Exxon Valdez Oil Spill
Restoration Project Final Report

Protocols for long-term monitoring of seabird ecology in the Gulf of Alaska

Restoration Project 00501
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Study History: Some seabird populations damaged by the *Exxon Valdez* oil spill (EVOS) have still not recovered and populations require long-term monitoring in order to assess both recovery and ecological conditions affecting recovery. However, strategies and protocols for monitoring are constantly evolving, and so we were funded by the EVOS Trustee Council to re-examine extant data and revise protocols for long-term monitoring of seabird ecology in the Gulf of Alaska (GOA). Detailed studies of individual seabird colonies and marine ecosystems in the GOA were conducted by the USGS and USFWS under the auspices of damage assessment and restoration programs of the EVOS Trustee Council— particularly under APEX, the Apex Predator Ecosystem Experiment. For this project, we analyzed a suite of data collected in Cook Inlet under APEX and used power analyses to assess their statistical power for monitoring aspects of seabird ecology over time. From this we make suggestions for monitoring seabirds, considering not only statistical power, but also whether the parameters being monitored are useful for management purposes and whether they may serve to indicate change in the marine environment.

Abstract: We examined seabird and forage fish data collected during APEX studies at three colonies (Barren, Gull and Chisik islands) in Cook Inlet during 1995-1999. These colonies presented a unique opportunity to study seabird biology at sites with radically different production regimes. Gull Island is thriving, with long-term population growth and breeding success levels that are at the extreme high end for Alaska. Chisik is at the other extreme, with kittiwakes that fail chronically, and populations that have declined for 30 years. The Barrens have exhibited modest growth in recent years. About 20 ecological parameters (including measures of population trend, breeding biology, diet, foraging behavior, physiology, and food abundance) were examined for both Black-legged Kittiwakes and Common Murres. We evaluated these parameters and assessed their overall value for long-term monitoring with respect to how important they were for managing populations, how much effort was needed to collect data, how well they correlated with food abundance, and what kind of sample size would be needed to assess inter-annual changes. We consider the implications of these results for long-term monitoring protocols.

Key Words: Cook Inlet, Kachemak Bay, Gull Island, Barren Islands, Chisik Island, *Exxon Valdez* oil spill, Common Murre, Black-legged Kittiwake, forage fish, population, demography, breeding biology, foraging behavior, physiology, power analysis, trends, protocols, monitoring.

Project Data: *Description of data* – data used for this project were summarized from other project data sets, including restoration projects 00163J, 00163M, and 00338. For further information, contact John Piatt, Alaska Science Center, USGS, 1011 E. Tudor Rd., Anchorage AK 99503.

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Executive Summary: We monitor seabirds in order to assess changes in their population biology over time and because seabirds themselves can be monitors of the marine environment, offering insight into ecological change. However, protocols for monitoring are constantly evolving, and functional relationships between seabirds and their environment are still poorly defined— making it sometimes unclear what seabirds are really telling us about their environment. As part of the *Exxon Valdez* Trustee Council (EVOSTC) restoration program, we studied seabirds and prey resources at colonies in lower Cook Inlet known from historical work to be chronically failing (Chisik Island), thriving (Gull Island) and possibly stable or recovering from the oil spill (Barren Islands). For 5 years, more than 20 ecological parameters (including measures of population trend, breeding biology, diet, foraging behavior, physiology, and food abundance) were examined for both Black-legged Kittiwakes and Common Murres at each colony. Owing to the extreme differences in ecology among these colonies, results of these studies provided us with 15 colony-years of data that varied over a wide— and natural— range of values for each parameter. From this, we set out to develop a long-term monitoring strategy, in part to help facilitate GEM, the Gulf Ecosystem Monitoring project initiated by the EVOSTC. We asked 4 basic questions of the data: 1) Which parameters have most value for managing seabirds? 2) What time investment is required to obtain the data? 3) Which parameters have most value for "monitoring the marine environment"? and, 4) What sample size is required to detect small, medium and large changes in a parameter value relative to the range of values likely to be observed? The first two questions were answered subjectively from our own experience. The third question was refined to ask which parameters are correlated with measures of food availability, which is itself presumed to be a proxy for quality of the environment. The answer to this question was provided by direct measure of the correlation between parameter values and local prey abundance, as determined in APEX studies. Finally, in our most exhaustive examination of the data, we used power analyses on data collected during the APEX studies to estimate sample sizes needed to measure inter-annual changes of 10, 20 or 50%. We ranked each parameter for each of the 4 questions, and calculated an overall index that we can use to rank all the parameters for their "quality" as a parameter for long-term monitoring. To summarize results and conclusions: The most important parameters for management are those that directly yield demographic data. Time investment in the field falls into three broad categories— work that takes multiple years to complete (assessing population trends), more than 1 month to complete (e.g., measuring reproductive success) or less than a month (e.g., sampling chick feeding rates). Parameters most closely correlated with food availability differ between murres and kittiwakes and are not always intuitive. For example, kittiwake— but not murre— fledging success is correlated with food supplies; and murre— but not kittiwake— adult co-attendance at nests is correlated with food abundance. For most parameters, it would require extraordinary or impractical sample sizes to measure change between years equivalent to 10% of the expected range. However, a 20% effect could be measured for most parameters with reasonable sampling. This includes sampling of prey abundance around colonies. Overall, the most desirable parameters (highest ranking) for long term monitoring of kittiwakes are: breeding success, fledging success, population trend (plot census), and stress hormone levels during chick-rearing. For murres, the most desirable parameters are: population trend, adult co-attendance at chick-rearing, breeding success, and hatch date. These specific results are now ready to be used in planning a long-term monitoring program for seabirds in the Gulf of Alaska. For example, with knowledge about the spatial scale of GEM studies, approximate funding levels, primary focus of seabird studies (e.g., do we want to use them as monitors?), and time frames, we can make objective decisions about which species and parameters to focus on, whether to concentrate intense effort at a few colonies or collect minimal data on selected parameters at multiple colonies, etc., etc.

Introduction:

Studies conducted after the *Exxon Valdez* oil spill (EVOS) suggested that some seabird populations in the Gulf of Alaska had undergone marked fluctuations during the past few decades, some of which were due to effects of the oil spill (Byrd et al. 1998, Piatt and Anderson 1996). Results of investigations conducted with funding of the *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) during the period 1989-2001 included damage assessment studies of populations (e.g., Nysewander et al. 1993) and restoration studies to evaluate the ecological conditions affecting seabird recovery. The latter studies have focused on how food availability, environmental conditions and biological constraints on seabirds at colonies affect overall population dynamics (e.g., Piatt et al. 1998, 1999; Zador and Piatt 1999, Robards et al. 1999, Roseneau et al. 1999, 2000; Piatt 2002). These detailed studies included many research components that required considerable funding and logistic effort.

In trying to assess the impacts of oil, and especially separating oil effects from those resulting from natural changes in the environment, it became apparent that the lack of rigorous baseline data was a serious problem (Nysewander et al. 1993). Biologists were polarized in debates over how to interpret historic information that was collected largely for descriptive purposes (Piatt 1997, Peterson 2001). Too few demographic and behavioral parameters had been measured prior to the spill to provide a basis for comparisons that could have helped separate causes of changes (i.e., influences of changes in demography from oil impacts or changes in prey due to environmental changes). The need for better data was apparent.

Now 15 years after the spill, the *Exxon Valdez* Oil Spill Trustee Council is developing a program to support long-term monitoring of marine ecosystems and species impacted by the spill in Prince William Sound and the Gulf of Alaska. The objectives and scope of a long-term monitoring program are still being evaluated (Gulf Ecosystem Monitoring (GEM) and Research Program, July 9, 2002), but it is clear that funds available annually for the long-term effort will be considerably less than funding levels available during the restoration and ecosystem studies. As a result, it is critical to gather data— the most useful data— as efficiently as possible.

In order to design an appropriate and cost-effective long-term monitoring strategy for seabirds, it is necessary to identify which parameters are most important to measure, and how to allocate sampling effort. In Cook Inlet, we measured forage fish abundance and aspects of breeding biology, behavior and physiology of Black-legged Kittiwakes (*Rissa trydactyla*) and Common Murres (*Uria aalge*) at three colonies (the Barren Islands, Gull Island and Chisik Island) from 1995 to 1999 (Piatt et al. 2000, Roseneau et al. 2000). Parameters measured included catch per unit effort (CPUE) of fish in beach seines and mid-water trawls, relative acoustic biomass of fish, adult and chick diets, chick feeding rates, chick growth rates, adult mass and corticosteroid levels, adult time-budgets (foraging trip duration, nest attendance), breeding phenology, breeding success (laying, hatching, fledging), and population size. Our study included a failing colony (Chisik) and an increasing colony (Gull), and the 1997-1998 El NiZo event, so our data were collected over a very wide range of foraging and breeding conditions.

The object of this report is to use our fifteen colony-years of data as a baseline study for evaluating the usefulness of these parameters for a long-term monitoring program. We considered the value of monitoring parameters in terms of (1) usefulness from a management perspective, and (2) utility in monitoring environmental conditions. We evaluated the cost of measuring different parameters in terms of (1) time needed at the colony for measurement, and (2) sampling effort necessary to detect desired effect levels.

Sampling effort for seabird monitoring is determined by the degree of statistical certainty that is sought by a researcher (reflected in the values of α and β), the variability among samples taken within a given colony-year, and the amount of difference among colony-years that the researcher wants to detect (effect size). While variability among samples is relatively straightforward to establish through a pilot study, decisions involving statistical certainty and effect size are more subjective, and must reflect the fundamental goals of a study design (Rossi 1995). In a monitoring context the harm of a type-II error (falsely concluding that no change is occurring) is potentially as great as the harm associated with a type-I error (falsely concluding that change is occurring). For this report we therefore set α, which can be understood as the chance of making a type-I error, equal to β, the chance of making a type-II error. Furthermore, since one of the fundamental purposes of a monitoring program is to act as a first indicator of environmental change, we believe that the traditional value of $\alpha = 0.05$ is too stringent a statistical standard for demonstrating environmental change for our purposes (Cowles and Davis 1982). We therefore relaxed α to 0.10.

