
Shipping, Postage				150
Supplies				70
============= =====	====	=====	=====	=====
FY99 Project Budget				$30,000
FY99 Budget Total				$32,100

PROJECT DESIGN

Not Applicable

SCHEDULE

A. Measurable Project Tasks for FY 99:

1 Oct. to 1 Mar. 99: Participate in spatial analysis of final acoustic survey data. Prepare for Trustee review of final data and analyses. Prepare for 1999 EVOS Workshop reports and presentations.

1 Mar. to 30 Sept.99: Interact with Principal Investigators in preparation of Final Reports and publication of technical papers in the open literature.

B. Project Milestones and Endpoints

Final reports and 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. We anticipate that relatively more time will be required in FY 99 than in FY 98, because of the more extensive data analyses expected for the final reports and professional publications.

John Kern is a co-author on one manuscript with Ken Coyle. We anticipate that at least one additional manuscript dealing primarily with unique applications of statistical methodology will be jointly authored with Ken Coyle. Joint authorship on publications with other Principle Investigators will be determined on the basis of the significance of unique or new statistical analyses conducted.

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.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

Dr. McDonald is a member of the Nearshore Vertebrate Predator Project. Sampling of nearshore forage fish will be coordinated between the two projects in so far as possible.

ENVIRONMENTAL COMPLIANCE

Not Applicable

PERSONNEL

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

Q
Modelling

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

Project Number:	99163Q
Restoration Category:	Research
Proposer:	H.T. Harvey & Associates
Lead Trustee Agency:	NOAA
Cooperating Agencies:	DOI, UA, OSU
Alaska SeaLife Center:	No
Duration:	3rd year
Cost FY 98:	$65,200
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. 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 year of effort we incorporated 1997 data, when fish and kittiwake data were collected more synoptically, worked with Pigeon Guillemot data as well, and worked more directly with field researchers to integrate bird with fish data. In the proposed, third year of effort we will adapt models to the Common Murre in Lower Cook Inlet. 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. Moreover, results will continue to integrate and "aim" the APEX research effort so that sufficient data are collected to fulfill the overriding APEX objective: to understand the ways in which food supply is limiting seabird recovery.

INTRODUCTION

The APEX Project underway in Prince William Sound is based on the assumption 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 assumption 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 assumption 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 will develop models of foraging effort and success as it relates to breeding productivity. Results not only will test the degree to which the assumption 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 will 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 <u>distribution</u> 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). These resources 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 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; and 3) Compoent 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 exploratory 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 foratge fish.

2. No differences in 1 will be evident in pre- and post-spill comparisons, where possible.

B. Methods

We will be keying analyses on APEX species and those identified as not recovering (kittiwake, murres, pigeon guillemots). We will consider marbled murrelets, but recognize the problematic nature of acquiring data on the natural history of this species.

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 effects 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 modelling 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 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.

Providing Input to the APEX Ecosystem Model. Seabird populations are important components of North Pacific marine ecosystems. Many of the data that would be required to estimate the impact of seabirds on lower trophic levels are already available. Predicting the effects that perturbation of lower trophic levels would have on seabird populations is more problematic. Such predictions will require understanding of the linkage between food availability in terms of the distribution, timing, and nature of the food supply, and the quantitative effect that this will have on various aspects of reproductive success. Establishing the exact nature of these relationships is beyond the scope of our study, but we will be able to determine what factors appear to be the most critical, and help to target ongoing research programs toward this goal.

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, University of Alaska, and Oregon State University.

SCHEDULE

A. Measurable Project Tasks for FY 99 (October 1, 1998 - September 30, 1999)

Jan. 1- :	Assemble data resulting from APEX during FY 95-98, from pre- and immediately post-spill studies, from the Alaska Seabird Colony Register, and the models prepared during year 1 and 2 of this project.
January 22-25:	Attend annual Restoration Workshop.
February 1 - 30 June:	Continue to assemble data; adapt models derived in year 1 and 2 to Lower Cook Inlet and species therein (especially Common Murre).
1 July - 31 August:	Refine models of seabird foraging effort/breeding productivity; refine demographic models.
1 - 30 September:	Finish final report for review.
Winter 1998-99:	Revise final report.

B. Project Milestones and Endpoints

30 September 1998:	Final report, with foraging/energetic model.
January 1999:	Present papers at annual meeting of Pacific Seabird Group: *A foraging/energetic model to explain lack of recovery of seabirds in Prince William Sound and Lower Cook Inlet.*
15 April 1999:	Submit final version of final report.
Spring 1999:	Submit two papers for publication in either *Condor, Auk* or *Colonial Waterbirds.*

C. Completion Date

A draft final report will be available by 30 September 1999.

PUBLICATIONS AND REPORTS

Besides a final report, we anticipate two publications as identified above under Milestones and Endpoints.

PROFESSIONAL CONFERENCES

We anticipate presenting two papers, as identified under Milestones and Endpoints, at the annual meeting of the Pacific Seabird Group in winter 1998-99.

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).

<u>Selected Ainley Publications</u>

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.Glen 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.

Selected Schneider Publications

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.

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R
Marbled Murrelets

Marbled Murrelet Productivity Relative to Forage Fish Availability, Diet, and Environmental Factors in Prince William Sound

Project Number:	99163R
Restoration Category:	Research
Proposer:	U.S. Fish and Wildlife Service (PI - Kathy Kuletz)
Lead Trustee Agency:	DOI-FWS
Cooperating Agencies:	NOAA, ADFG
Alaska SeaLife Center:	No
Duration:	1 year + 1 year synthesis
Cost FY 99:	$114,700
Cost FY 00:	$ (data analysis, reporting, publications)
Geographic Area:	Prince William Sound
Injured Resource:	Marbled Murrelet

ABSTRACT

This project investigates the hypothesis that forage fish abundance is limiting marbled murrelet reproductive success and recovery. We will compare forage fish abundance to at-sea densities of juvenile murrelets and juvenile:adult ratios. Intra- and inter-annual comparisons will be made among 3 sites in Prince William Sound. Second, we will describe murrelet diet, its relation to prey availability and impact on productivity. We will also examine differences in foraging patterns and prey use between adults self-feeding and those provisioning chicks. Prey will be identified visually and by sampling fish below foraging birds. Ultimately, we will integrate data on terrestrial and marine habitat use to model murrelet distribution and recruitment.

INTRODUCTION

Marbled murrelets (*Brachyramphus marmoratus*) are the most abundant seabird in Prince William Sound (PWS) in the summer, but their population has declined by 67% between 1972 and 1989 (Klosiewski and Laing 1994). A primary hypothesis of the Alaska Predator Ecosystem Experiment (APEX) project is that food has been the cause of decline and lack of recovery for marine species, including the murrelet. The murrelet project is based on the hypothesis that marbled murrelet productivity depends on the density and distribution of forage fish. We will test this hypothesis by comparing murrelet abundance and productivity spatially and temporally, relative to the distribution and abundance of forage fish. Murrelet productivity will be measured by a methodology developed by project 95031 (Kuletz et al. 1997a, see also Kuletz and Kendall 1998a).

