Exxon Valdez Oil Spill
Restoration Project Annual Report

Marbled Murrelet Productivity Relative to Forage Fish Abundance and Chick Diet

Restoration Project 97231
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Study History: This project was originally funded in 1996 as a separate restoration project that was coordinated with the APEX study and is currently part of APEX as 98163R. Therefore, 1997 results are incorporated into the 1997 APEX annual report. Project 97231 follows a study that developed the murrelet productivity index (Project 95031; see also Kuletz and Kendall 1998). Some analyses presented in this report include data from the 1995 project. A pilot murrelet productivity study was presented in Project 94102. Previous murrelet restoration studies, which will be incorporated in the final synthesis for this project, pertained to murrelet nesting habitat; these include Trustee reports 93051B, R15, and various publications.

Abstract:. In Prince William Sound (PWS), Alaska, marbled murrelets (*Brachyramphus marmoratus*) are the most abundant and widely dispersed seabird, but they have shown a decline since the 1970s and no recovery since the 1989 oil spill. As a step toward determining if food availability is restricting murrelet recovery, we tested for spatial and temporal differences in murrelet productivity in PWS relative to fish abundance. We conducted at-sea surveys to determine juvenile murrelet densities in 1995 (4 sites), 1996 (1 site) and 1997 (3 sites). Each murrelet study site had ~50 km of shoreline. Forage fish biomass was measured by hydroacoustic surveys (Project 97163A), from which we selected those nearshore transects that overlapped with the murrelet sites. We found a positive correlation between fish biomass and juvenile murrelet density at sites within years and when all sites and years were combined. At Naked Island, with 3 consecutive years of data, juvenile murrelet density paralleled annual changes in nearshore fish biomass. A pilot study in 1997 also suggested a link between murrelet diet, chronology, and productivity. We identified fish held by adult murrelets for chicks. At Naked Island, chicks received 95% Pacific sand lance and juveniles appeared earlier in the season and were more abundant than at Jackpot, where chicks received 75% Pacific herring. Possibly, low abundance and late arrival of herring at Jackpot resulted in lower murrelet productivity compared to Naked Island, where sand lance appeared to be available all summer.

Key Words: *Ammodytes*, *Brachyramphus*, *Clupiedae*, diet, *Gadidae*, forage fishes, hydroacoustics, marbled murrelet, marine surveys, Prince William Sound, productivity.

Project Data: To be addressed in the final report.

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INTRODUCTION

Recovery of the PWS marbled murrelet population, which was injured in the 1989 oil spill (Piatt et al. 1990, Kuletz 1996), may be inhibited by an apparent shift in the marine ecosystem of southcentral alaska that began in the late 1970s (Piatt and Anderson 1997, Kuletz et al. 1997). Seabird productivity is generally acknowledged to be linked to prey abundance, but it is not known if or how the reproductive success of birds in PWS has been restricted by the abundance of forage fish. In conjunction with the Alaska Predator Ecosystem Experiment (APEX, project 97163), our goal was to examine the relation between marbled murrelet productivity, diet, and forage fish abundance in PWS, Alaska.

Marbled murrelets (*Brachyramphus marmoratus*) are unusual among seabirds in that they nest inland and they are not colonial. In PWS, murrelets are the most abundant and widely dispersed seabird (Agler et al. in press). Because of their distribution at sea and nesting dispersal, we could surmise that murrelets are adapted to forage on widely dispersed prey of low abundance, whereas colonial seabirds require large prey concentrations. Most studies of seabird/prey interactions have focused on colonial seabirds and there is no comparable information on the effects of prey abundance on a non-colonial seabird like the marbled murrelet. A secretive, non-colonial seabird presents numerous challenges to examination of basic diet and reproductive parameters. In PWS, little information existed on murrelet diet, and nothing was known about chick diet. We have sought to develop the means to measure these parameters for murrelets, and to determine the best scale for approaching these questions. Our objectives were to determine if murrelet productivity in PWS differed spatially and with local prey abundance or with species composition.

The three primary questions we address compliment several APEX hypothesis (numbers 7, 8 and 9). First, we examine whether murrelet productivity reflects forage fish abundance. Second, does murrelet diet reflect changes in the relative abundance and distribution of forage fish? Finally, is murrelet productivity determined by spatial differences in prey type? Presented here are preliminary analyses that demonstrate a positive relationship between fish abundance and murrelet productivity. We also found intriguing correlations that require further study, such as concordance between murrelet chick diet, chronology and productivity.

METHODS

Study Area

All study sites were in Prince William Sound (PWS), Alaska, a 10,000 km^2 embayment along the north coast of the Gulf of Alaska. The shoreline of PWS is highly convoluted, creating approximately 4000 km of shoreline habitat and predominately protected waters. In 1997 we had 3 study sites, each approximately 50 km of shoreline, in the northeast, central and southwest portions of PWS (Fig.1). In the northeast the study site (Galena) stretched from Galena Bay to

Boulder Bay, excluding a shallow area in Tatitlik Narrows. The central site (Naked) was Naked Island, excluding the east side from Cadet to Rocky Point. The southwest site (Jackpot) included Ewan Bay to Jackpot Bay and both sides of Dangerous Passage between these bays and Chenega Island.

The boundaries of the 1997 study sites for Galena and Naked were adjusted from those of the 1995 sites to accommodate changes in nearshore coverage by the hydroacoustic surveys (Galena) or time constraints (Naked). At Galena, we surveyed Galena Bay and shorelines south of Galena, whereas in 1995 we had surveyed Galena Bay and north along Valdez Arm. Here, we treat 1995 and 1997 boundaries for the northern area as the same site, because habitats are similar and preliminary analyses showed no significant difference in murrelet abundance or distribution. At Naked, the entire island had been surveyed in previous years (1994-1996) and the east side of Naked, which was not surveyed in 1997, had consistently low numbers of murrelets and no juveniles. To avoid bias in among-year comparisons we equalized 1995 and 1996 data by recalculating murrelet densities without the 3 east side transects. At Jackpot, boundaries remained the same both years.

