Exxon Valdez Oil Spill
Restoration Project Report

Cook Inlet Seabird and Forage Fish Studies

Restoration Project (APEX) 98163M
Annual Report

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Study History: Since the late 1970's, seabirds in the Gulf of Alaska have shown signs of food stress: population declines, decreased productivity, changes in diet, and large-scale die-offs. Small-mesh fishing trawls conducted during the past 30 years reveal that a major shift in fish community composition occurred in the late 1970's: some forage species (e.g., capelin) virtually disappeared, while predatory fish (e.g., pollock) populations increased markedly. Restoration Project 98163M was initiated as part of APEX in 1995 to characterize relationships between seabird population dynamics, foraging behavior, and forage fish densities in lower Cook Inlet-- the area in which most seabirds were killed by the EVOS. CISeaFFS is a collaborative project of the Alaska Biological Science Center and the Alaska Maritime National Wildlife Refuge, with major funding and logistic support from the EVOS Trustees (APEX), the MMS, USGS, USFWS, ADF&G, the University of Alaska, Fairbanks and the University of Washington.

Abstract: Water temperatures through the summers of 1995-1997 were similar and near the long-term average, but temperatures in winter of 1997/98 were about 1-2 C higher than in previous years owing to warming from El Niño. Breeding success in all seabird species was lower in 1998 than in previous years. Murres on Chisik Island had a complete reproductive failure-- the first time we have observed a murre failure at any colony since studies began in 1995. Measures of baseline corticosteroid levels suggest that murres on Chisik were highly stressed even before they attempted to lay eggs in July. A large die-off of murres was observed in Cook Inlet in April and May, foreshadowing the poor breeding season for murres during summer of 1998. Over all years of study, seabird parameters (breeding success, foraging effort, diets, etc.) varied most between islands and least between years. We attribute this regional stability in biological responses to distinct oceanographic regimes around each colony that tend to strongly influence the biology of birds within those areas. Thus, all measured seabird parameters varied some between years, but, for example, murres at Gull Island always fared better than those at Chisik. While each colony responded differently to the ENSO perturbation of 1997/98, responses were commensurate with the underlying physical and biological regime observed in each area. As predicted, the numerical and functional responses of seabirds to food density is non-linear. Based on response curves of breeding success, foraging effort, attendance, etc., to prey density, it appears that food supplies at Gull and Barren islands— but not at Chisik— are presently adequate to support recovery of losses from the Exxon Valdez oil spill.

Key Words: Cook Inlet, murre, kittiwake, guillemot, forage fish, diet, pollock, capelin, sandlance, reproduction, growth rate, hydroacoustic, trawl, seine, *Exxon Valdez*, Kachemak Bay.

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In lieu of a report, we have attached a copy of a manuscript published by the North Pacific Marine Science Organization (PICES) in the "Proceedings of the 1998 Science Board Symposium on the Impacts of the 1997/98 El Nino Event on the North Pacific Ocean and its Marginal Seas" entitled:

Piatt, J.F., G. Drew, T.Van Pelt, A. Abookire, A. Nielsen, M. Shultz, and A. Kitaysky. 1999. Biological effects of the 1997/1998 ENSO event in lower Cook Inlet, Alaska. PICES Scientific Report No. 10:93-100.

This report contains many of the significant findings on seabirds and forage fish in lower Cook Inlet that we observed in summer, 1998. In addition, progress was also made on the following papers.

