



Can Murres Recover from Effects of the Exxon Valdez Oil Spill?

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BACKGROUND

Immediate impacts of the Exxon Valdez oil spill (EVOS) on seabirds in 1989 were well-documented. Common Murres comprised most (74%) of oiled bird carcasses recovered from beaches (>30,000), and putative short-term effects included a reduction in populations at affected colonies, delayed breeding phenology and low reproductive success (Piatt et al. 1990). The greatest impact was in the Gulf of Alaska and Cook Inlet, where large numbers of murres were beginning to gather near breed-

ing colonies such as the Barren Islands when oil swept through the region in April and May. Models of murre population dynamics (Ford, Wiens et al. 1982) suggested that it could take 20-70 years for murre populations to recover to a stable age distribution if environmental conditions were favorable (Piatt et al. 1990).

However, evidence accumulated in the 1990's that a "regime shift" had occurred in the Gulf of Alaska (GOA) in the early 1980's, resulting in marked changes in seabird diets and a lowering of reproductive success in some marine bird and mammal populations (Piatt and Anderson 1996, Francis et al. 1998). Further, this regime shift appeared to affect murres in similar ways to hypothesized effects of the spill. This information raised several questions: To what degree were seabirds affected by natural changes in the GOA environment before the spill? Could effects of the spill be separated from natural variability? In light of the regime shift, how long would it take murres and other seabirds to recover from effects of the spill?

To address these questions, the EVOS Trustee Council (EVOSTC) initiated the Apex Predator Ecosystem Experiment (APEX) in 1995 to assess whether current conditions favor a recovery of seabirds from the spill. Investigations included studies on oceanography, forage fish biology, distribution and abundance (requiring hydroacoustic surveys, and sampling with trawls and seines); and at colonies, studies of seabird foraging behavior, diets, time-budgets, chick growth rates, physiological stress and reproductive success. In conjunction with these

Figure 1. Sea surface temperatures in lower Cook Inlet. Upwelling at the east entrance to Cook Inlet results in plume of cold water carried north to Kachemak Bay by currents.

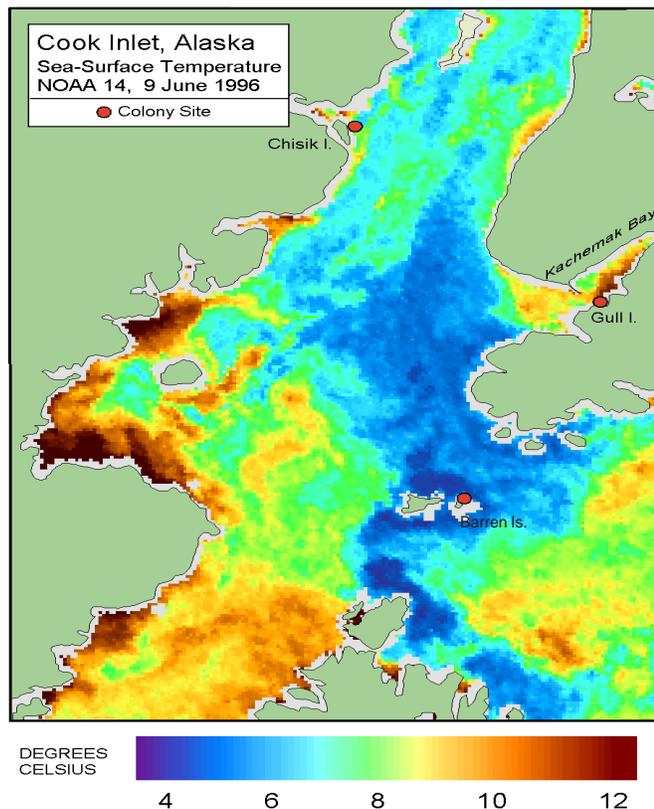
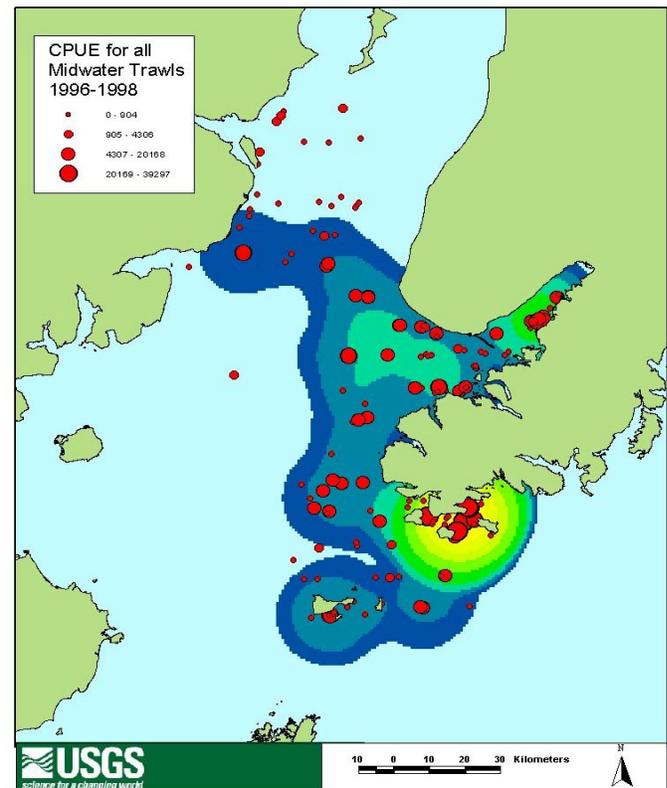


