SYMPOSIUM

SEABIRD BIOGEOGRAPHY: THE PAST, PRESENT, AND FUTURE OF MARINE BIRD COMMUNITIES

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INTRODUCTION TO THE SYMPOSIUM ON SEABIRD BIOGEOGRAPHY: THE PAST, PRESENT, AND FUTURE OF MARINE BIRD COMMUNITIES

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INTRODUCTION

"Overhead the albatross
Hangs motionless upon the air
And deep beneath the rolling waves
In labyrinths of coral caves
An echo of a distant time
Comes willowing across the sand
And everything is green and submarine.
And no one called us to the land
And no one knows the where's or why's.
Something stirs and something tries
Starts to climb toward the light."
Echoes, Pink Floyd, EMI Music 1971

The extreme life-histories of seabirds have long captured the imagination of artists and scientists alike. Recently, technological and conceptual advances have revolutionized the way researchers approach the study of seabird ecology and biogeography. Developments in the fields of genetics, wildlife telemetry, remote sensing, and geo-informatics; a growing appreciation of large-scale oceanographic patterns; and the compilation of long-term physical and biological time series have contributed to opening a window into the previously unknown habits of these majestic long-distance travelers.

Increasingly, marine ornithologists are adopting a broader approach to understand how oceanographic variability, changes in marine food-webs, and human activities affect seabirds over multiple spatial and temporal scales. Inter-disciplinary studies of seabird populations and communities have highlighted the important role these upper trophic-level predators play in marine ecosystems, and have enhanced the general understanding of biogeographic and ecological processes in the global ocean (Aebischer *et al*. 1990, Ballance *et al*. 1997, Veit *et al*. 1997, Hunt *et al*. 1999).

In addition to enhancing the understanding of marine biogeography and biotic responses to changing ocean climate, marine ornithologists can provide valuable insights into the management and conservation of entire ocean ecosystems. The value of marine birds as indicators of changing ocean productivity patterns and ecosystem structure is becoming increasingly apparent, as studies continue to document their sensitivity to fluctuations in pelagic food-webs, prey availability, and ocean climate (Montevecchi & Myers 1995, Furness & Camphuysen 1997, Kitaysky *et al*. 2000, Sydeman *et al*. 2001).

In particular, seabirds are increasingly being used to sample the physical and biological properties of the marine environment in real-time (Wilson *et al*. 2002). For instance, the movements and diving activity of individual foragers have been used to infer prey resource distributions and to ground-truth oceanographic conditions during periods (e.g., winter) and in locations (e.g., Southern Ocean) difficult to sample synoptically by more conventional means (Kooyman *et al*. 1992, Weimerskirch *et al*. 1995). These "biological sensors" will likely become an integral part of the developing Global Ocean Observing System (Block *et al*. 2002).

The study of seabird ecology is increasingly motivated by evidence that bird populations globally are being affected by human activities (Piatt *et al*. 1990, Croxall 1998, Tasker *et al*. 2000). In particular, an understanding of seabird distributions and habitats has important conservation implications. First, the accurate determination of population numbers at sea is essential to determine the status of rare and endangered species that are difficult to census at breeding colonies (Spear *et al*. 1995, Woehler 1996). Accurate population trends are urgently needed because mounting evidence suggests that many species are being impacted by anthropogenic activities (Wooller *et al*. 1992, Tasker *et al*. 2000) and are declining precipitously (Croxall 1998, Lyver *et al*. 1999). Secondly, an understanding of important foraging areas and migratory routes is essential for implementing large-scale conservation measures such as fishery closures and Marine Protected Areas (MPAs), (Boersma & Parrish 1999, Hyrenbach *et al*. 2000).

SYMPOSIUM SUMMARY

At the 30th annual meeting of the Pacific Seabird Group (19 - 22 February, 2003) held in Parksville, British Columbia, we convened a symposium to review the status of marine bird biogeography and to provide recommendations for further study. Eighteen oral papers, addressing a wide range of patterns and processes ranging from 10s to 1000s km and from weeks to centuries, were presented. Throughout this review, we will refer to these papers using the name of the first contributor. The eighteen symposium presentations are listed below, in alphabetic order:

ALLEN, S.G., & SCHIROKAUER, D. Keep it simple – selection criteria of marine protected areas for seabirds.