Manuscripts published or accepted since FY98 annual report:

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

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

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

Kitaysky, A.S., J.C. Wingfield, and J.F. Piatt. 1999. Dynamics of food availability, body condition and physiological stress response in breeding Black-legged kittiwakes. Functional Ecology. *Accepted.*

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

Kitaysky, A.S., J.F. Piatt, J.C. Wingfield, and M. Romano. 1999. The adreno-cortical stress-response of Black-legged Kittiwake chicks in relation to dietary restrictions. Journal of Comparative Physiology (B). *Accepted*

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

Kuletz, K. and J.F. Piatt. 1999. Juvenile Marbled Murrelet nurseries and the productivity index. Wilson Bulletin. *In press.*

Piatt, J.F., N.L. Naslund, and T.I. van Pelt. 1999. Nesting habitat selection and nest-site fidelity in the Kittlitz's Murrelet (*Brachyramphus brevirostris*). Northwestern Naturalist *In Press.*

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

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

Van Pelt, T.I., J.F. Piatt, and G.B. van Vliet. 1999. Vocalizations of the Kittlitz's Murrelet. Condor. *In press.*

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

Cook Inlet related manuscripts in progress in FY99.

Benson, J., R.M. Suryan, and J.F. Piatt. A multivariate approach to assessing growth of seabird nestlings from one-time measurements. Submitted to Condor.

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

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

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

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

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

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

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

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

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

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

Biological Effects of the 1997/98 ENSO in Cook Inlet, Alaska

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SUMMARY

We have been conducting detailed studies of the biology of seabirds in relation to oceanography and forage fish ecology in lower Cook Inlet, Alaska, since 1995. This fortuitously allowed us to document biological effects of the 1997/98 ENSO in this region. Anomalously warm sea surface temperatures (SST's) were observed in the Gulf of Alaska (GOA) beginning in June of 1997, but not in Cook Inlet until September, 1997. Warm temperature anomalies at the surface and at depth persisted until May of 1998, when temperatures returned to average in the GOA and Cook Inlet. Thus, temperature anomalies occurred outside the core window of productivity (June-August) for forage fish and seabirds in both 1997 and 1998. Abundance or production of phytoplankton, zooplankton, fish, and seabirds in lower Cook Inlet varied among years, and overall appeared to be depressed in 1998. We observed a few biological anomalies that might be attributed to ENSO effects: 1) a significant die-off of Common Murres occurred in March-May of 1998, 2) murres and Black-legged Kittiwakes were physiologically stressed during the 1998 breeding season, 3) murres failed to reproduce at one colony in 1998, 4) kittiwake breeding success was lower than usual at colonies in 1998, and 5) phenology of breeding was later in 1998 for both murres and kittiwakes. We presume that seabird die-offs, reduced productivity and delayed phenology were linked to a reduction or delay in food availability, but the mechanism by which anomalously warm water temperatures in winter reduce forage fish availability during the summer breeding season for seabirds is not known.

OCEANOGRAPHY

The 1997/98 ENSO was well developed at the equator by July of 1997. Anomalously warm sea surface temperatures (SST's) developed rapidly during June in the Gulf of Alaska (GOA) and Bering Sea, presumably via atmospheric tele-connection with the tropics. SST anomalies of 2+ C in the GOA persisted throughout summer of 1997 (Fig. 1), diminished to ~1 C in October; and persisted until May/June of 1998. Water temperatures at depth (0-250 m) differed markedly from surface temperatures during summer of 1997. Warming of deeper waters started much later (September) and peaked in February/March of 1998.

In lower Cook Inlet, effects of the 1997/98 ENSO were ameliorated by upwelling and tidal mixing at the entrance to Cook Inlet. Whereas the northern GOA was well-stratified during summer of 1997 and capped by warm surface layers, strong upwelling occurs around the Kodiak Archipelago and at the entrance to Cook Inlet, leading to complete mixing of the water column and reduced surface temperatures in these areas (Fig. 2). Cold, mixed waters are carried north by prevailing currents far into Cook Inlet. Strong tidal mixing limits stratification to protected areas such as Kachemak Bay where river outflows create shallow lenses of warm, low-salinity water at the surface. On the west side of Cook Inlet, currents flow south and waters are weakly stratified, warmer and less saline. Although they differ slightly in absolute temperature, SST's from Kachemak Bay, Chisik (on the west side, Fig. 2) and the Barren Islands (entrance to Cook Inlet) show similar seasonal and annual SST trends.