In 1995 the murrelet study included 3 additional study sites. These were Unakwik Bay (Unakwik), northern Knight Island (Knight) and Port Nellie Juan (PNJ) (Fig. 1). Of these, only Knight overlapped with the hydroacoustic surveys. In 1996, no field work was funded for the murrelet project, but the U.S. Fish and Wildlife Service conducted limited surveys at Naked. Thus, comparisons between murrelets and fish biomass were available for 4 sites in 1995, 1 site in 1996, and 3 sites in 1997.

Methods

Murrelet productivity

Because marbled murrelet nests are hard to find, we developed an index of productivity based on at-sea surveys to obtain juvenile densities and the ratio of juveniles-to-adults. Details of this method, and results of the 1995 surveys, are described in Kuletz and Kendall (1998). In brief, because adult murrelets leave breeding areas in August, we counted adults in early June (incubation) and juveniles in July-August (fledging period).

In 1997 we surveyed each of the 3 study sites 3 times during 1-15 June, and 7-10 times during 23 July - 24 August. Each survey took a full day (0700 - 1600 h). We surveyed from 7.5 m vessels traveling 100 m from shoreline. A driver and 2 observers recorded all birds 100 m either side of and ahead of the boat. In 1997 we entered observations into a computer using the program DLOG (Ecological Consulting, Inc.). The program was integrated with a Global Positioning System, so that every observation had a corresponding latitude and longitude. When we encountered potential juvenile murrelets (black-and-white plumage) we paused to identify the age class and record behavior of the bird, marine and shoreline habitat, and water depth (see Murrelet Protocols 1997). We assumed that most juveniles observed at a site originated there or nearby. This assumption will be examined more closely in 1998, but current information suggests that in PWS the assumption is reasonable during July-August (see Kuletz and Marks 1997, Kuletz and Kendall 1998).

Fish abundance and species composition

We examined fish biomass within specific murrelet study sites by extracting only those nearshore hydroacoustic transects within a 10 km radius of the center of each murrelet study site. Although we can not be certain that most adult murrelets on the water at our study sites nested in the vicinity, that was an assumption, and we used the 10 km radius to objectively identify which hydroacoustic transects to include. The 10 km radius was the average straight-line distance traveled between consecutive days for radio tagged murrelets in 1993 and 1994 (Kuletz et al. 1995a). For 1995 we used fish biomass values presented in Haldorson et al. (1996). Ken Coyle (Univ. Of Alaska, Fairbanks) provided the 1996 and 1997 data.

Fish biomass was determined for each transect by K. Coyle as average prey biomass per m^2. Each nearshore hydroacoustic survey block (roughly 10 km in length) consisted of a zig-zag series of approximately 1.2 km-long transects. We calculated biomass for each study site using the mean biomass of all transects in the selected nearshore blocks. In 1995, APEX conducted two surveys, of which we used the earlier July survey that best matched the timing of murrelet chick rearing.

A second index of fish abundance was obtained from aerial surveys of PWS conducted by E. Brown (University of Alaska, Fairbanks). The aerial surveys provided numbers of schools, and in most cases, school size (surface area), and species identification. E. Brown is perfecting a method to identify the species of fish from the air. In 1997 the murrelet crew participated in ground-truthing species identification by filming and sampling fish located by E. Brown. The full use of these data will not be presented here, pending finalization of the data by E. Brown and G. Ford.

Murrelet diet

In 1997 we conducted a pilot study to determine chick diet by observing murrelets holding fish on the water near dawn or dusk. At these times, adults are most likely to capture prey for their chicks and will often hold the single fish on the water for extended periods (Carter and Sealy 1987). Between 25 June and 20 August we conducted 58 diet "cruises" (22 between 0600-0845; 36 between 1730-2200) from a 5 m or 7.5 m vessel by slowly traveling through nearshore waters of our study sites. We identified all fish held by murrelets to the nearest taxon possible using binoculars. We also recorded all murrelets encountered during a diet cruise to obtain a percentage of birds feeding chicks.

We opportunistically observed adult murrelets feeding themselves during our surveys and while in transit between sites. We attempted to capture prey below feeding murrelets using a cast net or dip net or via an underwater camera connected to a boat-based camcorder. Prey samples caught in the same net were labeled with date, location and associated feeding activity, frozen within 6 h and transported to Kathy Turco (University of Alaska, Fairbanks) for identification. The films were sent to Evelyn Brown (University of Alaska, Fairbanks) for analysis and species identification.

Data analysis

Unless otherwise noted, we conducted analyses using juvenile murrelet densities, because that was the most complete data set available on murrelet productivity. The juvenile:adult ratios will be examined in detail in later reports. We regressed the average fish biomass at a site in July (main chick rearing period) with the juvenile density at the site during the core fledging period (average of 5 core surveys, primarily early-mid August). We did this among sites for 1995 and 1997 and for all sites and years combined (including the single 1996 site). We also examined among-year trends in productivity and fish biomass at Naked Island with 3 years data. At this stage, we provide only descriptive comparisons of juvenile murrelet density vs. number of fish schools counted during aerial surveys, and murrelet diet among areas.

To continue our test of the ratio productivity index we regressed average juvenile density at a site during 5 core surveys to both average June adult density at a site (sequential surveys) and the average adult density in July-August (concurrent surveys). We did this to test the hypothesis and 1995 results (see Kuletz and Kendall 1998) that, due to post-breeding dispersal of adults, June (incubation period) counts of adults should correlate better to July-August counts of juveniles than would concurrent counts of adults. If the relationship remains consistent, we will eventually compare slopes of the regression of the ratio index among sites and years.

RESULTS

During our surveys in 1997 we counted 186 juveniles at sites with hydroacoustic data. We found most juveniles (80%) as solitary individuals, with no evidence of clumping, although we consistently found juveniles at certain transects. We observed juveniles an average of 90 m from shore in average water depth of 66 m. The predominate habitat where we found juveniles was near rocky protected shoreline in bays. These averages mask seasonal and site effects, and detailed analyses of habitat associations for both adults and juveniles will be presented in the final report. Analyses presented below are considered preliminary and final results will be subject to additional statistical analyses.

Murrelet productivity and fish abundance

When all sites and years were combined, the relation between fish biomass and juvenile murrelet density was positive and significant ($r^2 = 0.77$, $N = 8$, $P = 0.006$; Fig. 2). Within years, we still found positive trends between fish biomass and juvenile density, but the relation was not always significant. In 1995, nearshore fish biomass was positively but non-significantly correlated with the density of juvenile murrelets among areas ($r^2 = 0.64$, $N = 4$, $P = 0.2$). In 1997, the biomass of fish schools was positively and significantly related to juvenile murrelet density among sites, but the low number of sites made the results less conclusive ($r^2 = 0.99$, $N = 3$, $P =$

0.003). Only 1 site, Naked, was surveyed in 1996.

