

UNDERSTANDING SEABIRDS AT SEA: WHY AND HOW?

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Received 2 February 2008, accepted 19 February 2008

SUMMARY

BALLANCE, L.T. 2007. Understanding seabirds at sea: why and how? *Marine Ornithology* 35: 127–135.

Studies of the at-sea component of seabirds' lives are essential to a comprehensive understanding of seabirds, simply because so many species spend the vast majority of their time at sea. At-sea data can be collected using data recorders and remotely-transmitting devices, and from ships. The latter is usually accomplished using strip transect methods, which quantify the number and species identification of birds within a pre-determined distance from a ship as it moves. A number of methodologic variations exist, but all include two critical assumptions: that the strip width is accurately maintained, and that all birds entering the strip are detected. These at-sea data provide insights at a number of ecologic scales. At-sea data provide insights into the biology of individual species including distribution, the relationship between distribution and physical and biologic characteristics of the ocean (often termed species–habitat relationships), and abundance (particularly for species that are difficult to census on colonies). At-sea data provide insights into communities, including community composition (because seabird breeding communities almost always differ from seabird feeding communities) and interspecific interactions (particularly predation, competition and commensalism). And at-sea data provide insights into oceanic ecosystems, because seabirds have attributes (easy to detect and identify; wholly dependent upon marine systems for food; highly mobile, thereby integrating ecosystems on large spatial scales) that make them important as indicator species. A host of threats, both direct and indirect, exist for seabirds at sea. Relative to direct threats, indirect threats tend to be poorly understood and are rarely acknowledged. In particular, the dependence of seabirds on fish of high commercial value or mammals subject to incidental mortality can be a significant indirect threat that is rarely acknowledged in management of those fish and mammal species. Because of the trans-habitat and trans-boundary nature of seabirds (they breed on land, yet feed in the sea and pay no attention to arbitrary political boundaries), the structure and function of many management schemes is a poor fit with seabird conservation needs. Integrating responsibility across agencies and countries is challenging. Seabirds provide a potential role model for successful management of oceanic resources that can provide a mechanism for conservation of other trans-habitat and trans-boundary species.

Key words: Seabirds at sea, strip transect methods, abundance, distribution, species-habitat relationships, community ecology, foraging ecology, ecosystem indicators, seabird conservation, indirect effects

INTRODUCTION

The defining feature of seabirds is that they must breed on land, and yet obtain their food from the sea. The constraints imposed individually by those habitats and the interactions of those constraints are the evolutionary drivers for a host of traits that are unique to seabirds, influencing their ecology, behavior, physiology and life history.

Seabirds are not easy to study. Most species nest on islands, often in remote regions of the world that are difficult to access and to live in, at least for a researcher. Studying seabirds at sea is even more challenging, for at least two reasons. First, the oceanic environment contrasts sharply with terrestrial systems in which humans are at home. To the untrained eye, open ocean systems appear homogeneous; the surface currents, physical features, and water masses that define distinct habitat types to oceanic organisms must be revealed to humans through the use of oceanographic instruments. And oceanic habitat is not static, but moves in space and time. Second, studying seabirds at sea requires expensive ship time or remotely sensed data, and significant infrastructure not only for research, but also for survival.

Despite these challenges, knowledge of the at-sea component of a seabird's life is essential for a comprehensive understanding

of seabird biology, simply because many seabirds spend the preponderance of their lives at sea. Studies of seabirds at sea can also provide significant information about the marine environment, because seabirds have attributes that make them important as indicator species. They spend nearly all of their time at or above the sea surface, and so they are among the easiest marine organisms to observe. Identification to species level is simple relative to most other marine organisms. They are highly mobile, thereby integrating an ecosystem on a large spatial scale. And they obtain all of their food from the sea. Results of at-sea research on seabirds can, therefore, provide a unique perspective on ecologic processes, health and change in the ocean.

The present paper provides an overview of what can be learned from studies of seabirds at sea. It is not an exhaustive treatment. Instead, it depends heavily on my own research background with respect to methods and geographic areas. I study seabirds from ocean-going research vessels, primarily in the temperate and tropical waters of the Pacific, and primarily in oceanic systems—waters beyond the continental shelves. The case studies highlighted here are drawn from the literature or based on cruises conducted in the California Current, the US Exclusive Economic Zone waters of the Hawaiian Archipelago and some islands in the central Pacific, and the greater eastern tropical Pacific (Fig. 1).

COLLECTING DATA ON SEABIRDS AT SEA

At-sea data for seabirds are collected in two primary ways: using data recorders or remotely-transmitting devices, and using ships at sea. Data recorders and remotely-transmitting devices store or transmit (or both) data that represent a real-time picture of an individual, and in some cases, that individual's environment, as it moves through a system. Ships at sea provide a platform for researchers to collect data that represent a real-time picture of seabird populations as the ship travels. The two approaches are, therefore, complementary: one provides information about seabirds at the individual level as they move through space and time; the other, about seabirds at the community level as the research platform moves. Recent and comprehensive reviews on the use and contributions of remotely-transmitting devices can be found in Wilson *et al.* (2002, 2008). Here, I focus on methods of data collection using ships at sea.

The primary and accepted method used to collect data on seabirds from ships is the strip transect method. That method and its variations have been extensively reviewed (Spear *et al.* 2004 and references therein). The general approach is to count seabirds that enter a designated area as a ship moves. Typically, a strip on one side of the ship with a width of 300 m is chosen, although the designated strip width may vary with platform characteristics (particularly height above the water), observer skill, and especially, bird density. The two critical assumptions of the strip transect method are that the strip width is accurately maintained, and that all birds entering the strip are detected. It has been shown quantitatively that at least two observers are required to meet this latter assumption (Spear *et al.* 2004), although funding and space constraints often preclude the use of two observers simultaneously. Two variations of the strip transect method are commonly used. In the "continuous" method, birds are recorded individually as they are

