Exxon Valdez Oil Spill
Restoration Project Annual Report

Survival of Adult Murres and Kittiwakes in Relation to Forage Fish Abundance

Restoration Project 98338
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 first funded in 1998 after reviewers recommended that the APEX project (Restoration Project 00163) obtain data on adult seabird survivial in order to better understand population-level effects of variability in food abundance. We are using traditional methods of banding and re-sighting to measure the survival of adult Common Murres and Black-legged Kittiwakes at two colonies in lower Cook Inlet. A pilot banding effort in 1997 was followed in 1998 by a full season of banding and re-sighting of birds banded in 1997. This effort complements our other studies in lower Cook Inlet that relate seabird breeding success and foraging effort to fluctuations in forage fish density.

Abstract: Populations of Common Murres and Black-legged Kittiwakes in lower Cook Inlet fluctuate over time, and changes in population size reflect the sum of three processes: adult mortality, recruitment of locally-produced offspring, and the immigration/emigration of breeding adults from/to other colonies. In APEX Project 00163M, we have been measuring population trends and productivity in relation to local food abundance since 1995, and there are also historical data spanning 25 years. With this project (00338), we have begun to measure adult survival by marking birds with color bands and re-sighting them in subsequent years. We now have one year of results on survival of murres and kittiwakes at Gull Island (food-rich, bird populations increasing) and Chisik Island (food-poor, bird populations decreasing). At least 3-4 years of re-sighting data are needed for statistical evaluation of survival data. However, preliminary results suggest there are marked differences in survival of murres and kittiwakes between Gull and Chisik islands, which may be related to costs of breeding in food-rich versus food-poor environments. The rate at which murre and kittiwake populations are declining at Chisik Island (7-9% per annum) can be attributed mostly to adult mortality. The rate at which populations have increased at Gull Island (8-15%) cannot be explained solely by recruitment of locally produced juveniles (despite high productivity), and must also result from substantial immigration of adults from elsewhere.

Key Words: Cook Inlet, murre, kittiwake, survival, forage fish, *Exxon Valdez* oil spill, Kachemak Bay, population, demography

Project Data: (will be addressed in the final report).

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Executive Summary: We have begun to measure adult survival by marking birds with color bands and re-sighting them in subsequent years. We now have one year of survival estimates for murres and kittiwakes at Gull Island and Chisik Island in lower Cook Inlet. However, at least 3-4 years of re-sighting data are recommended for statistical evaluation of survival data (e.g., Pollock et al. 1990, Lebreton et al. 1992, Erikstad et al. 1995). Here we report briefly on the results of our first year of work, but emphasize that these results are preliminary and are for illustrative purposes only. They have not been evaluated statistically. Among other problems, the estimates are based on small sample sizes (from our pilot banding effort in 1997) and re-sighting probabilities were reduced by El Niño effects on attendance of birds in 1998— particularly at Chisik Island. The latter problem also limited our ability to catch and band new adults in 1998, and therefore we are still short of our target population of banded birds (200 of each species on each island). We should exceed our quota during the upcoming (1999) field season, and re-sighting during this and the next (2000) summer should be sufficient to accurately estimate survival rates with appropriate confidence limits.

Introduction: Some seabird populations in the Gulf of Alaska have undergone marked fluctuations during the past few decades (Hatch and Piatt 1995; Piatt and Anderson 1996), including periods of decline or non-recovery. Ultimately, the ability of injured or declining seabird populations to recover depends on: 1) breeding success, or productivity; 2) fledgling survival and subsequent recruitment; and 3) overwinter survival of adults (Harris and Wanless 1988). Without concurrent measurement of at least two of these three parameters, it is difficult to determine which factor is limiting population recovery.

Mechanisms that regulate seabird populations are poorly understood, but food supply is clearly important (Cairns 1992). Studies sponsored by the *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) in 1995-99 (APEX, Restoration Project 00163) have shown linkages between food supply and population dynamics. To date, APEX has focused on forage fish availability and its relationship with seabird productivity and foraging effort. The link between food supply during the breeding season and adult survival remains unclear, but mounting evidence suggests that overwinter survival is linked to reproductive investment (Golet et al. 1998), which may in turn be partially a function of food supply during the breeding season (Kitaysky et al. 1999).