Standards for establishing effect size have long been debated in the psychological and ecological literature, and no standard is universally agreed upon among ecologists (Toft and Shea 1983, Rotenberry and Wiens 1985, Cohen 1992, Johnson 1999). However, this controversy generally deals with post-hoc power analysis of negative results, and effect size is more straightforward for study design questions such as ours (Toft and Shea 1983). Our approach is to use our baseline study as an indicator of the amount of variability inherent in each parameter in the Gulf of Alaska, and to use this observed variability in determining effect size and desired sampling effort. This approach reflects a fundamental goal of this report; efficiency can be maximized by studying parameters that naturally tend to be very different among different colonies and years, rather than by pouring limited resources into detecting small differences in parameters that tend to be similar even at thriving and declining colonies.

The results of our analysis provide a framework for comparing the monitoring value of different parameters with the effort required to measure them. This framework will allow researchers to select parameters most suitable to monitoring seabird demography and trophic interactions for the Gulf Ecosystem Monitoring Program.

Methods:

Species and parameters

Black-legged kittiwakes and common murres are both circumpolar in distribution (Harrison 1983), and they are subjects for monitoring in both the North Atlantic (e.g., Nettleship 1976, Nettleship and Birkhead 1980, Harris and Wanless 1988, Hamer et al. 1984) and North Pacific regions (e.g., Hatch and Hatch 1988, 1989; Byrd 1989, Sydeman et al. 2001, Dragoo et al. 2003). Between them, these species are useful indicators of ecosystem change in the ocean because kittiwakes are surface feeders and murres are able to feed deep into the water column (Byrd 1989, Furness et al. 1993). Perhaps because of these differing feeding methods, kittiwakes tend to be more sensitive to prey fluctuations than murres (Monaghan *et al*. 1994).

As part of the *Exxon Valdez* Trustee Council (EVOSTC) restoration program (Projects 00163J, 00163M, 00163N, 00449, 00306, 00338) we studied seabirds and prey resources at colonies in lower Cook Inlet known from historical work to be chronically failing (Chisik Island), thriving (Gull Island) and possibly stable or recovering from the oil spill (Barren Islands). For 5 years, more than 20 ecological parameters (including measures of population trend, breeding biology, diet, foraging behavior, physiology, and food abundance) were examined for both Black-legged Kittiwakes (Table 1) and Common Murres (Table 2) at each colony. Owing to the extreme differences in ecology among these colonies, results of these studies provided us with 15 colony-years of data that varied over a wide— and natural— range of values for each parameter.

Sample units

Measures of murre and kittiwake productivity and breeding chronology were derived from data recorded during regular observations of nest-sites (Birkhead and Nettleship 1980). Kittiwakes and murres nest in dense clusters and adjacent nests may share similar fates (Nettleship 1976, Birkhead and Nettleship 1980). As a result, individual nests do not always provide independent estimates of breeding success, and clusters of nests are probably more appropriate sample units for breeding parameters like reproductive success and timing of nesting events (Byrd 1989). We therefore used plots of 10-40 neighboring nests as the sample unit for measurements of nesting success and timing (Tables 3 and 4, Piatt 2002). A minimum of seven to ten plots was subjectively selected (to include different habitat types) at each study location (Chisik, Gull, and Barren Islands). Observations of each plot were made from designated sites. Plot boundaries— defined by recognizable, permanent features of the substrate— were clearly marked on photographs taken from the observation point, and on hand-drawn maps that show recognizable features of the terrain.

In contrast, we had no *a priori* reason to expect that assumptions of independence would be violated by treating neighboring nests as independent when measuring behavioral parameters (nest attendance, foraging trip length, etc.). We used a General Linear Model procedure to confirm this assumption of independence. Analysis of the effects of nest-site and sampling date on behavioral data generally showed that there was more variability among nests on a given day then among sampling days. We therefore concluded that an individual nesting pair was the appropriate sample unit for behavioral data (Tables 3 and 4). Adult time budgets were calculated from all-day observations of 8-12 nest-sites for each species at each study location (e.g., Zador and Piatt 1998). During observations, the time was recorded for each adult arrival, delivery of prey to chicks, exchange of incubation or brooding duty, and adult departure. Each observation-day began when nest-site activities became clearly visible and ended when it was too dark for observations to continue. Observations were spread out to sample the early, middle, and late parts of the incubation and nestling periods.

Adult kittiwakes regurgitate prey to young, and so the sample unit is the regurgitation (Table 4). To assess chick diet composition we collected chick regurgitations every 4 days during the chick-rearing period, when chicks were 10 to 30 days old (Schultz et al. 2002). Many of these samples were collected from chicks used for chick growth studies, and the remainder was taken from adults that were bringing back food for their chicks. Murres bring single fish to their chicks, held in line with the bill and with the tail outwards, leaving about half of the fish visible. We used binoculars to identify prey items to the lowest possible taxonomic level. Identification was based on the color and shape of the prey, and of the caudal, anal, adipose fins of fish (van Pelt 2002). Thus, the prey item is sample unit for murre diet (Table 4).

For the remaining parameters, including survival, body mass and plasma corticosteroid levels in adults, and growth rate, fledgling mass or age in chicks, the individual bird was the sample unit (Table 3 and 4). All of these measures required the capture of individual birds, whereupon they were weighed and measured, banded, and in the case of hormone studies, a small sample of blood was drawn for later analyses (Kitaysky et al. 1999a,b; Shultz 2002, van Pelt 2002, Piatt 2004)

Parameter criteria

We evaluated parameters by scoring them in four categories:

Management interest— Scored from 1 (lowest) to 3 (highest). Parameters that convey direct demographic information (e.g., breeding success) scored 3, those that allow managers to make inferences about demographic parameters (e.g., hatching success) scored 2, and those not conveying demographic information (e.g., attendance behavior) scored 1.

Utility as environmental monitor— Scored from 1 (lowest) to 3 (highest) by evaluating the response of the parameter to variability in food supply among colony years (Table 8), as determined in EVOS Restoration projects 00163M (Piatt 2002, Shultz et al. 2004) and 00338 (Piatt 2004). Parameters were scored high (3) if food supply explained a more than 60% of the variability in a parameter among colony-years, low (1) if food supply explained less than 30% of the variability in a parameter, and scored 2 for explaining intermediate levels of variation (30-60%). Some additional parameters that we did not compare against annual variability in food supply (e.g., population trends, diet composition) were given a rank based on decadal-scale associations demonstrated by other studies (Montevecchi 1993, Piatt and Anderson 1996, Springer 1998).

Time investment— We scored time demand for collecting parameter data according to whether it could be collected during a period of about one month or less (1), over a period of two or more months (2), or, in the case of plot census data, needs to be collected over several years (3) in order to be useful.

Required sampling effort— With some exceptions (e.g., population trends, Hatch and Hatch 1988, 1989), seabird breeding parameters would be expected to respond to changes in prey resources and other perturbations in a non-linear fashion (Cairns 1987). Furthermore, questions asked of seabird data often revolve around detecting impact of a one-time perturbation (e.g., acute oil mortality, El Niño effect). Therefore, we estimated the number of samples that would be needed to detect differences between years (one sample t-test or binomial test), rather than to detect a trend over a period of years (regression). The computer application "PASS 2000" (Hintze 2000) was used for calculations.

These calculations required us to predict the standard deviation of samples taken in a given colony-year, and specify the effect size that we wanted to detect. We averaged the standard deviations from every colony-year of the baseline study as the best estimate of standard deviation from a future colony-year. We set effect size at 10%, 20%, and 50% of the range observed in a parameter among all colony-years. Since the baseline study covered such a broad range of environmental conditions, the range that we measured for each parameter should be a good indicator of the range of possible values for that parameter. The three different effect sizes therefore correspond to a small, medium and large proportion of the variability typical for each parameter. In some cases, the data were transformed to ensure that the expectations for a parametric test were met. Following the decision rule of Clarke and Green (1988) we log(x+1) transformed CPUE and hydroacoustic biomass estimates to correct for heteroscedasticity. Hydroacoustic data were grouped into 10 min. bins, which corresponds to 2-3 km of transect distance.

We analyzed diet data for the two species as binomial proportions of the most common prey taxa in diets. This approach is superior to chi-square or log-likelihood analysis because it allowed us to calculate sample and effect sizes with the same approach we used for other parameters, and because it allowed us to use diet sample (e.g., kittiwake regurgitations) as our sample unit rather than individual prey organisms. We used to same approach to analyze binomial survival data. Because we only had data for 6 colony years in Cook Inlet (Piatt 2004), we also used survival data from other studies on Alaska kittiwakes (Hatch et al. 1993, Golet et al. 1998) and Pacific murres (at the Farallon Islands, Sydeman 1993).

In all cases, we scored sampling effort on a scale of 1-3, and considered sample size of 1-20 as low sampling effort (score 1), 21-100 as moderate sampling effort (score 2), and everything higher than 100 as high sampling effort (score 3).

Results and Discussion:

Populations

Population Trends— Population counts do not tend to reflect perturbations on an annual scale unless there is a large mortality of adult birds. More typically, population trends for long-lived seabirds tend to change slowly over many years, and most seabird population trends might be best described with non-linear models (e.g., Ainley et al. 1994, Hatch and Piatt 1995, Dragoo et al. 2003). Prior studies indicate that populations of Black-legged Kittiwakes and Common Murres can be monitored annually by counting index plots 5 times during the incubation and early chick-rearing period, and this provides enough statistical power to detect changes of 18-20% in populations between years (Hatch and Hatch 1988, 1989). Counting plots 10 times would allow detection of 12-14% changes in populations between years.

At the three colonies in Cook Inlet (Barren, Chisik and Gull islands), 6-10 counts of plots were conducted in each year of EVOSTC-funded study (1995-1999), and monitoring efforts in the future should continue to use this protocol. Given this level of sampling, our analyses suggest that it would take 5 consecutive annual surveys to detect a significant increasing trend at sites with similar coefficients of variation as East Amatuli and Gull Islands when the population was changing at a rate of 13% per year or more. It would take 6 years to detect a trend with a change as small as 8% (Table 5). It would take several more years to detect the same trends at Chisik, owing to higher variability in counts among years. In general, it would take about a year less to detect negative population trends at any colony (Table 5).