Figure 2. Catch-per-unit effort of forage fish in mid-water trawls, 1996-1998.



field studies, a retrospective analysis of small-mesh trawl catches in the Gulf of Alaska was undertaken to determine whether large-scale changes in forage fish abundance had occurred during the past few decades.

SUMMARY OF FINDINGS

Oceanography and Biological Productivity

At intermediate spatial scales of 10's to 100's of km, the distribution of seabirds at colonies and at sea in Cook Inlet reflects regional patterns of productivity and forage fish abundance. More seabirds breed on the Barren Islands at the entrance to Cook Inlet than do throughout the entire NE Gulf of Alaska, including PWS. Upwelling of cold, nutrient-rich GOA waters at the entrance to the shallow Cook Inlet estuary (Fig. 1) supports a high biomass of forage fish species such as juvenile pollock, sand lance, and capelin (Robards et al. 1999); which in turn are exploited by large numbers of murre, kittiwake, puffin and other species. A persistent feature is the plume of mixed GOA water that flows north from the entrance (Fig. 1), enhancing forage fish and seabird production on the shallow east side of lower Cook Inlet from the Barren Islands north to Kachemak Bay (Fig. 2). Waters on the west side of lower Cook Inlet are oceanographically distinct (warmer, less saline, outflowing), and much less productive for forage fish and seabirds. Patterns of seabird productivity and population change reflect forage fish dynamics at the above spatial scales, and over temporal scales of years to decades.

Seabird Biology

The breeding biology of seabirds differs markedly among colonies owing to differences in food supply, but within each colony, breeding and behavioral parameters were similar in 1995-1997. Breeding success in all species was lower in 1998 than in previous years, apparently owing to effects of the 1997/98 El Niño

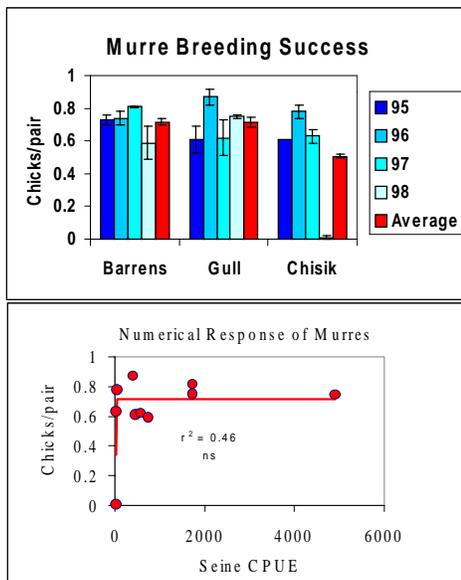


Figure 3. Murre breeding success at all colonies in 1995-1998 (above); breeding success versus prey abundance (below).