BADUINI, C.L. Biogeography of foraging strategies among Procellariiform seabirds: How productivity in surrounding waters influences foraging.

BURGER, A.E. Effects of the Juan de Fuca Eddy and upwelling on seabirds off southwest Vancouver Island, British Columbia.

DAVOREN, G.K., MONTEVECCHI, W.A. & ANDERSON, J.T. Distribution patterns of Common Murres *Uria aalge*: Underlying behavioural mechanisms in the context of predator-prey theory.

FORD, R.G., AINLEY, D.G., CASEY, J., KEIPER, C., SPEAR, L. & BALLANCE, L.T biogeographic analysis of seabird distributional data from central California.

HAAS, T. & PARRISH, J.K. Resolving fine-scale environmental patterns using beached bird surveys.

HATCH, S.A. & GILL, V.A. Geographic variation in Pacific Northern Fulmars: Are there two subspecies?

HIMES-BOOR, G.K., FORD, R.G., REED, N.A., DAVIS, J.N., HENKEL, L.A. & KEITT, B. Predictability of seabird distributions within the Gulf of Farallones at various temporal and spatial scales.

HYRENBACH, K.D. Marine bird response to interannual oceanographic variability in a dynamic transition zone: Southern California (1997-99).

KULETZ, K.J., BRENNEMAN K.M., LABUNSKI, E.A. & STEPHENSEN, S.W. Changes in distribution and abundance of Kittlitz's Murrelets relative to glacial recession in Prince William Sound, Alaska.

MORGAN, K.H. Oceanographic variability and seabird response off the British Columbia coast, 1996-2002.

PIATT, J.F. & SPRINGER, A.M. Biogeography of the northern Bering and Chukchi Sea shelf.

PITMAN, R.L., BALLANCE, L.T. & HODDER, J. Physiographic island evolution as a factor structuring seabird communities: Evidence from a temperate and a tropical setting.

SMITH, J.L. & HYRENBACH, K.D. Galapagos to B.C.: Seabird communities along a 7,800 km transect from the tropical to the subarctic eastern Pacific Ocean.

STEEVES, T.E., ANDERSON, D.J. & FRIESEN, V.L. Phylogeography of Sula: The role of physical and non-physical barriers to gene flow in the diversification of low latitude seabirds.

STEPHENSEN, S.W. & IRONS, D.B. A comparison of seabird colonies in the Bering Sea and Gulf of Alaska.

WILLIAMS, J.C., KONYUKHOV, N.B. & BYRD, G.V. Human influences on whiskered Auklet distribution and abundance through time.

YEN, P.P., SYDEMAN, W.J. & HYRENBACH, K.D. Bathymetric associations underlying marine bird and mammal dispersion in central California.

The symposium illustrated the cross-section of inter-disciplinary research approaches currently used to relate seabird distributions to prey dispersion, environmental variability, and anthropogenic impacts. The most prevalent topic addressed at the symposium was the relationship between seabird at-sea distributions and oceanographic variability (Burger, Davoren, Ford, Haas, Himes, Hyrenbach, Morgan, Piatt, Smith, Yen). Ten papers discussed changes in seabird communities with respect to water mass distributions and productivity domains over a broad range of spatial and temporal scales. Smith related the composition of seabird communities to oceanographic conditions along a 7,800 km spring-time transect across the tropical – subarctic Northeast Pacific Ocean, and documented three distinct assemblages associated with distinct water masses, defined by sea surface temperature and chlorophyll concentration. Two other presentations described seasonal and interannual changes in seabird communities off British Columbia (along a 1,500 km transect across the Northeast Subarctic Gyre; Morgan), and off southern California (grid of 6 survey lines, spanning from the coastline up to 700 km offshore; Hyrenbach) during the 1997-98 El Niño and the 1998-99 La Niña events. These large-scale studies confirmed that distinct seabird assemblages inhabit different water masses, characterized by specific physical (e.g., sea surface temperature) and ocean productivity (e.g., chlorophyll concentration) patterns. As the use of voluntary observing ships (VOS) expands, the capability to repeatedly survey marine bird distributions over basin-wide spatial scales will increase. A particularly exciting and pioneering research venue entails the integration of marine bird surveys and continuous plankton recorder (CPR) data along a 7,000 km east-west transect from B.C. to Japan (Sydeman *et al*. 2003).