For both murres and kittiwakes, monitoring of population trends ranked highly in a benefit-cost analysis (Tables 6 and 7). Counting census plots yields demographic data of high value to managers, and it is moderately reflective of changes in the environment, particularly food supply (Springer 1992, Ainley et al. 1994). Benefits are offset by the need for a large time commitment (counting plots over many weeks or months each summer, and over many years), but sample sizes are quite low (5-10 counts each summer of 5-10 plots).

Survival— 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. Measurement of breeding success is common (below), but measurement of recruitment is rare owing to the very small number of fledglings that survive and return to the same colony to be detected years later, and the large time commitment needed for banding and re-sighting of juveniles. Thus, measuring adult survival is a logistic compromise, and one that yields data on a very important demographic parameter.

However, measuring adult survival is costly. Because the variance in survival among years tends to be low (e.g., Sydeman 1993, Hatch et al. 1993a), it takes a rather large sampling effort to detect the small inter-annual changes that are commonly observed. Thus, it is impractical to measure changes of less than 10% of the range (Tables 3 and 4), i.e., a change in survival of about 1.5 % because you would have to catch and band thousands of adult birds. However, catching a sample of about 600 banded individuals is often logistically practical, and would allow detection of about a 3% difference in survival (Tables 3 and 4). This is useful for measuring large annual perturbations, such as those associated with ENSO (K. Mills and W. Sydeman, *in prep*.). Much smaller samples (e.g., 40-50 birds) are adequate to detect larger differences in survival of 5-15%, although this level of variation is more likely to be observed among sites than within sites and among years (Piatt 2004).

Survival has a low to moderate overall ranking as a monitoring parameter (Tables 6 and 7). While it has very high management value as a fundamental demographic parameter, it also has a high cost with respect to both time investment and sample size. It ranked much higher as an environmental indicator in kittiwakes than murres because survival was strongly correlated with food supply for kittiwakes (Table 8), but not at all for murres in Cook Inlet (Piatt 2004).

Chick Diet

In terms of detecting change among years, the most common way to examine chick diets is to test for differences among years in the proportion of different prey taxa found in the diet (e.g., Suryan et al. 2000, Litzow et al. 2001) as opposed, for example, to looking for differences in mean mass of prey, or mean number of prey delivered, etc. (which are legitimate but less common ways of measuring diets). For prey items that are generally abundant, e.g., sand lance in kittiwakes (Table 3) and osmerids in murres (Table 4), moderate samples sizes (60-90) are needed to detect a 20% difference in range among years, equivalent to about a 16-18% change in diet proportion. For less common taxa, it may only be practical to detect a 50% difference in range among years, although as for common species, this is equivalent to a 10-30% change in diet proportion.

In terms of rank, diet does not fall out as being a highly desirable monitoring parameter for either murres (3rd level ranking, Table 6) or kittiwakes (5th level ranking, Table 7). On the positive side, diet provides some moderate insights into environmental conditions and logistically easy in the field. On the negative side, diet data does not have high management value, and has moderate sampling requirements.

Reproductive Success

Laying Success— A portion of black-legged kittiwakes that build nests, never lay eggs. In Lower Cook Inlet, an average of 70% of the pairs laid at least 1 egg, but this statistic varied from 24% to 92% among years and sites (Table 3). Due to this variability, we estimated it would require study of 24 plots to detect a small effect, 8 plots for a moderate effect, and only 3 plots to detect differences as large as 50% of the range. Laying success ranked poorly when considering overall benefits and costs (Table 6). We could not determine the proportion of common murres that attempted unsuccessfully to breed because they do not build nests structures.

Clutch Size— Black-legged kittiwakes lay 1-3 eggs per nest, and annual averages tend to range between 1.0 and 2.0 for most sites in Alaska (Hatch et al. 1993b), similar to the range recorded during APEX in Lower Cook Inlet (Table 3). We estimated that it would take approximately 97 plots to detect small (10% of range) effects, 26 plots to detect medium effects (20%), but only 6 plots to detect large effects (50%) (Table 3). Clutch size ranked poorly when considering overall benefits and costs (Table 6). Common Murres lay only one egg.

Hatching Success— The range and mean of annual estimates of hatching success for common murres at the three colonies in Lower Cook Inlet was typical of common murres in Alaska and elsewhere in the North Pacific (Byrd et al. 1993). We estimated that it would take 56 plots to detect a small effect, but only 16 and 4 plots to detect medium and small effects, respectively (Table 4). Values for hatching success varied over a somewhat wider range for black-legged kittiwakes, so estimates of plot sample sizes needed to detect various effects were lower (Table 3) than those of common murres. Overall rankings for this parameter were moderate for both species (Tables 6 and 7).

Fledging Success— Fledging success for both murres and kittiwakes covered the range typically observed for these species in Alaska (Hatch et al. 1993, Byrd et al. 1993). The number of kittiwake fledglings that hatched in Lower Cook Inlet from 1995-1999 ranged from 0 to 0.76 per nesting pair, and we estimated that it would take about 25 plots to detect small effects, 8 plots for moderate effects, and only 3 plots for large effects (Table 3). For murres, the variability among years was lower than for kittiwakes, so it would take about twice as many plots (54) to detect small effects. Moderate effects could be detected with 16 plots, and it would take 4 plots to detect large effects (Table 4). Fledging success had a good overall rank for kittiwakes, owing to its importance in understanding demography, and strong correlation with food supply (Table 8). It has less value for monitoring of murres owing to its poor relationship with food supply.

Overall Breeding Success— This parameter incorporates all the individual components discussed above, and so it is not surprising that sampling needs are also similar (Tables 3 and 4). Once again, it would be difficult to obtain enough samples needed to detect a 10% difference in the range among years. For both murres and kittiwakes, however, one may reasonably expect to be able to detect a 20% difference in range among years with small sample sizes of 10-20 plots (although murres require more sampling because there is less variation in breeding success). This is equivalent to detecting a change of ±14 % in kittiwake or murre breeding success. Although APEX protocols (Shultz et al. 2002) used in Cook Inlet for monitoring kittiwakes would still be adequate, it appears that we would need to increase the number of plots used to sample murres from 10 to at least 15 plots.

Breeding success ranks highly as a parameter for monitoring in both kittiwakes and murres (Tables 6 and 7). This is because breeding success is a key demographic parameter, with low sampling requirements. It is the number one ranked parameter in kittiwakes owing to its strong correlation with food supply (Table 8).

Phenology

Lay Dates— For kittiwakes it appears about 30 plots would be needed to detect small effects, but only 7 and 3 plots, respectively, would be needed to detect medium and large effects (Table 3). For murres, this parameter had a smaller range than for kittiwakes, and it would take 70, 18, and 3 plots respectively for the three effect levels (Table 4). These effect levels are equivalent to detecting a difference in phenology of about 2, 5 and 12 days, respectively, in timing of laying among years. Laying phenology has a moderate to good overall rank for murres and kittiwakes owing to strong correlations with food supply (Table 8).

Hatch Dates— For kittiwakes we determined that only 14 plots would be needed for detecting small effects, whereas medium and large effects could be detected with 6 and 3 plots, respectively (Table 4). This may be a little optimistic since the range of hatch dates recorded at Lower Cook Inlet colonies was lower than occurs typically elsewhere in Alaska (Byrd et al. 1993, Dragoo et al. 2003). Nevertheless, murre hatch date variation was normal, and we estimated that it would take more than 43 plots to detect small effects, but only 7 plots to detect moderate effects. Large effects could be detected with only 2 plots (Table 4). Hatching phenology has a moderate to good overall rank for murres and kittiwakes owing to strong correlations with food supply (Table 8).

Behavior

Chick-feeding Rate— Once again, the sample size needed to detect small effects of 10% is prohibitively large. For kittiwakes it would take 290 nesting pairs in the sample to detect small differences among years in the number of chick meals delivered per hour; and 241 pairs for murres. However, medium effects could be detected by observing 73 nests for kittiwakes, 61 for murres. Large effects could be seen with only 12 and 10 nests, respectively (Tables 3 and 4). Sampling for the medium effect would allow us to detect differences of about 0.5 meals per day for either species (when about 4 meals per day is the ideal). Sampling is complicated by the fact that only 8-12 nest sites can be monitored on any one day owing to the logistics of monitoring behavior in the field. One can select different nest-sites on different days and build up a sufficient sample size on multiple days of observations. Nonetheless, while relatively easy to collect, these data come with a high sampling cost, which moderates their overall ranking (Tables 6 and 7).

Foraging Trip Duration— Foraging trip duration is calculated from the same data set as that used to calculate chick-feeding rates, and of course the two behaviors are intimately related. For both kittiwakes and murres it would require observing more than 180 nesting pairs to detect small effects, and more than 45 pairs to detect moderate effects. Detection of small effects would require observation of only 8-9 pairs (Tables 3 and 4). As for chick-feeding rate, the overall rank for monitoring foraging trip duration is moderate.

Adult Attendance— For the incubation period, we had adequate data only for murres. To detect small differences in the number of bird minutes per hour that adult murres were present at nests during the incubation period, it would require observing more than 100 individuals. Medium effects could be detected with a sample of 26, and only 5 would be needed for detecting large effects (Table 4). For the chick-rearing period, we calculated that observations of 261 kittiwakes compared to 88 murres would be needed to detect small effects (Tables 3 and 4). Detection of moderate ($n = 65$) and small ($n = 11$) effects for kittiwakes also required more sampling effort than for murres ($n = 22$ and 4, respectively). This parameter ranked very poorly for kittiwakes: it has low management value, is a poor indicator of food supply (Table 8), and requires moderate sample sizes. However, it ranked 2nd as an monitoring parameter for murres, largely because it was strongly correlated with food supply (Table 8), and one of the best indicators of environmental conditions in murres (Zador and Piatt 1999).