(Piatt et al. 1999). Murres on Chisik Island (on the 'low productivity' west side of Cook Inlet) had a complete reproductive failure—the first time we have observed a murre failure at any colony since studies began in 1995. Murres at Gull Island in Kachemak Bay and at the Barren Islands (both on the 'high produc-

tivity' east side of Cook Inlet) had average breeding success (Fig. 3). Breeding success of kittiwakes at Gull Island was lower in 1998 than in previous years, and kittiwakes failed at both Chisik and the Barrens (Fig. 4). Despite the anomalous signal in 1998 owing to El Niño, the results show that seabird parameters (breeding success, foraging effort, diets, etc.) vary more between islands than between years. We attribute this local stability in biological responses to distinct environments around each colony that tend to strongly influence the biology of birds within those areas. For example, the duration of murre foraging trips is remarkably consistent between years and within colonies (Fig. 5). A major constraint on foraging trip duration for murres is simply how far they must range to find fish schools, which is greatest for Chisik murres and least for Gull Island murres (Fig. 2). In addition to this physical constraint, interannual variability in forage fish abundance also affects murre foraging trip duration. At each colony, murres adjust their time budgets (Fig. 6) to compensate for both physical and biological constraints, allowing them to maintain consistent reproductive success between years at all colonies (Fig. 3). Only in 1998 were conditions so poor at Chisik that murres could not compensate (Fig. 6) and therefore failed completely (Fig. 3).

In contrast, kittiwakes appear to have fewer options for buffering against variability in prey abundance or distribution. Rarely did we observe both adults attending nests, which might suggest that kittiwakes work at

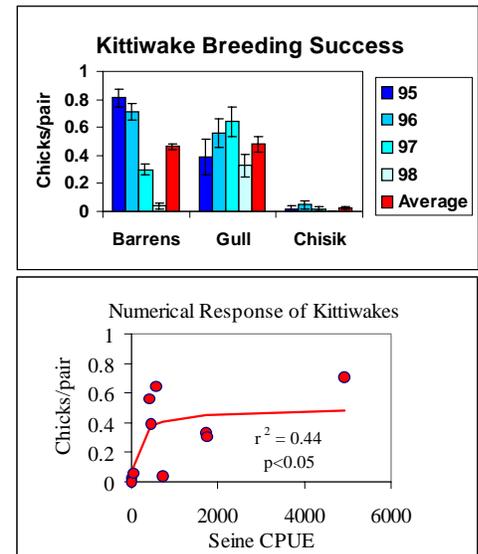


Figure 4. Kittiwake breeding success at all colonies in 1995-1998 (above); breeding success versus prey abundance (below).

full capacity most of the time to successfully rear chicks. Like murres, a major constraint on kittiwake foraging trip duration is how far they must range to find fish schools (Fig. 2), which results in the longest trips for Barrens and Chisik birds, and the shortest trips for Gull Island birds (Fig. 7). Unlike murres, kittiwakes can bring more than one prey item back to chicks in each meal delivery, and so chick growth rates (Fig. 8) reflect both meal size (Barrens > Gull > Chisik) and rates of delivery (Gull > Barrens > Chisik). As for growth rates, these parameters vary more among colonies than between years within colonies. However, it is important to recognize that chick feeding and growth rates can only be measured on nests that actually have chicks. So while these parameters tell us something about physical and biological constraints operating on successful birds, they

reveal less about constraints of food supply on overall populations. If adult kittiwakes have difficulty obtaining food for themselves and chicks, then both adults will abandon the nest—which almost always leads to breeding failure because of egg or chick mortality (often from predation). Thus, in contrast to murre, kittiwake breeding success is highly variable both among colonies and among years within colonies (Fig. 4). At Chisik Island, kittiwakes rarely overcome the dual constraints of long foraging trip distances and low prey abundance, and few birds ever fledge chicks. With long foraging trips, kittiwakes at the Barrens are apparently more susceptible to annual variability in prey abundance. At Gull Island, the close proximity of fish schools tends to buffer against annual variability in abundance, and creates more stability in annual production.