Therefore, we set out to determine the overwinter survival of adult Common Murres (*Uria aalge*) and Black-legged Kittiwakes (*Rissa tridactyla*) by using traditional banding and re-sighting methods at Gull and Chisik islands in lower Cook Inlet. Results of past work show clear differences in prey availability between the two colonies, with forage fish being scarce around Chisik Island and abundant around Gull Island (Robards et al. 1999). Seabirds must work significantly harder at Chisik to provide food to their chicks (e.g., Zador and Piatt 1999). This difference is manifested in markedly reduced kittiwake productivity at Chisik Island, and higher physiological stress (Kitaysky et al. 1999). Because kittiwake populations have been steadily declining at Chisik, but increasing at Gull, one might be tempted to conclude that weak productivity and recruitment are responsible for the decline in kittiwake population at Chisik. In contrast, murres exhibit similar levels of productivity at Chisik and Gull, but the Chisik Island murre population has historically declined at an even greater rate than the kittiwake population.

Thus, we suspect that the murre population decline at Chisik Island and concurrent increase at Gull Island may be attributable to differences in adult survival rates. Measurement of survival rates, in coordination with APEX's focus on food supply, foraging effort and colony productivity, should help to resolve the mechanisms underlying seabird population fluctuations, particularly for those species such as murres that are able to buffer productivity against periods of food shortage by increasing foraging effort (Burger and Piatt 1990; Zador and Piatt 1999). Presumably, such effort comes at a cost— perhaps in reduced adult survival.

Objectives:

1. To determine adult Common Murre and Black-legged Kittiwake overwinter survival rates, using conventional banding and re-sighting methods.

2. To relate differences in Common Murre and Black-legged Kittiwake overwinter survival to differences in prey availability, foraging effort and physiological stress during the breeding season.

3. To relate differences in Common Murre and Black-legged Kittiwake overwinter survival to differences in breeding success (reproductive investment).

Methods: To measure annual survival of kittiwakes and murres, we are employing traditional mark-recapture methods. Adult breeding birds are captured and marked using a uniquely numbered stainless steel leg band and a unique combination of colored plastic leg bands. Marked birds are then observed at the colony in subsequent years to determine recapture rates. Those recapture rates can then be translated into estimated survival rates using established statistical models (Pollock et al. 1990, Lebreton et al. 1992).

Assuming a binomial distribution (sample unit being an individual adult, with survival being a yes or no), a power analysis of sample size in a two by two table predicts that a sample size of 47 marked birds per island would resolve a 6% difference in survival between colonies with acceptable statistical power and confidence (Table 1). To double the resolution (3%) would require a sample size nearly five times greater. However, a sample size of 185 is predicted to resolve a 4% difference with strong power and significance at the 0.05 level. Previous studies have reported murre survival rates ranging from 87% to 98% (Hudson 1985, Sydeman 1993) and kittiwake survival rates ranging from 82% to 93% (Golet et al. 1998). Given that our study colonies represent relative extremes of population expansion and decline, it is not unreasonable to expect their survival rates to also be at the extreme ends of the normal range. Therefore, detection of a 4% difference with statistical significance should adequately address our primary hypothesis. To allow for a small percentage of known band loss, our goal is to individually mark a minimum of 200 birds of each species at each colony.

In addition to sample size issues, re-sighting must take place over at least 3-4 years to accurately measure survival (Lebreton et al. 1992). Re-sighting probabilities vary with observer effort and can also be lowered when birds occasionally skip breeding attempts— a common event for kittiwakes (Erikstad et al. 1995, Golet et al. 1998). Thus, several years of effort are recommended in order to ensure a high probability of re-sighting individuals that have, in fact, survived since banding but may be missed if re-sighting effort is limited to only one or two subsequent years.