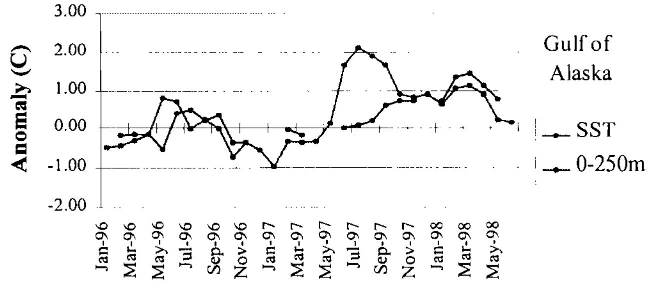


Figure 1. Temperature anomalies at the surface and over the entire water column in the Gulf of Alaska from January 1996 to May 1998.

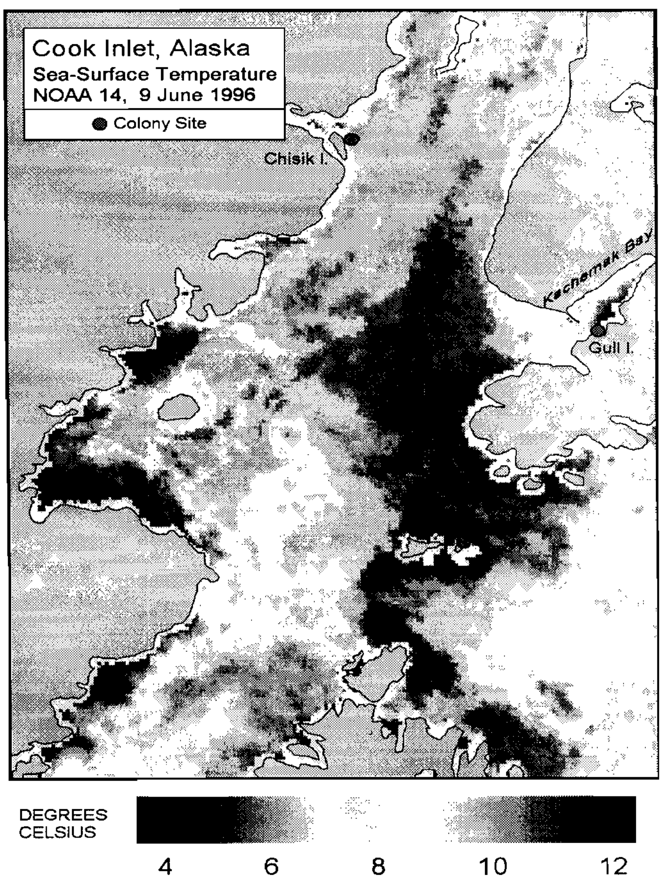


Figure 2. AVHRR image showing sea surface temperatures in Cook Inlet and seabird colonies under investigation.

As a consequence of this oceanographic regime, SST's in Kachemak Bay (Fig. 3) do not reflect SST's in the outer GOA; instead they reflect temperature fluctuations of the entire GOA water column (Fig. 1). SST's in Kachemak Bay and the GOA during 1996 were about average most of the year. The large

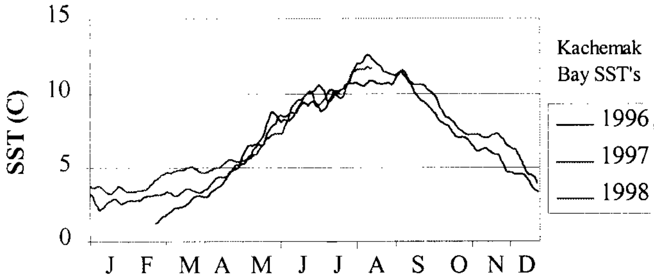


Figure 3. Sea surface temperatures (5 m below low-low tide) in Kachemak Bay, Cook Inlet, Feb. 1996 to Aug. 1998. Mean daily temperatures smoothed with 7-day running average.