Physiology

Adult Mass— Before considering body mass as a monitoring parameter, we examined seasonal variation. For murres, we examined a comprehensive seasonal data set from 1999 and calculated a PCA composite ‘body size index’ based on headbill, tarsus, and wing linear measurements, then regressed the body size against mass to derive residuals, or a ‘body condition index’. We grouped data into breeding phases: pre-laying, incubation and chick-rearing. We entered colony and phase as fixed factors in a GLM two-way ANOVA, with body condition as the response variable. Both factors were highly significant (phase $F_{2,143} = 14.642$, $P < 0.001$; colony $F_{1,143} = 8.543$, $P = 0.004$) but acted independently (phase and colony interaction term $F_{2,141} = 0.615$, $P = 0.542$). Based on these results, we would stratify sampling for murre body condition into at least three stages: prelay, incubation, and chick-rearing.

Similarly, kittiwake body condition was examined using one-way ANOVAs for representative colony-years. Breeding phases were delineated following the same method used for murres. Body condition was calculated as a simple size-corrected mass index (mass divided by wing length). Few ‘prelay’ data were available, since kittiwakes are very difficult to capture prior to egg-laying. We found that kittiwakes captured during incubation are in better condition than those captured during chick-rearing (1998 Chisik Island data, $F_{1,69} = 5.91$, $P = 0.018$; 1999 Gull Island data, one-way ANOVA on ranks $H = 16.00$, $df = 1$, $P < 0.001$). These results indicate that kittiwake body condition sampling should also be stratified into at least three stages: prelay, incubation, and chick-rearing.

Pre-laying mass varied little in murres. Consequently, we estimated that mass measurements would be needed for more than 1300 adults to detect a small effect. Medium and large effects require measuring 334 and 56 birds, respectively (Table 4). Measures of kittiwakes during the incubation period were more variable than for murres, and small effects could be detected by weighing about 1,000 adults (Table 3). Medium effects required 252 adult weights, and large effects could be detected with only 42 measurements. Murre weights were less variable relative to their range than kittiwakes during this period, therefore requiring smaller samples to detect similar levels of effects (Table 4). During the chick-rearing period, the weights of adult kittiwakes were much more variable than earlier in the season, and detection of small effects would require only 323 measures. Detection of medium and small effects also require less sampling (Table 3). Interestingly, the mass of murres varied over a smaller range during the chick-rearing period than during incubation, thus requiring more samples to detect various effect levels (Table 4).

Stress Hormone Levels— As for body condition, we examined seasonal variation in corticosteroid (CORT) concentrations for murres at Gull and Chisik in 97 and 98. CORT levels were measured at 4 stages of breeding; pre-laying, incubation, early chick-rearing, and late chick-rearing. Three-way ANOVA showed significant variation among colony ($F=21.8$, df 1, $p<0.001$) and breeding phase ($F=25.9$, df 3, $p<0.001$). Based on these results, we would stratify sampling for corticosteroids into breeding stages. Power analyses are conducted on corticosteroid levels for each strata.

For kittiwakes, blood samples would need to be taken from 414 birds to detect small effects in base levels during the incubation period, but this sample could be reduced to 50 during the late chick-rearing period (Table 3). Samples needed to detect moderate affects were 105 and 14, respectively, during incubation and late chick-rearing, and it would only take 18 and 3 samples, respectively, to detect large effects during the two periods. Base stress hormone measures in murres were more variable relative to range values during incubation than either pre-lay or chick-rearing, and so sample sizes were smallest at that time: 101, 27 and 6 for small, medium and large effects. In all cases, the size of samples needed to detect moderate (20%) changes was moderate as well for both kittiwakes and murres (Tables 3 and 4). Because CORT levels are correlated with food supply in both species, their value as monitoring parameters also ranked as moderate.

Chick Growth— We determined that kittiwake chick growth rates differed for “beta” or second chicks in two-chick broods from “alpha” or first chicks. To detect small effects for beta chicks would require sampling more than 1,200 chicks, and it would take a sample of 50 even to detect large effects (Table 3). If only first or single chicks are measured, fewer samples would be needed to detect various effects: 260 for small, 65 for medium, and only 11 for large effects. Single chick growth rates were modest monitoring parameters (Table 6).

Fledgling Mass— We did not measure murre chick growth during the chick-rearing period, but instead captured chicks soon after they fledged to determine mass. The variability was such that more than 218 chicks would need to be measured to detect small effects. Medium effects could be detected with 55 samples, and only 9 chicks would need to be measured to detect large effects (Table 4). Fledgling mass was a moderately ranked parameter (Table 7).

Fledging Age— This parameter varied from about 19 to 24 days among years and sites in Lower Cook Inlet. We calculated that the fledging age of 271 chicks would need to be determined to detect small effects. Medium and large effects could be detected with 68 and 11 samples respectively (Table 4). Fledging mass was a moderately ranked parameter (Table 7).

Measures of Food Availability

In addition to our studies of murres and kittiwakes, we also measured the abundance and species composition of prey schools in water around the main study colonies. These data complement any study of seabirds by revealing the type and quality of prey are available to birds, and in what range of abundance (e.g., Robards et al. 1999a,b, 2002; Abookire et al. 2002, Abookire and Piatt 2004, Litzow et al. 2004, Speckman 2004). Fish biomass can be estimated on systematic hydroacoustic surveys, where the sample unit is generally a parcel of water binned into some arbitrary distance by depth interval (Table 9). Abundance can also be estimated as catch-per-unit-effort (CPUE) in trawls or seines (Table 9).

Fish abundance data obtained from acoustic surveys or various fishing methods are notoriously variable, and it can be difficult to measure small changes in abundance or species composition among years (Robards et al. 1999a, Speckman 2004). However, the question we have asked of the bird data is: What proportion of variation in the anticipated *range* of values can we detect? Applying this question to the fish data, we found that because the range of possible values is large (Table 10), we can detect small to moderate changes in abundance (relative to range) among years. As for bird parameters, the sample sizes needed to detect a 10% change among years are large (ca. 200-500) and prohibitive logistically. However, sample sizes needed to detect a 20% effect on acoustic surveys (114) and from fishing nets (55-60) are quite reasonable, and in fact, routinely accomplished during APEX studies in Cook Inlet (Robards et al. 1999a, Litzow et al. 2004, Speckman 2004).

For individual species, we examined effect size on CPUE and species composition (Table 10). In most case, moderate to large sample sizes are needed to detect a moderate (20%) effect. For CPUE, a larger sample is needed to detect change in a common species (e.g., sand lance) than an uncommon species (e.g., capelin) because the range is lower for less common species. The sample size needed to detect changes in percent composition was of similar magnitude to that needed to detect change in CPUE (Table 10).

Summary and Conclusions:

During the course of EVOSTC funded research on seabirds and the marine environment of Cook Inlet, we gathered a wide array of data that was designed from the outset to assess functional relationships between seabirds and prey (Piatt 2002). Some of the data we collected is not routinely collected in seabird monitoring programs (e.g., attendance, stress hormones, prey abundance). In any case, only a few types of seabird monitoring data have been examined to assess the sampling effort required to detect change (e.g., census data, Hatch and Hatch 1988, 1989). The purpose of this exercise was to examine the full suite of data that we collected during EVOSTC-funded projects and determine which parameters would be most useful for long-term monitoring under the Gulf Ecosystem Monitoring program (actually designing a long term monitoring program is another exercise). We used power analyses to assess sampling effort for all these parameters, and ranked them for their benefits and costs. We reached the following major conclusions about our methods and results:

1) The effect most often tested in power analyses is that of varying the target value of a parameter by 10, 20 or 50% of its *mean* value (Toft and Shea 1983, Cohen 1992). In contrast, we set effect size as a proportion of the *range* of values observed in 15 colony years of study in Cook Inlet. We believe this was a superior approach because we studied an extreme range of failing and thriving colonies— a natural range in biology as wide as that found throughout the Gulf of Alaska and Bering Sea (Dragoo et al. 2003). It is more appropriate to ask about our ability to detect anticipated change as opposed to hypothetical change. For example, kittiwake breeding success (Table 3) was low on average (0.31 chicks/pair) and highly variable (range 0-0.72 chicks/pair). Sample size needed to detect a *20% of the mean* difference from the mean value is 52 plots. But the sample size needed to detect a *20% of the range* difference from the mean value is only 10 plots. The latter question is clearly more relevant for designing a monitoring protocol, and makes it more cost-effective and efficient: Why sample 52 plots when 10 will do under most conditions? Similarly, why would we want to estimate sample size needed to detect a *20% of the mean* change in body mass of incubating murres? Is it relevant to detect a difference between a 1053 g murre

(mean) and an 842 g murre (20% of mean) when the lowest average mass observed during 15 colony-years of study was 995 g (Table 4). Body mass is highly conserved in seabirds, exhibiting extremely low variation (Piatt 2002), and therefore it is more relevant to detect a *20% of the range* difference among years. However, we would need to increase our sample size from 30 to 101 individuals in order to detect a *20% of the range* difference. In this case, our study becomes more expensive, but we have some chance of detecting biologically relevant changes.

2) Effects as small as 10% of the range in means will be very expensive or logistically impractical to detect for nearly all parameters measured. Moderate (20%) effects are feasible to detect for most parameters of seabird breeding success and behavior, a few physiological parameters (stress, growth), and forage fish abundance. Only large effects (50%) can be reasonably detected for adult survival, changes in body condition, and changes in diet composition.

3) With existing (practical) protocols, and over a robust range of declining or increasing population scenarios, it can take 4 to 10 consecutive years of census effort to detect significant population trends.

4) Murres and kittiwakes have differing ecologies, and the choice of which parameters to monitor might differ depending on monitoring objectives. We ranked parameters according to 2 benefit criteria: utility for management, value for monitoring environment— and 2 cost criteria: time investment and sampling effort. A simple benefit-cost analysis suggests that overall, the most desirable parameters (highest ranking) for long term monitoring of kittiwakes are: breeding success, fledging success, population trend (plot census), and stress hormone levels during chick-rearing. For murres, the most desirable parameters to monitor are: population trend, adult co-attendance at chick-rearing, breeding success, and breeding phenology.

