Abstracts of Invited Papers for Seabirds as Indicators Symposium

FOUR THOUSAND YEARS OF INTERACTION BETWEEN HUMANS AND MARINE BIRDS OF THE ALEUTIAN ISLANDS

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A unique window into the biological history of the Aleutian Islands is provided by the zooarchaeology of early human sites. We focus on the palaeoavifauna hunted by early Aleuts who inhabited Amchitka and Buldir islands (central Aleutians), and Shemya Island (western Aleutians) from about 3,500 years ago to the present. Most of the seabird species recovered from these early sites varied widely in distribution and abundance through time and space. Pelagic procellariids such as Short-tailed Albatrosses (*Phoebastria albatrus*) and Short-tailed Shearwaters (*Puffinus tenuirostris*) were present and abundant at most sites and at most times. During periods of increased temperatures and precipitation (e.g., 650 – 1100 years before present), nearshore foragers such as cormorants and parakeet auklets increased in abundance, but during periods of cooling (e.g., 1800 – 2100 years before present), piscivorous birds feeding offshore, such as murres (*Uria* spp.) and kittiwakes (*Rissa* spp), predominated. Over four millennia, we found that marine birds were negatively correlated with temperature and positively correlated with precipitation. We detected hunter-related depletions of populations breeding in accessible colonies at small scales of space and time, but we did not observe widespread or long-term effects. We conclude that local oceanography and regional changes in prey bases caused by environmental and climate change in the past had a significant impact on the distribution of Aleutian marine birds.

SHIFTING SEABIRD DISTRIBUTION AND ABUNDANCE REFLECT A RAPIDLY CHANGING MARINE ENVIRONMENT IN THE WESTERN ARCTIC

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While the Bering Land Bridge allowed humans to disperse to the Nearctic during the Pleistocene, it was a major barrier to seabird dispersal on the Bering/Chukchi Shelf until approximately ten thousand years ago. Since then few seabird species have extended their ranges through Bering Strait, apparently due to climatic and oceanographic disparities between the subarctic Bering and arctic Chukchi. However, significant changes in the Arctic Basin over the last four decades have decreased the latitudinal environmental gradient in the region. Because the Chukchi Sea lacks a commercial fishery and systematic biological sampling, changes in seabird distribution and abundance may be the best indicators of the timing and magnitude of ongoing climate change. Recent indications of range expansions and population increases include both puffin species occupying colonies in northern Alaska and increasing numbers of other Bering Sea alcids on the northern shelf. Cold water species adversely affected by rapid warming include the Black Guillemot (*Cepphus grylle*) and Kittlitz's Murrelet (*Brachyramphus brevirostris*), both of which appear to be decreasing with reductions in pack ice. We discuss the species likely to have breeding or pelagic distributions and abundances modified by continued rapid environmental change and the conditions required for those modifications.

ADÉLIE PENGUINS AS CLIMATIC INDICATORS IN ANTARCTICA SINCE THE LATE PLEISTOCENE

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The Adélie Penguin (*Pygoscelis adeliae*) is an excellent indicator species for climate change and the marine environment in Antarctica. This species depends largely on sea ice for its foraging and winter habitat and is circum-Antarctic in distribution. Fossil and subfossil remains of Adélie Penguins have been recovered from numerous abandoned colonies in Antarctica since the 1950s. These remains are usually well preserved, along with dietary remains from guano, due to the cold, dry conditions in most of Antarctica. Thus, radiocarbon dates on these remains provide an occupation history of Adélie Penguins for specific regions that indicates the past presence of (1) open water near the colony during the austral summer, (2) adequate food within foraging range of the colony, and (3) sufficient ice-free coastal terrain for nesting sites. Research to date has indicated that Adélie Penguins respond to climate change

differently in the Antarctic Peninsula compared to the Ross Sea and East Antarctic regions. Here, this record is reviewed with recent data from the Ross Sea that suggest that two long periods of penguin abandonment occurred due to extensive and persistent sea ice during the Holocene. At least one of these episodes may have caused a massive population shift in this species at ~2000 years ago. Results also indicate that modern occupations in the Ross Sea are a relatively recent phenomenon, with most colonies dating to less than ~1000 years old. These data collectively demonstrate the highly dynamic and unstable nature of this marine ecosystem in Antarctica.