SST anomaly observed in the GOA during June-August of 1997 (Fig. 1) was not observed in Kachemak Bay (Fig. 3) or at Chisik and Barren islands. SST's in Kachemak Bay began to increase in August 1997 and were 1-2 C higher than average throughout fall and winter; returning to average in May of 1998. As for GOA temperatures at 0-250 m depth, SST's in Kachemak diverged most from average values during February and March of 1998 (Fig. 3).

BIOLOGICAL EFFECTS

Plankton: We began monitoring phytoplankton and zooplankton abundance in 1997. Phytoplankton concentrations were measured using a CTD with attached fluorometer. Zooplankton were collected seasonally at a single station in Kachemak Bay, and we measured settled volumes to estimate abundance (Fig. 4). Primary and secondary production in Kachemak Bay varied among and between seasons, but with only two years of data we can only conclude that there was no indication of any dramatic ENSO effects (e.g., total production failure) in either year. However, maximum zooplankton volumes in 1998 were about a third of those observed in 1997.

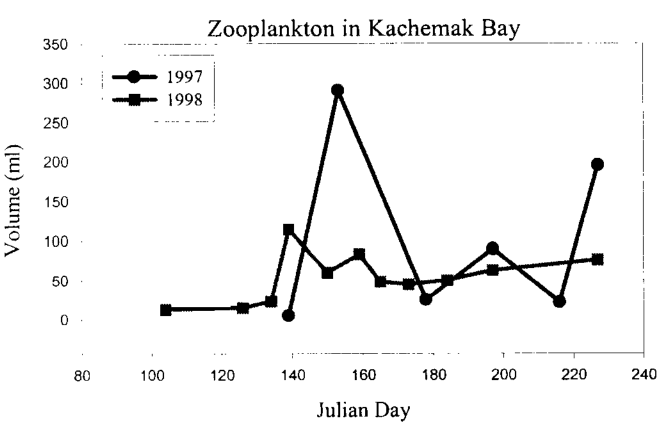


Figure 4. Seasonal variation in zooplankton volume in Kachemak Bay during 1997 and 1998. Zooplankton were collected using a 1-m ring net with 505 micron mesh.

Fish: Fish were sampled in both Kachemak Bay and around Chisik Island using a modified herring mid-water trawl (July) and beach seines (June-Aug.), and in Kachemak Bay using a small bottom trawl (Aug.). The same gear and methods were used in all years of study. We targeted small forage fishes consumed by seabirds. More than 300,000 fish comprising over 60 species have been caught on these surveys. Dominant taxa include juvenile pollock, sand lance, osmerids, and herring. In general, fish catches are much higher in Kachemak Bay (Fig. 5a) than around Chisik Island (Fig. 5b) owing to regional differences in productivity. Catches of forage fish increased in Kachemak Bay, but decreased around Chisik Island, between 1997 and 1998. Catches in both areas in 1997/98 were higher or similar to those observed in 1996. However, trawl catches are highly variable and biased because we conduct trawls only where hydroacoustic signals indicate the presence of fish. Analyses of hydroacoustic data (in prep.) suggest that biomass of fish was reduced in most areas of Cook Inlet in 1998. Beach seines suggest that fish were delayed in arriving nearshore in 1998.

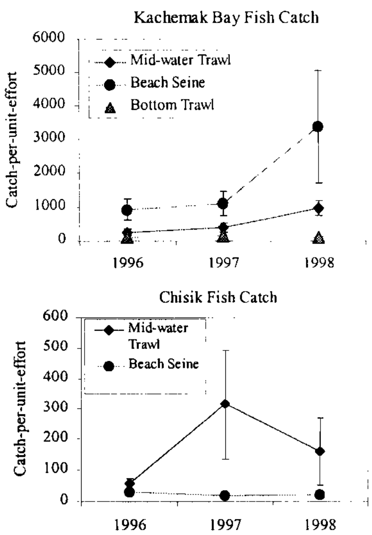


Figure 5. Catches of fish in mid-water trawls, beach seines and bottom trawls: a) in Kachemak Bay , and, b) around Chisik Island, 1996-1998.