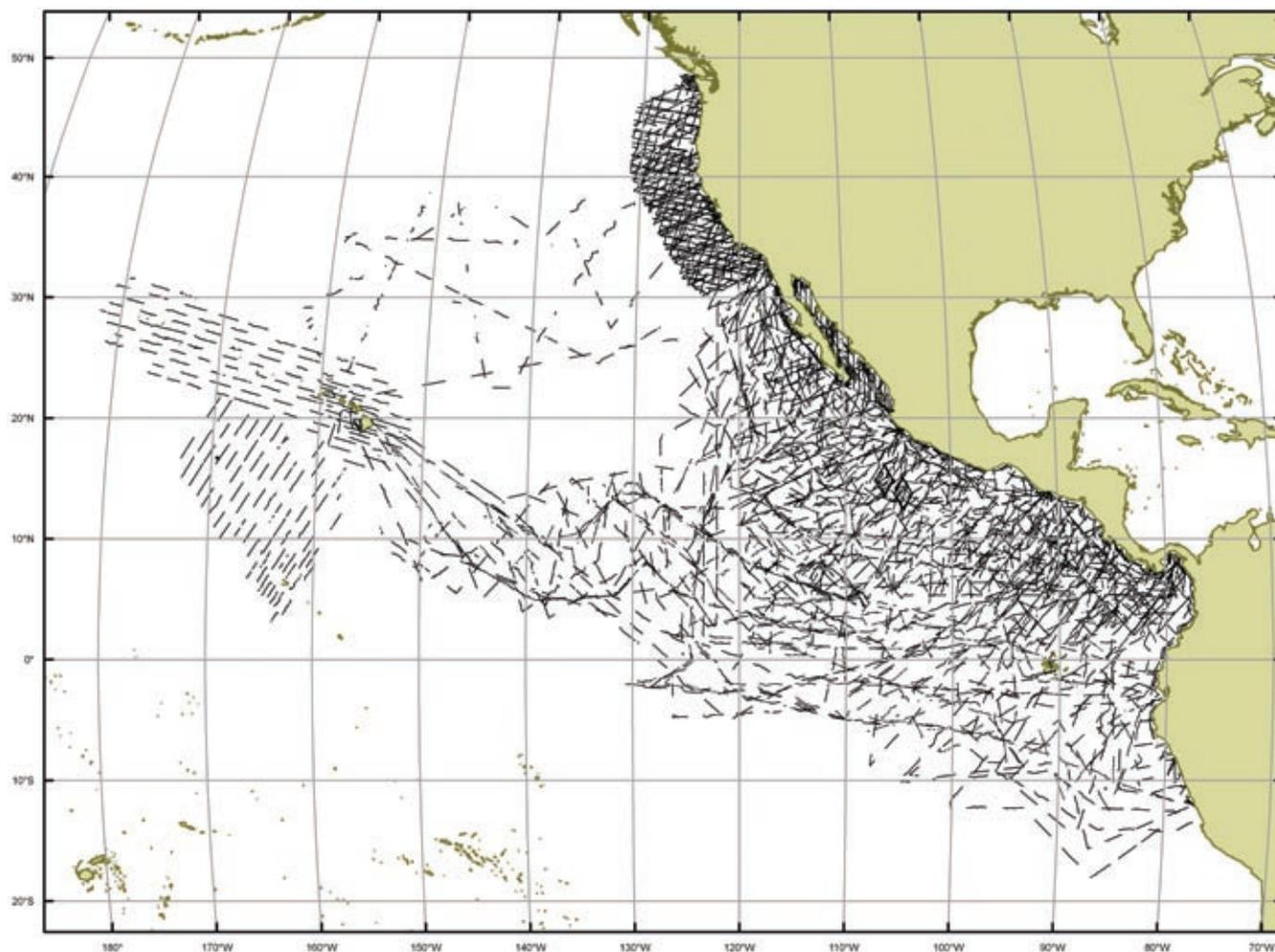


Fig. 1. Ship survey tracks of marine mammal and ecosystem assessment surveys conducted by the Southwest Fisheries Science Center. Seabird data were collected on most of these surveys and form the basis for the overview presented in this paper. California Current surveys were conducted in 1991, 1996, 2001 and 2005, and are scheduled to be conducted at three-year intervals into the future. Eastern tropical Pacific surveys were conducted in 1986–1990, 1998–2000, 2003 and 2006, and are scheduled to be conducted at three-year intervals into the future. Central Pacific cruises were conducted in 2002 and 2005 with the next survey scheduled for 2010. Number of sea days per cruise averages between 120 (California Current and central tropical Pacific) and 240 (eastern tropical Pacific).

seen; in the “snapshot” method, birds are recorded by relevant time segments, with the choice of time segment (e.g. 3-, 5-, or 10-minute intervals) depending on conditions (Fig. 2).

Two general types of data are collected when surveying seabirds: effort and species. Effort data include start and stop time, observer identification, and sighting conditions. The latter generally include sea state (often quantified using the Beaufort scale) and additional descriptors that ideally are quantitative (e.g. percent cloud cover, horizontal and vertical sun angle). In addition to the foregoing data, a comprehensive assessment of an observer’s ability to detect birds that is subjectively determined by the observer for each survey period is useful (see Appendix A in Philbrick *et al.* 2003). This “observation condition” represents the survey strip width on a taxon-specific basis and addresses a critical assumption of the strip transect method (that all birds entering the strip are detected), while also allowing for differences in observer skill or bird detectability. For example, boobies are large and generally light colored, and therefore easier to detect than are storm-petrels, which are small

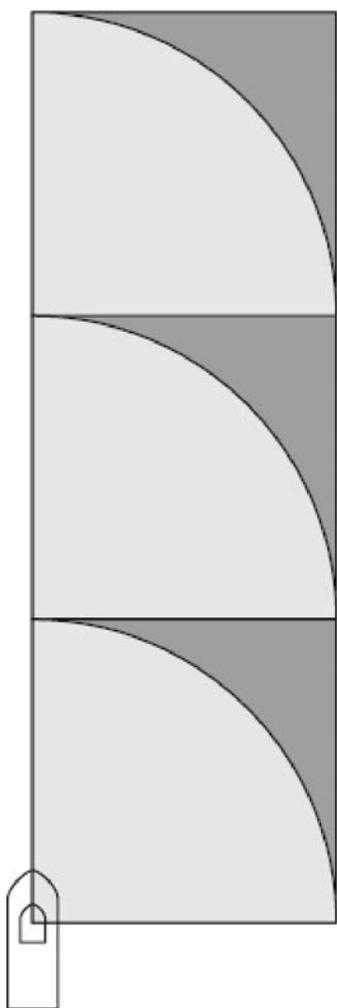


Fig. 2. Representation of area being surveyed using two different strip transect methods, with the ship moving from bottom to top. The three squares represent the snapshot method, in which seabirds are counted instantaneously during three separate time intervals. The radial-shaped quadrant (gray) represents the continuous method, in which seabirds are recorded in real time as they enter the quadrant. From Spear *et al.* (2004).

and dark. An observation condition variable allows for the strip width to be wider for boobies than for storm-petrels during the same observation period. Similarly, a veteran seabird observer may be able to reliably detect birds at a greater distance than can someone more recently trained; the observation condition value for these two individuals may therefore vary within the same sighting conditions. Effort data also include information about the ship (course and speed) and about location, usually derived from a global positioning system.