In 1995 and 1997, we found that murrelet productivity (juvenile densities at sea during the fledging period) was positively correlated to nearshore fish biomass within 10 km of the murrelet study sites (Kuletz and Kendall 1998b). The chronology of murrelet breeding also showed a relation between fledging and the timing of the spring plankton bloom (Kuletz et al. 1997a) and to the types of prey fed to chicks (Kuletz and Kendall 1998b). These results gave strong support to the hypothesis that murrelet recruitment depends on forage fish abundance and distribution, and possibly, to the types of prey as well.

In addition to the abundance and timing of prey, the quality of prey can be equally important to the reproductive success of seabirds (Harris and Hislop 1978, Hunt et al. 1981, Vermeer 1980, Monaghan et al. 1989). Murrelets depend on forage fish such as Pacific sand lance, (*Ammodytes hexapterous*), capelin (*Mallotus villosus*), juvenile herring (*Clupea pallasi*) and juvenile pollock (*Gadidae spp*) (review in Burkett 1995, Kuletz and Kendall 1998b). In most of its range, murrelets appear to select sand lance (Sealy 1975, Carter 1984, Burkett 1995). In PWS, the diet of adult murrelets has changed from primarily sand lance in the early 1970's to primarily cod species between 1989 and 1991 (Kuletz et al. 1997b). This change in prey type may be one of the factors responsible for the population decline in PWS.

The second objective of this project is based on the hypothesis that murrelet productivity is positively correlated with the proportion of high-quality prey, ie., sand lance, in chick diets. Indeed, in 1997, we found the highest juvenile murrelet densities and the earliest fledging dates, occurred where sand lance was fed to chicks. Results were not conclusive, however, because there were also spatial differences in prey use by murrelets. Also in 1997, we found a general concordance between murrelet diet and the relative abundance of prey species (Kuletz and Kendall 1998b).

The final objective of this project is based on the hypothesis that the foraging and nesting ecology of murrelets enables them to dominate the avifauna of PWS because they can exploit prey that is dispersed. However, at some scale, murrelet distribution and productivity must be determined by a combination of terrestrial (nesting) and marine (foraging) habitats. Even within

PWS, some areas consistently have more adult and juvenile murrelets (Kuletz and Kendall 1998a,b). We will attempt to define what combination of features promote high murrelet density and productivity.

Marbled murrelets forage on small schools of fish in nearshore, shallow waters, or areas of upwelling (Kuletz et al. 1995a, Ostrand et al. in press). The foraging locations of radio-tagged birds and density of murrelets relative to marine habitat have suggested that some hydrographic features attract murrelets, presumably because prey are consistently available there (Kuletz et al. 1995a, 1997a). Although murrelets can use small, dispersed patches of prey typical of PWS, certain hydrographic features probably result in regions of relatively high prey abundance (Haney and McGillivary 1985, Hunt et al. 1990, Coyle et al. 1992), or bring prey to the surface at frequent and predictable intervals (review in Hunt 1995). Such regions should support higher densities of murrelets than less productive or less predictable sites. We will use the murrelet survey data to test predicted patterns of habitat use.

The mechanisms of how murrelets obtain food, or what physical and biological features they respond to, will be examined in conjunction with the seabird/fish interaction portion of APEX (Project 99163B). To further examine the effect of prey species on murrelet productivity, project 99163R will compare murrelet diet with the relative abundance of species within and among sites and years. The murrelet project, as a component of APEX, provides a rare opportunity to examine the relationships between forage fish and murrelet foraging, prey selection, and productivity.

NEED FOR THE PROJECT

A. Statement of Problem

The marbled murrelet is a threatened species under the Endangered Species Act in California, Oregon and California and a species of concern in Alaska. The murrelet is the most abundant seabird in PWS in summer, and the *Exxon Valdez* oil spill caused the largest single-event mortality of marbled murrelets in the world (Carter and Kuletz 1995). Although murrelets suffered high mortality in the 1989 spill (Piatt et al. 1990, Kuletz 1996), the spill cannot account for the 67% reduction in numbers observed in post-spill years (Klosiewski and Laing 1994); nor has the population increased since 1989 (Agler et al. 1994).

B. Rationale / Link to Restoration

Marbled murrelet populations have declined in other areas primarily due to the loss of old-growth forest nesting habitat (Ralph et al. 1995). However, a comparatively small proportion of potential nesting habitat has been harvested in PWS. Changes in the food supply can also affect seabird populations (Monaghan et al. 1989, Furness and Nettleship 1991). Murrelet reproduction may be limited by food if adults can not provide sufficient quantity or quality of prey to their chicks. Because other piscivorous birds and marine mammals in PWS have declined as well, (Kuletz et al. 1997b), a lack of food resources is the main hypothesis of the APEX project.

If food is limiting murrelet reproductive success, it is likely that recruitment is limiting recovery of the population. Because murrelets are probably long-lived (Beissinger 1995), changes in the population due to low reproduction may not be evident for a decade or more, which may preclude timely management decisions. We will use APEX fish studies to determine if murrelet productivity responds to changes in prey abundance, distribution or species composition. If productivity does not respond to changes in prey availability, the low murrelet population may be a result of factors outside of the breeding season. This is a unique opportunity to approach the restoration of the marbled murrelet within the context of its ecosystem. Ultimately, we will improve our ability to predict how management options will affect the recovery of murrelets, and how changes in the murrelet population affect the PWS ecosystem.

C. Location

This project will occur in Prince William Sound. Comparisons will also be made to data collected in lower Cook Inlet/Kachemak Bay (Project 99163M). The 3 PWS study sites will be Galena Bay to Boulder Bay (Galena), Naked Island (Naked), and Jackpot Bay/Dangerous Passage (Jackpot). These areas were studied in 1995 and 1997 and were originally selected because of the availability of historic data on murrelets and overlap with APEX fish sampling. They are separated by at least 16 km, the average distance traveled between feeding and nest sites by murrelets in PWS, and twice the distance that a juvenile murrelet tagged at its nest moved over a 2 week period (Kuletz and Marks 1997c).

During surveys of Galena we will use facilities at the community of Tatitlek and occasionally the U.S. Coast Guard dock and city facilities at Valdez. At Naked and Jackpot we will share field camps used by project 99163F (guillemots), which will require a U.S. Forest Service permit. The camp site at Jackpot was purchased by the *Exxon Valdez* Trustee Council in 1997.

COMMUNITY INVOLVEMENT AND TRADITIONAL ECOLOGICAL KNOWLEDGE

Murrelets are not used for subsistence by local communities. They are, however, subject to gillnet mortality (Wynne et al. 1992). Gillnet by-catch, and reports by fishermen, can identify areas of high juvenile murrelet or post-breeding adult murrelet concentrations. The principal investigator is currently a member of the Seabird Network Bycatch Working Group (fish1ifr@aol.com), an international group working to reduce seabird bycatch.

In late summer, dead juvenile murrelets have been found by residents in the spill area. These carcasses often show evidence of starvation and they can be a valuable source of data. Samples will be solicited through posters and notification of local fishing and recreation groups in PWS and Kachemak Bay communities. We will also maintain contact with the Bird Treatment and Learning Center in Anchorage, and the Alaska Sea Life Center, both of which have notified us of captive murrelet fledglings they receive. These contacts have provided data on body weight and juvenile plumages. The PI, in turn, has provided these facilities with information and protocol regarding the fledging patterns of murrelets and types of data to collect.