SEABIRDS AS INDICATORS OF PREY ABUNDANCE AND CLIMATE IN THE NORTH SEA

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The breeding performance of seabirds is generally thought to be linked to marine environmental conditions, but what exactly does it indicate? A measured variable (e.g. the breeding success of a given species) will be affected by at least three types of factors: generic aspects of the marine environment, species-specific responses to environmental factors such as food supply, population size or weather, and measurement error. Arguably, a useful indicator should be responsive mainly to factors affecting several species in the top predator community. Principal component analysis offers a way of extracting the common signal from a number of correlated time series and eliminating confounding factors. We used principal component analysis to analyse time series of breeding success of five species of seabirds on the Isle of May, and phenology of seven species on the Isle of May as well as the Farne Islands 100 km further south on the E coast of Britain. In each case, we found high correlations between four species, although not exactly the same set in each case. The first principal component of breeding success was positively correlated with the abundance of lesser sandeel (*Ammodytes marinus*) larvae in the previous year, indicating reliance on 1-year-old fish. The first principal component of phenology was negatively correlated with the North Atlantic Oscillation index, indicating that seabirds use widely available environmental cues to for timing of breeding. Correlations were at least as strong for principal components as for the original variables, showing that this method can help select robust indicators with general applicability.

SEABIRDS AS INDICATORS OF CONTAMINANTS

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It is often stated that seabirds are good monitors of contaminants because seabirds are top predators in marine food webs, yet many seabirds feed at low trophic levels, and only certain contaminants increase in concentration up food webs. However, seabirds can offer many advantages because their ecology is well known, they are easy to sample, they integrate signals over time and spatial scales, and some historical time series can be developed using archived material. Toxicity of contaminants to seabirds is generally poorly known. It is unlikely that changes in seabird demography give useful information on contaminants as these parameters are affected much more by factors such as food supply, predators, disturbance and climate. This leaves measurement of contaminants in/on seabirds as the main focus. Sampling eggs is an established means of monitoring contaminants, especially organochlorines. Levels in eggs closely reflect uptake by the female over days prior to laying, so reflect relatively local contamination. Feathers may be best for monitoring mercury, and may be useful for other metals and even for organic contaminants. Analyses of feathers from museum skins show ca.4-fold increases in mercury exposure in northern hemisphere marine ecosystems but little increase in the southern hemisphere, a pattern consistent with predictions based on known emissions and atmospheric circulation. Current advances include combining contaminant measurements with stable isotope analysis (including compound-specific SIA), and selection of appropriate feathers in relation to the annual molt cycle of seabirds to assess seasonal patterns of exposure/excretion.

SEABIRDS AS MONITORS OF ARCTIC CLIMATE CHANGE

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Arctic waters are characterized by the presence of seasonal or year-round ice cover. Seabirds are an important element in Arctic marine ecosystems where open water persists for 3 or more months of the year. The position of the seasonal ice zone and the duration of open water is very sensitive to air

temperatures and hence fluctuates strongly with variation in climate. This makes seabirds adapted to the seasonal ice zone especially sensitive to climate change. During the past several decades (since the 1960s) air temperatures in the Arctic, especially the North American portion, have warmed rapidly, leading to changes in ice conditions that have resulted in changes to the timing of breeding and reproductive success of several seabird species. For the Thick-billed Murre, one of the most abundant species of Arctic seabird, reduction in summer ice cover in the southern portion of its range have resulted in a deterioration in conditions for reproduction. Conversely, in northern parts of its range, conditions may be improving. As ice conditions have changed, diets have also changed, suggesting that the entire marine food-web has been transformed. However, because there are no commercial fisheries in the eastern Canadian Arctic, we have no confirmation of this. Seabird research in Canada's eastern Arctic demonstrates the power of seabird studies to illuminate ecosystem changes that would otherwise be difficult to identify.