Species data always include species identification (to the lowest possible taxon) and number of individuals. Depending on the goals of the survey, additional information for each bird may be recorded. If density is to be calculated, behavior must be recorded to avoid overestimates or underestimates resulting from ship-attracted or ship-avoiding species respectively (Spear *et al.* 2004, Borberg *et al.* 2005). If absolute abundance estimates are a survey goal, “flux” (movement of birds relative to the ship) must be taken into account. A number of methods make that adjustment (Tasker *et al.* 1984, Gaston *et al.* 1987, Spear *et al.* 1992), but if the data are collected using the continuous method, flight direction and speed should be recorded. Behavior, age and sex are often recorded, as is distance from the ship.

Time may be recorded as local or Greenwich. If seabird data are to be linked with other data collected aboard the ship, analysis will be easier if all data are collected in the same time format. Because local mean time can be relatively arbitrarily set by the ship’s crew, it is best to record both local and Greenwich time. And time should ideally be recorded from a single source. The ship’s global positioning system is ideal, because it can be used as a central source of information for oceanographic and other biologic data.

Data management has become an issue for almost every scientist. Included are documentation of field methods, data processing procedures and data format; editing to remove errors; and archiving. Rescue of data that exist only in hard copy format has become a real concern as scientists retire and the value of long time series is more widely appreciated. For these reasons, data should be entered electronically in the field if at all possible. Many data entry programs are available, and new ones can be created. The data entry program should be coupled with data edit programs; errors are more easily fixed by those who collected the data and immediately after collection.

INSIGHTS INTO THE BIOLOGY OF INDIVIDUAL SPECIES

Distribution

Distribution is among the most basic of information about seabird biology. Yet because seabirds can disperse widely from their colonies and because they can be rare or difficult to identify, comprehensive distribution patterns for a particular species can be difficult to obtain. Additionally, distribution often varies seasonally because of migratory movements, and interannually because of oceanographic and climatic factors (discussed later in the text).

A comprehensive picture of average, or typical, distribution can best be obtained by piecing together results of numerous studies over long periods of time (e.g. Harrison 1983). And so, for example, it is clear that the Juan Fernandez Petrel *Pterodroma externa*, a species that breeds only on the Juan Fernandez Islands off the coast of Chile, occurs throughout the eastern tropical Pacific in the boreal fall and is found in highest density in a latitudinal band between 0 degrees and 10 degrees north (Fig. 3).

Species–habitat relationships

Comprehensive distribution patterns provide clear evidence that species are typically not evenly distributed throughout their range. Instead, some areas are more important than others (e.g. Fig. 3). Why this is so forms the basis of the study of species–habitat relationships.

It is clear that seabirds preferentially associate with physical features (e.g. fronts, thermal domes, topographic features), surface currents and water masses (reviewed in Ballance *et al.* 2006). These habitat preferences are species-specific. And so, for example, in the eastern tropical Pacific, Juan Fernandez Petrels are found in highest density in waters with sea surface temperature near 28°C, salinity near 35 psu and a thermocline deeper than 100 m; Leach's Storm-Petrels *Oceanodroma leucorhoa* are found in highest density in waters with sea surface temperatures near 22°C, a low surface chlorophyll concentration and a shallower thermocline, with a gradient of approximately 3°C 10 m⁻¹ (Fig. 4; Vilchis *et al.* 2006).

It is commonly accepted that the physical features or combinations of oceanographic parameters with which a given species associates represent proxies for prey abundance or availability, and not the physiologic tolerance of a seabird for physical characteristics of its environment. In other words, species–habitat relationships reflect species–prey relationships.

Although it is clear that a seabird should occur in highest density where prey are most abundant, demonstrating such associations has proved to be challenging (reviewed in Ballance *et al.* 2001). In general, the strength of the correlation between seabird and prey density increases with spatial scale; correlations are stronger for piscivorous seabirds than for planktivorous seabirds; and correlations are often found only with repeated surveys. Explanations of why seabird densities do not match the apparent abundance of their prey very accurately include

- inability of seabirds to consistently locate dense prey patches;

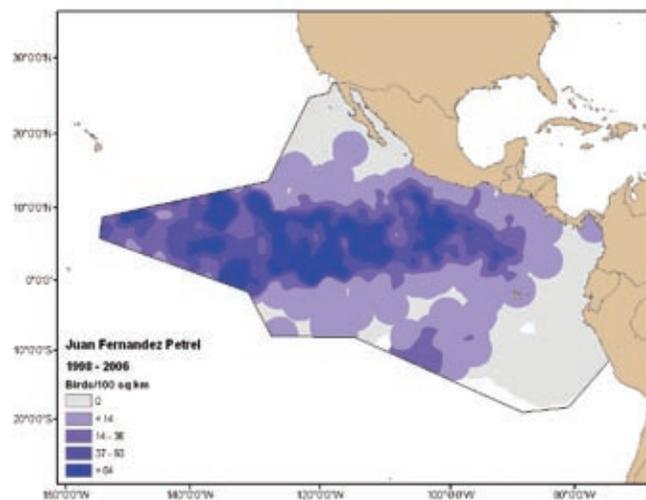


Fig. 3. Distribution of the Juan Fernandez Petrel *Pterodroma externa* in the eastern tropical Pacific based on five years of data (1998–2000, 2003, 2006) collected August through November, 240 sea days each year. Density was calculated along the surveyed trackline and then interpolated using negative exponential distance weighting with a decay of 80 km and a neighborhood of 300 km (L.T. Ballance & R.L. Pitman unpubl. data).

- sufficient abundance of prey such that seabirds do not need to locate dense prey patches;
- successful avoidance of seabirds by prey;
- a time lag between prey patch formation, discovery of the patch by seabirds, and measurement by researchers;
- a disproportionate importance of dense patches such that seabirds ignore other prey patches (i.e. the functional response is highly nonlinear).

Species–habitat relationships also provide the answer to why distribution patterns exhibit interannual variation. For example, interannual variation in distribution of the Juan Fernandez Petrel in the eastern tropical Pacific (Fig. 5) reflects the fact that hydrographic features are not static in space or time (Fiedler & Talley 2006). As the distribution of its preferred habitat changes, Juan Fernandez Petrels track that distribution, so that species–habitat relationships remain relatively constant (Fig. 6, Ballance *et al.* 2002). Such constancy tends to be the case for many seabirds (reviewed in Ballance *et al.* 2006).