What's Next?

The specific results of this study are now ready to be used in planning a GEM long-term monitoring program for seabirds in the Gulf of Alaska. Before this takes place, however, we need to have guidelines about the scope and purpose of a GEM program. For example, what would be the spatial scale of a GEM program— would we have an opportunity to sample many colonies at fine spatial scales, or focus on only a few colonies and gather more extensive data at each? What would be the primary focus of a GEM study of seabirds— do we emphasize demographic parameters (focus on status of seabirds), or do we include parameters that allow us to use seabirds as indicators of food supplies (focus on ecosystem interactions)? What is the temporal scale of study— can we plan for long-term, annual collection of data on survival and population trend? This planning process would benefit from a group approach, with participants from the EVOSTC scientific council and biologists with expertise in marine bird and forage fish ecology.

Literature Cited:

Abookire, A.A. and J.F. Piatt. 2004. Structure of forage fish communities in relation to oceanographic conditions in lower Cook Inlet, Alaska. *Marine Ecology Progress Series, accepted.*

Abookire, A.A., J. F. Piatt and M.D. Robards. 2000. Nearshore fish distributions in an Alaskan estuary in relation to stratification, temperature and salinity. Estuarine, Coastal and Shelf Science 51: 45-59.

Ainley, D. G., W. J. Sydeman, and J. Norton. 1995. Upper trophic level predators indicate interannual negative and positive anomalies in the California Current food web. Mar. Ecol. Progr. Ser. 118: 69-79.

Anderson, P.J., and J.F. Piatt. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series 189:117-123.

Baird, P.H. 1994. Black-legged Kittiwake (*Rissa tridactyla*). In The Birds of North America, No. 92 (A. Poole and F. Gill, Eds.). Philadelphia: The Academy of Natural Sciences; Washington D.C.: The American Ornithologists Union.

Birkhead, T.R. and D.N. Nettleship. 1980. Census methods for murres *Uria* species? a unified approach. Canadian Wildlife Service Occasional Papers No. 43. 1-25.

Burger, A.E. and J.F. Piatt. 1990. Flexible time budgets in breeding Common Murres: Buffers against variable prey availability. Studies in Avian Biology 14:71-83.

Byrd, G.V. 1989. Seabirds in the Pribilof Islands, Alaska: trends and monitoring methods. M.S. thesis, Univ. of Idaho.

Byrd, G. V., E. C. Murphy, G. W. Kaiser, A. Y. Kondratyev, and Y. V. Shibaev. 1993. Status and ecology of offshore fish-feeding alcids (murres and puffins) in the North Pacific. Pp. 176-186 *in* The status, ecology and conservation of marine birds of the north Pacific (K. Vermeer, K. T. Briggs, K. H. Morgan, and D. Siegel-Causey, eds.). Can. Wildl. Serv. Spec. Publ., Ottawa.

Byrd, G.V., R.L. Merrick, J.F. Piatt, and B.L. Norcross. 1997. Seabird, marine mammal and oceanography coordinated investigations (SMMOCI) near Unimak Pass, Alaska. Pp. 351-364 *in*: Forage Fishes in Marine Ecosystems. Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems. Alaska Sea Grant College Program Report No. 97-01. University of Alaska Fairbanks.

Cairns, D.K. 1987. Seabirds as indicators of marine food supplies. Biol. Oceanogr. 5:261-271.

Cairns, D.K. 1992. Population regulation of seabird colonies. Current Ornithol. 9:37-61.

Cohen, J. 1992. A power primer. Psychol. Bull. 112:155-159.

Cowles, M., and C. Davis. 1982. On the origins of the .05 level of statistical significance. Am. Psychol. 37: 553-558.

Dragoo, D. E., G. V. Byrd, and D. B. Irons. 2003. Breeding status, population trends and diets of seabirds in Alaska, 2001. U.S. Fish and Wildl. Serv. Report AMNWR 03/05.

Erikstad, K.E., T. Tveraa, and R.T. Barrett. 1995. Adult survival and chick production in long-lived seabirds: a 5-year study of the kittiwake *Rissa tridactyla*. Pp. 471-477 in: Ecology of Fjords and Coastal Waters (Skjoldal, H.R., C. Hopkins, K.E. Erikstad, and H.P. Leinaas, eds.). Elsevier Science, London.

Furness, R.W., Greenwood, J.J.D. and Jarvis, P. 1993. Can birds be used to monitor the environment? Pp. 1-41. *In* Furness, R. W. and Greenwood. J.J.D. (eds.), Birds as monitors of environmental change. Chapman and Hall, London.

Gaston, A.J., D.G. Noble, and M.A. Purdy. 1983. Monitoring breeding biology parameters for murres Uria spp.: Levels of accuracy and sources of bias. Journal of Field Ornithology 54:275-282.

Gill, V.A., Hatch, S.A., Lanctot, R.B., 2002. Sensitivity of breeding parameters to food supply in black-legged kittiwakes, *Rissa tridactyl*a. Ibis 144, 268–283.

Golet, G.H., D.B. Irons, and J.A. Estes. 1998. Survival costs of chick rearing in black-legged kittiwakes. Journal of Animal Ecology 67:827-841.

Hamer, K.C., P. Monaghan, J.D. Uttley, P. Walton and M.D. Burns. 1994. The influence of food supply on the breeding ecology of Kittiwakes *Rissa tridactyla* in Shetland. Ibis 135:

Harris, M.P., and S. Wanless. 1988. The breeding biology of guillemots *Uria aalge* on the Isle of May over a six year period. Ibis 130:172-192.

Harris, M. P., and R. S. Bailey. 1992. Mortality rates of Puffin *Fratercula arctica* and Guillemot *Uria aalge* and fish abundance in the North Sea. Biol. Conserv. 60: 39-46.

Harrison, P., 1983. Seabirds: An Identification Guide. Houghton Mifflin, Boston.

Hatch, S.A. and M.A. Hatch. 1988. Colony attendance and population monitoring of Black-legged Kittiwakes at the Semidi islands, Alaska. Condor 90:613-620.

Hatch, S.A. and M.A. Hatch. 1989. Attendance patterns of murres at breeding sites: implications for monitoring. J. Wildl. Manage. 53:486-493.

Hatch, S.A., B.D. Roberts, and B.S. Fadley. 1993a. Adult survival of Black-legged Kittiwakes *Rissa tridactyla* in a Pacific colony. Ibis 135: 247-254.

Hatch, S. A., G. V. Byrd, D. B. Irons, and G. L. Hunt Jr. 1993b. Status and ecology of kittiwakes (*Rissa tridactyla* and *R. brevirostris*) in the North Pacific. Pages 140-153 *in* K. Vermeer, K. T. Briggs, K. H. Morgan, D. Siegel-Causey (eds.). The status, ecology, and conservation of marine birds of the North Pacific. Can. Wildl. Serv. Spec. Pub. Ottawa, Canada

Hatch, S.A., and J.F. Piatt. 1995. Seabirds in Alaska. *In*: Our Living Resources; National Biological Service, Report on Status and Trends of the Nation's Wildlife, Washington D.C. Pp. 49-52.

Hintze, J.L. 1999. NCSS 2000 Statistical System for Windows. Kaysville, Utah.

Hudson, P.J. 1985. Population parameters for the Atlantic Alcidae. *In*: The Atlantic Alcidae (D.N. Nettleship and T.R. Birkhead, eds.). Pp. 233-261.

Johnson, D. H. 1999. The insignificance of statistical significance testing. Journal of Wildlife Management 63: 763-772.

Kitaysky, A.S., J.C. Wingfield, and J.F. Piatt. 1999a. Dynamics of food availability, body condition and physiological stress response in breeding Black-legged kittiwakes. Functional Ecology.13:577-584.

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

Litzow, M.A., J.F. Piatt, A.A. Abookire, A.K. Prichard, and M.D. Robards. 2000. Monitoring behaviour, diving efficiency and time allocation of breeding Guillemots *Uria aalge*. Ibis 136:214-222. temporal and spatial variability in sandeel (*Ammodytes hexapterus*) abundance with pigeon guillemot (*Cepphus columba*) diets. ICES Journal of Marine Science 57:976-986.

Litzow, M.A., J.F. Piatt, A.A. Abookire, and M. Robards. 2004. Energy density and variability in abundance of pigeon guillemot prey: support for the quality-variability tradeoff hypothesis. Journal of Animal Ecology, *in press.*

Monaghan, P. P. Walton, S. Wanless, J.D. Uttley, and M.D. Burns. 1994. Effects of prey abundance on the foraging

Montevecchi, W. A. 1993. Birds as indicators of change in marine prey stocks. Pp. 217-266 *in* Birds as monitors of environmental change (R. W. Furness and J. J. D. Greenwood, eds.). Chapman and Hall, London.

Nettleship. 1976. Census techniques for seabirds of arctic and eastern Canada. Canadian Wildlife Service Occasional Papers 25:1-33.

Nysewander, D., C.H. Dipple, G.V. Byrd, and E.P. Knudtsen. 1993. Effects of the T/V Exxon Valdez oil spill on murres: A perspective from observations at breeding colonies. Bird Study No. 3. Final Report, U.S. Fish and Wildl. Serv., Homer AK.

Peterson, C.H. 2001. The *Exxon Valdez* oil spill in Alaska: acute, indirect and chronic effects on the ecosystem. Advances in Marine Biology 39: 1-103.

Piatt, J.F. 1997. Alternative interpretations of oil spill data. Bioscience 47: 202-203.

Piatt, J.F (ed.). 2002. Response of seabirds to fluctuations in forage fish density. Final Report to *Exxon Valdez* Oil Spill Trustee Council (Restoration Project 00163M) and Minerals Management Service (Alaska OCS Report 2002-068). Alaska Science Center, U.S. Geological Survey, Anchorage, Alaska. 454 pp.

Piatt, J.F. 2004. Survival of adult murres and kittiwakes in relation to forage fish abundance, *Exxon Valdez* oil spill, *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 00338), U.S Geological Survey, Alaska Biological Science Center, Anchorage, Alaska.