HYPOTHETICO-DEDUCTIVE, PREDICTIVE, AND INDUCTIVE APPROACHES IN SEABIRD BIOLOGY

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Most of today's seabird science is hypothesis-driven. This reflects the frame of mind of researchers in our community and the policy of leading scientific journals. For some time a second, predictive approach has been put forward. This research avenue is based on the premise that most seabirds function as apex predators within marine food webs, and that they might be used as indicators of marine ecological processes, in particular in the context of global change. But is this approach really viable? I address this question using a case study of Arctic cormorants (*Phalacrocorax carbo*) and insights from the literature. From my own investigations I conclude that it is difficult to use seabirds as indicators of climate change without detailed knowledge of their biology throughout the yearly cycle. More specifically, my studies stress how little we know about the wintering ecology of seabirds, and how crucial such knowledge is if we are to integrate these organisms into predictive ecosystem models. Further, I show that most current seabird studies are neither hypothetico-deductive, nor predictive, but inductive. This means that we are facing particularly complex biological systems, and that we need to observe and explore them first, before we can describe underlying ecological processes. I therefore conclude that the use of a predictive approach in seabird science is attractive, yet rather premature. We should all remain critically aware and publicly advertise the fact that marine sciences are still in the exploratory phase, and that seabird research is part of this endeavour.

SEABIRDS AS INDICATORS OF MARINE ECOSYSTEMS: UNRESOLVED ISSUES OF SCALE

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The use of seabirds as indicators of marine environments has advanced greatly over the past 20 years but there are still many unresolved problems, especially concerning issues of scale. In particular, we have only limited answers to the following key questions: (1) at what spatial scale do different species of seabird respond to variation in marine environments? (2) what are the scales and magnitudes of changes in marine environments indicated by observed variation in seabird ecology? (3) what is the relationship between temporal and spatial scales of variation? Here I shall present recent data from my research group and project partners, indicating some possible approaches to addressing these issues. In particular I shall examine the spatial scale of correspondence in data from neighbouring colonies, the application of population dynamic principles to calibrate variation in breeding ecology against variation in prey availability, and the integration of spatially and temporally explicit information to examine responses of seabirds to long-term environmental change. These approaches provide a possible means of not only gaining a better understanding of past variation in marine environments but also predicting likely future changes. Two main conclusions arise from this work: (i) we now have a wealth of high-quality data for some species at some sites; rapid progress may be made by developing tools to integrate this information across species and across networks of monitoring sites; (ii) the geographical distributions of species contain powerful but often ignored information, which may provide a framework for integrating temporal and spatial patterns of variation.

SEABIRDS AS INDICATORS OF THE MARINE ECOSYSTEM: A PERSPECTIVE FROM COLONY-BASED MONITORING IN ALASKA

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Thirty years of seabird monitoring in Alaska support a few principles for using birds as indicators of their environment. Because it is generally impossible to set up relevant experiments, it is important to use a comparative approach on species selected for the diverse ways in which they sample the environment: inshore versus offshore foragers, divers versus surface feeders, and planktivores versus fish eaters. Within those categories, it is important to control for genetics and ecological niche by targeting species that can be monitored concurrently over a wide geographic range. Several kinds of numerical analysis are well-suited for quantifying the relevant effects: key factor analysis, sensitivity analysis, and concordance analysis. Adult survival is a parameter that integrates much of what the individuals of a population experience throughout the annual cycle, but to interpret the data it is important to know where the birds from a given colony go in winter. The best examples of value-added monitoring are cases where seabirds have been employed as fish samplers. To realize fully the value of seabirds as indicators of the marine ecosystem, it is essential to collate the distilled results of monitoring in a single repository (read Pacific Seabird Monitoring Database). Hatch's top ten list of seabirds to include in a synoptic program of monitoring intended to capitalize on seabirds as indicators (North Pacific outside the tropics): northern fulmar (*Fulmaus glacialis*), Leach's storm-petrel (*Oceanodroma leucorhoa*), fork-tailed storm-petrel (*O. furcata*), pelagic cormorant (*Phalacrocorax pelagicus*), black-legged kittiwake (*Rissa tridactyla*), common murre (*Uria aalge*), pigeon guillemot (*Cepphus columba*), Cassin's auklet (*Ptychoramphus aleuticus*), rhinoceros auklet (*Cerorhinca monocerata*), and tufted puffin (*Fratercula cirrhata*).