Abundance

Estimates of seabird population size are commonly obtained from colony censuses; however, for species that nest in inconspicuous or inaccessible locations such as burrows, trees, cliff faces or mountain tops, colony censuses can be difficult. An alternative method is to estimate abundance from at-sea surveys, where density is calculated for the surveyed area and then extrapolated to the larger area of interest to obtain total abundance (e.g. Piatt & Ford 1993, Spear *et al.* 1995, Spear & Ainley 2007). These at-sea abundance estimates also directly account for the non-breeding component of a population, a

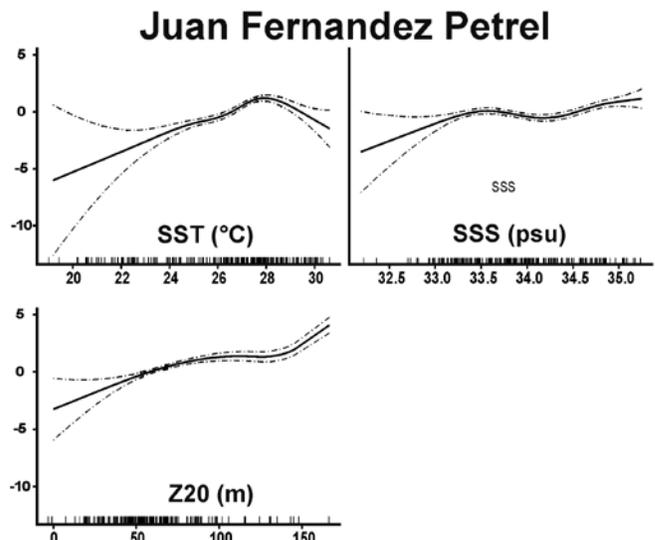


Fig. 4. Results of generalized additive models constructed to model the relationships between two seabird species and oceanographic variables using data collected from the eastern tropical Pacific in 1989. For each plot, the vertical axis represents the effect of an oceanographic variable on seabird density; ticks along the horizontal axis represent data from each survey day; dashed lines represent the upper and lower pointwise twice-standard error curves. SST = sea surface temperature; SSS = sea surface salinity; log Chl = log₁₀ surface chlorophyll; Z₂₀ = depth of the 20°C isotherm; Z_{DIF} = vertical temperature gradient between the 20°C and 15°C isotherms. (From Vilchis *et al.* 2006)

component that must be estimated using demographic parameters when the abundance estimate is based on colony censuses.

The methods used for extrapolation of density to unsurveyed areas vary. Among the best are generalized additive models [GAMs (Clarke *et al.* 2003)]. GAMs use environmental variables to model density along the surveyed area. The model is then used to predict density in areas not sampled. Because environmental information used in the model must be available throughout the region of interest, basic variables are typically used (e.g. latitude and longitude, depth, distance from land). GAMs allow for survey effort to be nonrandomly distributed and for relationships between species density and environmental parameters to be nonlinear.

Abundance estimates produced using GAMs have been validated for three species by comparing estimates based on at-sea data with those produced from colony counts (Clarke *et al.* 2003). In all cases (Western Gull *Larus occidentalis*, Common Murre *Uria aalge*, and Waved Albatross *Phoebastria irrorata*) colony-based estimates were within the 95% confidence intervals of the sea-based estimates.

INSIGHTS INTO SEABIRD COMMUNITIES

Community composition

Breeding communities of seabirds almost always differ from feeding communities of seabirds. Feeding communities are the at-sea component of seabird community ecology and often comprise species that come from widely scattered breeding locations.

The eastern tropical Pacific provides a good example. More than 100 seabird species have been recorded in the area between the US–Mexico border, the Hawaiian Archipelago and the Ecuador–Peru border (L.T. Ballance & R.L. Pitman unpubl. data). Of the 54 species that regularly occur in oceanic waters (species for which at least 100 individuals were recorded in at least one year in which eight sea months of ship time were devoted to seabird surveys), 30 are seasonal residents (breeding elsewhere but dispersing to the eastern tropical Pacific during the non-breeding season to feed) and four are migrants (moving through the eastern tropical Pacific between breeding and feeding regions elsewhere; see Appendix B in Ballance *et al.* 2006). Therefore, 63% of the seabird species in this oceanic community do not breed in the region.