Two other presentations focused on seabird associations with smaller-scale bathymetric (e.g., shelf-breaks, seamounts), and hydrographic (e.g., eddies, coastal upwelling) habitat features. Burger described year-round seabird distributions off SW Vancouver Island with respect to sea surface temperature and bathymetry, and highlighted the aggregation of these predators within an area of strong upwelling associated with the edge of the Juan de Fuca Canyon. Yen analyzed the spring-time (May – June) associations between marine bird distributions and bathymetric habitats in the Gulf of the Farallones, central California, and reported substantial variability in seabird habitat use patterns across weeks (repeated sweeps within a survey) and across years (different spring cruises between 1996 and 2002). Together, these papers reinforced the often well-defined association of seabirds with specific ocean habitats over multiple spatial scales, ranging from the large-scale dynamic hydrography (e.g., water masses, 1000s km) to the small-scale bathymetry (e.g., shelf-breaks and canyons, 10s km).

Five synthetic presentations illustrated the biogeographic and management applications of time series of marine bird distribution and abundance patterns (Allen, Ford, Himes, Kuletz, Piatt). Piatt's discussion of the biogeography of the northern Bering and Chukchi Sea shelf related the habitat preferences of different seabird foraging guilds (piscivores and planktivores) to physical (e.g., water column mixing) and biological (e.g., ocean productivity) regimes. Himes addressed the predictability of marine bird distributions within the Gulf of the Farallones, central California, over a wide range of temporal (24 hours – 6 months) and spatial (1 – 100 nm^2) scales. The paper by Ford provided an example of an applied biogeographic assessment of individual marine bird species dispersion and community composition (e.g., overall density and biomass, species diversity) off central California, conducted in support of the National Marine Sanctuary management plan review. Kuletz's presentation highlighted the value of long standardized time series to detect climatic impacts on seabird populations. Between 1972 and 2000, Kuletz documented a 85-95% decline in Kittlitz's Murrelet *Brachyramphus brevirostris* abundance in Prince William Sound, Alaska, linked with the retreat of glaciers in the area.

Two presentations explicitly addressed steps for the design of marine zoning strategies to protect important seabird habitats (Allen, Davoren). Allen proposed a framework for delineating Marine Protected Areas (MPAs) for seabirds, including (i) ecological (e.g., species rarity, diversity, sink-source dynamics), (ii) sociological (e.g., commercial and sport-fishing effort), and (iii) regulatory (e.g., jurisdiction, existing designations, enforcement capabilities) criteria. An alternative route to MPA designation was presented by Davoren, who used repeated vessel-based visual and hydro-acoustic surveys to delineate “habitat hotspots” of predictable predator (Common Murre *Uria aalge*) and prey (capelin *Mallotus villosus*) aggregations off Newfoundland, Canada.

Several studies examined how prey influenced seabird distribution and abundance patterns over a variety of spatial and temporal scales (Baduini, Burger, Davoren, Kuletz, Piatt, Stephensen). Piatt and Stephensen invoked ocean productivity patterns and prey transport and retention mechanisms to explain the disparity between breeding seabird populations within different bathymetric domains of the Bering Sea and the Gulf of Alaska. Baduini investigated how large-scale (100s – 1000s km) ocean productivity patterns influence the foraging strategies of Procellariiform (tubenose) seabirds, and proposed several hypotheses to explain the alternation of long and short foraging trips observed in many of these far-ranging species. Burger, Kuletz and Davoren pointed out the significance of prey distributions and availability, as determinants of seabird distributions at smaller (10s – 100s km) spatial scales. Additionally, Davoren emphasized the importance of previous experience (e.g., remembering where predictable prey patches are located), and local enhancement (e.g., locating prey patches by cueing on conspecifics at sea). These presentations raised two particularly exciting concepts that deserve additional study: the reliance of foraging birds on memory and the fidelity to specific foraging areas.