At Naked Island, in 1995, 1996, and 1997, juvenile murrelet density paralleled changes in fish biomass (Fig. 3). Fish biomass declined between 1995 and 1996 around Naked and climbed to its 3-year high in 1997. Similarly, the average density of juvenile murrelets in 1996 declined from 1995 to 1996 and rebounded to a 3-year high in 1997.

Juvenile murrelet density at sites (Table 1) also corresponded to the number of fish schools counted from the air in 1997 (Table 2). In 1997 both hydroacoustic and aerial surveys in July indicated that Naked had more fish, relative to Galena and Jackpot. Pacific herring (*Clupea pallasi*) were the most common prey observed within 10 km of Galena and Jackpot, and sand lance (*Ammodytes hexapterous*) was the primary species around Naked (Table 2).

Murrelet abundance and chronology in 1997

We observed higher densities of adult murrelets at all 3 sites in 1997 compared to 1995 (Table 1). The higher numbers of murrelets was particularly apparent during the early June surveys, when numbers are typically lower than in July, but in 1997 were among the highest recorded. Despite the high numbers of adults, juvenile densities were similar or slightly lower in 1997 than in 1995 (Table 1). However, among sites, the relative abundance of murrelets was similar to that of previous years; Naked had the highest productivity indices (both juvenile density and ratio), compared to those of Jackpot and Galena (Table 1).

In 1997, as in 1995, we found a positive relation between June adult densities at a site and average density of juveniles at the site in July-August ($r^2 = 0.59$, $P = 0.007$; Fig. 4) As in 1995, concurrent counts (July-August surveys) of adults and juveniles were not correlated. In 1997 the appearance of juveniles also followed patterns similar to 1995, with juveniles appearing first at Naked and peaking earliest at Naked (Fig.5).

Murrelet diet

In 1997, murrelet chick diets varied considerably among study sites, particularly between Naked and Jackpot. Although the main chick food was herring (48%) and sand lance (43%), birds at Naked primarily used sand lance, birds at Galena used both species (although few fish were identified there), and birds at Jackpot used herring (Fig. 6).

The fish species that we caught in nets and on film, or that were identified during aerial surveys, showed spatial concordance with the fish species taken by adults for themselves and their chicks. Our sample size for fish identified below self-feeding adults was too small to be conclusive, but the samples we took at Naked (4 sand lance schools) and Galena (5 herring and 2 sand lance schools) corresponded to the same fish species fed to chicks in those areas (see Fig. 6). Similarly, aerial surveys identified sand lance as the primary fish available around Naked, whereas herring predominated at Galena, and a few schools of herring were observed at Jackpot (Table 2). However, fish that adults were feeding on appeared to be small compared to those destined for chicks. Adults often foraged on fish estimated as age class 0, but they fed their chicks almost exclusively larger fish estimated as 1+ age class.

We found the highest proportion of birds holding fish during our evening cruises. The mean number of murrelets holding fish was 3.6 (SE = 0.77, N = 36 cruises) per cruise in the evening compared to 0.27 (SE = 0.15, N = 22 cruises) observed during morning cruises. The proportion of birds holding fish showed a similar pattern, with an average of 6.2% (SE = 1.8, range 0 - 40%) birds holding fish in the evening compared to 0.2% (SE = 0.1, range 0 - 2%) holding fish in the morning. The number of birds holding fish per hour of observation was highest at Naked between 25 June and 21 July, whereas Jackpot showed a steep increase in late July and peak numbers during 29 July- 4 August (Fig. 7). The highest single count of birds holding fish, however, occurred at Jackpot on 20 August (21 birds with fish). These results will aid the study design and protocol for 1998 field work on murrelet diet.

DISCUSSION

We found strong evidence of a relation between nearshore forage fish abundance and juvenile murrelet densities, both spatially and temporally. We can not conclude that the relationship is a causal one yet, as both fish biomass and murrelet abundance could be responding to another or combination of environmental variables. The consistency among sites and years, however, suggests that a causal relation is likely. Although a relation between prey abundance and seabird productivity has been demonstrated for other species (Furness and Nettleship 1991), and makes sense intuitively, this is the first demonstration of such an effect on a non-colonial seabird. An estimated 30-60 % of marbled murrelets are solitary foragers, (Carter 1984, Kuletz, unpubl. data) and murrelet nests are widely dispersed in PWS (Kuletz et al. 1995b), yet these birds appear to remain, at some level, subject to the same restraints as group nesters and foragers. Indeed, the influence of prey abundance on murrelet productivity may be more evident (in terms of juvenile recruitment) than for other seabirds because confounding factors such as nest predation or weather-related loss would be dissipated. Our results also suggest that the biomass necessary for a given murrelet recruitment level can be modeled, although the model would likely need to include available inland nesting habitat as well.

Aerial counts of fish schools also showed concordance with juvenile density at sites, and provided comparisons of relative abundance between June and July. The influx of herring at Galena in late July may have been too late to increase juvenile recruitment at that site, but densities of adult murrelets remained high and exceeded the other 2 sites. The fish we caught below feeding flocks in the area at that time were considerably smaller than the fish fed to chicks. Self-feeding adult murrelets used the same prey species, but smaller sizes, than when provisioning chicks. Carter (1984) had similar results with murrelets in British columbia, and speculated that birds were using different foraging strategies, such as foraging more solitarily on smaller patches of large fish near twilight hours. Rhinoceros auklets (*Cerorhinca monocerata*) display a similar shift in foraging technique when provisioning chicks (Davoren and Burger, in review) and a variety of studies indicate that different prey and foraging patterns are used by provisioning birds (review in Ydenberg 1994). Thus, both the timing and sizes of fish available are important, and any model of murrelet recruitment should incorporate the dual needs of adults foraging for themselves and those foraging for chicks.