PROJECT DESIGN

A. Objectives

Using the murrelet productivity index, our goal is to determine if food is limiting marbled murrelet productivity, and if so, what are the mechanisms. The objectives are:

1. Assess the relationship between relative prey abundance and distribution and murrelet productivity within and between sites in Prince William Sound.

2. Describe the diet and foraging patterns of marbled murrelets in PWS during the chick rearing period, including differences between birds feeding themselves and birds provisioning chicks.

3. Model the distribution of adult and juvenile murrelets in Prince William Sound relative to terrestrial and marine features.

B. Methods

Objective 1: Assess the relationship between food and murrelet productivity.

The hypothesis of this objective is that murrelet productivity will be higher in areas and in years when forage fish availability is relatively higher. Data on food availability will be obtained through the APEX forage fish studies (99163A, B, M). It is not possible to study murrelet reproductive success by standard means at nest sites because of their highly dispersed, secretive, inland nesting habits. We will use a productivity index, based on the at-sea density of juveniles or the ratio of juveniles : adults (see Kuletz and Kendall 1998a). We use the foraging ranges of adults (Kuletz et al. 1995a) and the APEX study areas to define our study sites.

Data Collection

Murrelet Productivity.-- We will conduct shoreline at-sea surveys at 3 of the PWS sites surveyed in 1995 and 1997 (Fig. 1). One crew (1 driver and 2 observers) will survey from 25 ft. Boston Whalers using a standard protocol (Kuletz and Kendall 1998b, Murrelet Productivity Protocols for 1998). The surveys will follow established FWS shoreline transects that are digitized on Atlas/GIS files (Strategic Mapping, Inc. 1992). At each site, a total of approximately 40 km of shoreline will be surveyed. Surveys will be conducted between 0600-1600 hours (murrelet counts vary significantly earlier or later in the day [Carter and Sealy 1990]). Each site will take one day to survey per sample.

Because adults leave in late summer, the June population is most representative of the local breeding population, and thus June adult counts may be the most reliable for juvenile : adult ratios (Kuletz and Kendall 1998a). In 1999 we will conduct baseline surveys 1-15 June. The numbers of murrelets in each area in June will be used for comparison to late summer juvenile counts. Juvenile surveys will be conducted 25 July - 25 August. Each site will be surveyed about twice per week, with the crew rotating among sites to minimize temporal effects. In early June, day-to-day variability is relatively low, and 3 replicates per site is adequate. Surveys in late summer must accommodate inter-annual changes in peak fledging dates and higher day-to-day variability (Kuletz et al. 1997a), therefore, each site will have at least 7 replicates. Thus, there will be at least 9 surveys in June (3 sites x 3 replicates) and 21 surveys in July-August (3 sites x 7 replicates). More replicates will be obtained in July-August if weather and logistic arrangements permit, since higher sample sizes improve power to detect changes in juvenile abundance (Kuletz and Kendall 1998a).

Observers will be trained to score birds by plumage and behavioral characteristics (Kuletz et al. 1997a), using photos, study skins, drawings and on-sight training to standardize observers. (See Murrelet Productivity Protocols for details). All survey data will be entered directly into a computer database (DLOG; Ecological Consulting, Inc., Portland, OR). The program associates a latitude and longitude for each observation, via integrated Global Positioning System.

Fish abundance. -- We will test the hypothesis that food is limiting murrelet productivity by comparing the average juvenile ratio among sites relative to local prey availability. APEX surveys will provide forage fish biomass via boat-based hydroacoustics, or by aerial surveys of fish schools. The latter provides more information on temporal variability of fish and can be used for immediate analysis until biomass constants are determined for hydroacoustic data. We will coordinate with aerial surveys to provide ground-truthing of prey species whenever possible.

Data analysis. -- As in 1995 and 1997, we will test for differences among sites in juvenile densities and ratios of juveniles : adults, using Z tests on the standard error of the ratios. The ratio of juveniles will also be calculated relative to total murrelets in June and compared among sites with a Kendall *taub* correlation test. We will use regression to determine if prey abundance (counts of fish schools or density estimates) among sites is correlated with relative juvenile murrelet density. Non-parametric tests will be used to compare murrelet productivity to the number of schools or surface area of fish schools.

Objective 2: Describe the diet of marbled murrelets, for both adults and chicks, in PWS during the chick rearing period.

Chick diet. -- We will document murrelet prey species by visual observations of murrelets on the water holding fish in their bill. We will primarily target prey items destined for chicks (Carter and Sealy 1987) and thus will concentrate "diet cruises" during peak chick-rearing period, and near dawn and sunset. In 1997, we found evidence of spatial differences in the timing of fish-holding behavior, but because of insufficient numbers of personnel, we could not sample sites equally. To insure adequate and equal coverage at all sites, in 1998 and 1999, 2 people will be assigned to the diet component of this study from late June to late August. The crew will cruise nearshore waters within our study sites, and rotate among sites such that each site is surveyed for diet at least twice per week. In 1997, the number of birds holding fish was consistently higher during evening cruises (Kuletz and Kendall 1998b) so most effort will be focused at this time period. We will attempt to obtain a minimum of 50 identified prey items per site.

Adult diet. -- Adult murrelet diet will be determined by observations of adults foraging, concurrent with our efforts to sample fish. In 1997 we made opportunistic observations of murrelets feeding in forage flocks and we sampled the fish below feeding birds using cast nets and dipnets, or we visually identified fish brought to the surface. In 1999, we will make similar observations, but will also make targeted observations of murrelets foraging singly. Birds will be observed from a boat or a fixed point on land using visual scans. One-hour observation periods, separated by at least one hour, will be conducted periodically throughout the summer.

For both chick and adult diets, we will determine if murrelets are taking prey in relation to their relative abundance by making spatial and temporal comparisons to the relative fish abundance data collected by related APEX projects.

Objective 3: Factors affecting murrelet distribution and modeling murrelet distribution

This portion of the project will be a synthesis effort following the successful completion of the previous objectives and compilation of data from other APEX and SEA projects and previous studies of murrelet nesting habitat (Kuletz et al. 1995b). Project 99163B, the seabird/fish interaction component of APEX, will continue to examine the mechanisms that influence seabird distribution at sea. However, the study of seabird/fish interactions often examines small-scale relationships to describe mechanisms. Because of the distribution and scarcity of juvenile murrelets, the murrelet productivity project will work primarily on a larger scale, with the study sites as sample units. Our results will be integrated with data collected by 99163A (fish abundance) or aerial surveys to describe murrelet distribution relative to food availability and environmental factors. On a smaller scale, the transects that comprise each study site will be used to examine murrelet habitat use.

The distribution of adults and juveniles at sea may be partially determined by nesting distribution, or the combination of terrestrial and local marine habitats. Therefore, environmental data for the murrelet study areas will include spatial data from GIS bathymetric and terrestrial coverages as well as temporal data collected on-site. Temporal data will be collected during the murrelet surveys prior to each transect, and will include air and surface temperature and salinity, presence of glacial ice, water clarity (by Secchi disk), sea conditions, weather, time and observed feeding activity. We will calculate tide with a Paradox (Borland, Inc. 1992) script.

For the site (mid scale) and transect (small scale), shoreline and bathymetric features will be taken from GIS. Descriptive statistics and non-parametric ranking will be used to distinguish areas of low and high murrelet density. We will test for differences between adult and juvenile habitat associations with log-linear analysis at the transect level. Additionally, for data since 1997 (when DLOG data entry was used), the location of each sighting of murrelets (adults and juveniles) can be mapped and correlated with spatial data. Murrelet habitat associations and distribution patterns could then be analyzed at various spatial scales.

