PAPER for Plastic Debris Rivers to the Sea Conference 2005

Seabirds as indicators of plastic pollution in the North Pacific

Hannah Nevins[1, 2], David Hyrenbach[3], Carol Keiper[2], Jenny Stock[4], Michelle Hester[2], and Jim Harvey[1]

[1]BeachCOMBERS, Moss Landing Marine Laboratories, 8272 Moss Landing Road, Moss Landing, CA 95039, hnevins@mlml.calstate.edu
[2]Oikonos Ecosystem Knowledge, P.O. Box 979, Bolinas, CA 94924
[3]Duke University Marine Laboratory, Beaufort, NC 28516
[4]Cordell Bank National Marine Sanctuary, P.O. Box 159, Olema, CA 94950

Abstract

As far-ranging top predators, seabirds are valuable biological indicators of climatic and human-related perturbations of marine food webs because they sample marine ecosystems over large space and time scales. These same ecological reasons make seabirds valuable indicators of plastic pollution in coastal and oceanic waters. In this paper we review studies of the incidence and impacts of plastic ingestion on North Pacific seabirds, and identify several ecological factors that influence the susceptibility of different species. Foraging mode, habitat use, and body size are important factors to consider when quantifying the magnitude of plastic ingestion and its potential impacts on seabird populations. Large-bodied, oceanic species that feed opportunistically at the surface are most susceptible to plastic ingestion. In particular, far-ranging tubenose (Procellariiformes) species, like fulmars and albatrosses, are ideal bio-indicators of marine plastic pollution. In this paper we report on plastic ingestion by Northern Fulmars (*Fulmarus glacialis*) collected in California during 2003–2004, and review past research on far-ranging Hawaiian albatrosses. These results underscore the value of studies of seabird diet and stomach contents to monitor trends in North Pacific marine pollution. Although it is difficult to quantify population-level impacts resulting from the documented patterns of plastic ingestion in seabirds, the incidence of plastic debris in many long-lived North Pacific species is an emerging ecological problem that warrants further investigation. The mitigation of plastic ingestion in seabirds is a complex problem that will require broad-reaching cooperation between industry and wildlife resource managers, as well as education and public outreach. We present an educational program, designed to increase public awareness of the threats posed to seabirds by marine pollution, and to promote public stewardship of North Pacific seabirds.

Introduction

Seabirds are abundant upper-trophic level predators in marine ecosystems, where they forage on zooplankton, fish, and squid. By virtue of their charismatic nature, their ecological position high on the marine food web, and their vast foraging ranges —seabirds provide an ideal vehicle for monitoring plastic pollution in the world’s oceans (Ryan and Fraser 1988, Furness and Camphuysen 1997, Van Franeker 2004). Moreover, because seabirds eat the same zooplankton, fish, and squid prey consumed by commercially-valuable fish species (e.g., salmon), they also may provide valuable information on the pollutant loads of marine resources consumed by humans (e.g., Montevecchi 1993, Burger and Gochfeld 2004, Blais et al. 2005). Most research on marine debris and seabirds has been motivated by the need to understand contaminant pathways in marine ecosystems, and has been largely limited to documenting plastic ingestion. The available research has shown an increasing trend in plastic ingestion in seabird populations worldwide, from the tropics to polar regions (Collins 2005, Edwards 2005). Thus, the study and remediation of marine pollution has important implications for seabird conservation globally, and will require greater attention in the future.

Oceanic birds occupy vast ranges spanning multiple national economic exclusive zones, and often migrate across ocean basins and between hemispheres (Birdlife International 2004). Thus, international efforts are needed to study and mitigate the global conservation challenge of marine debris pollution. This presentation addresses the widespread incidence of plastic ingestion in marine birds, with an emphasis on North Pacific species, and reviews evidence of the resulting detrimental impacts. The patterns documented for North Pacific species are likely indicative of the trends and impacts in other ocean basins. Yet, no data are available for many colonies, species, and regions. Although there currently is no systematic scientific study to assess the global magnitude and impacts of plastic debris, local and regional monitoring programs of seabird populations (e.g., Van Franeker 2004) and marine litter surveys (e.g., Ryan and Moloney 1993) provide a foundation for a future comprehensive program.