Numerical and Functional Responses

Another useful way to examine the data is to plot the value of measured parameters against the local abundance of forage fish

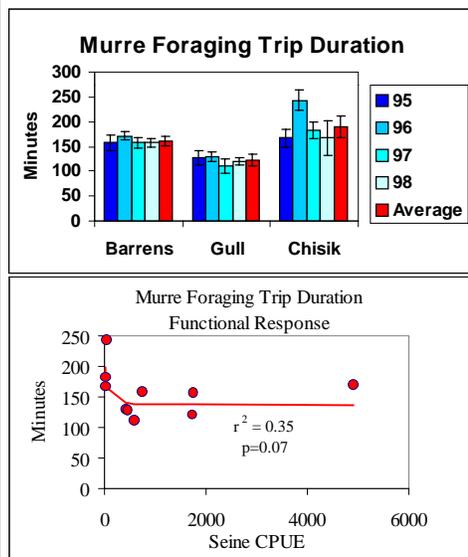


Figure 5. Murre foraging trip duration at all colonies in 1995-1998 (above); trip duration versus prey abundance (below).

response) and foraging behavior (functional response) reveal that most seabird responses to variation in prey density are non-linear. For example, the numerical response of kittiwakes to variation in prey density is best described by a hyperbolic curve (Fig. 4). Breeding success increases rapidly up to some critical level of prey abundance, but above that level breeding success remains more-or-less constant over a wide range of prey densities. The poor fit of some values resulted from El Niño effects in 1998, when reproductive success was impaired during egg-laying rather than during chick-rearing (when fishery data were obtained). Nonetheless, a significant non-linear relationship was observed, suggesting that overall kittiwake breeding success is strongly constrained by food supply. Parameters that are subject to physical constraints (e.g., foraging trip duration, Fig. 7) or behavioral modification (e.g., chick growth rate, Fig. 8) are not as well-explained by variations in prey density.

In contrast, murre breeding success is relatively insensitive to changes in food supply (Fig. 3) except at extremely low abun-

dance of food, and the relationship is best described by a step function. Murres can buffer against fluctuations in food supply (Zador and Piatt 1999) by adjusting their time budgets (e.g., ‘loafing time’) and the relationship between this behavioral parameter and prey density is best described by a hyperbolic curve (Fig. 6). As for kittiwakes, parameters such as

foraging trip duration are also subject to physical constraints and not as well-explained by variations in prey density (Fig. 5).

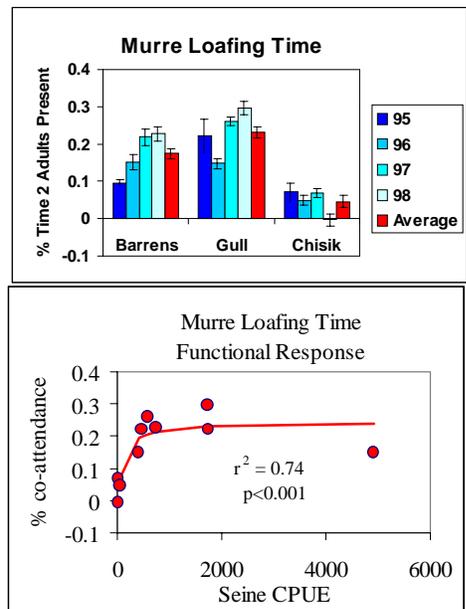


Figure 6. Murre “loafing time” at all colonies in 1995-1998 (above); loafing time versus prey abundance (below).

CONCLUSIONS

Can Murres Recover from Effects of the EVOS?

We can now begin to address this question for the Barren Islands, which was the colony most affected by the EVOS (Piatt et al. 1990). Our study provides comparative data from a “food-poor” colony (Chisik), where murre and kittiwake populations have been declining at rates of 8-9% per annum for the past 20 years, and a “food-rich” colony (Gull) where murre and kitti-