C. Cooperating Agencies, Contracts and Other Agency Assistance

We have the expertise and technical support to perform the majority of our geographic information system (GIS) needs. As coverages are developed for nearshore and pelagic areas of Prince William Sound by other projects, we may require agency support to obtain files. Our study will integrate data on forage fish and oceanographic conditions obtained by APEX (NOAA) and the SEA studies.

SCHEDULE

A. Measurable Project Tasks for FY 99 (October 1, 1998-September 30, 1999)

Oct. 1- Dec. 31:	Prepare GIS coverage of transects and study sites Prepare NEPA compliance documents and USFS permits Rewrite and submit manuscripts submitted to journals
January:	Present paper at Pacific Seabird Group meeting Attend annual Restoration Workshop
Feb 1-March 15:	Arrange logistics for boats, equipment, contracts
March 1-May 30:	Hiring and training
April 15:	Submit Annual Report (FY98 findings)
June 1 - 15:	Conduct baseline surveys
June 15-Aug 25:	Prepare for late-summer surveys Conduct diet and foraging observations
July 21-August 25:	Conduct juvenile surveys
Aug 26-Sept 1:	Store equipment, data management
September 1- 30:	Analysis of field data

B. Project Milestones and Endpoints

The primary objective of this project (Objective 1) depends on obtaining a reliable index of relative forage fish abundance to correlate with the murrelet productivity index. Fish abundance may be estimated via hydroacoustics or by aerial counts of fish schools. Our analysis will proceed as the different sources of fish data become available. Intra- (1999) and inter-annual (1995-1999) comparisons of the productivity and fish indices will be made available in the annual report. A synthesis of inter-annual comparisons will be presented in the final report.

The second objective will be met by improving the sampling scheme of the diet component, based on FY97 results. The objective will be met when we can describe murrelet diet in the context of the relative abundance of prey species as described by APEX, as well as the relative importance of different species to murrelet reproductive success.

The third objective will be a synthesis of results from FY95-99 (for APEX forage fish results) and earlier murrelet restoration studies regarding inland nesting habitat. Forage fish distribution and species composition (APEX studies) will be necessary to complete these objectives, so that interim analyses will be finalized after all field work is completed.

C. Completion Date

All of the objectives will be met by FY00.

PUBLICATIONS AND REPORTS

April 15, 1999:	Annual Report and Summary of work accomplished in summer 1998, and preliminary findings.
April 15, 2000:	Draft final report of research, 1997-1999.

Interim aspects of this study will be submitted for publication in journals periodically between 1998-2000. Following the final field season, synthesis papers will be submitted. In addition, the Principal Investigator will be co-author on papers related to the pigeon guillemot project. Proposed articles derived from the murrelet project are listed below:

> Marbled murrelet productivity relative to forage fish abundance: prey effects on productivity of a non-colonial seabird.
>
> Forage fish biomass affects juvenile murrelet recruitment within Prince William Sound, Alaska.
>
> Marbled murrelet diet, chronology and productivity: the effect of different prey species on timing and breeding success.
>
> Factors influencing the distribution of juvenile marbled murrelets in Prince William Sound, Alaska.

Spatial and temporal differences in the diet of marbled murrelets in southcentral Alaska and possible effects on productivity.

Terrestrial and marine factors determining the distribution and productivity of marbled murrelets: Management implications for a non-colonial seabird.

PROFESSIONAL CONFERENCES

Annual findings will be presented at symposia and conferences, including the Pacific Seabird Group annual meeting in winter, 1999.

NORMAL AGENCY MANAGEMENT

It is not part of normal agency management in Region 7 of U.S. Fish and Wildlife Service to monitor the productivity of marbled murrelets.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

The marbled murrelet is one of the injured species that is targeted by the APEX project (99163). Previously, the murrelet project was closely coordinated with, but not a part of APEX. In FY98, the murrelet project became component 98163R of APEX. This project is dependent on the APEX project to provide fish abundance data to test the main hypothesis. The mechanistic interactions between murrelets and forage fish described by Project 99163B (seabird foraging) will be used to develop the integrated terrestrial/marine murrelet distribution model. Productivity comparisons among years will be made in the context of other seabirds (Projects 99163E, kittiwakes and 99163F, guillemots). The relative value of different prey species will be described by Project 98163G (seabird energetics).

The PI has been coordinating with Rob DeVelice (U.S. Forest Service, Anchorage, Alaska) on the mapping of murrelet nesting habitat in PWS. Additional ground-truthing will be conducted by the USFS in 1998 and subsequent GIS coverage of terrestrial habitat will be used in the final synthesis of the murrelet project. Information exchange relative to herring and other nearshore prey will occur between this project and the SEA and NVP projects. Although this project was initiated for the marbled murrelet, and results may be relevant to both *Brachyramphus* species (marbled and Kittlitz's), and thus will benefit the Kittlitz's murrelet restoration effort.

EXPLANATION OF CHANGES IN CONTINUING PROJECTS

The murrelet productivity study was previously a separate project that coordinated with APEX, but in FY98 became component 99163R of APEX. In FY98 and FY99, increased emphasis will be placed on the use of aerial counts of fish schools and coordinating with E. Brown (PI for aerial surveys) to ground-truth species identification. In addition, greater survey effort will be directed towards identification of murrelet diet throughout the chick-rearing period.

PROPOSED PRINCIPAL INVESTIGATOR:

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PRINCIPAL INVESTIGATOR

Kathy Kuletz received her B.S. degree in Biology from California Polytechnic State University, San Luis Obispo (1974), and her M.S. degree in Ecology and Evolutionary Biology from University of California, Irvine (1983). Her thesis was on the foraging and reproductive success of pigeon guillemots at Naked Island, Prince William Sound. Ms. Kuletz has worked in Alaska since 1976 for Dames and Moore Consulting, LGL Alaska Research and the U.S. Fish and Wildlife Service. Since 1989 she has been Principal Investigator for the marbled murrelet damage assessment and restoration studies. She has been working with the Pacific Seabird Group Marbled Murrelet Technical Committee to develop protocols for inland and at-sea murrelet surveys. She participated in and assisted in the writing of the Pacific Seabird Group Restoration Workshop in 1995.

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OTHER KEY PERSONNEL

Field Supervisor/GIS Assistant: Not known.

This person will supervise data collection in the field in the absence of the project leader. Duties will include logistics with other projects, conduct at-sea surveys and provide some of GIS data and analysis for reports.