Many North Pacific seabirds ingest anthropogenic marine debris, including post-consumer plastics, also called "user" plastics (Baltz and Morejohn 1976, Robards et al. 1995, Blight and Burger 1997). Many of the surface feeding species - such as albatrosses, petrels, and fulmars - which forage opportunistically on a broad range of fish and squid prey seem especially prone to ingesting a broad array of user plastics. In particular, Laysan (*Phoebastria immutabilis*) and Black-footed (*Phoebastria nigripes*) albatrosses, and Northern Fulmar (*Fulmarus glacialis*) frequently ingest a variety of large-sized (a few cm long) items such as bottle caps, cigarette lighters, toys, party balloons, and fragments of broken user plastics. During chick provisioning, adults then feed these items to their young, resulting in detrimental effects on chick growth and survival (Ryan 1987, Sievert and Sileo 1993). By virtue of their long life-spans (> 30 years), adult birds bio-accumulate the toxic compounds leached from the ingested plastics, with potential detrimental effects on fecundity rates and egg breakage rates (Jones et al. 1996, Auman et al. 1997). Other species that capture zooplankton - such as phalaropes, shearwaters, and auklets - ingest small-sized (few millimeters long) fragments of user plastics and pre-production industrial plastic pellets (a.k.a. nurdles; Robards et al. 1995, Blight and Burger 1997, Vlietstra and Parga 2002).

We are working to encourage public participation in *Coastal Cleanup Day* and *Adopt a Beach* program activities, by supporting web-based animal tracking, public outreach lectures, and teacher workshops designed to supplement the California Coastal Commission Science Activity Guide "Waves, Wetlands, and Watersheds". These efforts, which aim to link seabird ecology with the sources of marine debris, illustrate the diverse venues available to raise awareness of plastic pollution, and to promote stewardship for seabirds and ocean conservation.

Methods

In this inter-disciplinary paper we present three components of our work on plastic debris and its associated impacts on seabirds: (i) a field study of plastic ingestion in California, (ii) a literature review of plastic ingestion for North Pacific species, and (iii) the development of outreach and educational materials to disseminate this information to the public.

We investigated the incidence of plastic in the gut contents of two migratory seabirds, the gull-sized (600 g) Northern Fulmar and the small- bodied (80 g) Red Phalarope (*Phalaropus fulicarius*). During the winter of 2003-04, a "wreck" of fulmars and phalaropes occurred along the entire west coast of North America, from British Columbia, Canada to Baja California, Mexico (Nevins et al., unpublished data). In central California, the Coastal Ocean Mammal and Bird Education and Research Survey (COMBERS) documented this unusual mortality event and collected carcasses for laboratory examinations. Necropsies and stomach analyses were performed at the Moss Landing Marine Laboratories of the California State Universities, and the Marine Wildlife Veterinary Care and Research Center, California Department of Fish and Game, Santa Cruz, California. We examined the stomach contents of 190 Northern Fulmars and three Red Phalaropes, and determined the incidence (frequency of occurrence) and the magnitude (mean number of items per individual) of plastic ingestion.

To place the results of this field study in a broader context, we completed a review of the scientific literature to summarize the incidence of plastic ingestion in North Pacific seabirds. We used this information to illustrate several of the ecological and life-history factors that influence plastic ingestion in seabirds, including foraging strategy, habitat use, and body size.

Finally, we report ongoing collaborative efforts to promote marine stewardship and awareness of seabird conservation issues through creative public outreach and education.