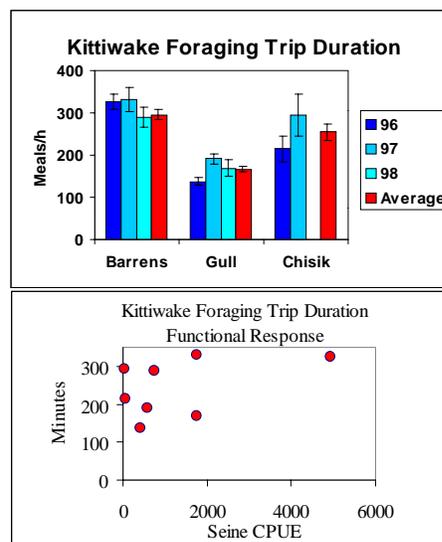


Figure 7. Kittiwake foraging trip duration at all colonies in 1995-1998 (above); trip duration versus prey abundance (below).

wake populations have increased by 8-15% per annum during the past 20 years. We can therefore put the biology of seabirds at the Barren Islands into perspective by comparing their overall performance to that of birds at Gull and Chisik islands. The functional and numerical response curves tell us that murres and kittiwakes respond in non-linear fashion to

fluctuations in prey density. The non-linearity, *per se*, is not important to us here. What *is* important is that we are able to define the form of parameter response curves and observe that below some critical density of prey, certain aspects of breeding biology or foraging behavior are impaired. With respect to the

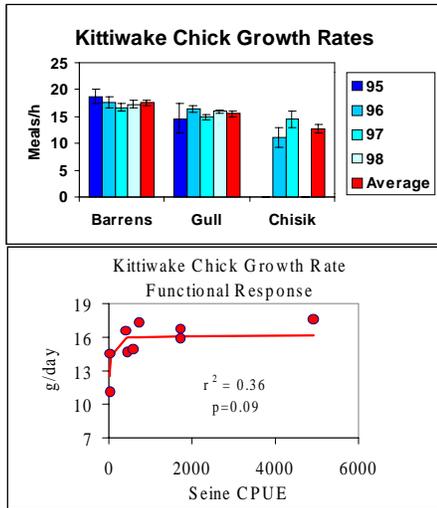


Figure 8. Kittiwake chick growth rates at all colonies in 1995-1998 (above); growth rates versus prey abundance (below).

Barren Islands, we note that most of the parameters we have measured there for murre and kittiwakes in any given year fall *above* critical densities. In other words, the reproductive and behavioral performance of seabirds at the Barren Islands is usually not impaired by food deficiency.

Another way to assess seabird performance at the Barrens is to examine the deviation of parameter values from average at all three colonies (Fig. 9). For example, the average chick feeding rate for murre in 12 colony-years (3 colonies in 1995-1998) of study was 0.26 meals/chick/hour. Murre at the Barrens delivered less than this average number of meals in 2 years of study, and greater than this average in 2 other years. Similarly, we calculated the deviations in other parameters, standardized the deviations, and arbitrarily ranked them from largest to smallest so we could compare them all together (Fig. 9). This provides a holistic assessment of how well seabirds are supported at each colony during the years of our study. This preliminary analysis reveals (Fig. 9) that birds at Gull Island do better than average most of the time (mean deviation = +0.37), while those at Chisik do poorly most of the time (mean deviation = -0.48). At the Barrens, measured parameters were above average slightly more

often than they were below average (mean deviation = +0.05). Because Chisik and Gull islands exemplify failing and thriving colonies, respectively, this analysis provides a calibration for seabird performance at the Barren Islands. The analysis of deviations suggests that seabirds at the Barrens are doing OK—not really great, but not poorly either. This conclusion is corroborated by data on population trends: Post-spill murre population numbers remained relatively stable at the Barren Islands until 1997, when a positive trend was found on a set of plots that supported about 30% of murre censused at the largest colony (Roseneau et al. 1997, 1998). We conclude that current ecological conditions are adequate to sustain a stable population at the Barrens, but not to promote rapid growth in the population. Gull and Chisik comprise relatively small seabird colonies that were largely unaffected by the oil spill, and their population dynamics reflect meso-scale habitat characteristics that are apparently not shared by the Barrens, which contain orders-of-magnitude more breeding birds. Evidence suggests that ecological conditions and food supplies for murre at the Barrens will have to improve considerably before murre can recover at the rate observed on Gull Island (i.e., 8-15% per annum). It will be interesting to compare growth rates of other colonies affected by the EVOS, such as Puale Bay and the Chiswell Islands, as data continue to be collected in the future.