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Signed: ______________________________

Katherine J. Kuletz
U.S. Fish and Wildlife Service

Date prepared: ________________

S
Jellyfish

JELLYFISH AS COMPETITORS AND PREDATORS OF FISHES

Project Number:	99163S
Restoration Category:	Research and Monitoring
Proposer:	University of Maryland Center for Environmental Science, Horn Point Laboratory
Lead Trustee Agency:	
Cooperating Agencies:	
Alaska SeaLife Center:	
Duration:	Second year, 4-year project
Cost FY 99:	$109.2
Cost FY 00:	$ 70.2
Cost FY 01::	$ 67.0
Geographic Area:	Prince William Sound
Injured Resource/Service:	Predators of forage fish e.g. pigeon guillemots, murrelets, and zooplanktivorous fishes i.e. Pacific herring, pink salmon

ABSTRACT

At high densities, jellyfish can seriously effect populations of zooplankton and ichthyoplankton, and may be detrimental to fisheries through competition for food with fishes and by direct predation on the eggs and larvae of fish. I propose to examine the roles of jellyfish as competitors and predators of fishes. This will be accomplished by participating in ongoing APEX research cruises in Prince William Sound, in which zooplankton, ichthyoplankton, and gelatinous zooplankton distributions and densities will be determined. Additionally, medusae will be collected for gut content analysis and gut passage time experiments to calculate feeding rates on zooplankton and ichthyoplankton. Feeding rates will be correlated with medusa size and prey densities in order to be able to predict the importance of predation and competition in future years from population data only. This project will coordinate with other APEX investigators, who will provide logistic support in the field, and sampling for zooplankton and ichthyoplankton. I will compare jellyfish diets with forage fish diets from previous APEX research, in order to determine dietary overlap and the potential for competition. In collaboration with APEX and SEA scientists, I am compiling historical, existing and future data in order to obtain the most comprehensive picture of the importance of jellyfish in the food web of PWS.

INTRODUCTION

I propose to examine the importance of jellyfish and ctenophores as competitors and predators of fishes. When herring larvae hatch, a suite of jelly and ctenophore species are present in British Columbia that eat the larvae (PURCELL, 1990). Population densities of these predators are higher in bays and inlets than along open coast (PURCELL, 1990). The same species are present in Alaskan waters, including *Aequorea victoria*, which was the key predator at herring spawning grounds of Vancouver Island. *Aequorea* and large scyphomedusae present in Alaska during the summer (i.e. *Cyanea capillata, Phacellophora camtschatica, Chrysaora fuscescens*) are predators of the pelagic eggs and larvae of fish species in addition to herring, many of which are commercially important (e.g. rockfish, cod, flatfish; FANCETT, 1988; PURCELL, 1989, 1990) and are important as forage fish of marine vertebrates, specifically piscivorous fish, sea birds, and harbor seals. Medusae have potentially great effects on fish populations because of their often great abundances and feeding that increases directly with prey density without saturation.

Not only do these predators feed directly on the early stages of fish, but they eat the same zooplankton foods as well (Table 1)(PURCELL, 1990, PURCELL and GROVER, 1990; BAIER and PURCELL, 1997). The dual role of soft-bodied plankton as predators and competitors of fishes has been suggested many times (e.g. PURCELL, 1985; ARAI, 1988), but seldom has been evaluated directly (existing studies are PURCELL and GROVER, 1990; BAIER and PURCELL, 1997). The following background provides details of research on gelatinous species to determine their effects on ichthyoplankton and zooplankton populations.

Dietary analyses. Copepods are the main prey items of most gelatinous predators, however, the diets of some species include high proportions of fish eggs and larvae when available (Table 1). Such predators include hydromedusae, in particular *Aequorea victoria*, whose diet consisted of almost exclusively Pacific herring (*Clupea harengus pallasi*) larvae in April when the larvae hatched (PURCELL and GROVER, 1990) and a variety of eggs and larvae of other species of fish later in the spring in addition to gelatinous and crustacean prey (PURCELL, 1989). Semaeostome scyphomedusae may also contain large numbers of ichthyoplankton prey when available in addition to gelatinous and crustacean prey (e.g. *Cyanea capillata, Chrysaora quinquecirrha* in FANCETT, 1988 and PURCELL *et al.*, 1994, respectively). Prey selection by these predators for fish eggs and larvae has been positive in every case in which it was calculated (FANCETT, 1988; PURCELL, 1989; PURCELL *et al.*, 1994).

Predation effects by pelagic cnidarians on fish larvae often are substantial ($\geq 30\%\ d^{-1}$ of the populations) in environments where predators are numerous, as for the scyphomedusan *Chrysaora quinquecirrha*, the hydromedusan *Aequorea victoria*, and the siphonophores *Rhizophysa eysenhardti* and *Physalia physalis* (PURCELL, 1981, 1984, 1989; PURCELL and GROVER, 1990; PURCELL *et al.*, 1994). The numbers of bay anchovy eggs and larvae in the gut contents of *C. quinquecirrha* were significantly related to prey density and medusa diameter (PURCELL *et al.*, 1994). Predation by *C. quinquecirrha* on bay anchovy eggs averaged 19% of the population over 9 sampling days in Chesapeake Bay. Other estimates of predation effects by pelagic cnidarians on fish eggs were low (0.1 to 3.8% d^{-1}; FANCETT and JENKINS, 1988). Intense daily predation on ichthyoplankton can have serious consequences since the spawning period of the fishes may be limited (e.g. Pacific herring spawn once annually).

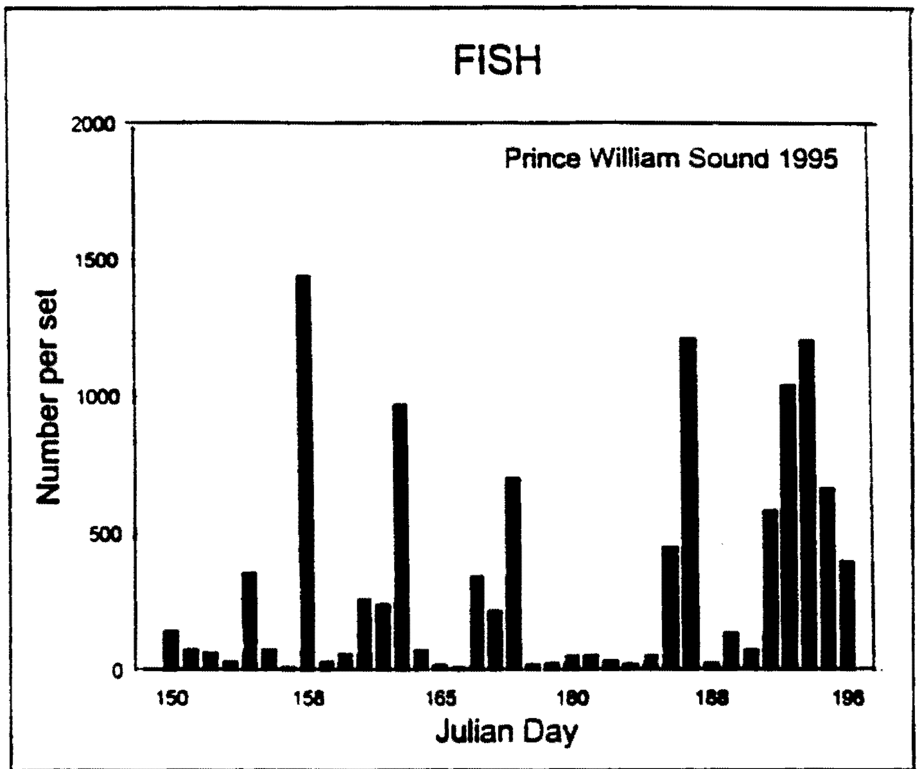
Several estimates of predation effects of gelatinous species on copepod populations suggest that the effects are too small to cause prey population declines (e.g. ≤ 10% d^{-1}; KREMER, 1979; LARSON, 1987a; PURCELL and NEMAZIE, 1992; PURCELL, WHITE, and ROMAN, 1994). However, some studies indicate much higher predation and possible reduction of zooplankton standing stocks (e.g. ≤ 20% d^{-1}; DEASON, 1982; MATSAKIS and CONOVER, 1991; PURCELL, 1992). Copepod capture by *Chrysaora quinquecirrha* was significantly related to prey density, medusa size, and temperature. During July and August 1987 and 1988 in two tributaries of Chesapeake Bay, medusae consumed from 13 to 94% d^{-1} of the copepod standing stocks, and may have caused the observed copepod population decline.