Diet may also influence murrelet nesting chronology. Both fish-holding and the appearance of juveniles indicated that murrelets at Naked initiated nests and fledged chicks 1-2 weeks earlier than murrelets at Jackpot or Galena. Fledging began and peaked earliest at Naked, where sand lance appeared to be available throughout the breeding season. At Jackpot, where herring use predominated, most of the juveniles did not appear until mid-late August. The timing of fish availability may have been more important than differences in prey quality. Sand lance is a nutritionally valuable fish among those used by seabirds in PWS, but herring are also high, although more variable, in lipid content (Anthony and Roby 1997). Another factor affecting prey value may be the relative predictability of occurrence among species (Ydenberg 1994). Sand lance, when present, often display predictable patterns of habitat and diel availability (Blackburn 1980), which can be critical during chick rearing. Future studies will need to separate spatial effects on murrelet productivity from those of diet and timing of prey availability.

For the second year we found a positive relation between the June density of adults and July-August density of juveniles at sites, and no such relation during concurrent July-August surveys. This pattern persisted despite unusually high numbers of adult murrelets at these sites in June 1997. The phenomena of high murrelet numbers was not unique to our study sites. High marbled murrelet numbers were observed in Unakwik Inlet, Blackstone Bay, and College Fjord (R. Day, pers. comm.) and in large feeding flocks at the southern borders of PWS (R. Suryan, pers. comm.). The high numbers of adults (which include unknown proportions of non-breeding after-hatch-year birds) did not result in higher numbers of juveniles, suggesting that non-resident or more non-breeding murrelets were present in June 1997. If oceanic events related to El Nino extend to PWS in 1998, we might observe lower juvenile murrelet densities regardless of adult numbers at sea.

The marbled murrelet is the most abundant seabird in PWS, which makes it both an important part of the PWS ecosystem and accessible throughout APEX study areas. Separating the effects of total fish biomass, the nutrient value of different prey, and their temporal availability, will require the integration of multi-year data from related APEX projects. The final objective of the murrelet project will be a synthesis that will model the distribution of adult and juvenile murrelets in Prince William Sound (PWS) relative to terrestrial and marine variables.

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FIGURES

Table 1. Mean (± SE) adult and juvenile murrelet densities (birds/km2) for June (adults only) and July-August surveys for sites with fish biomass data in 1995 and 1997 in Prince William Sound, Alaska.

Site	Mean Adult Density				Mean juvenile density (5 core)	
1995	*n*	June	*n*	July-Aug	*n*	July-Aug
Naked[a]	4	13.09 (3.63)	9	15.80 (2.96)	5	1.45 (0.25)
Jackpot	4	16.58 (1.32)	9	12.50 (2.90)	5	1.02 (0.17)
Galena	3	5.87 (1.53)	7	9.08 (1.49)	5	0.21 (0.08)
1997						
Naked	3	65.91 (15.35)	7	19.17 (5.38)	5	1.51 (0.04)
Jackpot	3	34.11 (2.05)	7	10.10 (2.02)	5	0.68 (0.19)
Galena	3	16.27 (7.19)	7	21.85 (8.12)	5	0.68 (0.08)

a Naked densities were calculated without east side transects to match 1997 coverage.

Table 2. Observations of fish schools within 10 km radius of the marbled murrelet survey areas in 1997. Data taken from aerial surveys of fish schools conducted by E. Brown (University of Alaska, Fairbanks) in June and July, 1997.

Area	Number of schools - June (10 km radius)	Number of schools- July (10 km radius)	Total surface area (m^2) of fish schools (sand lance)	Total surface area (m^2) of fish schools (herring)
Galena	23	52	1340	1299
Jackpot	3	5	158	554
Naked	61	40	3065	300