In addition to habitat-use considerations (e.g., oceanographic conditions, prey dispersion) known to influence seabird distributions over hours – decades, several papers addressed biogeographic determinants operating over longer ecological – evolutionary time scales. Stephensen and Williams highlighted the impacts of humans on seabird breeding populations since the 1700s, through the introduction of predators to subarctic islands. Two other presentations discussed the influence of geo-morphology on the density and the distribution of seabird breeding populations. Stephensen ascribed some of the differences in seabird breeding populations in the Aleutians and the Gulf of Alaska to geographic disparities in the extent and type of volcanic soil. A novel presentation by Pitman described the influence of changing island physiography on the structure of breeding seabird communities.

The symposium also highlighted novel techniques and approaches to the study of marine bird biogeography, including genetics, morphometrics, and satellite telemetry. Baduini reviewed the value of telemetry to study the foraging behavior of far-ranging seabirds. Steeves showcased the value of genetic techniques to study seabird speciation. Her paper discussed the role of physical and non-physical gene flow barriers as factors inhibiting the diversification of low latitude seabirds. Hatch reviewed the patterns of geographic variation in Northern Fulmars *Fulmarus glacialis,* prompting the question of the existence of yet to be identified subspecies. Haas illustrated the potential of long-term monitoring programs as sources of valuable ecological data. The Coastal Observation and Seabird Survey Team (COASST), a beached bird survey in Oregon and Washington, is a prime example of the novel approaches being used to involve volunteers in seabird research. In addition to monitoring potential die-off events, these programs provide valuable specimens for genetics, morphometrics, and contaminant studies.

FUTURE AVENUES AND OPPORTUNITIES

Maintaining and expanding existing time series

A pervasive take home message from many of the symposium presentations was the recognition of the inherent difficulties associated with documenting long-term changes in biological communities. Temporal trends are difficult to quantify because they require a series of repeated standardized surveys, and long-term data archiving. Both the field sampling and data management components of monitoring programs are expensive, and difficult to support with the existing framework of 3-4 year funding cycles. Fortunately, visionary researchers had the foresight to start various marine bird population time series several decades ago. Today, these data sets provide a priceless historical perspective necessary to interpret present conditions and to forecast the future. These observations, which become more valuable every year, constitute one of the most precious resources at our disposal. As inferred by several of the symposium presentations, the true value of long time series is only apparent after major regime shifts and population changes. In anticipation of future oceanographic variability (e.g., ENSO, PDO), climate change (e.g., global warming, glacial recession), and potential anthropogenic impacts (e.g., oil spills, fisheries bycatch, exotic predator introductions) maintaining and expanding the coverage of existing time series is a main research priority.

Ideally, existing long-term monitoring programs will be enhanced with short-term hypotheses-driven studies aimed at elucidating the mechanisms underlying specific patterns or observations. Previously, short-term studies have shown how seabird assemblages quickly respond to shifting physical characteristics (e.g., water mass distributions), and that these changes can be non-linear, with variable magnitude and direction (Hyrenbach, Morgan). However, little is understood about how these short-term population responses to oceanographic variability (e.g., redistribution during an El Niño event) translate into population-level changes (e.g., survivorship and reproductive success).

Previous studies have clearly substantiated the notion that marine bird assemblages are not fixed in space and time, but are susceptible to changes in water mass distributions, ocean productivity, and prey availability. However, it is also recognized that species-specific differences in life-history and ecology influence the habitat associations and the responses of individual bird species to environmental change. Thus, a better understanding of how different biotic and abiotic factors influence the susceptibility of certain populations and species to climatic and anthropogenic impacts is essential to forecast the fate of marine bird communities. This improved knowledge will require comparative studies involving large data sets spanning a broad geographic and taxonomic scope.

Promoting inter-disciplinary research

Future seabird biogeography research will be inextricably linked to the study of climate change and anthropogenic impacts. The increasing awareness of the importance of the underlying oceanographic variability has promoted a multi-scale understanding of the ecology of marine birds (e.g., Hunt & Schneider 1987). This integrative perspective should be enhanced in the future, by integrating marine birds within broader oceanographic research programs. In particular, three interrelated aspects deserve additional study: (i) how ocean productivity affects the distribution and aggregation of prey; (ii) how prey dispersion influences the distribution, prey selection, and foraging effort of seabirds; and (iii) whether enhanced foraging effort impacts the reproductive success and survivorship of seabird populations.