Seabird Productivity: Here we consider two species (Common Murres and Black-legged Kittiwakes) from colonies at Chisik Island and Gull Island. Murres maintained relatively high productivity among all years of study at Gull Island in Kachemak Bay (Fig. 6). Diets were similar among years, and analyses of time budgets (foraging trip duration, "loafing time") suggest that murres had no difficulty finding food in 1997 or 1998. At Chisik Island, however, murres experienced a complete breeding failure in 1998 (Fig. 6). They started breeding later than usual (Fig. 7), displayed erratic attendance, and had significantly higher levels of stress hormones in their blood plasma in 1998

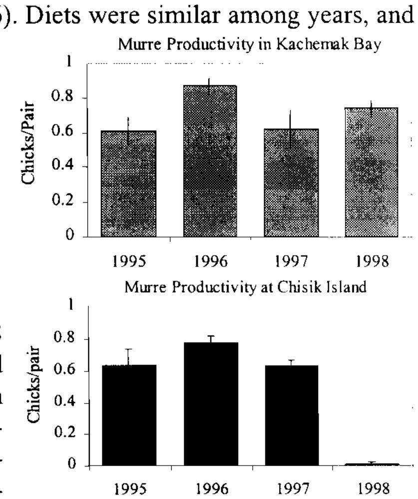


Figure 6. Breeding success of Common Murres in 1995-1998.

than in 1997 (Fig. 8). Complete breeding failure is rare in murres because they can compensate for wide fluctuations in food supply by adjusting their time budgets-- which is why they usually manage to produce chicks at Chisik despite poor food supplies. We therefore view the delayed phenology and subsequent breeding failure of murres at Chisik in 1998 as particularly significant.

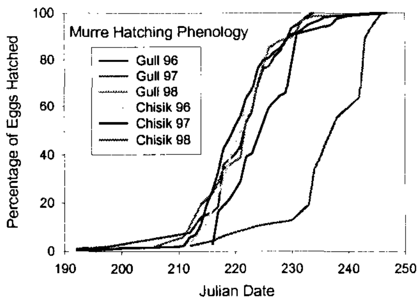
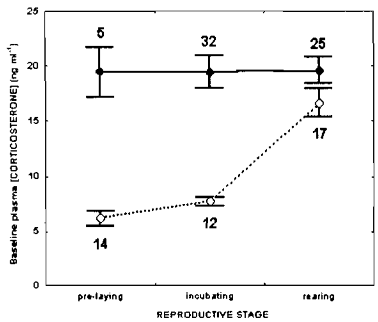
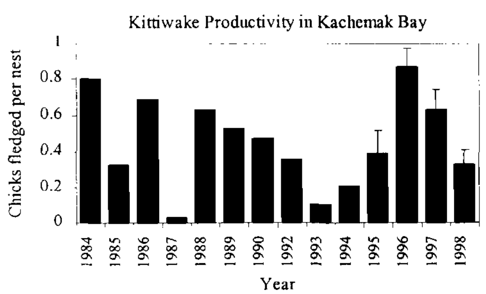


Figure 7. Phenology of egg hatching in murres at Gull and Chisik islands, 1996--1998.

Figure 8. Stress hormone levels in murres at Chisik during a 'normal' year (1997, open circles) with seasonal increase in food stress, and ENSO year (1998, closed circles) with high stress load at beginning of the breeding season.



In contrast, kittiwake breeding success is typically more variable and sensitive to fluctuations in food supply. In Kachemak Bay, kittiwake breeding success was much reduced in 1998 compared to 1996/1997-- but fell within range of variability observed in previous years of study (Fig. 9a). However, notable low production events in the past also correspond to years with moderate ENSO warming of winter water temperatures in Alaska (1987, 1993, 1994). Low production in 1998 was largely due to low laying and hatching success, which was about 3 weeks later than usual (Fig. 10). Once hatched, chick survival was high. At Chisik Island, kittiwakes have always done poorly in recent years (Fig. 9b).



