Exxon Valdez Oil Spill
Restoration Project Annual Report

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

Restoration Project 00338
Annual Report

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

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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, 1999 and 2000 by banding and re-sighting of birds banded in 1997, 1998 and 1999. 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 three 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 (4-9% per annum) can be attributed mostly to adult mortality. The rate at which populations have increased at Gull Island (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 three 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 third 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 third year of work, but emphasize that these results are preliminary and will ultimately be supplanted by future data. We use two techniques to estimate survival: enumeration to calculate survival (Golet et al. 1998) and mark-recapture analysis (Program MARK) 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 by simple enumeration (Golet et al. 1998, 2001) or by using established statistical models (Pollock et al. 1990, Lebreton et al. 1992). In enumeration, one calculates survival simply as the proportion of birds marked in year one observed alive in year two. Enumeration requires that resighting effort be adequate to assume that all birds that can be observed are, in fact, observed. In other words, resighting probability is assumed to be 100 percent. 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. In 1997 we undertook our 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 and 2000, we met our objective of banding a minimum of 200 birds per species per colony.

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 enumeration and MARK suggests that survival of kittiwakes is much higher on Chisik than on Gull island (Table 2). Like Golet et al. (2001), we find that enumeration and MARK survival estimates are similar, except that MARK tends to overestimate survival because the program treats absences due to skipping as missing data and therefore underestimates resighting probabilities, thereby inflating survival estimates (Golet et al. 2001). We found that about 15-20% of kittiwakes skip at least one year of breeding, and 0-3% skip two years. The best fitting MARK model (ΔAICc=0.00; weight=0.63) was one in which survival and re-sighting probabilities were unequal between colonies, but were set equal across years. This model provided a 11.5 times better fit to the data than the global (general) model (ΔAICc=4.89; weight=0.055) in which all parameters differed across colonies and years. It was also much better fitting than a model (ΔAICc=8.33; weight=0.0098) 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 =8.35, df=2, p<0.0039).

The MARK analysis will provide more accurate survival estimates with more years of additional re-sighting effort. In the meantime, we consider the enumeration estimates to provide the best overall point estimate of adult kittiwake survival (Golet et al. 1998, 2001). We can have greatest confidence in the estimate of survival for the 1997 cohort because we have three subsequent years of resighting with which to establish survival of that cohort, and account for birds that skipped breeding for one or two years. Those data suggest a huge difference in survival among colonies: 96% at Chisik compared to only 81% at Gull— a 4.8-fold difference in mortality rate among islands. We will have more confidence in the survival estimate of the 1998 cohort after another year of resighting. For now, we can take the mean estimate of survival of the 1997 and 1998 cohorts as a reasonable mean estimate of survival at each island (Table 2, Fig. 1).

Similar analyses were conducted for murres (Table 2). MARK results are complicated by the fact that re-sighting rates were low (0.58) in 1998 at Chisik Island owing to effects of the ENSO on murre attendance (Piatt et al. 1999), and low (0.87) in 1999 at Gull, which was an unusually poor food year there. With these re-sighting rates, which do not account for skipped years in estimating resighting probability (Golet et al. 2001), MARK estimates of adult survival are inflated-- particularly at Chisik. Preliminary enumeration analysis shows that 9-30% of murres skipped at least one year of breeding, and 4-8% skipped two years. Given that enumeration methods show that only 92% of all Chisik murres banded in 1997 have ever been resighted, the MARK estimate of 100% survival is obviously a gross overestimate (not to mention extremely unlikely, see Fig. 2). Accuracy may be improved with another year of data, although the unusually low resighting rate of 1998 may ultimately doom the MARK analysis. In the meantime, the most accurate estimate of survival can be obtained by enumeration analysis of the 1997 cohort, which suggests a marked difference in survival between Gull (96%) and Chisik (92%)-- a 2-fold difference in mortality rates. Survival appears to have plummeted in 1999 at both islands, and there was little difference among colonies in survival (83% vs 82%, Table 2). However, given the confounding effects of attendance in 1998 at Chisik and 1999 at Gull, and the fact that a significant proportion of murres may skip one or two years, we need data from 2001 resighting before we place much faith in these 1999 estimates.

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 (93%) 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 82% 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 (92%) is lower than at Gull (96%). 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 (4-9% 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 immigration/emmigration also occurs at Chisik (Table 3). The rates at which populations have increased at Gull Island (8-9%) cannot be explained solely by recruitment of juveniles from Gull, and must therefore also result from substantial immigration rates (6-18% p.a.) of adults from elsewhere.