Banding progress to date is shown in Table 2. Our effort in 1996 was minimal. In 1997 we undertook a serious pilot effort. After receiving FY98 EVOSTC funding for the 1998 field season, we initiated re-sighting and greatly increased our banding effort. Unfortunately our 1998 banding effort was undermined by effects of the 97/98 El Niño event (Piatt et al. 1999). Colony attendance at both Gull and Chisik Islands was reduced, and birds that did attend were exceptionally skittish and difficult to capture. Abnormal behavior was particularly evident at Chisik Island, where only a small percentage of the usual murre breeding sites were occupied. The few birds that did attempt to breed eventually abandoned the colony, resulting in a rare breeding failure. With focused effort we were able to band substantial numbers of adults, but not enough to meet our objective of banding 200 birds per species per colony (above). One more year of banding followed by a further year of re-sighting is necessary for a conclusive result from this project.

For this preliminary analysis of survival, we did not use all of the birds in our banded population at Chisik Island (compare Tables 2 and 3) because some plots with banded murres were occupied only briefly by adults before they abandoned breeding attempts. Re-sighting at those plots was therefore incomplete. A few kittiwake plots at Chisik were not visited frequently enough to ensure complete re-sighting, and these were also excluded from calculations. Despite a a variety of problems, our re-sighting effort for murres was probably sufficient to observe most or all of the murres that returned to occupied study plots in 1998. Therefore, the actual re-sighting rates (Table 3) may serve as estimates of annual survival (Hatch et al. 1993). For kittiwakes, we started our re-sighting effort a little late in the season, and it became difficult to re-sight bands on birds that were sitting tight on eggs. Also, other duties precluded a continuation of thorough re-sighting effort for kittiwakes during the incubation period. Therefore 'actual' re-sighting rates are probably low, minimal estimates of survival (Table 3). In addition to this analysis, we extrapolated from a non-linear regression of the re-sighting probability curve (cumulative number of birds re-sighted versus cumulative effort; Golet et al. 1998) to estimate what survival rates would have been at the asymptote of the curve (i.e., with unlimited re-sighting effort). Because the relationship between the number of birds re-sighted and effort was so well described by non-linear (hyperbolic) curves at both Gull ($r^2=0.92$, $p<0.001$) and Chisik ($r^2=0.96$, $p<0.001$), the estimated asymptotic re-sighting rates (Table 3) are probably reasonable estimates of annual survival (Table 3).

Measures of food supply, foraging effort, and physiological stress are being obtained from other concurrent studies (Restoration Projects 00163M, 00479). Results of these studies will be integrated with survival results in the final report.

Results: We reiterate our disclaimer that results from our one year of re-sighting are tentative and lack any statistical treatment. Nonetheless, if these results hold up in subsequent years, they will demonstrate that food supply during the breeding season has a marked impact on adult survival and colony population dynamics.

Preliminary results suggest there are marked differences between Gull and Chisik islands in the survival of murres and kittiwakes (Table 3), which may result from differential costs of breeding in food-rich versus food-poor environments. For example, kittiwakes at Chisik Island almost always fail prior to egg hatching (ultimately producing on average only 0.02 chicks/pair; Table 4), and most birds invest little in reproduction after incubation. Annual adult survival is quite high (93%) and similar to that observed in other failing colonies in Alaska (Fig. 1). In contrast, kittiwakes at Gull are usually quite productive (averaging 0.46 chicks/pair over 15 years of study), but this investment apparently takes a toll on breeding adults because survival is only about 84% per annum (similar to productive Atlantic colonies). The situation for murres is quite different (Tables 3 and 4). Murres maintain high productivity at both Gull (0.71 chicks/pair) and Chisik (0.51 chicks/pair) islands (Table 4), but birds at Chisik must work harder all summer to maintain this level of productivity (e.g., >50% longer foraging trips). This extra effort apparently has some cost, since adult murre survival at Chisik (89%) is lower than at Gull (93%). These survival rates are similar to those observed elsewhere (Fig. 2), with lower values found at declining colonies (e.g., Karlso) and higher values found at increasing colonies (e.g., Isle of May).

With measures of survival rates, productivity and population trends (Table 4), we can also draw some conclusions about recruitment and immigration. The rates at which murre and kittiwake populations are declining at Chisik Island (7-9% per annum) can be explained almost entirely by adult mortality. There would appear to be little or no immigration or emigration at Chisik. However, the rates at which populations have increased at Gull Island (8-15%) cannot be explained solely by recruitment of juveniles from Gull (unless we accept extraordinarily high rates [61-104%] of juvenile survival to breeding), and must therefore also result from substantial immigration of adults from elsewhere.