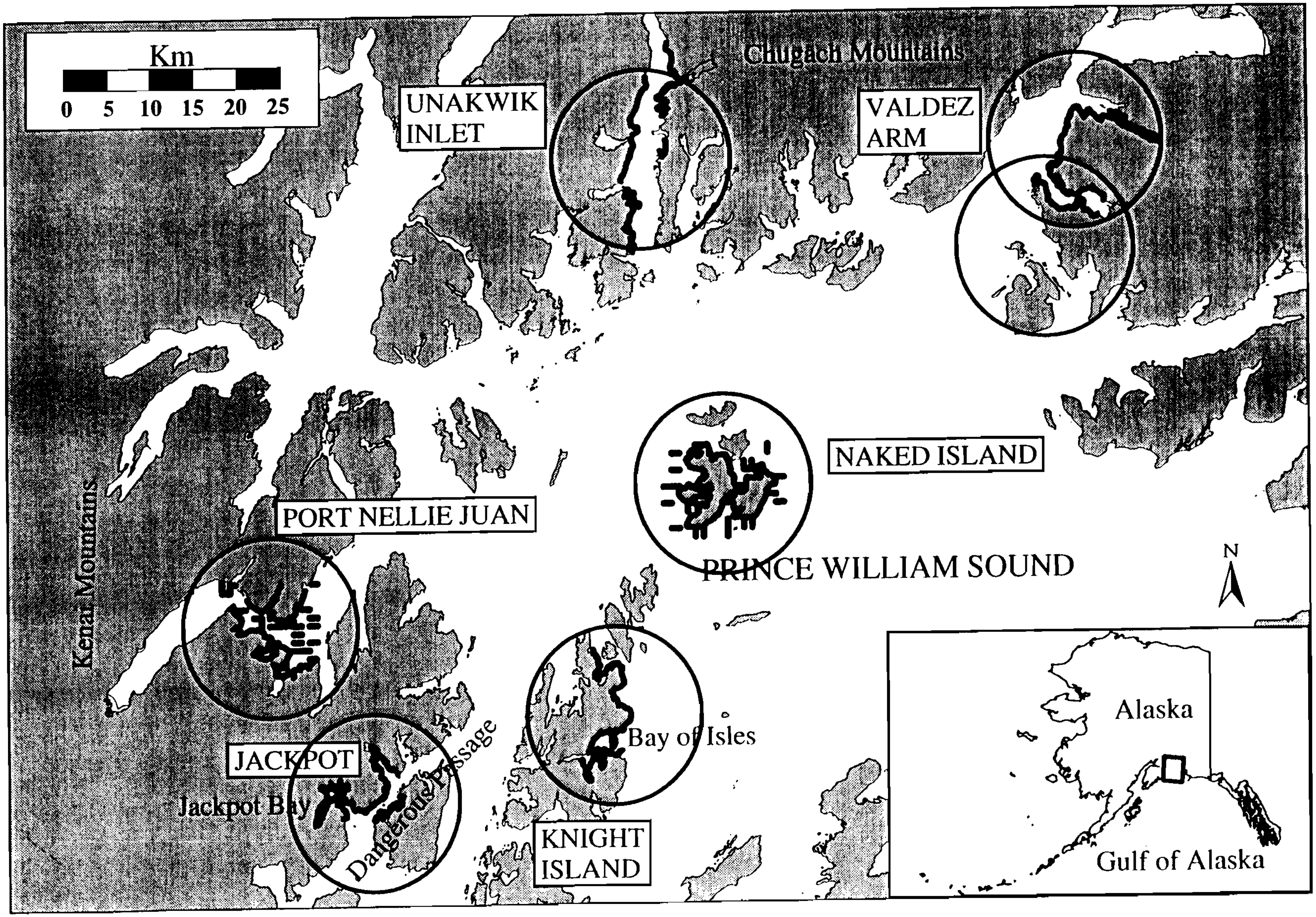

Km
0 5 10 15 20 25
Chugach Mountains
UNAKWIK INLET
VALDEZ ARM
NAKED ISLAND
PORT NELLIE JUAN
PRINCE WILLIAM SOUND
N
Kenai Mountains