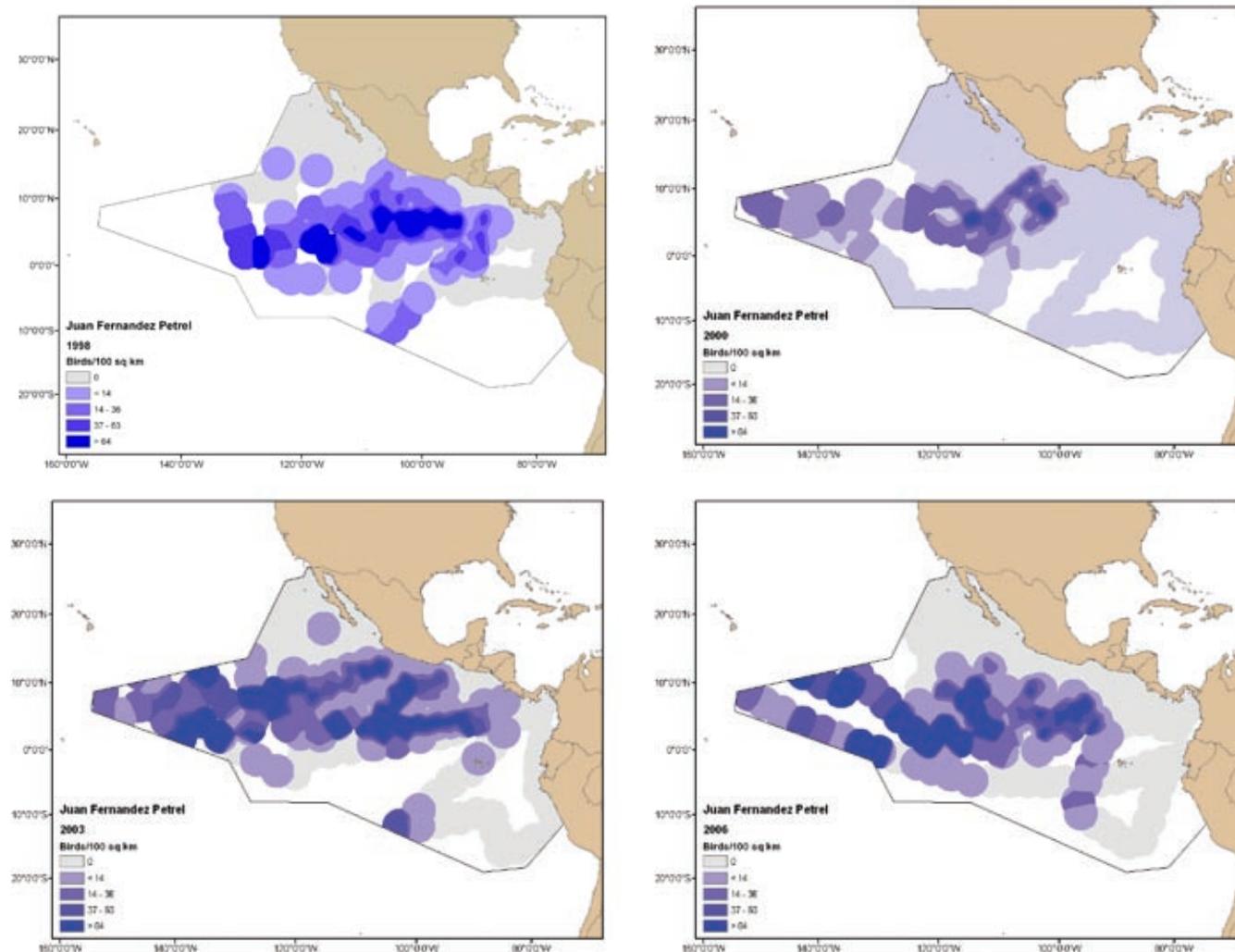


Fig. 5. Interannual variation in distribution of the Juan Fernandez Petrel *Pterodroma externa* in the eastern tropical Pacific, August through November, 240 sea days each year. Density was calculated along the surveyed trackline and then interpolated using negative exponential distance weighting with a decay of 80 km and a neighborhood of 300 km (L.T. Ballance & R.L. Pitman unpubl. data).

These seasonal resident and migrant species that use the eastern tropical Pacific come from many parts of the Pacific. For example, Leach's Storm-Petrels breed on islands off the west coast of North America and Alaska; Wedge-tailed Shearwaters *Puffinus pacificus* and Sooty Terns *Onychoprion fuscatus* breed on islands in the central Pacific; Caledonian Petrels *Pterodroma leucoptera caledonica* breed in New Caledonia, Tahiti Petrels *Pseudobulweria rostrata* in the Society Islands, and South Polar Skuas *Catharacta maccormicki* in Antarctica (Elliott *et al.* 1992, del Hoyo *et al.* 1996).

Interspecific interactions

Most of a seabird's life at sea is focused on obtaining and capturing prey. Foraging and feeding set the stage for a host of interactions, including predation, interspecific and intraspecific competition, and commensalism. Colony-based studies can provide insights into some of these at-sea interactions. For example, Ashmole and Ashmole (1967) surmised that many tropical seabirds must depend on predatory fishes to drive prey to the surface, because many of the prey that those authors identified at their Christmas Island research site were not known to occur at the ocean surface. But much of the detail regarding interspecific seabird interactions must be obtained by studying seabirds at sea.

Competition is widely believed to occur among seabirds at sea, mostly in the context of feeding flocks (Hoffman *et al.* 1981, Harrison *et al.* 1991, Ballance *et al.* 1997). It is clear to anyone who has observed an actively feeding flock of birds that direct interference competition for access to prey can be intense. This competition can structure the composition of a particular flock and of a particular community. For example, tropical boobies can dive to deeper depths than can tropical terns. Both feed in multispecies flocks, and it has been suggested that interference competition allows Masked Boobies *Sula dactylatra* to numerically dominate feeding flocks in highly productive waters, whereas Sooty Terns are constrained to feed in greatest numbers in flocks in areas of relatively low productivity (Ballance *et al.* 1997). These relationships are often a function of body size, because size often determines the outcome of interference competition (Persson 1985). Body size also greatly affects energetic requirements and, therefore, foraging range and prey density requirements.

Seabirds have a variety of commensal relationships centered on foraging. In the oceanic tropics, one of the most significant of

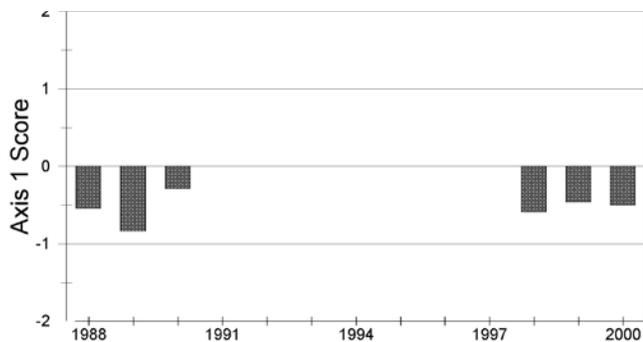


Fig. 6. Results of a canonical correspondence analysis using 10 seabird species and nine environmental variables to quantify species-habitat associations in the eastern tropical Pacific. The figure shows the relationship between Juan Fernandez Petrel *Pterodroma externa* density and habitat (y axis) over six years (x axis). Juan Fernandez Petrel association with habitat defined by Axis 1 remains consistent over time. (Modified from Ballance *et al.* 2002)

these is the dependence of seabirds on subsurface predators. That dependence is particularly the case in the eastern tropical Pacific, where yellowfin tuna *Thunnus albacares* and spotted *Stenella attenuata* and spinner *S. longirostris* dolphins can be considered the most significant resource for feeding seabirds (Au & Pitman 1986, 1988; Ballance 1993; Ballance *et al.* 1997; Ballance & Pitman 1999; Spear *et al.* 2007). In the eastern tropical Pacific, a total of 91 seabird species have been recorded feeding in association with these predatory fishes and mammals, including 46 procellariiforms, 29 charadriiforms, and 16 pelecaniforms. For some seabird species, these tunas and dolphins represent most of their feeding opportunities. For example, 96% of feeding Galapagos Petrels *Pterodroma phaeopygia* were associated with those predators. And in the eastern tropical Pacific, tunas and dolphins support many of the most abundant seabird species.

INSIGHTS INTO OCEANIC ECOSYSTEMS

Seabirds have long been used as indicators of oceanic ecosystems. "The use of food samples from sea birds in the study of seasonal variation in the surface fauna of tropical oceanic areas" (Ashmole & Ashmole 1968) was one of the first papers to use colony-based studies of seabirds to infer properties of the oceanic environment, an idea that has caught the attention of seabird and fisheries biologists and managers ever since. Much of this research is conducted on colonies, using metrics describing prey brought to chicks (e.g. prey species, size or age, and relative abundance) or reproductive performance to infer ecosystem state (e.g. Harris & Wanless 1990, Monaghan 1996). Studies of seabirds at sea have more recently been added to the body of literature providing examples of seabirds as indicators of ecosystem state (reviews by Sydeman *et al.* 2006, Piatt *et al.* 2007).