Discussion and Conclusions: Results are preliminary and may change after addition of data from subsequent years of study. Therefore, any conclusions we draw now are tentative and much discussion is unwarranted. If these initial results are accurate, however, and hold up over several years of study, we may conclude that:

1) The population dynamics of murres and kittiwakes in the EVOS spill zone are strongly influenced by food supplies that are available during the breeding season. Food supply not only affects productivity (as demonstrated clearly by core APEX investigations), but also adult

survival (measured) and recruitment (inferred). This conclusion supports the hypothesis that long-term changes in forage fish abundance in the Gulf of Alaska (Anderson and Piatt 1999) could have a profound influence on the ability of seabirds to recover from losses incurred during the *Exxon Valdez* oil spill.

2) Adult survival of murres and kittiwakes differs markedly between food-rich and food-poor colonies. Differences in survival may result from inter-colony differences in parental investment required to successfully rear and fledge chicks (Golet et al. 1998). Fledging chicks at Chisik requires a sustained higher level of foraging effort and results in higher levels of physiological stress (Zador and Piatt 1999, Kitaysky et al. 1999). This apparently reduces overwinter survival.

3) Murres and kittiwakes exhibit different patterns of survival between colonies. Kittiwake survival at Chisik is greater than at Gull, despite the fact that food supplies are worse at Chisik. This may result from the fact that Chisik birds usually fail during incubation and therefore do not invest a full season of effort in reproduction. In contrast, murre survival is higher at Gull than Chisik— perhaps because murres at both colonies raise chicks to fledging, and it requires more effort to accomplish this at Chisik.

4) The rate of declines in populations (>90%) of murres and kittiwakes at Chisik Island during the past 25 years can be accounted for largely by adult mortality. There appears to be little or no recruitment or immigration. The rate of increases in populations (>90%) of murres and kittiwakes at Gull Island during the past 25 years cannot be explained solely by recruitment of locally-produced offspring, and must also result from immigration.

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Table 1. Power analysis of sample size (in a two by two table). One minus beta is power; a power of <0.50 is typical in survival estimations. One minus alpha is the confidence interval. Ps and Pe are estimated survival fractions at two hypothetical colonies. Thus, with a sample size of 47 (banded birds per colony), we would expect to resolve a 6% difference (Ps minus Pe) with a power of 0.51 and 90% confidence intervals. With a sample size of 185, we would expect to resolve a 4% difference with a power of 0.75 and 95% confidence intervals. In general, as sample size doubles, variance is halved (Heisey and Fuller, 1985). Resolution of differences <4% demands unacceptably large sample sizes.

alpha	Zalpha	beta	Zbeta	Ps	Pe	n =
0.10	1.18	0.25	0.68	0.92	0.89	352
0.10	1.18	0.49	0.01	0.92	0.89	226
0.05	1.65	0.25	0.68	0.95	0.91	185
0.05	1.65	0.25	0.68	0.95	0.90	125
0.10	1.18	0.25	0.68	0.95	0.90	100
0.10	1.18	0.49	0.01	0.94	0.89	72
0.10	1.18	0.49	0.01	0.95	0.89	47

Table 2. Number of birds color-banded by year, location, and species.

Year	Gull Island		Chisik Island	
	Murre	Kittiwake	Murre	Kittiwake
1996	0	9	0	0
1997	30	40	132	69
1998	101	108	56	71
Total	**131**	**157**	**188**	**140**

Table 3. Preliminary analysis of seabird survival (re-sighting rate) from 1997 to 1998.

	Gull Island		Chisik Island	
	Murre	Kittiwake	Murre	Kittiwake
No. used for survival analysis	30	49	38	53
No. birds re-sighted	28	38	34	43
Actual re-sighting rate	0.933	0.775	0.895	0.811
Estimated re-sighting rate		0.843		0.928

Table 4. Preliminary estimate of population parameters for seabirds at Chisik and Gull Islands.