USING STABLE ISOTOPE MEASUREMENTS OF SEABIRDS AS INDICATORS OF MARINE ENVIRONMENTS: GOOD NEWS AND BAD

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The measurement of stable isotope composition of tissues of seabirds has been shown to indicate seabird trophic level and, in some cases, diet. This technique can also supply information on relative inputs of prey derived from inshore or benthically linked vs. offshore or pelagically linked food webs. More recently, sources of nutrients to reproduction have been established through isotopic tracing techniques linking diet and reserves of laying females with their egg macronutrients. Other areas of interest involve the possibility of delineating origins of migratory species during the non-breeding season. The combination of stable isotope and contaminants assays has also provided key information of the behavior and fate of toxins in marine environments. The integrative nature of the isotope technique and the possibility of combining analyses from various tissue types means that this approach represents a powerful tool to assist in the use of seabirds as indicators of marine environments, especially when combined with conventional dietary analyses, trace element and fatty acid assays. However, there are drawbacks to the technique. Only in simple food webs can quantitative estimates of individual prey be estimated. A key factor usually missing from current applications is knowledge of how isotopic profiles within marine food webs can change temporally and spatially. Studies must now address these data gaps and new emphasis should be placed on retrospectively interpreting archived materials and on establishing long-term isotopic datasets of both seabirds and their prey at key locations.

MARINE BIRD COMMUNITIES AT-SEA AS INDICATORS OF SPATIAL AND TEMPORAL OCEANOGRAPHIC VARIABILITY

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Assessing the value of seabirds as indicators of ocean processes requires an understanding of their scale dependent response to the physical and biological patterns in their environment. Marine bird distributions and community structure are influenced by oceanographic variability at multiple spatial and temporal scales (Hunt & Schneider, 1987). Over macro-mega scales (1000s km) seabird assemblages are related to large-scale productivity and circulation patterns. More productive ocean regions sustain higher overall seabird densities, and a disproportionate amount of diving species with high energetic requirements. Conversely, low productivity areas sustain impoverished avifauna dominated by surface-foraging and plunging species with low energetic requirements. Over smaller coarse - meso scales (1 – 100s km), marine bird communities are influenced by the location of breeding colonies and by physical processes that aggregate and make prey available close to the surface. These ecological patterns

suggest that distinct seabird assemblages are adapted to exploit specific marine environments and prey types within particular oceanic water masses and habitats. Herein, we review the influence of scale dependent processes in the physical and biological environment of seabirds. We first update the conclusions outlined by Hunt & Schneider (1987) thirty years ago. Using this conceptual foundation, we discuss the relevance of marine bird surveys for monitoring physical and biological processes at-sea, including water mass distributions, ocean productivity, prey dispersion, and changing ecosystem structure.