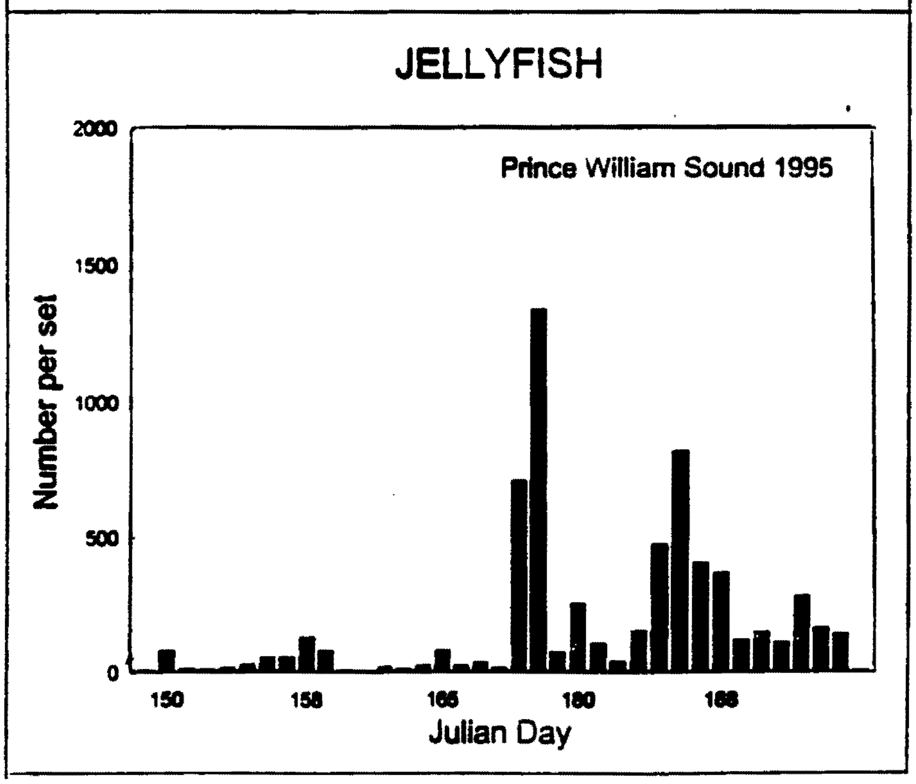
The possibility of competition for food among jellyfish and fish has been directly examined in only a few studies. Potential competition between medusae and first-feeding herring during one spring in British Columbia was found unlikely to be important due to the great abundance of copepod nauplii consumed by the larvae (PURCELL and GROVER, 1990). However, when the prey were copepodites, chaetognaths consumed significant percentages of the same prey as fish larvae off the southeast U.S. coast (BAIER and PURCELL, 1997).

At high jellyfish densities, as can occur especially in semi-enclosed bodies of water such as 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 that specialize on soft-bodied prey like ichthyoplankton (*Aequorea, Cyanea, Chrysaora*) often occur in areas of intense spawning activity and are major sources of fish egg and larva mortality.

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 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 (Fig. 1). Researchers from SEA and APEX observed the great abundance of jellyfish in PWS and recognized the need to understand their effects on the zooplankton and fish populations there.

In anticipation of EVOS funding starting in October, 1997, APEX investigators invited me to participate in the July-August cruise. The jellyfish ppulations were considerably different from 1996, being generally less abundant and with *Aequorea* in low numbers. Specimens of five species (*Cyanea, Aurelia, Aequorea, Clytia, Pleurobrachia*) were collected for gut content analysis (Table 1). I also have begun analysis of historical data on jellyfish abundance in the Gulf of Alaska provided by APEX investigator Dr. Paul Anderson, which showed a dramatic





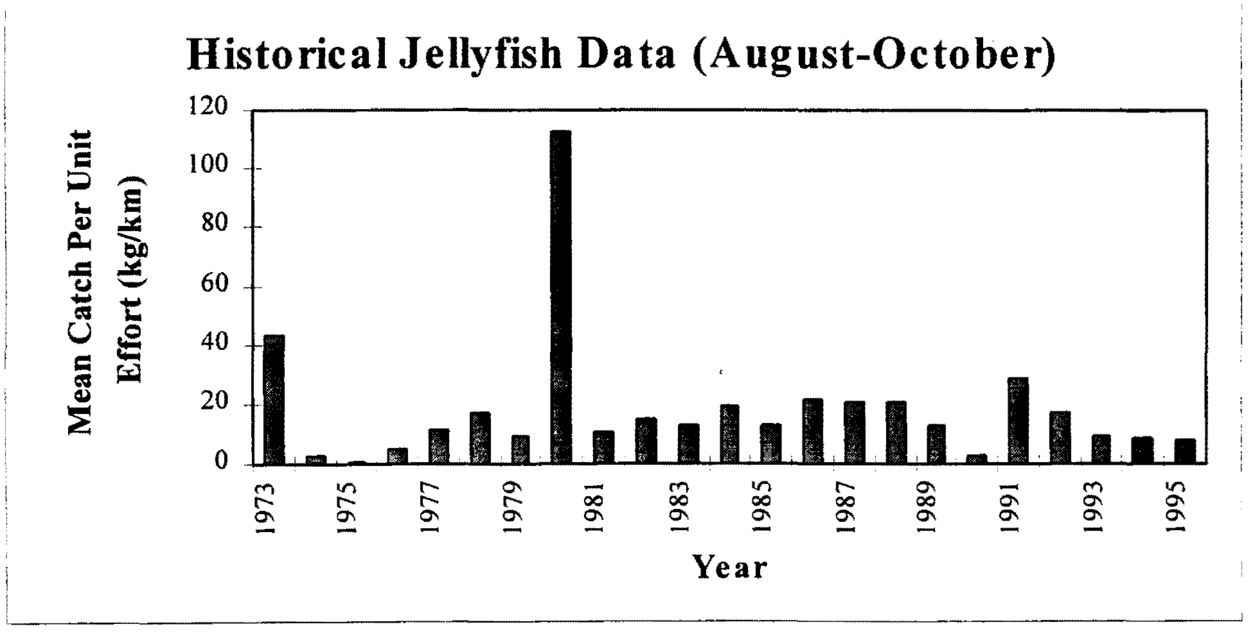
Catches of jellyfish in drift trawls often exceeded catches of fishes in June 1995 in PWS. Data courtesy of Dr. Mark Willette, Alaska Dept. of Fish and Game, Cordova, AK.

peak in abundance in 1980, during the faunal transition observed (Anderson et al. 1997) from mainly shrimp to predominantly groundfish (Fig. 2). In addition, I have begun data compilation on jellyfish distributions and abundance from the SEA project (Cooney, Coyle, Brown, Foy, Norcross, and Stokesbury) and earlier APEX work (Haldorson, Shirley, Sturdevant). Preliminary data have been incorportated into the EcoPath model of PWS in collaboration with Dr. Daniel Pauly.

