Exxon Valdez Oil Spill
Restoration Project Annual Report

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

Restoration Project 99338
Annual Report

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John F. Piatt

Alaska Biological Science Center
U.S. Geological Survey
1011 E. Tudor Rd.
Anchorage, Alaska 99503

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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 survival 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 and 1999 by banding and re-sighting of birds banded in 1997 and 1998. 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 are measuring adult survival by marking birds with color bands and re-sighting them in subsequent years. We now have estimates of survival for two years of murres and kittiwakes at Gull Island (food-rich, bird populations increasing) and Chisik Island (food-poor, bird populations decreasing). At least 4-5 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 (2-9%) 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 are measuring adult seabird survival by marking birds with color bands and re-sighting them in subsequent years. We now have two years of survival estimates for murres and kittiwakes at Gull Island and Chisik Island in lower Cook Inlet. However, the survival probability estimates for the second year cannot be decoupled from re-sighting probabilities until the next year of re-sighting is completed (Lebreton et al. 1990). At least 4 years of re-sighting data are recommended for statistical evaluation of survival data (Pollock et al. 1990, Lebreton et al. 1992, Erikstad et al. 1995). Here we report briefly on the results of our second year of work, but emphasize that these results are preliminary and will ultimately be supplanted by future data. In last year's analysis and report, we could only assess survival over one year, and used only simple resighting statistics to do so. Now we have two years of re-sighting data and it is possible to apply mark-recapture statistics to calculate both survival and re-sighting probabilities (White and Burnham 1999).

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). Live recaptures are the basis of the standard Cormack-Jolly-Seber model. Program MARK (White and Burnham 1999) provides parameter estimates from marked animals when they are re-encountered at a later time. The basic input to program MARK is the encounter history for each animal. Parameters can be constrained to be the same across re-encounter occasions, or by sex, or by group (e.g., colony), using the parameter index matrix (PIM). A set of common models for screening data initially are provided, with time effects, group effects, time*group effects, and a null model of none of the above provided for each parameter. Program MARK computes the estimates of model parameters via numerical maximum likelihood techniques. The program that does this computation also determines numerically the number of parameters that are estimable in the model, which is used to compute the quasi-likelihood AIC value (QAICc) for the model. Thus, the approach generally taken with MARK is to find a model that provides the best fit for the data, as indicated by the lowest possible AICc value.

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. 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 was 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 4-5 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 1. 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 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 in 1999 we met our objective of banding 200 birds per species per colony-- except for kittiwakes on Chisik Island. It remains a challenge to find, capture and band accessible kittiwakes there, and the problem is exacerbated by their tendency to fail early during incubation, particularly in 1999.

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.

<u>Results</u>: Analysis of data using MARK suggests that survival of kittiwakes is much higher on Chisik than on Gull island (Table 2). Survival estimates on Chisik are inflated by relatively low re-sighting probabilities, and estimates will improve with re-sighting in subsequent years. The best fitting model (ΔAICc=0.00; weight=0.86) was one in which survival and re-sighting probabilities were unequal between colonies, but were set equal across years. This model provided a 6.5 times better fit to the data than the next best model (ΔAICc=3.67; weight=0.13), which was the global (or general) model of all parameters differing across colonies and years. It was also much better fitting than a model (ΔAICc=15.4; weight=0.0004) setting survival and re-sighting probabilities equal across colonies and years. A likelihood ratio test suggests this difference in fit of models (colony effect vs. no colony effect) is highly significant (χ^2 =19.4, df=2, $p<0.0001$).

With only two years of re-sighting, however, the kittiwake survival estimates are not independent of re-sighting rates in the second year. The above MARK analysis will provide much more accurate survival estimates with two or more years of additional re-sighting effort. For now, it is instructive to examine the apparent survival of birds banded in 1997, where two opportunities for re-sighting (in 1998 and 1999) greatly increase the probability that all survivors from that cohort have been observed. From this analysis, more reasonable survival estimates are 0.77 and 0.94 on Gull and Chisik islands, respectively (Table 2). In other words, the inter-annual mortality rate for adult kittiwakes was nearly 4 times greater on Gull than on Chisik.

Similar analyses were conducted for murres (Table 2). Results are complicated by the fact that re-sighting rates were low in 1998 at Chisik Island owing to effects of the ENSO on murre attendance (Piatt et al. 1999), and low in 1999 at Gull for unknown reasons. Productivity at Gull in 1999 was the lowest ever observed (0.14 chicks/pair), with most of the failure occurring during incubation. With these re-sighting rates, the MARK estimates of adult survival are similar at Gull (0.89) and Chisik (0.91). The best model is one in which survival does not vary among years or colonies, and in which re-sighting probabilities do not vary among years for a given cohort (ΔAICc=0.00; weight=0.46). This model gives only a slightly better fit than one in which survival and re-sighting do vary among colony, year, with cohort re-sighting held constant (ΔAICc=0.44; weight=0.37). Essentially, either model could be correct (White and Burnham 1999). Accuracy will be improved with more years of data. In the meantime, the most accurate estimate of survival can be obtained by considering survival of the 1997 cohort, for which we had two opportunities for re-sighting in 1998 and 1999. These data suggest that survival of murres at Gull Island (0.91) is considerably higher than survival at Chisik Island (0.85). In other words, the inter-annual mortality rate for adult murres was 1.7 times greater on Chisik than Gull.