Piatt, J.F., B.D. Roberts, and S.A. Hatch. 1990. Colony attendance and population monitoring of Least and Crested Auklets on St. Lawrence Island, Alaska. Condor 92: 109-116.

Piatt, J.F. and P.J. Anderson 1996. Response of Common Murres to the *Exxon Valdez* Oil Spill and Long-term Changes in the Gulf of Alaska Marine Ecosystem. *In:* Rice, S.D., Spies, R.B., Wolfe, D.A., and B.A. Wright (Eds.). *Exxon Valdez* Oil Spill Symposium Proceedings. American Fisheries Society Symposium No. 18.

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.

Pollock, K.H., J.D. Nichols, C. Brownie, and J.E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs 107, 1-97.

Robards, M., J.F. Piatt, A. Kettle, and A. Abookire. 1999a. Temporal and geographic variation in fish populations in nearshore and shelf areas of lower Cook Inlet, Alaska. Fisheries Bulletin 97: 962-977.

Robards, M.D., J.F. Piatt, and G.A. Rose. 1999b. Maturation, fecundity and intertidal spawning of Pacific Sand Lance (*Ammodytes hexapterus*) in the northern Gulf of Alaska. Journal of Fish Biology 54: 1050-1068.

Robards, M.D., G.A. Rose, and J.F. Piatt. 2002. Growth and abundance of Pacific sand lance, *Ammodytes hexapterus*, under differing oceanographic regimes. Environmental Biology of Fishes. 64: 429-441.

Roseneau, D.G., A.B. Kettle, and G.V. Byrd. 1999. Barren Islands seabird studies, 1998. Appendix J in APEX: Alaska Predator Ecosystem Experiment (D.C. Duffy, Compiler), Exxon Valdez Oil Spill Restoration Project Annual Report (Restoration Proj. 98163), Alaska Heritage Program, Univ. Of Alaska, Anchorage, AK.

Rossi, J.S. 1995. Statistical power of psychological research: What have we gained in 20 years? J. Consult. Clinical Psychol. 58: 646-656.

Rotenberry, J. T. and Wiens, J. A. 1985. Statistical power analysis and community-wide patterns. American Naturalist 125: 164-168.

Shultz, M., J.F. Piatt, A. Kettle, A. Harding, T. van Pelt. 2003. Timing of breeding in seabirds: response to current or anticipated food supply? Submitted J. Animal Ecol.

Speckman, S.G. 2004. Characterizing fish schools in relation to the marine environment and their use by seabirds in lower Cook Inlet, Alaska. Unpubl. Ph.D. thesis, University of Washington, Seattle, WA.

Springer, A.M. 1992. A review: walleye pollock in the North Pacific-how much difference do they really make? Fisheries Oceanography 1: 80-96.

Springer, A. M. 1998. Is it all climate change? Why marine bird and mammal populations fluctuate in the North Pacific. pp. 109-119 *in* G. Holloway, P. Müller and D. Henderson (Eds), Biotic impacts of extratropical climate variability in the Pacific, Proceedings of 'Aha Huliko'a Winter Workshop, University of Hawaii at Manoa.

Suryan R.M., Irons D.B., Benson J. 2000. Prey switching and variable foraging strategies of black-legged kittiwakes and the effect on reproductive success. Condor 102:375–385

Sydeman, W.J. 1993. Survivorship of common murres on southeast Farallon Island, California. Ornis Scandinavica 24:135-141.

Toft, C. A. and Shea, P. J. 1983. Detecting community-wide patterns: estimating power strengthens statistical inference. American Naturalist 122: 618-625.

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

Table 1. Black-legged kittiwake parameters or reproductive ecology suitable for a monitoring program.

Category	Parameter	Interval	Measurement
Populations	Plot census	Trend	number of adults in plots
	Adult survival	Annual	proportion of adults surviving between years
Chick diet	Sand lance in diets	Annual	frequency of occurrence
Reproductive success	Laying success	Annual	proportion of nests where at least one egg is laid
	Clutch size	Annual	eggs per nest with eggs
	Hatching success	Annual	chicks per egg
	Fledging success	Annual	fledglings per chick
	Breeding success	Annual	fledglings per nest
Phenology	Lay date	Annual	lay date
	Hatch date	Annual	hatch date
Behavior	Chick feeding rate	Annual	chick meals per hour
	Foraging trip duration	Annual	trip duration (min.)
	Adult attendance during chick rearing	Annual	"bird-minutes" per hour
Physiology	Incubation mass of adults	Annual	mass (g)
	Chick-rearing mass of adults	Annual	mass (g)
	Incubation baseline corticosteroid levels	Annual	baseline corticosteroid concentration
	Late chick-rearing baseline corticosteroid	Annual	baseline corticosteroid concentration
	Chick growth rate (alpha / singleton chicks)	Annual	slope of linear regression of mass on age (6-22 d)
	Chick growth rate (beta chicks)	Annual	slope of linear regression of mass on age (6-22 d)

Table 2. Common murre parameters of reproductive ecology suitable for a monitoring program.

Category	Parameter	Interval	Measurement
Populations	Plot census	Trend	number of adults in plots
	Adult survival	Annual	proportion of adults surviving between years
Chick diet	Osmerids in diets	Annual	proportion of diet
	Sand lance in diets	Annual	proportion of diet
	Gadids in diets	Annual	proportion of diet
Reproductive success	Hatching success	Annual	chicks hatched per egg laid
	Fledging success	Annual	fledglings per chick
	Breeding success	Annual	fledglings per egg
Phenology	Lay date	Annual	lay date
	Hatch date	Annual	hatch date
Behavior	Chick feeding rate	Annual	chick meals per hour
	Foraging trip duration	Annual	trip duration (min.)
	Attendance during incubation	Annual	"bird-minutes" per hour
	Attendance during chick rearing	Annual	"bird-minutes" per hour
Physiology	Prelay adult mass	Annual	mass (g)
	Incubation adult mass	Annual	mass (g)
	Chick-rearing adult mass	Annual	mass (g)
	Late incubation maximum corticosteroid	Annual	maximum corticosteroid levels
	Incubation baseline corticosteroid	Annual	baseline corticosteroid levels
	Late chick-rearing baseline corticosteroid	Annual	baseline corticosteroid levels
	Fledging mass	Annual	mass (g)
	Fledging age	Annual	age (d) determined from plots

Table 3. Sampling effort required to detect typical variability among colony years in various black-legged kittiwake reproductive parameters. Three values of n refer to effort required to detect 10, 20 or 50 % of colony-year range if alpha = beta = 0.1.

Parameter	Sample unit	*N*** (colony-years)	Colony-year		Range of colony-year values	Grand colony-year mean	Mean SD within colony-years	*n* 10%	*n* 20%	*n* 50%
			Min	Max						
Populations										
Survival	individual adult	14	0.818	0.971	0.153	0.915	n/a	2621	607	54
Chick diet										
Sand lance in diets	regurgitation	9	0.03	0.83	0.80	0.40	n/a	342	87	13
Reproductive success										
Laying success *	plot	15	0.24	0.92	0.68	0.70	0.15	24	8	3
Clutch size	plot	15	1.08	1.83	0.75	1.52	0.25	97	26	6
Hatching success *	plot	14	0.12	0.91	0.79	0.56	0.19	35	10	4
Fledging success *	plot	14	0	0.76	0.76	0.37	0.15	25	8	3
Breeding success *	plot	15	0	0.72	0.72	0.31	0.15	32	10	4
Phenology										
Lay date	plot	15	5-Jun	29-Jun	24	15-Jun	3.62	30	7	3
Hatch date	plot	15	2-Jul	28-Jul	26	11-Jul	3.51	14	6	3
Behavior										
Chick feeding rate	nesting pair	11	0.11	0.25	0.14	0.18	0.08	290	73	12
Foraging trip duration	nesting pair	11	167.3	381.1	213.8	270.6	97.5	179	45	8
Chick rearing attendance	nesting pair	11	48.3	61.0	12.6	57.1	7.0	261	65	11
Physiology										
Incubation mass	individual adult	8	396.8	434.3	37.5	418.4	40.6	978	252	42
Chick-rearing mass	individual adult	8	363.6	421.3	57.7	390.0	35.6	323	84	14
Incubation base cort.	individual adult	9	4.28	9.98	5.70	6.80	3.96	414	105	18
Late chick-rearing base cort.	individual adult	7	3.31	21.10	17.80	9.79	4.22	50	14	3
Chick growth rate (a / s)	individual chick	12	11.0	19.1	8.2	16.2	4.4	260	65	11
Chick growth rate (b)	individual chick	9	12.6	16.5	3.9	15.3	4.8	1244	311	50

* Proportional data was arc-sine transformed prior to power analysis to estimate sample size.

** Most studies were conducted at 3 colonies over 5 years, and so 15 is the maximum sample size for evaluating parameters. However, it was not possible to obtain 15 samples in all cases; for example, kittiwakes often failed to rear any chicks at Chisik Island, and so we have fewer values for certain behaviors and measures of chick physiology. We also have fewer measures of adult physiology because these studies did not begin until later in the project.

Table 4. Sampling effort required to detect typical variability among colony years in various common murre reproductive parameters. Three values of *n* refer to effort required to detect 10, 20 or 50 % of colony-year range if alpha = beta = 0.1.