Results and Discussion

Field Study

Plastic fragments occurred in 71% of the fulmar and 100% of the phalarope stomachs we examined. Natural prey items (e.g., squid beaks) occurred in 72% of the fulmars and 0% of the phalaropes. Fulmar stomachs contained an average of nine post-consumer fragments (range = 1–41), two pre-production pellets or "nurdles" (range = 1–8), two styrofoam fragments (range = 1–10), and two other pieces of debris (range = 1–6; including rubber bands, party balloons, fishing line and lure fragments, plastic film, artificial sponge, unidentified items). The mean size of user plastics ingested by fulmars was 5.7 ± 2.8 mm (n = 733). Fulmars ingested predominantly white plastic fragments (61%), but they also ingested a variety of colors, including green (8%), brown (8%), blue (6%), red (6%), yellow (5%), and pink (2%). Phalaropes consumed mainly plastic fragments (range = 1–25), one individual had ingested a single nurdle. Because Phalaropes have a smaller stomach capacity than the larger-sized fulmars, and thus ingested smaller plastic fragments (mean = 2.6 ± 0.6 mm, n = 22).

Literature Review

Seabirds depend upon ocean ecosystems exclusively to feed themselves and their young, and thus are likely to encounter potentially detrimental marine debris throughout their lives. Furthermore, because many seabirds are extremely long-lived (e.g., shearwaters >50 years, albatross >80 years), they are especially susceptible to chronic effects from low levels of pollutants accumulated over the long term (Jones et al. 1996, Auman et al. 1997).

A review of the literature highlights the pervasive nature of marine plastic pollution, from the tropics to sub-polar regions (Day and Shaw 1987, Van Franeker and Bell 1988, Spear et al. 1995, Auman et al. 2004). Even remote areas like Inaccessible Island, in the sub-Antarctic Atlantic Ocean, are polluted by marine debris (Ryan and Moloney 1993). Nevertheless, this research suggests that foraging mode, body size, habitat use, influence the incidence and susceptibility of seabirds to plastic ingestion. An understanding of these patterns can help wildlife managers to target those species that are especially susceptible to plastic debris, thereby defining conservation priorities for research and mitigation.

Several studies provide a broad sense of species-specific differences in the incidence of plastic ingestion among North Pacific seabirds. In a survey of breeding seabirds in Alaska, 62.5% (15 out of 24 species, n = 1799 individual birds) had ingested plastic debris (Robards et al. 1995). Overall, of the 4417 plastic items examined, 76% were industrial pellets, 22% were fragments of user plastic, and 2% were unidentified. This study highlighted the differential incidence of plastic ingestion among seabird feeding modes; surface-feeding species showed a greater rate of plastic ingestion than diving species (86% vs. 47%), and took a relatively greater proportion of user plastics (Robards et al. 1995). A comparison of plastic ingestion rates in the 1970s and the 1980s revealed a higher incidence for surface-feeding species. For example, the plastic ingestion rate for the Northern Fulmar increased from 58% (1969–77) to 84% (1988–90).

A study of seabirds incidentally killed by an experimental squid gillnet fishery off British Columbia, Canada, provided a snap-shot of plastic occurrence in a northeast Pacific seabird community (41–50 ^{o} N, 131–134 ^{o} W). Fifty-eight birds and 11 taxa were sampled, 100% of five surface-feeding species contained plastics while only 50% of the diving species had ingested plastics. The mean number of plastic items per bird was an order of magnitude greater for the surface feeders (20.8) than for the divers (1.4). Overall, of 353 plastic items found in seabird stomachs, 29% were industrial pellets and 71% were fragments of user plastic (Blight and Burger 1997).