Table 1. The major prey items of the two most abundant jellies in PWS in the summer of 1997 were mostly copepods, cladocerans and larvaceans. Those prey were also most abundant in the major fish diets (Sturdevant et al. 1997).

% of prey in jellyfish and fish diets					
Species	**Copepods**	**Cladocerans**	**Mero-plankton**	**Larvaceans**	**Fish eggs and larvae**
Cyanea	18.6	4.1	9.3	67.4	0.6
Pleurobrachia	37.7	50.0	12.3	-	-
sandlance	60.0	12.7	6.8	5.5	0
pollock	80.7	0	0.8	10.1	0
herring (116)	5.8	0.2	5.0	84.9	0
herring (271)	76.7	13.9	0.2	0	0

Fig. 2. Extremely large biomasses of jellyfish occurred in the Gulf of Alaska in 1980. This was during the dramatic faunal shift from shrimps to groundfish (Anderson et al. 1997).



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 and direct predation on their eggs and larvae. 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 nnual variation in species composition, size distributions, and abundances of jellyfish and ctenophores in Prince William Sound.

2. Collect additional gut content data for key gelatinous predators (*Aurelia, Cyanea, Chrysaora, Phacellophora, Aequorea* and other hydromedusae, *Pleurobrachia* ctenophores) in order to comprehensively evaluate the diet of the several key species and to evaluate interannual variation..

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

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 dietary overlap indices for medusae and forage fish species.

6. Calculate predation impacts on key prey taxa based on feeding rates and densities of predator and prey species.

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

8. Compile historical data (Gulf of Alaska) and all available EVOS data (PWS) on jellyfish distributions and abundances.

Hypotheses

This project will test the following null hypotheses:

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

2. Abundances of key predator species are similar among years (specifically addressing environmental factors that differ among years, such as temperaure and salinity).

3. Jellyfish diets do not overlap with forage fish diets, and consequently, they are not competitors for zooplankton prey. Competition for copepods could amplify diet switching by fishes from copepods to fish.

4. Jellyfish predation does not limit zooplankton populations, and consequently competition for food does not occur between them.

5. Jellyfish are not important predators of ichthyoplankton.

6. Long-term jellyfish population abundances along the Alaskan Peninsula do not correlate with environmental factors or abundances of other species (i.e. shrimps, fish).

B. Methods

Distribution and abundance. This project will utilize zooplankton samples collected by APEX investigators using standard plankton nets. All but one gelatinous species (lobate ctenophore *Bolinopsis*) from this area preserve well in 5% Formalin. My technician will assist APEX in the analysis of these samples; the data will be stored in the APEX data base. Zooplankton will be identified and counted from subsamples. Ichthyoplankton and small gelatinous species will be removed from whole samples. Small hydromedusae, ctenophores and ichthyoplankton will be identified and counted by my technician. Data on zooplankton and ichthyoplankton densities, as well as CTD data, will be made available to me from APEX for all appropriate cruises.

Quantitative trawl samples will be taken at the same times and locations as the zooplankton samples to determine abundances of large medusae (*Cyanea, Chrysaora, Phacellophora, Aurelia, Aequorea*). The samples will be processed on board ship; the medusae will be identified, counted, the swimming bell diameter measured, and biovolumes of each species measured. I trained SEA investigators during 1996 so that such data will be taken routinely on all SEA cruises, and I will train APEX investigators according to the same protocol.

These data on gelatinous zooplankton distributions and abundances will be compared with those for zooplankton, ichthyoplankton, and forage fish species, with the cooperation and assistance of APEX investigators. Data management and analysis will be accomplished in direct collaboration with APEX scientists in order to maximize the comparability of results.

Gut contents. Gut contents of small hydromedusae and ctenophores will be analyzed from specimens picked out of the above zooplankton samples. Additional specimens may need to be collected in gentle net tows using a 0.5 m diameter plankton net. Individual collection, which is preferable, is often not practical for small species. Individual large medusae (*Cyanea, Chrysaora, Phacellophora, Aurelia, Aequorea*) will be dipped from the surface at sampling locations. This will be done during trawls and net collections, and will not interfere with APEX operations. At least six specimens of each species present will be collected at each station, if possible. The medusae will be immediately preserved in 5% Formalin. The samples will be transported to J. Purcell's laboratory for later gut analysis using a dissecting microscope (available at HPL). Prey taxa in the guts will be identified, counted, measured with the aid of a CUE-2 image analysis system available at HPEL. Collection of uncontaminated gut contents in this way is preferable to retrieval of specimens from plankton nets, which can result in extraneous prey being ingested from the net, or in evacuation of gut contents (see PURCELL, 1989). 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 laboratory-determined rates (SULLIVAN and REEVE, 1982; PURCELL, 1982, 1992; PURCELL and NEMAZIE, 1992).

Alternatively, feeding rates can be measured in laboratory containers by determining the change in prey densities over time. Such methods may be adequate for small, inactive predators (but see PURCELL and NEMAZIE, 1992). However, the key jellyfish species in Prince William Sound are large and active, especially considering the extension of tentacles, and extremely large containers would be necessary for undisturbed feeding. When comparisons of results among container sizes have been made, feeding always has been lower in the smaller containers, indicating interference with feeding in containers. For example, DE LAFONTAINE and LEGGETT (1987) found significantly lowered feeding rates by *Aurelia aurita* in all containers less than 6 m^3 in volume. Therefore, the gut content method is clearly preferable for this study.

The diameter of an additional 20 specimens of each species will be measured live and then remeasured after preservation (1, 3, and 6 months storage) to determine correction factors for shrinkage due to preservation, in order to convert sizes of preserved gut content specimens to sizes of specimens collected in the trawls.

Gut passage times. Individual medusae will be collected in dip nets and transported in buckets of water to a shore-based laboratory (School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, located in Juneau, AK). They will be maintained at water temperatures found in PWS in $\geq$ 20 liter containers of seawater with *Artemia* nauplii. The medusae will be allowed to clear their guts of natural prey (8-12 h), then they will be allowed to feed briefly on copepods. The medusae then will be transferred immediately, and at 1 h intervals, to clean containers of filtered seawater with *Artemia*, which promotes natural gut emptying as digestion of the test prey proceeds. After each medusa transfer, the water will be poured through a 60 µm screen and the crustacean exoskeletons counted and measured using a dissecting microscope, thus recording all copepods egested each hour (as done for *Chrysaora* in PURCELL, 1992). Alternatively, for soft-bodied prey, such as larvaceans or fish larvae, the disappearance of prey will be monitored visually for individual specimens (as done for *Aequorea* in PURCELL, 1989). If prey cannot be seen in the guts, individual medusae will be preserved at 1 hr intervals and their gut contents analysed for partly digested prey (as done for *Muggiaea atlantica* in PURCELL, 1982). The time between ingestion and egestion of the prey remains (or inability to recognize prey items in the gut contents) will be used in calculations of feeding rates.