USING FATTY ACIDS TO STUDY TROPIC PATHWAYS AND DIETS IN SEABIRDS: QUALITATIVE AND QUANTITATIVE ANALYSES

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The dynamics of predator-prey relationships, the structure of food webs, and the foraging behavior of individuals are critical to understanding animal ecology, interactions of predators with their environment, and effects of environmental variability on ecosystems. Like other top predators, seabirds are good samplers of prey populations, and their diets can provide information about lower trophic levels over a range of spatial and temporal scales. Various methods have been employed to study seabird diets, the most recent of which uses fatty acids (FAs). This technique relies on the diversity of FAs and patterns in marine organisms, coupled with narrow limitations on their biosynthesis, properties of digestion in monogastric animals, and the prevalence of large lipid reservoirs in many predators. Through a combination of controlled feeding trials, field studies, and a traditional approach for estimating diet, and using calibration methods that account for metabolism of specific FAs, we have validated the use of FA signatures for estimating diets of free-ranging seabirds. Results were consistent with variable habitat structure and other aspects of seabird ecology. Nevertheless, while we can measure both diet and nutritional quality of prey using FA analysis, the time frame the diet represents, the ability to resolve differences in FA signatures between certain prey, and the magnitude of temporal and spatial variability in FAs of individual prey species remain less clear. The nature of what seabirds can tell us about their ecosystems will likely depend on the foraging behavior of a species and the complexities of the ecosystem it occupies.

COMMON AND THICK-BILLED MURRE CHICK DIET AT THE GANNET ISLANDS, LABRADOR, 1981-2005: HOW DOES IT REFLECT LARGE-SCALE CHANGES IN THE MARINE ENVIRONMENT?

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Capelin *Mallotus villosus* and daubed shannies *Leptoclinus* (*Lumpenus) maculatus* make up most of murre chick diet at the Gannet Islands, Labrador (53º57'N 56º31'W). A study there during 1981-1983, led by Tim Birkhead, showed that Common Murre (*Uria aalge*) chicks were fed predominantly (80%) capelin, while Thick-billed Murre (*U. lomvia*) chicks were fed predominantly (60-70%) daubed shannies. During 1996-2005, we evaluated how changes in chick diet might be related to changing environmental conditions, using our long-term chick diet, murre flight directions, and travel time datasets as well as information concerning changes in abundance and distribution of capelin in the northwest Atlantic. Common Murre chicks received more daubed shannies than capelin in six of our ten study years, while Thick-billed Murre chicks received >90% daubed shannies. Most chick meals were probably captured within 10 km of the colony and productivity remained high throughout the study. Because we had no data concerning abundance and distribution of prey species near the Gannet Islands, we were unable to say whether diet reflected changing prey availability, prey preference by birds, or both. The proportion of capelin in Common Murre chick diet was not related to capelin abundance the nearest surveys off NE Newfoundland. However, the proportion of capelin in Common Murre chick diet was positively correlated with the North Atlantic Oscillation index, declined following the period in the early to mid-1990s when Labrador current water was unusually cold, and declined coincident with capelin moving to > 200 m depth according to hydroacoustic surveys off NE Newfoundland.

FIELD ENDOCRINOLOGY OF SEABIRDS AND FOOD WEB DYNAMICS IN THE BERING SEA

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The field endocrinology approach substantially enhances traditional methods used to assess food availability for marine top-predators. Traditional methods are indirect and have limited implementation on large spatial and temporal scales. The field endocrinology approach provides a direct measure of changes in recent food availability and foraging history integrated over periods of weeks. Specifically, temporal changes in food availability can be quantified by measuring concentrations of the stress hormone corticosterone (cort) in the blood of undisturbed individuals, and the rise in blood levels of cort in response to a standardized stressor. A long-term study of seabirds has revealed that baseline levels of cort were negatively correlated with current food abundance, whereas acute stress-induced levels of cort were negatively correlated with food abundance four weeks prior. Cort levels were also negatively correlated with reproductive performance, and baseline accurately predicted persistence of individuals affected by food shortages in a population. Using the field endocrinology approach, we are investigating the relationships between climate and food web dynamics at several trophic levels and in several distinct oceanographic sites in the Bering Sea. Here we report the effects of physical forcing (ice retreat and wind mixing) on seasonal (May-September) and inter-annual (1999-2005) dynamics of food availability in planktivorous and piscivorous seabirds.

USING SEABIRDS AS INDICATORS IN ECOSYSTEM-BASED MANAGEMENT OF ALASKA FISHERIES.