Bay of Isles
JACKPOT
Jackpot Bay
Dangerous Passage
KNIGHT ISLAND
Alaska
Gulf of Alaska

Figure 1

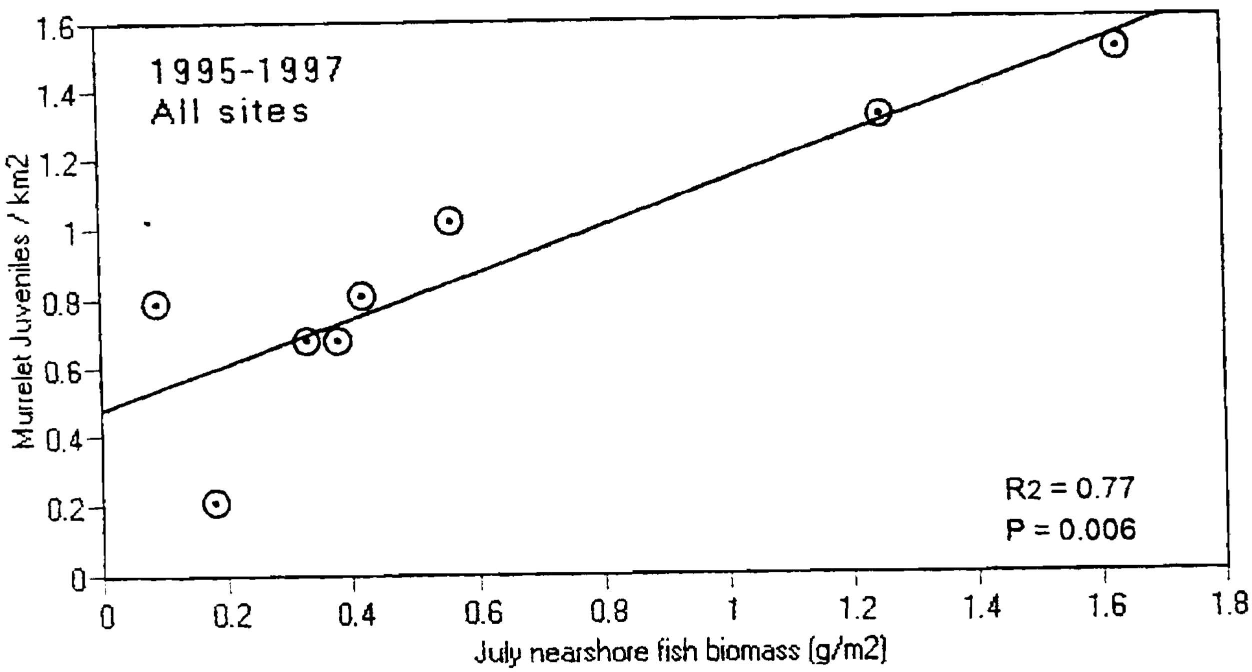
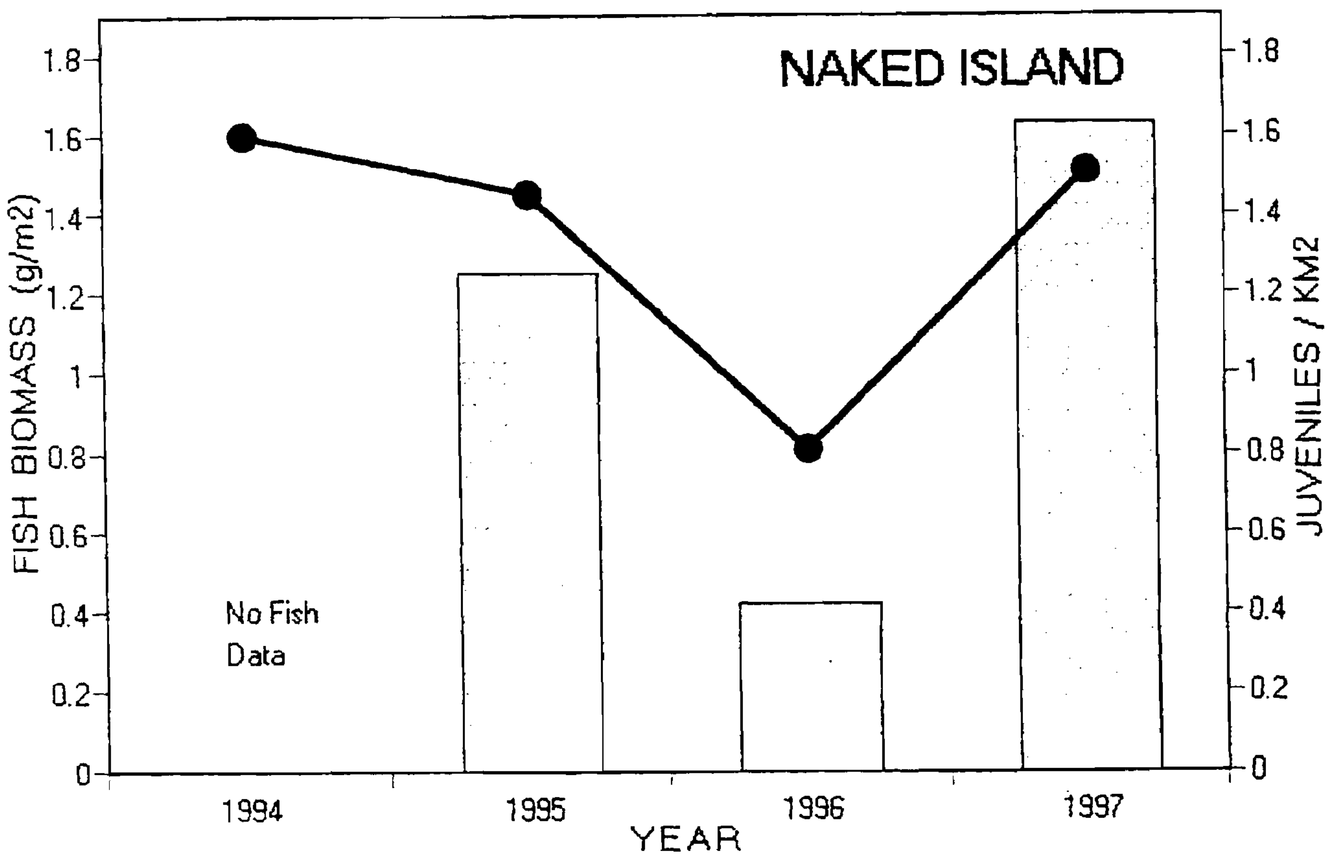