Parameter	Sample unit	N** (colony-years)	Colony-year Min	Colony-year Max	Range of colony-year values	Grand colony-year mean	Mean SD within colony-years	*n* 10%	*n* 20%	*n* 50%
Populations										
Survival	individual adult	11	0.859	1.00	0.141	0.93	n/a	2626	593	42
Chick diet										
Osmerids in diets	prey item	14	0.06	0.93	0.88	0.57	n/a	267	62	9
Sand lance in diets	prey item	14	0.01	0.60	0.59	0.18	n/a	411	113	22
Gadids in diets	prey item	14	0.00	0.23	0.23	0.05	n/a	904	263	64
Reproductive success										
Hatching success *	plot	14	0.37	0.90	0.53	0.74	0.14	56	16	4
Fledging success *	plot	13	0.21	0.92	0.71	0.73	0.20	54	16	4
Breeding success *	plot	14	0.13	0.81	0.68	0.59	0.20	63	17	5
Phenology										
Lay date	plot	9	6-Jul	26-Jul	20	14-Jul	6	70	18	3
Hatch date	plot	14	2-Aug	25-Aug	23	10-Aug	4	43	7	2
Behavior										
Chick feeding rate	nesting pair	15	0.19	0.35	0.16	0.26	0.08	241	61	10
Foraging trip duration	nesting pair	15	113.7	241.7	128.1	162.0	62.5	205	52	9
Incubation attendance	nesting pair	14	64.1	87.6	23.4	73.0	8.0	102	26	5
Chick rearing attendance	nesting pair	15	60.2	75.9	15.7	68.0	5.0	88	22	4
Physiology										
Prelay adult mass	individual adult	8	1018.2	1076.0	57.8	1044.8	72.4	1335	334	56
Incubation adult mass	individual adult	8	995.0	1089.3	94.3	1053.1	72.2	506	127	22
Chick-rearing adult mass	individual adult	8	982.5	1041.0	59.0	1007.2	74.7	1374	344	57
Pre-lay base cort.	individual adult	10	4.71	19.50	14.80	9.41	6.15	150	39	8
Incubation base cort.	individual adult	11	3.83	19.50	15.70	8.27	5.35	101	27	6
Late chick-rearing base cort.	individual adult	10	3.72	18.69	15.00	8.50	6.02	140	36	8
Fledging mass	individual chick	10	199	253	54	229	27	218	55	9
Fledging age	individual chick	8	19	24	5	21	3	271	68	11

* Proportional data was arc-sine transformed prior to power analysis to estimate sample size.

** Most studies were conducted at 3 colonies over 5 years, and so 15 is the maximum sample size for evaluating parameters. However, it was not possible to obtain 15 samples in all cases; for example, it was not possible to capture adults or chicks in most years, or monitor laying phenology at the Barren Islands, and so we have fewer values for certain parameters. We also have fewer measures of adult physiology because these studies did not begin until later in the project.

Table 5. Analysis of the number of years (assuming annual surveys) required to detect significant trends in populations of black-legged kittiwakes and common murres using data from Lower Cook Inlet colonies from 1995-1999 to approximate expected coefficients of variation (alpha = beta = 0.1). Estimates are based on 6 to 10 replicate counts per year.

Species	Island	Rate of Change[a]	C.V.[b]	Number of Years to Detect Trend
Bl.-legged Kittiwake	East Amatuli	0.08 (-0.08)[c]	0.07	6 (5)
		0.13 (-0.13)	0.07	5 (4)
	Gull	0.08 (-0.08)	0.07	6 (5)
		0.13 (-0.13)	0.07	5 (4)
	Chisik	0.08 (-0.08)	0.19	10 (9)
		0.13 (-0.13)	0.19	7 (7)
Common Murre	East Amatuli	0.08 (-0.08)	0.13	8 (7)
		0.13 (-0.13)	0.13	6 (6)
	Gull	0.08 (-0.08)	0.11	7 (7)
		0.13 (-0.13)	0.11	6 (5)
	Chisik[d]			

[a] Reasonable range in rates of change (from Roseneau et al. 1998, 2000, Piatt 2002). [b] Coefficient of Variation based on standard error of the estimate from a regression divided by the mean count among years. [c] Values in parentheses are for declining trends. [d] Insufficient number of years from Chisik to estimate C.V.

Table 6. Benefits and costs of collecting data on Black-legged Kittiwake parameters, scored for management interest (MAN, scores 1-3), value for monitoring environment (ENV, scores 1-3), logistic demand (LOG, scores 1-3 for time required to collect data) and sample size needed to detect change (SAM, scores 1-3) . For "Benefit" scoring, a high score reflects high value. For "Cost" scoring , a high score indicates high cost in time or sampling effort required. Benefit/Cost ratio calculated as (MAN*ENV/LOG*SAM).

Category	Parameter	Benefit		Cost		Benefit / Cost Ratio	Overall ranking
		MAN (1-3)	ENV (1-3)	LOG (1-2)	SAM (1-3)		
Populations	Plot census	3	2	3	1	2.00	*** 3
	Survival	3	3	2	3	1.50	**** 4
Chick diet	Diet composition	1	2	1	2	1.00	***** 5
Reproductive success	Laying success	1	1	2	1	0.50	******* 7
	Clutch size	2	1	2	2	0.50	******* 7
	Hatching success	2	2	2	1	2.00	*** 3
	Fledging success	2	3	2	1	3.00	** 2
	Breeding success	3	3	2	1	4.50	* 1
Phenology	Lay date	1	3	2	1	1.50	**** 4
	Hatch date	1	3	2	1	1.50	**** 4
Behavior	Chick feeding rate	1	3	1	2	1.50	**** 4
	Foraging trip duration	1	3	1	2	1.50	**** 4
	Chick rearing attendance	1	1	1	2	0.50	******* 7
Physiology	Incubation mass	1	1	1	3	0.33	******** 8
	Chick-rearing mass	1	1	1	2	0.50	******* 7
	Incubation base cort.	1	2	1	3	0.67	****** 6
	Late chick-rearing base cort.	1	2	1	1	2.00	*** 3
	Chick growth rate (a / s)	1	3	1	2	1.50	**** 4
	Chick growth rate (b)	1	1	1	3	0.33	******** 8

* Minimum time required to measure breeding success or entire breeding phenology, consult Fig. 1 for requirements of individual components of breeding success and phenology.

Table 7. Benefits and costs of collecting data on Common Murre parameters, scored for management interest (MAN, scores 1-3), value for monitoring environment (ENV, scores 1-3), logistic demand (LOG, scores 1-3 for time required to collect data) and sample size needed to detect change (SAM, scores 1-3) . For "Benefit" scoring, a high score reflects high value. For "Cost" scoring , a high score indicates high cost in time or sampling effort required. Benefit/Cost ratio calculated as (MAN*ENV/LOG*SAM).

Category	Parameter	Benefit		Cost		Benefit / Cost Ratio	Overall ranking
		MAN (1-3)	ENV (1-3)	LOG (1-2)	SAM (1-3)		
Populations	Plot census	3	2	3	1	2.00	* 1
	Survival	3	1	2	3	0.50	**** 4
Chick diet	Diet composition	1	2	1	2	1.00	*** 3
Reproductive success	Hatching success	2	1	2	1	1.00	*** 3
	Fledging success	2	1	2	1	1.00	*** 3
	Breeding success	3	1	2	1	1.50	** 2
Phenology	Lay date	1	3	2	1	1.50	** 2
	Hatch date	1	3	2	1	1.50	** 2
Behavior	Chick feeding rate	1	2	1	2	1.00	*** 3
	Foraging trip duration	1	2	1	2	1.00	*** 3
	Incubation attendance	1	2	1	2	1.00	*** 3
	Chick rearing attendance	1	3	1	2	1.50	** 2
Physiology	Prelay adult mass	1	1	1	3	0.33	***** 5
	Incubation adult mass	1	1	1	3	0.33	***** 5
	Chick-rearing adult mass	1	1	1	3	0.33	***** 5
	Pre-lay baseline corticosteroid	1	2	1	2	1.00	*** 3
	Incubation base corticosteroid	1	2	1	2	1.00	*** 3
	Chick-rearing base corticosteroid	1	2	1	2	1.00	*** 3
	Chick fledgling mass	1	2	1	2	1.00	*** 3
	Chick fledging age	1	2	1	2	1.00	*** 3

* Minimum time required to measure breeding success or entire breeding phenology, consult Fig. 2 for requirements of individual components of breeding success and phenology.

Table 8. Seabird parameters ranked according to the strength of their functional relationship with prey density. BLKI= Black-legged Kittiwake; COMU= Common Murre; n= number of colony-years of data. Ranks are low ($r^2 < 30$), med ($30 < r^2 < 60$) and high ($r^2 > 60$) according to their value as a proxy for environmental conditions. Most data from Piatt (2002). Phenology data from Shultz et al., 2004. Corticosteroid data from Kitaysky, unpubl.

Species	Parameter	n	Relationship with Fish Density			Rank
			model r^2	model p	best-fit model	value
BLKI	Beta Chick Growth Rate	9	0.00	NS	none	1
	Laying Success	15	0.00	NS	none	1
	Clutch Size	15	0.01	NS	none	1
	Adult Body Condition	15	0.03	NS	none	1
	% Time Adult Present with Chick	11	0.08	NS	none	1
	Corticosteroid level	16	0.25	NS	none	1
	Hatching Success	14	0.53	0.049	sigmoidal	2
	Brood Size at Fledging	11	0.59	0.084	sigmoidal	2
	Foraging Trip Duration	11	0.61	0.008	neg. exponential	3
	Breeding Success	15	0.64	0.009	sigmoidal	3
	Chick Feeding Rate	11	0.71	0.045	sigmoidal	3
	Alpha/Singleton Chick Growth Rate	12	0.73	0.012	sigmoidal	3
	Adult Survival	6	0.74	0.030	neg. linear	3
	Laying Phenology	7	0.76	0.010	linear	3
	Density at Sea	12	0.80	<0.001	sigmoidal	3
	Fledging Success	13	0.89	<0.001	sigmoidal	3
COMU	% Time Adult Present with Chick	15	0.00	NS	none	1
	Fledging Success	13	0.00	NS	none	1
	Breeding Success	14	0.02	NS	none	1
	Adult Body Condition	13	0.04	NS	none	1
	Adult Survival	6	0.10	NS	none	1
	Hatching Success	14	0.11	NS	none	1
	Chick Feeding Rate	15	0.41	0.011	linear	2
	Chick Age at Fledging	8	0.44	0.073	neg. hyperbolic	2
	Foraging Trip Duration	15	0.49	0.005	neg. exponential	2
	Corticosteroid Level	16	0.51	0.050	linear	2
	Discretionary Time at Incubation	14	0.54	0.040	sigmoidal	2
	Laying Phenology	7	0.64	0.030	linear	3
	Discretionary Time at Chick-rearing	15	0.65	0.008	sigmoidal	3
	Density at Sea	12	0.70	0.017	sigmoidal	3
	Chick Body Condition	10	0.71	0.044	sigmoidal	3

Table 9. Measurements of food availability suitable for a seabird ecology monitoring study.