These differences between Gull and Chisik islands in the survival of murres and kittiwakes 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 (producing on average only 0.02 chicks/pair), and most birds invest little in reproduction after incubation. Annual adult survival is quite high (94%) and similar to that observed in other failing colonies in Alaska (Fig. 1). In contrast, kittiwakes at Gull are highly 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 77% per annum (similar to productive Atlantic colonies). The situation for murres is quite different. Murres maintain high productivity at both Gull (0.71 chicks/pair) and Chisik (0.51 chicks/pair) islands (Table 3), but birds at Chisik must work harder to maintain this level of productivity (e.g., >50% longer foraging trips). This extra effort has some apparent cost, since adult murre survival at Chisik (85%) is lower than at Gull (91%). 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 independent measures of survival rates, productivity and population trends (Table 3), we can also draw some conclusions about recruitment and immigration. The rate of survival of juveniles to breeding age is generally much lower than annual adult survival, and for both Common Murres (Hudson 1985, Harris and Wanless 1988) and Black-legged Kittiwakes (Baird 1994) is likely to be no more than about 40% (Table 3). 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. Even with optimistic rates of juvenile survival (above), however, and assuming that all fledglings return to their natal colonies to breed, the observed population trends suggest that some emigration (2-3%) from Chisik must also occur (Table 3). The rates at which populations have increased at Gull Island (2-9%) cannot be explained solely by recruitment of juveniles from Gull, and must therefore also result from substantial immigration rates (4-16% p.a.) of adults from elsewhere.

Discussion and Conclusions: Results are preliminary and will change after addition of data from subsequent years of study. If the parameter estimates made from 2 years of re-sighting hold up over several years of study, however, 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 increase 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. 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
1999	68	114	74	29
Total	**199**	**271**	**262**	**169**

Grand Total: 901 (Gull 470; Chisik 431)
Note: Not included in total are 30 murres and 40 kittiwakes banded on Gull in 1997, but experimentally manipulated.

Table 2. Survival parameter estimates for murres and kittiwakes in lower Cook Inlet

Species	Parameter	Gull Island	Chisik Island
BL. Kittiwake	MARK Survival Probability	0.74	1.00
	MARK Resighting Probability	0.96	0.78
	97 Cohort Survival Estimate	**0.77**	**0.94**
Common Murre	MARK Survival Probability	0.89	0.91
	MARK Resighting Probability (98)	0.87	0.60
	MARK Resighting Probability (99)	0.56	0.88
	97 Cohort Survival Estimate	**0.91**	**0.85**

Table 3. 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	0.020	-0.070	0.090
Measured	Annual adult survival (% p.a.)	0.940	0.770	0.850	0.910
Measured	Mean productivity (chicks/pair)	0.022	0.460	0.510	0.710
Estimated	Juvenile survival to breeding	0.400	0.400	0.400	0.400
Estimated	Immigration (% p.a.)	-0.029	0.158	-0.021	0.038

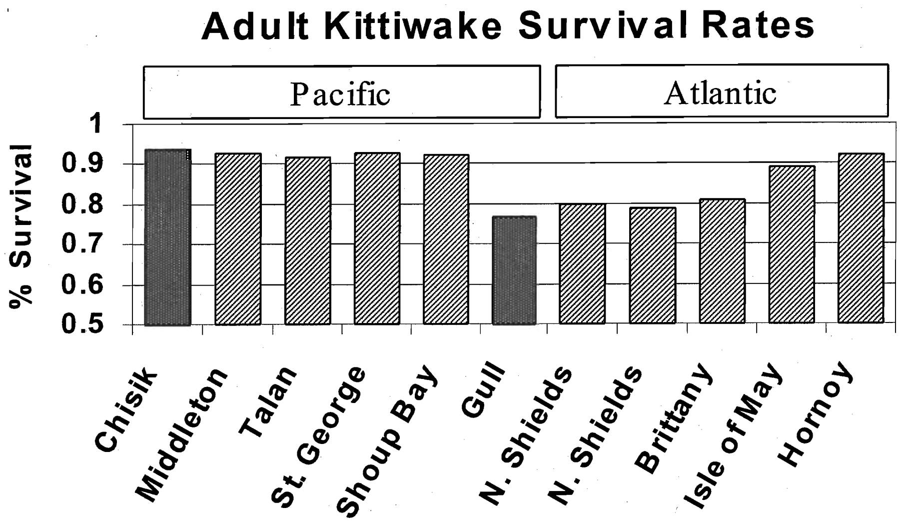

Figure 1. Preliminary estimate of Black-legged Kittiwake survival rates at Chisik and Gull Islands, compared with rates at other colonies in the Atlantic and Pacific.

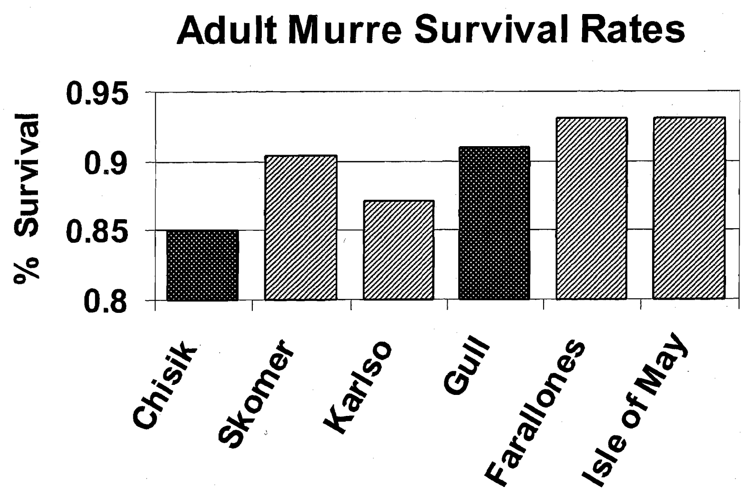

Figure 2. Preliminary estimate of Common Murre survival rates at Chisik and Gull islands, compared with rates observed at other colonies (all Atlantic except for Farallones in California).