1995-1997
All sites
Murrelet Juveniles / km2
July nearshore fish biomass (g/m2)
R2 = 0.77
P = 0.006
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

Figure 2



Annual Murrelet Productivity and Fish Biomass at Naked Island

Figure 3

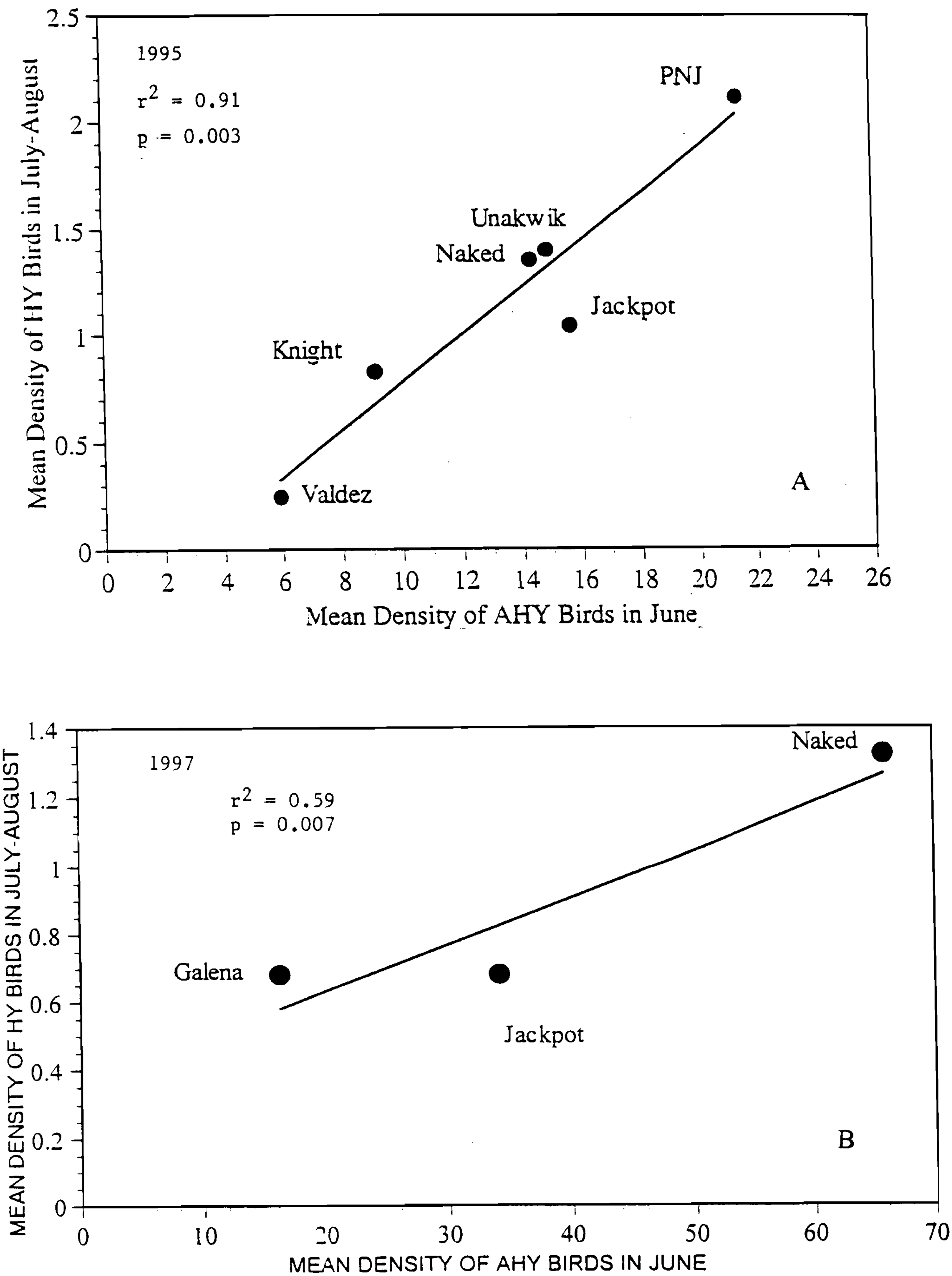
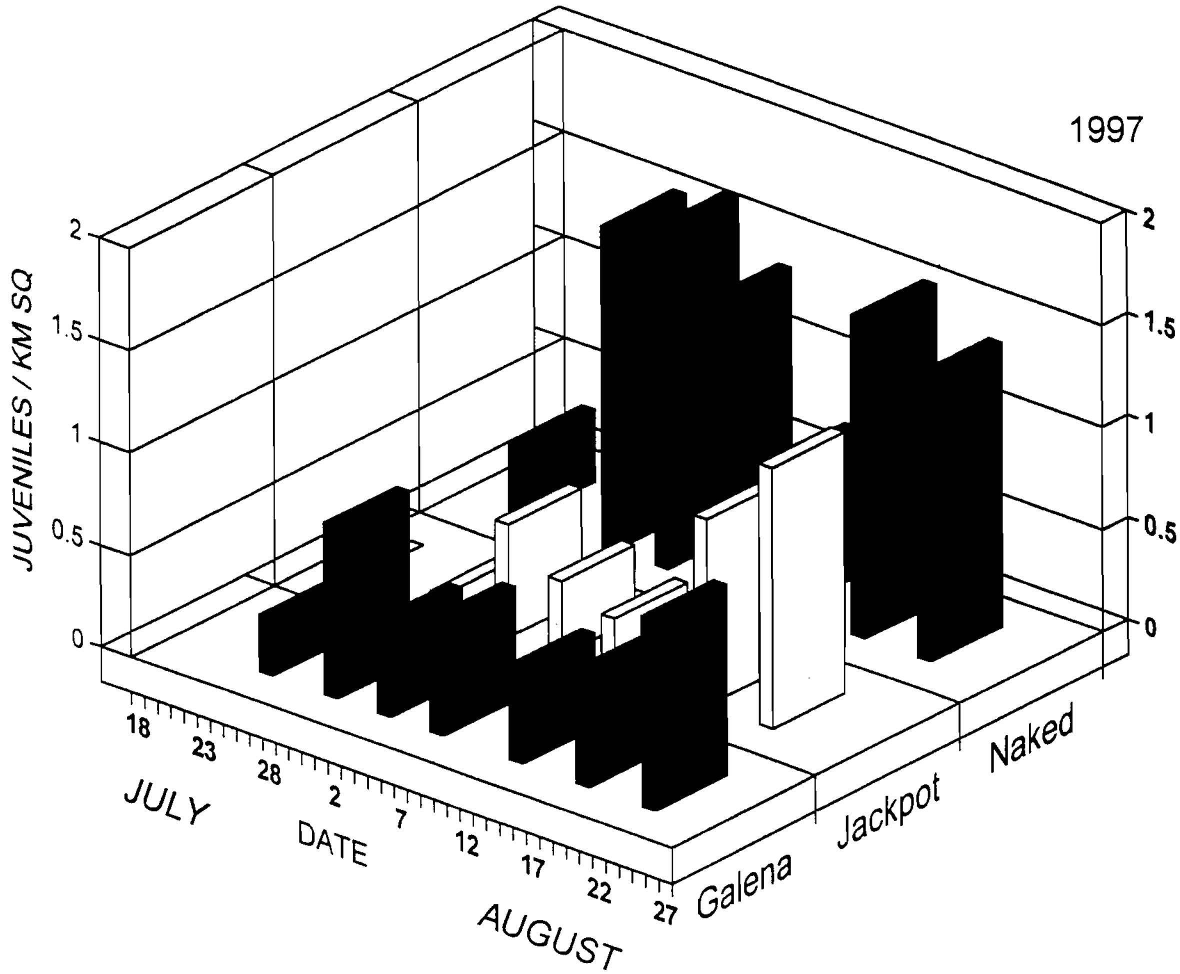