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The Alaska groundfish fishery of the Bering Sea (BS) and Gulf of Alaska (GOA), is one of the largest in the world. Ecosystem-based management is a guiding principal for this fishery, as mandated by the Magnuson-Stevens Act. The goals are to maintain or restore diversity and sustainability, by assessing historic and future effects of climate and fishing on ecosystem structure and function. Seabirds are one of the resources used as ecosystem status indicators, but incorporating seabirds into ecosystem models and management plans is challenging. Data comes from seabird colonies monitored by the U.S. Fish and Wildlife Service (FWS), and from at-sea surveys, which provide information on distribution, abundance, and seasonal patterns of birds on the fishing grounds. The NOAA-Fisheries 'Plan Team' works with FWS to incorporate seabird trend data into ecosystem anomaly charts, and to chart patterns in seabird chronology, productivity, abundance, and diet. Seabird data is generally consistent with other indicators of climate shifts that occurred in 1977, 1989, and 1997. Seabird productivity data indicate that while there may be regional and decadal patterns, changes are not uniform across regions, or even among feeding guilds in the same region. There are usually species or colonies that are exceptions to a regional pattern, indicative of local environmental effects. Nonetheless, there are suggestions that regions within both the BS and the GOA may be in opposition, in terms of conditions beneficial to seabird productivity. As we improve out understanding of these patterns, we can better integrate seabirds into ecosystem-based management of fisheries.

MARINE BIRDS AS SAMPLERS OF PREY CONDITIONS – SIMPLE IS USEFUL

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Seabirds sample pelagic (albatrosses, fulmars, petrels, kittiwakes), near-shore (gannets, gulls, auks) and benthic (cormorants, guillemots, ducks) environments. To engage seabirds as bio-indicators, a diversity of species' constraints and capabilities need to be considered and integrated in multi-species assessments of food web and ecosystem dynamics. Major problems relating to the exploitation of information from seabirds about prey conditions relate to 1) the tolerances of different predator responses, 2) sampling and scaling issues, 3) prey abundance and availability, 4) prey condition, 5) generalist vs specialist consumers, 6) parental vs chick diets, 7) qualitative vs quantitative data and 8) predictive capability. Some of these problems are resolvable through integrated multi-disciplinary oceanographic research programs that can provide important information about food web and ecosystem dynamics. Some are not resolvable. While complexity needs to be engaged it is not a solution.

Qualitative binary data (breeding success/failure, warm/cold water prey) and their concordances and dis-concordances can provide robust information when interrogated over large oceanographic and decadal and longer time scales. The employment of lightweight devices that measure physiological and physical variables attached to free-ranging birds during and beyond breeding seasons will advance indicator predator information capabilities. These studies permit assessments of a) the intersections of avian predators with exothermic prey, b) habitat use, c) hotspots and importantly of d) foraging decisions that are the mechanisms of population responses to environmental change. Realistic considerations of the utility of avian assessments of prey and food web conditions need to take into account the uncertainty in which ecosystem processes are enveloped, and also the limited predictive capabilities of the enormous efforts of fisheries biology that have to date been directed at single-species research, assessment and management.

DEAD BIRDS DON'T LIE, BUT WHAT ARE THEY REALLY TELLING US?

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Seabirds have long been touted as environmental indicators, because of their collective potential to integrate top-down, bottom-up, and anthropogenic signals. But long-term data on live birds is difficult to collect. Beached bird programs offer a relatively inexpensive alternative dataset, as programs are largely manned by volunteers. The Coastal Observation and Seabird Survey Team (COASST) program currently has over 150 observation beaches spread over 5300 lineal kilometers of Pacific Northwest coastline. In an ''average' year, volunteers discover and tag 2000 carcasses of over 55 species. What do dead birds indicate? (1) geographic patterns pertaining to relative use and relative stress, (2) temporal and geographic patterns pertaining to breeding phenology, breeding success, and post-breeding migration, (3) temporal patterns pertaining to local-to-regional physical forcing at the event (weeks) and seasonal (months) scales. In combination, these patterns allow us to define 'normal,' identify significant deviations from mean response, and rank those factors, both episodic and chronic, most likely to affect marine bird mortality dynamics in the coastal Pacific Northwest. COASST data have so far shown that: post-breeding mortality and winterkill account for 50-75% of beaching; adult-chick ratios in local species such as the Common Murre (*Uria aalge*) can be used to indicate breeding success; and deviation from normal beaching patterns, as was the case in spring-summer 2005 with murres and Brandt's Cormorants (*Phalacrocorax penicillatus*), can be used to alert the scientific and management community to the occurrence and impacts of physical forcing factors that might otherwise be missed.