<u>**Discussion and Conclusions**</u>: Results are preliminary and will change after addition of data from the final year of resighting (2001) funded by the EVOSTC. If the parameter estimates made so far hold up, 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 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
1997	57	67	132	69
1998	102	107	55	71
1999	70	62	74	29
2000	59	59	69	36
Total	**288**	**295**	**330**	**205**

Grand Total: 1118 (Gull 583; Chisik 535)

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

Species	Parameter	Gull Island	Chisik Island
BL. Kittiwake	MARK Survival 1997 to 1998	0.81	0.97
	MARK Survival 1998 to 1999	0.86	0.92
	MARK Survival Both Years	**0.85**	**0.94**
	Enumeration Survival 1997 to1998	0.81	0.96
	Enumeration Survival 1998 to 199	0.84	0.90
	Enumeration Mean of Both Years	**0.82**	**0.93**
Common Murre	MARK Survival 1997 to 1998	0.98	1.00
	MARK Survival 1998 to 1999	0.85	0.84
	MARK Survival Both Years	0.87	0.91
	Enumeration Survival 1997 to1998	**0.96**	**0.92**
	Enumeration Survival 1998 to 199	0.83	0.82
	Enumeration Mean of Both Years	0.89	0.87

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 (prop. per annum)	-0.043	0.088	-0.089	0.091
Measured	Annual adult survival (p.p.a.)	0.930	0.820	0.920	0.960
Measured	Mean productivity (chicks/pair)	0.022	0.460	0.510	0.710
Literature	Juvenile survival to breeding	0.400	0.400	0.400	0.400
Estimated	Maximum recruitment (p.p.a.)	0.004	0.092	0.102	0.142
Estimated	Maximum immigration (p.p.a.)	0.022	0.176	-0.110	-0.011

Note: recruitment and immigration must balance. For example, if estimate of murre recruitment at Chisik (10.2% pa) were actually 2.1%, then immigration would have to be +2.0% to account for population trends.

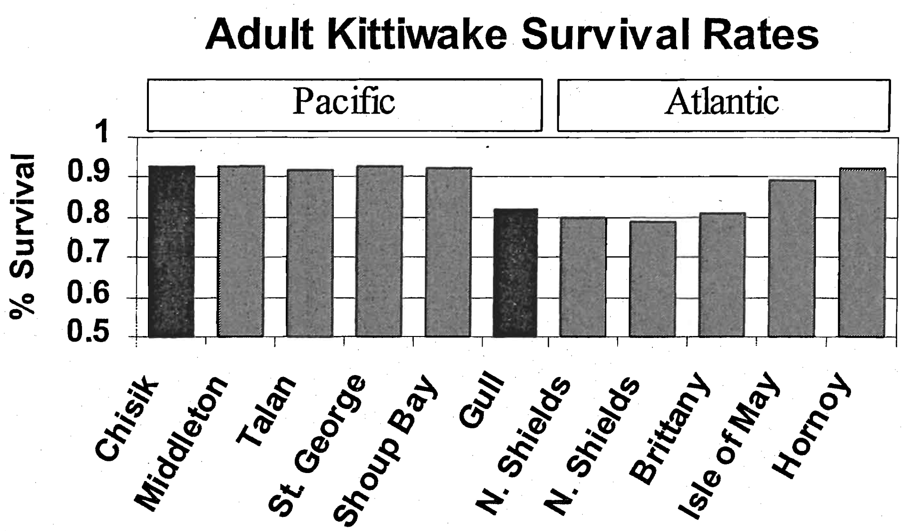

Figure 1. Preliminary estimate of Black-legged Kittiwake survival rates at Chisik and Gull Islands, compared with rates at other colonies in the Atlantic and Pacific.

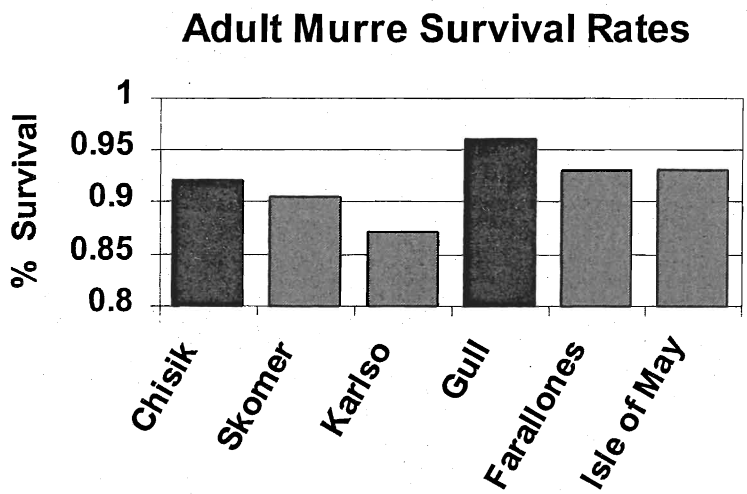

Figure 2. Preliminary estimate of Common Murre survival rates at Chisik and Gull islands, compared with rates observed at other colonies (all Atlantic except for Farallones in California).