Type	Parameter	Black-legged Kittiwake		Common Murre	
		Chisik	Gull	Chisik	Gull
Measured	Population change (% per annum)	-0.085	0.080	-0.070	0.150
Measured	Annual adult survival (% p.a.)	0.928	0.840	0.890	0.933
Measured	Mean productivity (chicks/pair)	0.022	0.460	0.510	0.710
Estimated	Recruitment rate (% p.a.)	-0.013	0.240	0.040	0.217
Estimated	Juvenile survival needed to balance	0.000	1.040	0.157	0.611

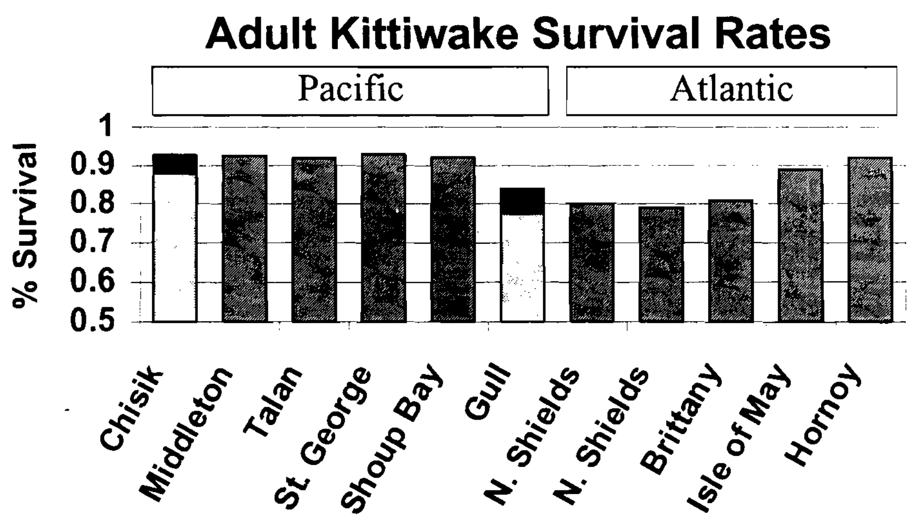

Figure 1. Preliminary estimates of Black-legged Kittiwake survival rates at Chisik and Gull Islands, compared with rates at other colonies in the Atlantic and Pacific. Note Chisik and Gull values range from those actually measured (pale part of bar) to those estimated by extrapolating re-sighting probabilities (dark part of bar).

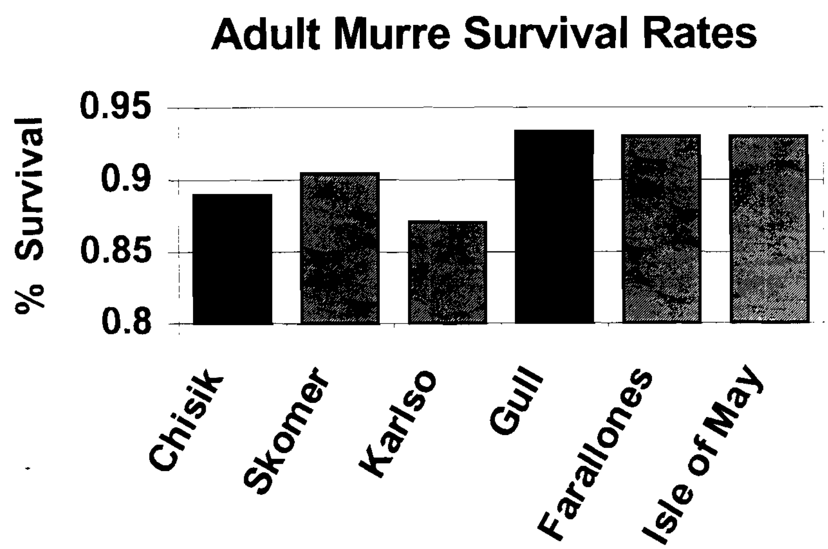

Figure 2. Preliminary estimates of Common Murre survival rates at Chisik and Gull islands, compared with rates observed at other colonies (all Atlantic except for Farallones in California).