TRENDS IN NUMBERS AND BREEDING SUCCESS OF FOUR SPECIES OF SEABIRD ON UK COASTS

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A co-ordinated monitoring programme has been tracking seabird numbers and breeding success at a representative sample of colonies around the UK since 1986. The programme assists the UK in meeting its international obligations and in monitoring aspects of the health of UK's seas. Four seabird species, northern fulmar (*Fulmarus glacialis*), black-legged kittiwake (*Rissa tridactyla*), common guillemot (*Uria aalge*) and European shag (*Phalacrocorax aristotelis*) comprise nearly half of the UK's breeding seabird population and each occupies distinctive feeding niches. Trends in numbers and breeding success through time will be presented for parts of the UK coast. Breeding success for many species/areas was at an all time low in 2004, with 2005 being more productive. A presumed scarcity of young sandeels (*Ammodytes* sp) in 2004, led to widespread starvation of chicks on UK North Sea coasts. In 2005, young sandeels appeared later than usual, and coupled with alternative feed fish, allowed some chicks to fledge relatively late in the breeding season. In contrast to the North Sea, breeding success in NW Scotland was moderate in 2004 but was very poor in 2005. The available data on diet are inconclusive in this region, but it is assumed that a food shortage was to blame also.

SEABIRDS AS INDICATORS OF MARINE FOOD SUPPLIES: CAIRNS REVISITED

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Cairns (1987) predicted that: 1) parameters of seabird biology would vary in curvilinear fashion with changes in food supply, 2) the range of densities over which birds responded would be different for

each parameter, and, 3) different seabird species would respond differently depending on diet and ability to adjust time budgets. When tested with data collected at colonies of Common Murre and Black-legged Kittiwake in Cook Inlet, Alaska, these predictions were found to be *mostly* True, False and True, respectively. Kittiwakes worked hard all the time, and had little discretionary time to compensate for declining prey density. Variability in prey abundance translated directly (r^2=0.89) into variation in fledging success in a non-linear, threshold relationship. Murre breeding success was buffered by reallocation of discretionary time and was a poor indicator of food supply, whereas 'loafing time' at the colony was a non-linear function (r^2=0.65) of prey density. For parameters that were sensitive to fluctuations in food supply, most responded at similar thresholds of prey density— presumably because all responses ultimately depend on the rate of prey acquisition at sea. Murres and kittiwakes minimized variability in their own body condition (CV<10%), and in growth of chicks (CV<25%) in the face of high variability in prey abundance (CV=80%). Both species exhibited similar moderate variability (CV= 25-40%) in laying and hatching success, and in foraging effort. However, while variability in kittiwake breeding success (CV=87%) tracked prey variability, murre breeding success did not (CV=29%). Implications of these results for "seabirds as indicators" will be discussed.