1995
r^2 = 0.91
p = 0.003
PNJ
Unakwik
Naked
Jackpot
Knight
Valdez
A
Mean Density of HY Birds in July-August
Mean Density of AHY Birds in June
1997
r^2 = 0.59
p = 0.007
Naked
Galena
Jackpot
B
MEAN DENSITY OF HY BIRDS IN JULY-AUGUST
MEAN DENSITY OF AHY BIRDS IN JUNE

Figure 4



JUVENILE MURRELET DENSITY

Figure 5

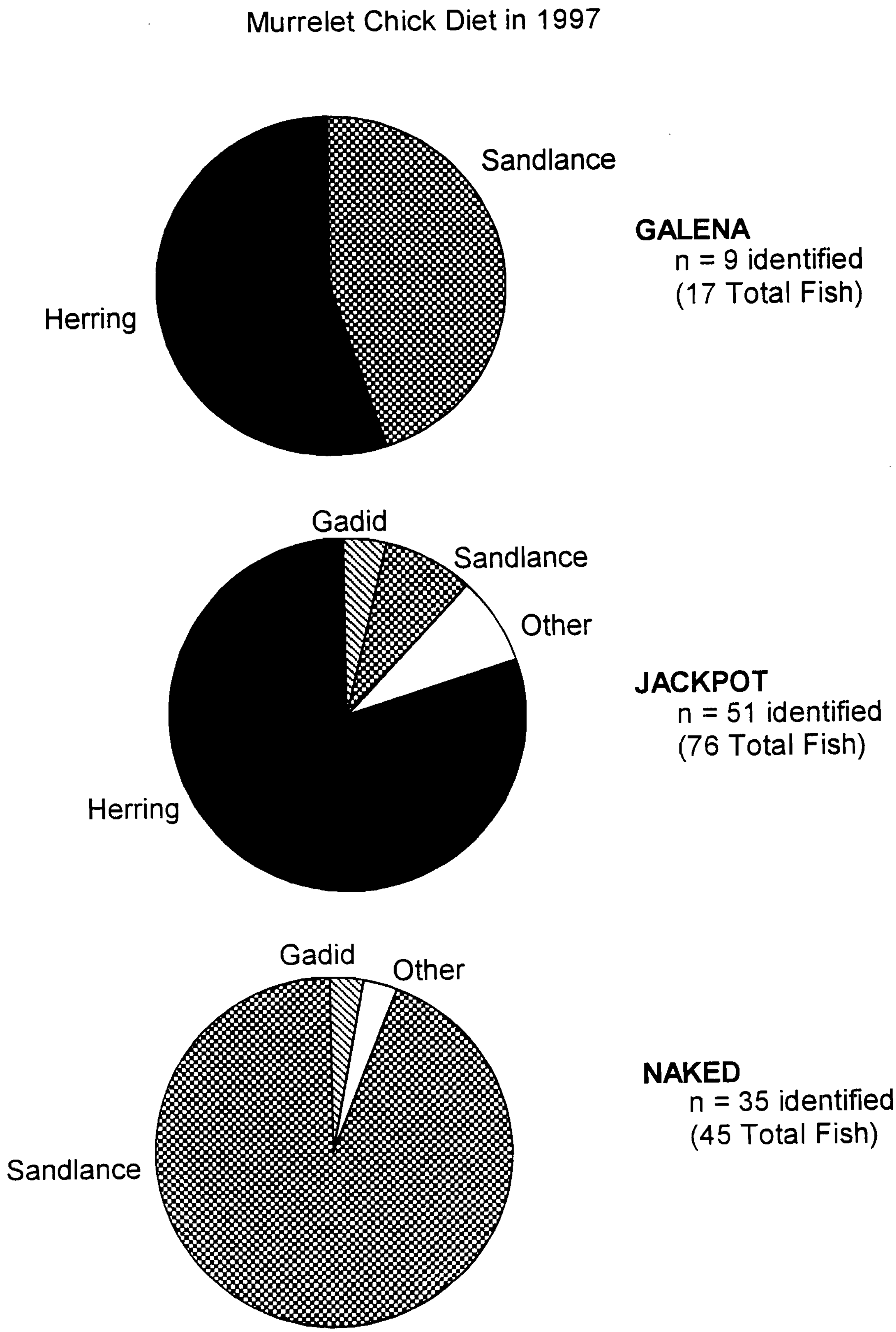

Murrelet Chick Diet in 1997
Sandlance
Herring
GALENA
n = 9 identified
(17 Total Fish)
Gadid
Sandlance
Other
Herring
JACKPOT
n = 51 identified
(76 Total Fish)
Gadid
Other
Sandlance
NAKED
n = 35 identified
(45 Total Fish)

Figure 6

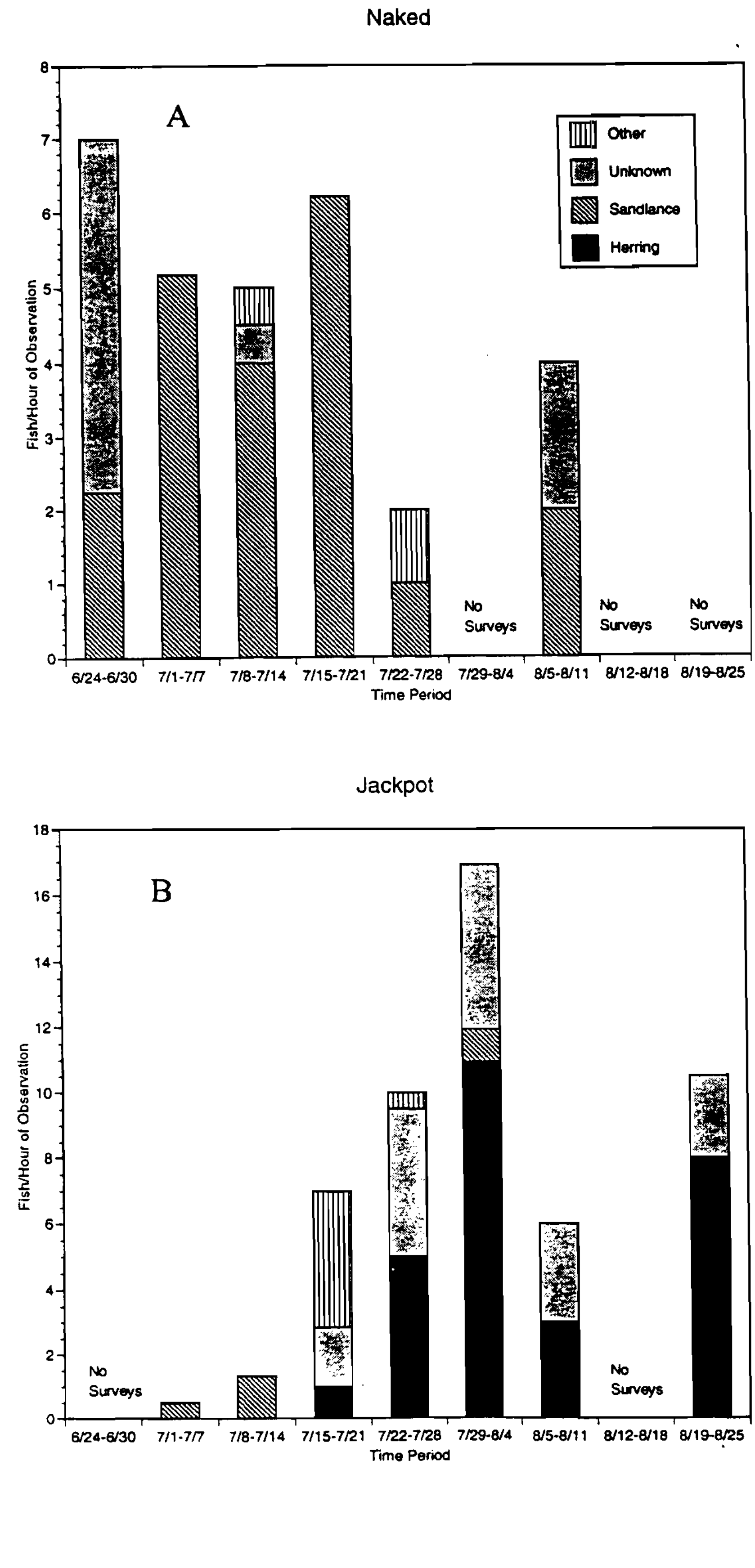

Naked
A
Other
Unknown
Sandlance
Herring
Fish/Hour of Observation
0
1
2
3
4
5
6
7
8
No Surveys
No Surveys
No Surveys
6/24-6/30
7/1-7/7
7/8-7/14
7/15-7/21
7/22-7/28
7/29-8/4
8/5-8/11
8/12-8/18
8/19-8/25
Time Period
Jackpot
B
Fish/Hour of Observation
0
2
4
6
8
10
12
14
16
18
No Surveys
No Surveys
6/24-6/30
7/1-7/7
7/8-7/14
7/15-7/21
7/22-7/28
7/29-8/4
8/5-8/11
8/12-8/18
8/19-8/25
Time Period

Figure 7