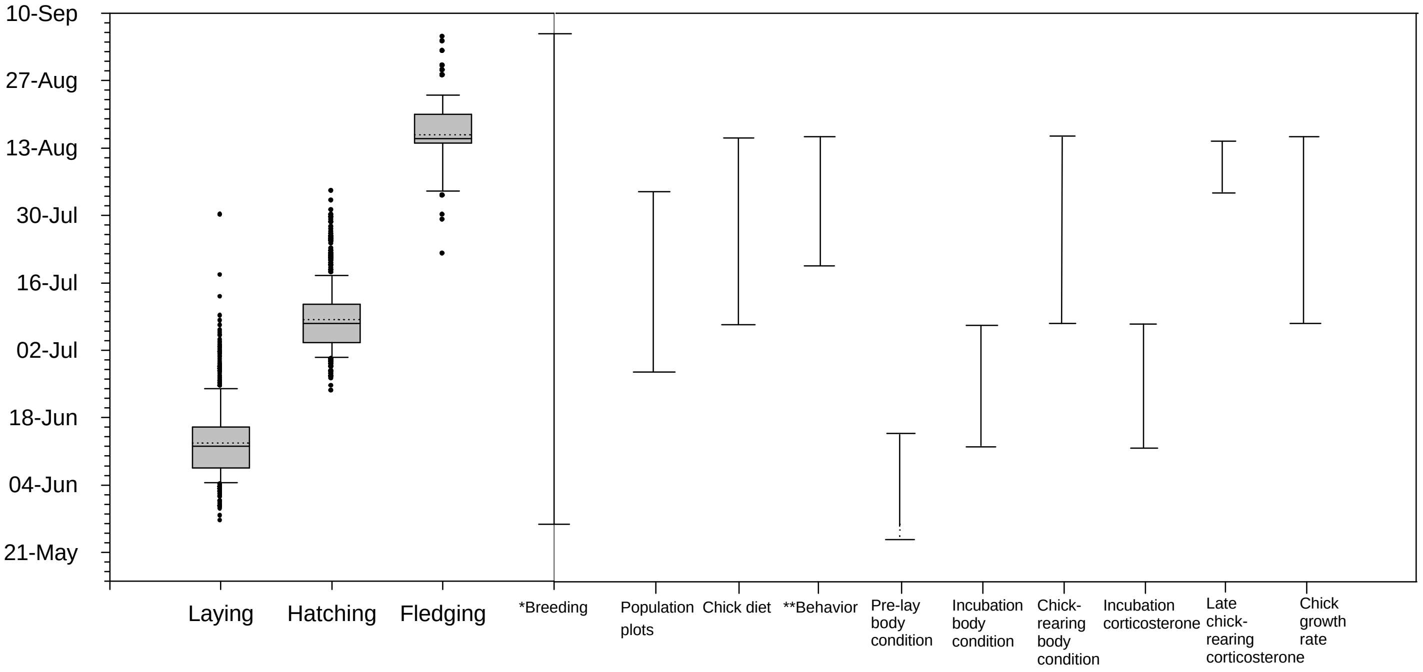
Method	Parameter	Interval	Measurement	Sample unit
Hydroacoustics	Acoustic biomass (relative or absolute)	Annual	mass/volume	depth/distance bin
Mid-water trawl	Total catch-per-unit effort (CPUE)	Annual	fish / set	trawl set
Beach seine	Total catch-per-unit effort (CPUE)	Annual	fish / set	seine set
Trawl/seine	Abundance of common species (sand lance)	Annual	CPUE or % Catch	set
	Abundance of less common species (herring)	Annual	CPUE or % Catch	set
	Abundance of rare species (capelin)	Annual	CPUE or % Catch	set

Table 10. Sampling effort required to detect typical variability among in fish abundance among colony years. Analyses conducted for measures of total fish abundance using 3 different gear types, and for abundance of individual species as measured by CPUE and proportion of catch. Species were selected to represent abundant (sand lance), commmon (herring) and uncommon (capelin) species in catches. Three values of *n* refer to effort required to detect 10, 20 or 50 % of colony-year range if alpha = beta = 0.1.

Method	Parameter	*N* (colony-years)	Colony-year		Range of colony-year values	Grand colony-year mean	Mean SD within colony-years	*n* 10%	*n* 20%	*n* 50%
			Min	Max						
Hydroacoustics	Biomass (g/m3) *	15	0.0034	0.0691	0.0657	0.0243	0.0801	451	114	20
Mid-water trawl	Fish/km trawled *	12	56	12596	12540	2078	2941	213	55	11
Beach seine	Fish/set *	14	23	4032	4009	841	2966	232	60	11
Beach seine	Sand lance CPUE *	14	0	3995	3995	763	4671	367	93	17
(by species)	Herring CPUE *	14	0	415	415	103	1113	225	58	11
	Capelin CPUE *	14	0	31	31	6	55	69	19	5
	Sand lance % **	14	0	99.1	99.1	49.6	n/a	140	36	8
	Herring % **	14	0	22.1	22.1	6.3	n/a	641	162	28
	Capelin % **	14	0	12.9	12.9	1.4	n/a	48	14	4

* Abundance data was log(x+1) transformed prior to power analysis to estimate sample size.

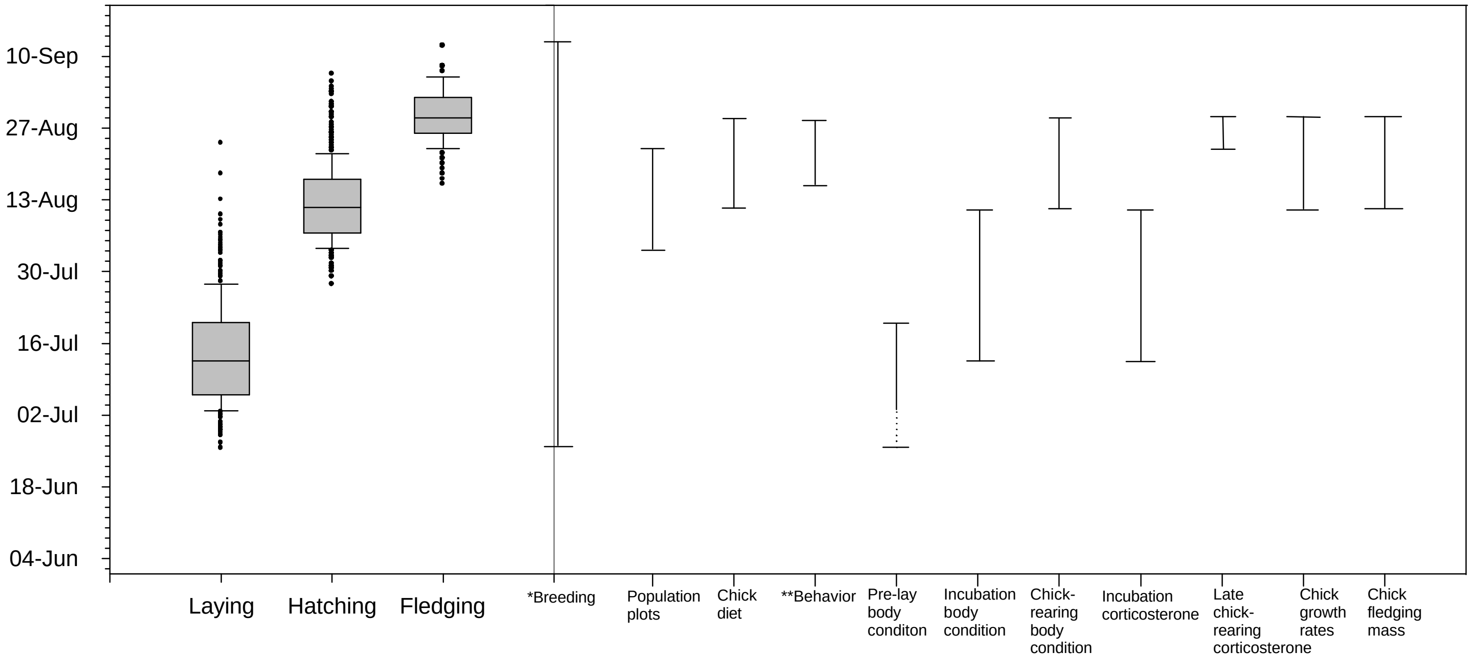
** Proportional data was arc-sine transformed prior to power analysis to estimate sample size



* Includes the following parameters: laying success, clutch size, hatching success, brood size at hatch, fledging success, brood size at fledge, productivity, hatch date and lay date.

** Includes the following parameters: chick feeding rate, forage trip duration and adult attendance during chick-rearing.

Figure 1. Box and whisker plots of average laying, hatching and fledging chronology for Black-legged Kittiwakes in Cook Inlet (grouped data from Gull and Chisik islands, 1995-1999). Windows of time for collection of data on seabird parameters are shown to the right as vertical lines. In box and whisker plots the horizontal line is median value, the box includes the inter-quartile range (IQR, middle 50% of observations), the vertical lines indicate values 1.5x the IQR. Outlying values shown as points.



* Includes the following parameters: laying success, clutch size, hatching success, brood size at hatch, fledging success, brood size at fledge, productivity, hatch date and lay date.

** Includes the following parameters: chick feeding rate, forage trip duration and adult attendance during chick-rearing.

Figure 2. Box and whisker plots of average laying, hatching and fledging chronology for Common Murres in Cook Inlet (grouped data from Gull and Chisik islands, 1995-1999). Windows of time for collection of data on seabird parameters are shown to the right as vertical lines. In box and whisker plots the horizontal line is median value, the box includes the inter-quartile range (IQR, middle 50% of observations), the vertical lines indicate values 1.5x the IQR. Outlying values shown as points.