SEABIRDS AS INDICATORS OF MARINE ECOSYSTEMS: FROM RINGING ALARM BELLS TO FINDING SOLUTIONS

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In most marine ecosystems, our abilities to measure changes in lower-trophic levels is often restricted. As integrators, indices of the performance and population size of upper-trophic level species can provide the first indications of changes in the ecosystem. The high profile and amenability to measurement of seabirds has made them a popular and very successful choice as indicators of ecosystem change. This role may be considered at two levels; firstly as 'response indicators' providing an observation that some change in ecosystem status has occurred, and secondly as 'mechanism indicators' where the information gathered by seabirds provides insights into the reasons underlying that observation of change, e.g. by providing data on the dynamics of key prey species. Marine ecosystems are inherently variable at a range of spatio-temporal scales; therefore, when examining causality it is essential to match the scales of response of seabirds to appropriate ecosystem scales. Where there are multiple responses, e.g., those reflecting changes in local foraging conditions to those reflecting basin-scale processes, a combination of indices at appropriate scales may provide more powerful indicators of ecosystem change. The use of seabirds as indicators is justifiably widespread. However, non-linear responses may create biases towards indicating poor environmental conditions. As a consequence, seabirds are frequently perceived as indicators of the failure of management policies. Opportunities abound, but the challenge for seabird ecologists is to deliver unbiased policy-relevant outputs than can be integrated into the successful management of marine resources.

SEABIRDS AS ECOSYSTEM INDICATORS IN THE NORTH PACIFIC: A CRITIQUE OF THE EVIDENCE

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For decades marine ornithologists have argued that seabirds are good indicators of environmental 'health' (i.e., pollution) and ecosystem constituents (e.g., forage fish stocks). As interest grows in developing novel approaches to marine conservation, including 'ecosystem management' and an 'ecosystem-based approach' to fisheries conservation, there is renewed interest in the role of seabirds as indicators, and its potential application to management science. There are at least 10 ways that seabirds can serve as indicators including: (1) seabirds as indicators of meso- and large-scale (e.g., water mass) marine habitat characteristics, (2) seabirds as indicators of temporal environmental variation and climate change, (3) seabirds as indicators of ecosystem controls (bottom-up, top down, wasp-waist), (4) seabirds as indicators of fish stocks, (5) seabirds as indicators of zooplankton stocks, (6) seabirds as indicators of fish and zooplankton communities (i.e., the multi-species level), (7) seabirds as indicators of contaminants (metals, OCs, and other contaminants, oil), (8) seabirds as indicators of harmful algal blooms (HABs), (9) seabirds as indictors of fisheries and other human impacts on marine ecosystems, and (10) seabirds as indicators for fisheries management and ecosystem-based management (EBM) in general. While there are many compelling examples of reliable seabird indicators, spatial and temporal

variation in underlying bio-physical processes may change the utility of seabird indicators – e.g., a good indicator in one decade may be relatively useless in another. Therefore, understanding scale-dependent responses and fundamental ecological mechanisms will be required to establish the significance and value of marine birds as North Pacific ecosystem indicators.

RESPONSES OF A GENERALIST AND A SPECIALIST DIVER TO THE ANNUAL CHANGE OF MARINE ENVIRONMENT

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Breeding seabirds forage within a range from the colony. Therefore, their diet and breeding success may respond to the annual changes of local marine environment. On the other hand, the changes of diet of seabirds may influence local impact on alternative prey species. How does the ability of seabirds to switch prey constraint these responses and impact? We compared the responses and food consumptions of a short-range (<30 km) generalist diver (Japanese Cormorants) feeding both on epipelagic and demersal fish and those of a long-range (<100 km) specialist diver (Rhinoceros Auklets) feeding only on epipelagic fish breeding on Teuri Island in the Japan/East Sea where the annual change of the warm Tsushima Current influences the marine ecosystem. Based on the 14 -17 years data (1984 to 2005), we examined the effects of the current on their diet and reproductive performance. In years of strong current flow, hence higher summer SST, both species forage more on anchovy; indicating that the northward expansion of warm water determines regional availability of anchovy. While in years of weak current flow, Rhinoceros Auklets foraged mainly on other epipelagic species and decreased chick growth rate but Japanese Cormorants foraged on mid water and demersal fish and maintained breeding success. Breeding performance of generalist diver did not give us signals of the change of the current flow. We propose a hypothesis that the current flow affects local demersal fish population directly and also indirectly through the impact by top predator.