A case study from the eastern tropical Pacific provides an applied example. The eastern tropical Pacific ecosystem supports one of the world's largest fisheries for yellowfin tuna, with between 100 000 and 300 000 metric tons caught each year (IATTC 2002). The success of the fishery is in large part a result of the as-yet unexplained association between yellowfin tuna and spotted and spinner dolphins. All three regularly associate in mixed-species schools (Perrin & Gilpatrick 1994, Perrin & Hohn 1994) and attract large and diverse flocks of seabirds (Au & Pitman 1986). The high visibility of these assemblages, and the fact that tuna and dolphin remain together in non-feeding situations, has made it possible to detect, follow and capture tuna schools using the associated dolphins and seabirds (Perrin 1969).

During 1960–1972, more than four million dolphins were incidentally killed in the fishery (Wade 1995), and the decline in their populations resulted in three stocks being declared depleted under the Marine Mammal Protection Act (Smith 1983). Since the early 1990s, because of the ingenuity of fishers, regulatory measures implemented since declaration of depletion, and international conservation efforts, observed mortality has been reduced to thousands of dolphins annually (Gosliner 1999). With this dramatic reduction in direct mortality, recovery of the depleted dolphin populations has been expected, yet abundance estimates through 2000 show no evidence of an expected increase in population levels (Gerrodette & Forcada 2005).

Studies of seabirds at sea in the eastern tropical Pacific dating back to 1986 have provided an independent indication of ecosystem state since that time to address the hypothesis that a change in

the ecosystem may have prevented recovery of the depleted dolphin stocks (Ballance *et al.* 2002, Reilly *et al.* 2005). Year-to-year variability in distribution occurred for a suite of nine focal species, including five tuna-dependent and four tuna-independent species. Species–habitat relationships were identified for each of these species, and those relationships were relatively stable over time. This consistency largely explained interannual variation in distribution, because species appeared to track preferred habitat as it moved in space and time. For all but one species, no long-term trends in abundance were observed. And no pattern differences were detected between tuna-dependent and tuna-independent species. This research provided support for the conclusion that the carrying capacity of the ecosystem for the two dolphin species was unlikely to have been reduced to the degree required to explain the low growth rates in their populations.

CONSERVATION AND MANAGEMENT CHALLENGES

Indirect threats

Threats to seabirds at sea are direct—including fisheries bycatch, pollutants (e.g. oil, heavy metals, plastics) and entanglement in marine debris—and indirect—including competition with fisheries and effects of climate change. Direct threats tend to be widely acknowledged, but indirect threats tend to be poorly understood and are rarely acknowledged, despite being potentially significant (as discussed later in this paper).

For example, Parkinson's Petrel *Procellaria parkinsoni* is an endangered seabird that breeds on two islands off northern New Zealand (Imber 1987). During the non-breeding season, it migrates to the eastern tropical Pacific, where it preferentially associates with two relatively rare dolphins, melon-headed whale *Peponocephala electra* and false killer whale *Pseudorca crassidens*. Although melon-headed whales and false killer whales comprised only 0.4% and 0.9% of all cetacean sightings made during a four-year period (1986–1989), Parkinson's Petrel was often recorded in association with those species [33.3% and 25.7% of all sightings of those cetacean species respectively (Pitman & Ballance 1992; Fig. 7)]. Fisheries bycatch of these two dolphins is a significant problem in some tropical regions (Forney & Kobayashi 2007). This bycatch is recognized and actively managed in at least some areas (Carretta *et al.* 2007), but the potentially significant indirect impacts on Parkinson's Petrel are not considered in management decisions.

A second example stems from the reliance of a great many tropical seabirds on tropical tunas to provide feeding opportunities, as described earlier. Management of tropical tunas receives a great deal of attention, but the indirect effects of industrial-scale tuna fishing on seabirds is not considered in any tuna management decisions, despite the fact that fewer tuna mean fewer feeding opportunities for tropical seabirds.

TRANS-HABITAT AND TRANS-BOUNDARY CHALLENGES

Like seabirds, a number of marine vertebrates rely on two very different habitat types, spending part of their lives on land and part at sea. Seals, sea lions and marine turtles are obvious examples, breeding on land and feeding at sea. This “trans-habitat” characteristic tends to be a poor fit, structurally and functionally, for many management schemes. For example, in the United States, the federal branch of government generally responsible for management

of land-based organisms is the Fish and Wildlife Service (USFWS); for management of marine organisms, it is the National Marine Fisheries Service (NMFS). The management authority for trans-habitat organisms varies. NMFS has management responsibility for seals and sea lions, USFWS for Walrus *Odobenus rosmarus* and Sea Otter *Enhydra lutris*. USFWS has management authority for seabirds; the responsibility of NMFS for seabirds relates almost exclusively to fisheries bycatch issues.

This structural division means that conservation issues are often addressed in a piecemeal manner rather than an integrative one, and institutional funding for significant management needs often cannot be justified. For example, relative to USFWS, NMFS has rich resources in the form of sea-going ships. Yet although populations of many seabirds can be more effectively monitored through at-sea censuses than through colony-based counts, NMFS rarely funds such work because the management authority for seabirds lies with USFWS.

Seabirds are also truly trans-boundary, paying no attention to arbitrary political boundaries. They can spend much of their lives far from their breeding colonies, utilizing the high seas and waters belonging to a host of different countries. Their trans-boundary nature poses a daunting management challenge, because monitoring and enforcement policies and resources vary between nations. Seabirds are not the only trans-boundary marine organisms. In fact, many large-bodied marine vertebrates regularly cross political boundaries: whales and dolphins, seals and sea lions, sharks and predatory tunas, and marine turtles. The challenges of effective management apply equally to those taxa.

Marine turtles provide a model for addressing the trans-habitat and boundary challenges. In the United States, management authority for marine turtles is shared jointly between USFWS and NMFS. And management actions include activities focused on the high seas and within the territorial boundaries of a host of countries where turtles either breed on beaches or forage in near-shore waters. The same features of seabirds that make those birds good ecosystem indicators also provide an opportunity to use them as a

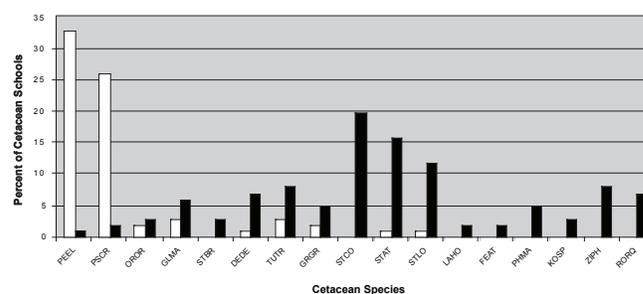


Fig. 7. Relative sighting frequency of cetacean species (or species groups) recorded during 1986–1989 and frequency of association with Parkinson's Petrels *Procellaria parkinsoni*. Example: 0.4% of all cetacean herds were PEEL, but 33.3% of all PEEL herds were with associated Parkinson's Petrels. (Modified from Pitman & Ballance 1992) PEEL = *Peponocephala electra*; PSCR = *Pseudorca crassidens*; OROR = *Orcinus orca*; GLMA = *Globicephala macrorhynchus*; STBR = *Steno bredanensis*; DEDE = *Delphinus delphis*; TUTR = *Tursiops truncatus*; GRGR = *Grampus griseus*; STCO = *Stenella coeruleoalba*; STAT = *Stenella attenuata*; STLO = *Stenella longirostris*; LAHO = *Lagenodelphis hosei*; FEAT = *Feresa attenuata*; PHMA = *Physeter macrocephalus*; KOSP = *Kogia species*; ZIPH = *Ziphiid species*; RORQ = *Rorqual*.