Thus, of the four main types of foraging modes used by seabirds (surface-feeding, diving, piracy, and plunge-diving), surface feeders, including many of the procellariiformes (e.g., albatrosses, shearwaters, fulmars, storm-petrels) frequently encounter and ingest floating plastic debris. The incidence (frequency of individuals of a given species with plastic in the stomach) is generally high in these species, ranging from 50 to 80% (Table 1). Whereas diving birds appear to be less susceptible to plastic ingestion, they likely are more vulnerable to other types of marine debris, such as entanglement in fishing nets and monofilament line. Among diving alcids, those which feed on zooplankton (e.g., puffins, auklets) appear to ingest plastic more frequently than predominantly fish-eaters such as murres (Table 1).

Body size likely plays a vital role determining the types of plastics that seabirds can ingest (Fry et al. 1987). The larger species albatrosses are capable of ingesting large prey and debris (up to 90–160 mm in length), including cigarette lighters, bottle tops, toy army men, and chemical light sticks used for fishing lures (Gould et al. 1997, Kinan and Cousins 2000, Cooper et al. 2004). Conversely, small-sized shearwaters, storm-petrels, and phalaropes ingest small fragments (1–5 mm diameter) of user plastics and nurdles. These seabirds likely mistake brightly colored plastic fragments for prey items (e.g., squid, crustaceans, gelatinous zooplankton). Large-bodied scavengers and predatory species, such as skuas, may ingest plastics secondarily when consuming other seabirds or regurgitated pellets containing plastic fragments (Ryan and Fraser 1988).

Habitat use is another important determinant of the type and amount of plastics ingested by seabirds (Spear et al. 1995). Whereas nearshore species (e.g., pelicans, cormorants, and murres) are most affected by coastal human activities (e.g., gillnet by-catch, entanglement in fishing gear, oil spills), offshore species are affected by more widely-dispersed human activities spread over the entire North Pacific Ocean. Far-ranging seabirds, which cover vast distances in search for food and often concentrate at frontal systems, encounter plastic debris at-sea far away from the localities where they breed (Cooper et al. 2004). In fact, due to their seasonal migrations and the action of currents, seabirds are affected by marine pollution throughout the globe. These global impacts are best illustrated by the plight of species which, despite breeding in uninhabited remote islands in the Southern Ocean, are impacted by plastic debris originating from distant sources (Auman et al. 2004).

In addition to transporting debris long distances, ocean currents and wind patterns concentrate plastics within certain oceanic regions (Wong et al. 1974, Ebbesmeyer and Ingraham 1992, Kubota 1994, Moore 2003). For instance, large (> 25 mm length) plastic fragments are on average twice more abundant within subtropical (35–39 ^{o} N) than sub-arctic (45–48 ^{o} N) latitudes in the North Pacific, and small fragments are 30 times more abundant (Day and Shaw 1987). Thus, we would expect subtropical seabirds to encounter and ingest greater amounts of plastics than species from higher latitudes. For instance, the Black-footed Albatross (population size: 0.2 million) and the Laysan Albatross (population size: 2.5 million) are most numerous within subtropical and sub-arctic latitudes during the summer-time (June – September) post-breeding dispersal. Conversely, the Northern Fulmar (population size: 4.6 million) is most numerous in the Bering Sea continental shelf close to its breeding colonies. These species occur in the California Current System throughout the year, though their numbers peak during the post-breeding dispersal stage (Briggs et al. 1987).

In addition to these large-scale disparities in plastic concentrations, the same smaller-scale physical oceanographic processes (e.g., frontal systems and convergence zones) that often define seabird foraging habitats, likely influence the abundance and availability of floating plastic debris to foraging seabirds. For instance, albatrosses seem especially susceptible to plastic ingestion because they forage along oceanic frontal systems, where they encounter buoyant prey (e.g., *Velella velella,* dead floating squid) and inadvertently ingest plastics accumulated at surface convergence zones (Gould et al. 1997). Off the west coast of North America, Black-footed albatrosses concentrate along shelf-slope habitats, offshore of coastal upwelling plumes (Hyrenbach et al. 2002, Ainley et al. 2005).