The widely recognized patterns of climatic variability in the Pacific Ocean underscore future opportunities to investigate the response of seabird populations to changing ocean climate across the globe. Analyses of global ocean temperature since the beginning of the 20th century have revealed three dominant regimes of climate variability in the North Pacific: (i) a progressive temperature increase associated with global warming, (ii) 20-30 year periods or "regimes" of alternating warm and cold water conditions termed the Pacific Decadal Oscillation (PDO), and (iii) shorter 1-2 year warm (El Niño) and cold (La Niña) water periods linked to the El Niño Southern Oscillation (ENSO) (Mantua *et al*. 1997, Folland *et al*. 1999, Levitus *et al*. 2000).

The long-term warming trend has been linked with drastic changes in the physical structure of North Pacific temperate and subpolar marine ecosystems since the 1950s (McGowan *et al*. 1998, Arendt *et al*. 2002, Bograd & Lynn 2003). Yet, little is known about potential synergies between this long-term variability and higher frequency fluctuations associated with shorter-term ENSO and PDO oscillations. Understanding the coupling of high (i.e., ENSO) and low (i.e., PDO) frequency environmental variability, and the influence of these phenomena on future global warming trends will require continued time series of physical and biological properties. These data will be essential to interpret and forecast changes in marine ecosystem constituents (McGowan 1990, McGowan *et al*. 1998).

Because anthropogenic impacts in the global ocean are pervasive, marine ornithologists must also consider changes in seabird prey availability, foraging effort, reproductive success, and mortality caused by human activities (e.g., overfishing, oil spills, introduced predators, bycatch). As the fields of oceanography, climate change, and ocean conservation merge, marine ornithologists will find themselves at an inter-disciplinary cross-roads (Hyrenbach *et al*. 2000, Ainley 2002, Block *et al*. 2003). This integrative science will be founded on international collaboration, multi-disciplinary research, and the creation of "data commons" for standardization and sharing of information.

Creating a Data Management Infrastructure

The same way atmospheric scientists and oceanographers have amassed long-term databases of physical and biological variability, efforts are underway to compile global distribution and abundance data for several marine taxa. These initiatives are driven by large-scale biogeographic studies, and by efforts to better manage protected species and marine ecosystems. The Ocean Biogeographic Information System (OBIS), a bio-informatics initiative under the auspices of the Census of Marine Life (CoML) and the U.S. National Oceanographic Partnership Program (NOPP), has initiated several projects to characterize global species distributions and biogeographic patterns for a broad array of marine taxa, ranging from hexacorals to seabirds (Decker & O'Dor 2002).

In addition to these biogeographic initiatives, a rapidly growing number of conservation programs are compiling databases of species distribution and abundance to guide the management of protected taxa (e.g., Procellariiform tracking database), to delineate important marine habitats (e.g., Patagonian Shelf project), and to facilitate the design of networks of Marine Protected Areas (Bering to Baja initiative).

Biogeographic data on North Pacific seabirds are currently being compiled in three regional archives: North Pacific Seabird Colony Database, North Pacific Seabird Monitoring Database, and the North Pacific Pelagic Seabird Database. These databases will include distribution and abundance data, spanning from the equator to the pole along both sides of the basin. The colony database, being managed by the U.S. Fish and Wildlife Service in Anchorage, contains information on nesting sites of colonial seabirds, including species, numbers, and locations. The monitoring database, to be managed by P.S.G., U.S.G.S. and U.S.F.W.S., includes many different colonial seabird population and productivity parameters, which have been measured repeatedly to allow detection of change over time. The pelagic seabird database contains distribution and abundance data on marine birds at-sea and will be managed by the U.S.F.W.S. in Anchorage, Alaska. All databases will be accessible on the internet, and will allow scientists and managers to quickly access information on seabird populations over broad temporal and spatial scales. Used in conjunction with other existing physical and biological data sets, these resources will enhance our understanding about how, when, where, and why seabird populations change over time. Identifying the underlying mechanisms responsible for population variability represents a critical first step, necessary to build predictive habitat use and demographic models required to forecast the fate of seabird populations and species in a dynamic marine environment.

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