Future Prospects

We can shed some light on the potential for future seabird recovery by examining the historical data on small-mesh trawl catches in the Gulf of Alaska (Anderson and Piatt 1999). A shift in ocean climate during the late 1970s triggered a reorga-

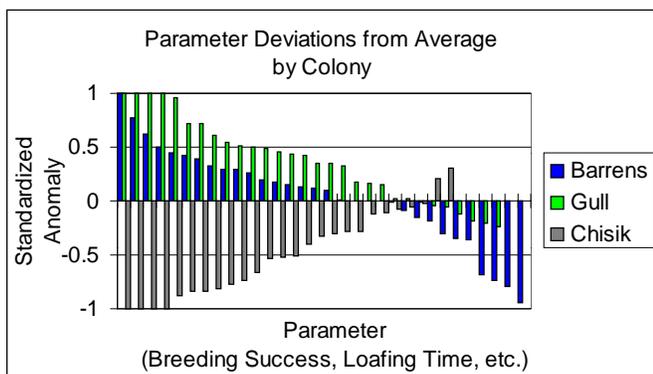


Figure 9. Deviation from average of seabird parameters at each colony. Each bar represents deviation of one parameter in one year. Deviations ranked from highest to lowest.

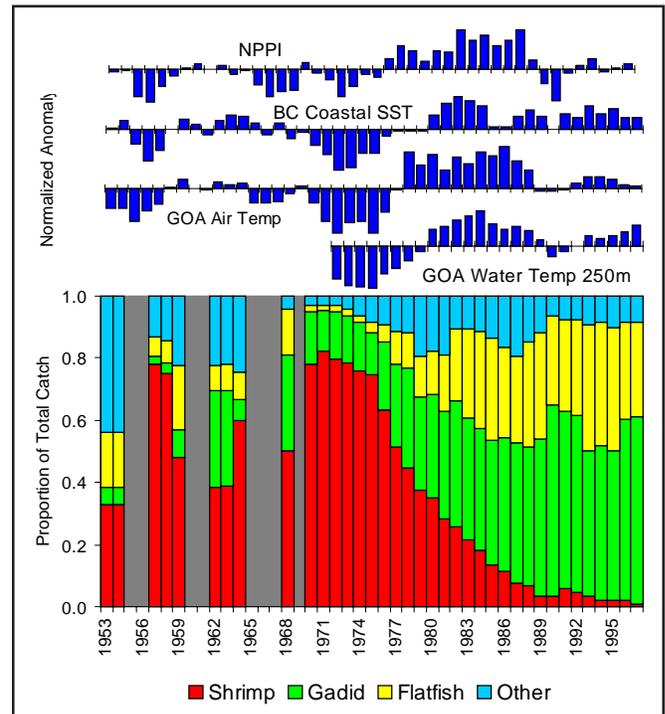


Figure 10. Long-term changes in marine communities in the Gulf of Alaska as indicated by small-mesh trawl catches.

nization of community structure in the Gulf of Alaska ecosystem, as evidenced in changing catch composition on long-term (1953-1997) small-mesh trawl surveys (Fig. 10). Forage species such as pandalid shrimp and capelin declined and never recovered because of recruitment failure and predation. Total trawl catch biomass declined > 50% and remained low through the 1980s. In contrast, recruitment of high trophic-level groundfish improved during the 1980s, yielding a > 250% increase in catch biomass during the 1990s. This trophic reorganization apparently occurred at the expense of piscivorous sea birds and marine mammals.

Analyses of long-term climate data reveal significant cycles in North Pacific climate, including those due to El Niño events (5-7 year cycle) and those to decadal-scale shifts in the position and intensity of the Aleutian Low pressure cell in winter (as indicated by the North Pacific Pressure Index [NPPI] in Fig. 10). The recent 'warm regime', which has not favored seabirds, has now exceeded in duration any previous decadal-scale warm cycle event on record. It is predicted that we should return to a 'cold regime' again in the very near future (Ware 1995). If so, then one can reasonably predict that ecological conditions will return to those that favor seabirds in the Gulf of Alaska. In turn, this would enhance the recovery of seabirds from damages incurred from the EVOS.

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