successful model for dealing with trans-habitat and trans-boundary management challenges. Joint management, between agencies and between countries alike, is not only desirable, it is necessary, and success will pave the way for successful management of a host of other marine organisms.

ACKNOWLEDGMENTS

Robert Pitman taught me virtually everything I know about seabirds and set me on a course that has lasted the duration of my professional career. Additionally, because I work at sea, I never work alone. The data and ideas presented in this paper are the result of collaborations with a small army of field and laboratory researchers, and critical support from technicians and others that I have received over the past 20 years. Deserving of special mention are Jenna Borberg, Paul Fiedler, Michael Force, Robert Holland, Kathy Hough, Jessica Redfern, Steve Reilly, Larry Spear, and the officers and crew of the NOAA Research Vessels *David Starr Jordan* and *McArthur*.

REFERENCES

- ASHMOLE, M.J. & ASHMOLE, N.P. 1968. The use of food samples from sea birds in the study of seasonal variation in the surface fauna of tropical oceanic areas. *Pacific Science* 22: 1–10.
- ASHMOLE, N.P. & ASHMOLE, M.J. 1967. Comparative feeding ecology of sea birds of a tropical oceanic island. Peabody Museum of Natural History (Yale University), Bulletin 24. 131 pp.
- AU, D.W.K. & PITMAN, R.L. 1986. Seabird interactions with tuna and dolphins in the eastern tropical Pacific. *Condor* 88: 304–317.
- AU, D.W.K. & PITMAN, R.L. 1988. Seabird relationships with tropical tunas and dolphins. In: Burger, J. (Ed). Seabirds and other marine vertebrates. Competition, predation and other interactions. New York: Columbia University Press. pp. 174–212.
- BALLANCE, L.T. 1993. Community ecology and flight energetics in tropical seabirds of the eastern Pacific: energetic correlates of guild structure [PhD dissertation]. Los Angeles: University of California–Los Angeles. 173 pp.
- BALLANCE, L.T., AINLEY, D.G. & HUNT, G.L. Jr. 2001. Seabird foraging ecology. In: Steele, J.H., Thorpe, S.A. & Turekian, K.K. (Eds). Encyclopedia of ocean sciences. Vol. 5. London, UK: Academic Press. pp. 2636–2644.
- BALLANCE, L.T. & PITMAN, R.L. 1999. Foraging ecology of tropical seabirds. In: Adams, N. & Slotow, R. (Eds). Proceedings of the 22nd International Ornithological Congress, Durban. Johannesburg: BirdLife South Africa. pp. 2057–2071.
- BALLANCE, L.T., PITMAN, R.L. & FIEDLER, P.C. 2006. Oceanographic influences on seabirds and cetaceans of the eastern tropical Pacific: a review. *Progress in Oceanography* 69: 360–390.
- BALLANCE, L.T., PITMAN, R.L. & REILLY, S.B. 1997. Seabird community structure along a productivity gradient: importance of competition and energetic constraint. *Ecology* 78: 1502–1518.
- BALLANCE, L.T., PITMAN, R.L., SPEAR, L.B. & FIEDLER, P.C. 2002. Investigations into temporal patterns in distribution, abundance and habitat relationships within seabird communities of the eastern tropical Pacific. Administrative report LJ-02-17. La Jolla, CA: NOAA Fisheries, Southwest Fisheries Science Center. 79 pp.
- BORBERG, J.M., BALLANCE, L.T., PITMAN, R.L. & AINLEY, D.G. 2005. A test for bias attributable to seabird avoidance of ships during surveys conducted in the tropical Pacific. *Marine Ornithology* 33: 173–179.
- CARRETTA, J.V., FORNEY, K.A., MUTO, M.M., BARLOW, J., BAKER, J., HANSON, B. & LOWRY, M.S. 2007. US Pacific Marine Mammal Stock Assessments: 2006. NOAA technical memorandum NOAA-TM-NMFS-SWFSC-398. La Jolla, CA: NOAA Fisheries. 312 pp.
- CLARKE, E.D., SPEAR, L.B., MCCRACKEN, M.L., MARQUES, F.F.C., BORCHERS, D.L., BUCKLAND, S.T. & AINLEY, D.G. 2003. Validating the use of generalized additive models and at-sea surveys to estimate size and temporal trends of seabird populations. *Journal of Applied Ecology* 40: 278–292.
- DEL HOYO, J., ELLIOTT, A., SARGATAL, J. & CABOT, J. 1996. Handbook of the birds of the world. Vol. 3 (hoatzin to auks). Barcelona: Lynx Edicions. 821 pp.
- ELLIOTT, A., DEL HOYO, J., SARGATAL, J. & CABOT, J. 1992. Handbook of the birds of the world. Vol. 1 (ostriches to ducks). Barcelona: Lynx Edicions. 696 pp.
- FIEDLER, P.C. & TALLEY, L.E. 2006. Hydrography of the eastern tropical Pacific: a review. *Progress in Oceanography* 69: 143–180.
- FORNEY, K.A. & KOBAYASHI, D.R. 2007. Updated estimates of mortality and injury of cetaceans in the Hawaii-based longline fisheries, 1994–2005. NOAA Technical Memorandum NMFS-SWFSC-412. La Jolla, CA: NOAA Fisheries. 30 pp.
- GASTON, A.J., COLLINS, B.L. & DIAMOND, A.W. 1987. The “snapshot” count for estimating densities of flying seabirds during boat transects: a cautionary comment. *Auk* 104: 336–338.
- GERRODETTE, T. & FORCADA, J. 2005. Non-recovery of two spotted and spinner dolphin populations in the eastern tropical Pacific Ocean. *Marine Ecology Progress Series* 291: 1–21.
- GOSLINER, M.L. 1999. The tuna-dolphin controversy. In: Twiss, J.R.Jr. & Reeves, R.R. (Eds). Conservation and management of marine mammals. Washington, D.C.: Smithsonian Institution Press. pp. 120–155.
- HARRIS, M.P. & WANLESS, S. 1990. Breeding success of British Kittiwakes *Rissa tridactyla* in 1986–88: evidence for changing conditions in the northern North Sea. *Journal of Applied Ecology* 27: 172–187.
- HARRISON, N.M., WHITEHOUSE, M.J. HEINEMANN, D., PRINCE, P.A., HUNT, G.L. Jr & VEIT, R.R. 1991. Observations of multispecies seabird flocks around South Georgia. *Auk* 108: 801–810.
- HARRISON, P. 1983. Seabirds: an identification guide. Boston: Houghton Mifflin Company. 448 pp.
- HOFFMAN, W., HEINEMANN, D. & WIENS, J.A. 1981. The ecology of seabird feeding flocks in Alaska. *Auk* 98: 437–456.
- IATTC (INTER-AMERICAN TROPICAL TUNA COMMISSION). 2002. Annual report, 2000. La Jolla, CA: IATTC. 171 pp.
- IMBER, M.J. 1987. Breeding ecology and conservation of the Black Petrel (*Procellaria parkinsoni*). *Notornis* 34: 19–39.
- MONAGHAN, P. 1996. Relevance of the behaviour of seabirds to the conservation of marine environments. *Oikos* 77: 227–237.
- PERRIN, W.F. 1969. Using porpoise to catch tuna. *World Fishing* 18: 42–45.
- PERRIN, W.F. & GILPATRICK, J.W. Jr. 1994. Spinner dolphin—*Stenella longirostris* (Gray, 1828). In: Ridgway, S.H. & Harrison, R. (Eds). Handbook of marine mammals. Vol. 5: the first book of dolphins. San Diego, CA: Academic Press. pp. 99–128.
- PERRIN, W.F. & HOHN, A.A. 1994. Pantropical spotted dolphin—*Stenella attenuata*. In: Ridgway, S.H. & Harrison, R. (Eds). Handbook of marine mammals. Vol. 5: the first book of dolphins. San Diego, CA: Academic Press. pp. 71–98.
- PERSSON, L. 1985. Asymmetrical competition: are larger animals competitively superior? *American Naturalist* 126: 261–266.