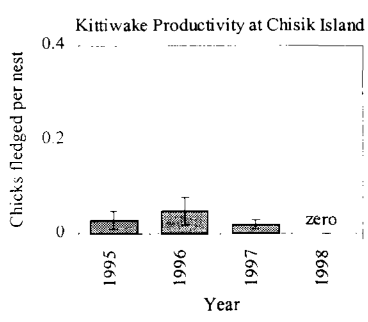


Figure 9. Breeding success of Black-legged Kittiwakes at a) Gull Island, Kachemak Bay (upper) and b) Chisik Island (lower).

Evidence suggests this is because of generally poor food supplies around Chisik and because, in contrast to murres, kittiwakes cannot adjust their time budgets to deal with fluctuations in food supply, nor can they range as far to find food. The 1998 breeding season at Chisik was notable because birds failed much earlier than usual (during incubation), phenology of egg-laying was about 2-3 weeks later than usual, and adults produced absolutely zero chicks.

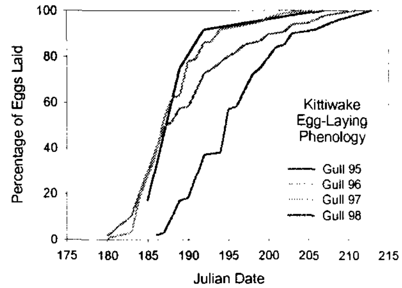


Figure 10. Phenology of kittiwake egg-laying on Gull Is., 1995-1998.

Seabird Die-offs:

A large and extensive seabird die-off was observed in Alaska during summer 1997; largely confined to the southern Bering Sea and Aleutians. Surface-feeding species such as shearwaters (and much lesser numbers of kittiwakes) died *en masse* from apparent starvation. Some hundreds of thousands of birds were probably affected, and peak mortality occurred in August when SST anomalies were highest. Smaller die-offs of murres were also reported from the northern Bering Sea, mostly in May and June. Although SST anomalies were also high in the GOA during the summer of 1997, no die-offs were reported there. In 1998, however, a moderate die-off of Common Murres was observed in the northern GOA. Dead murres were reported over a wide area (Fig. 11) from about March through May, with peak mortality occurring in mid-April. This followed a long period of anomalously warm water temperatures in the GOA (Fig. 1). Most murres were apparently subadult (non-breeders) and died of starvation. A preliminary tally indicates that at least 1300 dead murres were observed on beaches in the GOA. Previous studies indicate this would be a small fraction of the total mortality, which probably numbered in the tens of thousands. The most recent large seabird die-off observed in the GOA occurred during late winter of 1993 following a prolonged period of anomalously warm SST's associated with the 1992/93 ENSO. In that die-off, about 120,000 murres died from starvation in the northern GOA.

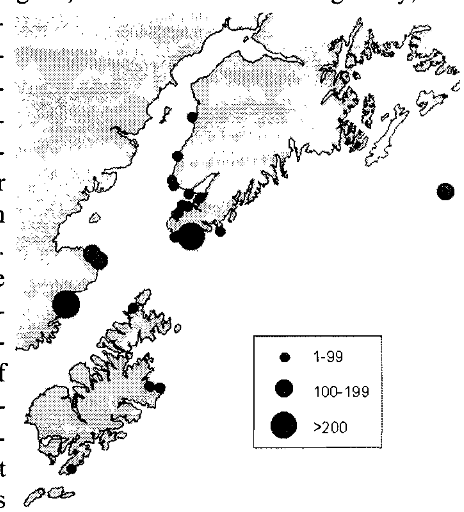


Figure 11. Distribution of dead murres recovered from beaches in the northern Gulf of Alaska during March-May, 1998.