Accurate determination of gut passage times is laborious because the times may depend on prey size or type, temperature ($p = 0.001$), and numbers of prey in the gut ($p = 0.08$)(PURCELL, 1992). Medusa size did not significantly affect gut clearance times (PURCELL, 1992; PURCELL et al., 1994). 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; PURCELL, 1982, 1992; PURCELL AND NEMAZIE, 1992). Gut passage times for fish larvae are dependent on larval size, with small larvae (e.g. bay anchovy < 4 mm) being digested in 1 h at 26°C and large larvae (e.g. herring 8 to 15 mm) being digested in 2 to 6 h at 8°C (PURCELL, 1981, 1989; PURCELL *et al.*, 1994). Gut passage times will be measured over the range of temperatures appropriate for each species (between 5 and 15°C), for the key prey types, and for different numbers of ingested prey, and analyzed in a multiple regression for each species, which then can be used to calculate digestion rates from field data (as in PURCELL, 1992).

Calculations of feeding rates and impacts. Data on the numbers of prey in the guts will be divided by gut passage 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.*, 1994). 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.

C. Cooperating Agencies, Contracts, and Other Agency Assistance

SCHEDULE

A. Measurable Project Tasks for FY 99 (October 1, 1998 - September 30, 1999)

Oct. 1 - June 30:	Analyze field samples from summer 1998, data analysis, manuscript preparation
March 23-27	Attend Annual Restoration Workshop
April 15:	Submit annual report (FY 98 findings)
July - August:	Field sampling
July 1 - August 31:	Gut clearance rate experiments
September:	Begin analysis of 1999 field samples

B. Project Milestones and Endpoints

1998. Complete analysis of 1997 field samples and data. Qualitatively evaluate effects of each key predator species on each key prey species in order to plan future work. Compile historical data from the Alaskan Peninsula, and begin compilation of earlier SEA and APEX jellyfish population data. Prepare jellyfish data for contribution to modeling efforts. Intensive gut clearance rate experiments. Collect field data in PWS during July-August process cruise. Begin analysis of 1998 field samples and data.

1999. Complete analysis of 1998 field samples and data. Collect field data in PWS during July-August process cruise. Intensive gut clearance rate experiments. Begin preliminary 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. Collect and begin analysis of 1999 field samples and data. Preparation of manuscripts.

2000. Complete analysis of 1999 field samples and data. Continue calculations of feeding rates and impacts. Complete compilation of EVOS jellyfish population data and continue multi-year data analyses. 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 ongoing nature of the gut passage experiments and because 1999 will include 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 will cover the distributions and abundances of jellyfish historically along the Alaska Peninsula, and the second will cover aggregations of the jellyfish *Aurelia* and the association of juvenile pollock.

Manuscripts in early preparation (tentative authorship order and and titles):

PURCELL J.E., BROWN E., STOKESBURY K., HALDORSON L.,-- Aggregations of the jellyfish *Aurelia aurita* in Prince Willian Sound, Alaska: prevalence, characteristics, and associations of juvenile fishes.

PURCELL J.E., ANDERSON P.J., -- Trends in scyphomedusae abundance in the Gulf of Alaska 1972 - 1996: peak abundance in 1980 during faunal transition.

A separate manuscript will cover jellyfish distributions and abundances in PWS using data from SEA and APEX (with Coyle, Cooney, Stokesbury, Norcross, Haldorson, Shirley, Sturdevant). Future manuscripts are anticipated featuring the predation effects of key predator species, and an overview manuscript on the 3-year predation effects on the main prey species. A separate manuscript on dietary overlap among jellyfish and forage fishes, and the potential for competition for zooplankton prey is anticipated. Because I will rely on APEX investigators for zooplankton, ichthyoplankton and fish gut content data, and on APEX and SEA investigators for some population data on jellyfish, the analyses and manuscript preparations will be highly collaborative efforts and the manuscripts multi-authored. The required reports will be prepared in each year.

PROFESSIONAL CONFERENCES

I will present results from this research at one meeting in 1999, The American Society of Limnology and Oceanography, or another meeting if more appropriate. I will also present results at te 10th Anniversary Symposium of the Exxon Valdez Oil Spill in March 1999.

COORDINATION AND INTEGRATION OF RESTORATION EFFORT

This project will coordinate with the APEX project sampling. As planned, my project will be able to utilize their ship time and their zooplankton, ichthyoplankton, 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 hope to be able 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 have been sent to me from Anderson, Brown, Coyle, Cooney, Haldorson, and Sturdevant, and are currently being analysed. I believe a great deal can be learned through these multiple collaborations. The major equipment items will be provided by the APEX project.

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, and Visiting Scientist, 1984-1986.
Assistant Professor, College of Oceanography, Oregon State University, 1984-1986.
Visiting Assistant Professor, Friday Harbor Laboratories, University of Washington, 1986-1987.
Assistant Professor, Horn Point Environmental Laboratory, University of Maryland System, 1987-1992.
Visiting Assistant Professor, The Whitney Laboratory, University of Florida, 1990-1991.
Associate Professor, Horn Point Environmental Laboratory, University of Maryland System, 1992-present.
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 soft-bodied zooplankton as predators and competitors of larval fishes. I have 11 peer-reviewed publications (of 43 total) specifically on that topic, most of which are in the following Literature Cited section. The remaining are listed below. I also have considerable experience in the waters of the northeast Pacific from Oregon to Alaska. I spent all or part of eight years working in those waters, including nearshore and offshore operations. The following citations include 3 on salps from Ocean Station P. My experience with sampling includes the special techniques for gelatinous zooplankton, including dry-suit diving; MOCNESS, Tucker Trawl, plankton net and diaphragm pump sampling for zooplankton and ichthyoplankton; and Otter Trawl and Mid-water Trawl collection of fish.

PURCELL J.E., SIFERD T.D, MARLIAVE J.B., 1987.-- Vulnerability of larval herring (*Clupea harengus pallasi*) to capture by the jellyfish *Aequorea victoria*. *Mar. Biol.*, **94**:157-162.

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MADIN L.P., PURCELL J.P., 1992.-- Feeding, metabolism and growth of *Cyclosalpa bakeri* in the subarctic Pacific. *Limnol. Oceanogr.*, **37**:1236-1251.

MADIN L.P., PURCELL J.P., MILLER C.B., 1997.-- Abundance and grazing effects of *Cyclosalpa bakeri* in the subarctic Pacific. Mar. Ecol. Prog. Ser.157:175-183.

In July 1996, I participated in field sampling with the SEA program. This enabled me to observe the incredible abundances of jellyfish in PWS firsthand, and to see the seining operations and aerial surveys as well as the plankton sampling. In July 1997, samples were collected in PWS on the APEX process study cruise.

My responsibilities will be to participate in the summer APEX cruises in 1998 and 1999. In 1998, I will train APEX personnel in the methods needed so that data can be collected in the future. I will oversee all aspects of this research, closely supervise my assistant, and have primary responsibility for data analysis and preparation of reports and manuscripts.

OTHER KEY PERSONNEL

Ms. Kimberly Black began her training for this project with me in June, 1997. She has been conducting the data base management and the gut content analysis. Her work is totally devoted to this project. In 1998 and 1999, she will be responsible for gut analysis of the jellyfish, for the gut passage experiments, and zooplankton sample analysis. She also will participate in the cruises. Additional responsibilities will include data base management (data sent from SEA and APEX, as well as data from this project) and analyses of the data with my direction.

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