- PHILBRICK, V.A., FIEDLER, P.C., BALLANCE, L.T. & DEMER, D.A. 2003. Report of ecosystem studies conducted during the 2001 Oregon, California, and Washington (ORCAWALE) marine mammal survey on the research vessels David Starr Jordan and McArthur. NOAA technical memorandum NOAA-TM-NMFS-SWFSC-349. La Jolla, CA: NOAA Fisheries, Southwest Fisheries Science Center. 50 pp.
- PIATT, J.F. & FORD, R.G. 1993. Distribution and abundance of Marbled Murrelets in Alaska. *Condor* 95: 662–669.
- PIATT, J.F., SYDEMAN, W.J. & WIESE, F. 2007. Introduction: a modern role for seabirds as indicators. *Marine Ecology Progress Series* 352: 199–204.
- PITMAN, R.L. & BALLANCE, L.T. 1992. Parkinson's Petrel distribution and foraging ecology in the eastern tropical Pacific: aspects of an exclusive feeding relationship with dolphins. *Condor* 94: 824–834.
- REILLY, S.B., DONAHUE, M.A., GERRODETTE, T., FORNEY, K., WADE, P., BALLANCE, L., FORCADA, J., FIEDLER, P., DIZON, A., PERRYMAN, W.F., ARCHER, A. & EDWARDS, E.F. 2005. Report of the scientific research program under the International Dolphin Conservation Program Act. NOAA technical memorandum. La Jolla, CA: National Marine Fisheries Service, Southwest Fisheries Science Center. 100 pp.
- SMITH, T.D. 1983. Changes in size of three dolphin (*Stenella* spp.) populations in the eastern tropical Pacific. *Fishery Bulletin* 81:1–13.
- SPEAR, L.B. & AINLEY, D.G. 2007. Storm-petrels of the eastern Pacific Ocean: species assembly and diversity along marine habitat gradients. *Ornithological Monographs* 62.
- SPEAR, L.B., AINLEY, D.G., HARDESTY, B.D., HOWELL, S.N.G. & WEBB, S.W. 2004. Reducing biases affecting at-sea surveys of seabirds: use of multiple observer teams. *Marine Ornithology* 32: 147–157.
- SPEAR, L.B., AINLEY, D.G., NUR, N. & HOWELL, S.N.G. 1995. Population size and factors affecting at-sea distributions of four endangered procellariids in the tropical Pacific. *Condor* 97: 613–638.
- SPEAR, L.B., AINLEY, D.G. & WALKER, W.A. 2007. Foraging dynamics of seabirds in the eastern tropical Pacific Ocean. *Studies in Avian Biology* 35: 1–99.
- SPEAR, L.B., NUR, N. & AINLEY, D.G. 1992. Estimating absolute densities of flying seabirds using analyses of relative movement. *Auk* 109: 385–389.
- SYDEMAN, W.J., BRODEUR, R.D., BYCHKOV, A., GRIMES, C. & MCKINNELL, S. 2006. Marine habitat 'hotspots' and their use by migratory species and top predators in the North Pacific Ocean: Introduction. *Deep Sea Research II* 53: 247–249.
- TASKER, M.L., JONES, P.H., DIXON, T. & BLAKE, B.F. 1984. Counting seabirds at sea from ships: a review of methods employed and a suggestion for a standardized approach. *Auk* 101: 567–577.
- VILCHIS, L.I., BALLANCE, L.T. & FIEDLER, P.C. 2006. Pelagic habitat of seabirds in the eastern tropical Pacific: effects of foraging ecology on habitat selection. *Marine Ecology Progress Series* 315: 279–292.
- WADE, P.R. 1995. Revised estimates of incidental kill of dolphins (*Delphinidae*) by the purse-seine tuna fishery in the eastern tropical Pacific, 1959–1972. *Fishery Bulletin* 93:345–354.
- WILSON, R.P., GRÉMILLET, D., SYDER, J., KIERSPEL, M.A.M., GARTHE, S., WEIMERSKIRCH, H., SCHÄFER-NETH, C., SCOLARO, J.A., BOST, C.A., PLÓTZ, J. & NEL, D. 2002. Remote-sensing systems and seabirds: their use, abuse and potential for measuring marine environmental variables. *Marine Ecology Progress Series* 228: 241–261.
- WILSON, R.P., SHEPARD, E.L.C. & LIEBSCH, N. 2008. Prying into the intimate details of animals lives: use of a daily diary on animals. *Endangered Species Research* 4: 123–137.