The negative effects of plastic ingestion at the shelf-slope habitat are transferred from the adults to their chicks on remote islands, distant from the mainland sources of plastic pollution. Sievert and Sileo (1993), for instance, found that plastic ingestion hindered growth and survival of Laysan albatross chicks. During the chick-rearing season, Laysan albatrosses forage along the North Pacific Transition Domain (Hyrenbach et al. 2002), in a region where prevailing wind patterns concentrate floating debris (Day and Shaw 1987, Kubota 1994). While a pilot study at Kure Atoll in 1999 – 2000 revealed that all (100 %) the pellets regurgitated by chicks contained plastic, these sympatrically-breeding albatrosses differed in the types of items ingested. Namely, there was a higher incidence of cigarette lighters in the pellets of Laysans (19% of 88 boluses) compared with those from Black-foots (0% of 56 boluses; Kinan 2000). These differences in pollutant loads have been ascribed to the segregation of the foraging grounds, and the dietary differences of these two species (Gould et al. 1997, Hyrenbach et al. 2002, Finkelstein et al. 2003). This result underscores the inter-related nature of seabird foraging habitats, diets, and oceanography.

Off the west coast of North America, millions of resident and migratory seabird species rely on the food resources of the productive California Current upwelling system (Briggs et al. 1987; Table 1). Thus, pollution of coastal and offshore regions poses a threat not only to locally-breeding species, but also to far-ranging seasonal visitors from the arctic (e.g., Northern Fulmar; Black-legged Kittiwake, *Rissa tridactyla*) and from the southern hemisphere (e.g., Sooty Shearwater, *Puffinus griseus;* Pink-footed Shearwater, *Puffinus creatopus*; Short-tailed Shearwater, *Puffinus tenuirostris*; Baltz and Morejohn 1976). For example, globally-threatened Pink-footed Shearwaters migrate from a few nesting islands off Chile to forage in shelf waters of California, where they are vulnerable to oil pollution, fishery entanglement, ingestion of plastics, and other toxic pollutants. Yet, the incidence of plastic ingestion and the susceptibility of many of these species to marine debris in the California Current System has not been well documented (Table 1).

Currently, there are no standardized programs to document regional patterns in the types, amount, and provenance of plastic pollution and marine debris at-sea in the North Pacific. Nor are there any programs set up to investigate long-term trends in the magnitude of marine debris pollution and plastic ingestion by seabirds. In fact, only two studies have documented long-term (decadal) trends in seabird ingestion of plastics in the North Pacific (Robards et al. 1995, Vlietstra and Parga 2002). Robards et al. (1995) documented an increased incidence, magnitude, and number of species plastic ingestion among Alaskan seabirds between 1969–1977 and 1988–1990. Vlietstra and Parga (2002) documented a change in the types of debris, from predominantly industrial pellets (1970–1978) to user plastics (1997–2001), but no change in the incidence (86%) of plastic ingestion by Short-tailed Shearwaters in the southeastern Bering Sea. These studies underscore the need to initiate and maintain long-term standardized studies to quantify trends in the abundance, types, and origin of the plastics ingested by North Pacific seabirds.

Education program

We have formed an inter-disciplinary collaboration among scientists, non-profit groups, National Marine Sanctuaries, and marine educators to engage students and teachers in marine stewardship, and to increase the public awareness of seabird conservation issues. During 2004–2005, we shared real-time satellite tracking data of Black-footed Albatross and Sooty Shearwater migrations online via the Seaturtle.org (http://www.seaturtle.org/tracking) and Signals of Spring (http://www.signalsofspring.net/) web-sites. In 2005, we conducted public lectures and teacher workshops during beach clean-ups in support of the California Coastal Clean-up Day. As part of this outreach effort, we have produced stickers bearing the slogan "Protect Seabirds, Prevent Plastic Pollution", for dissemination to beach clean-up participants. Education at many levels is required to reach a diverse audience both locally and globally. By educating and engaging the public, particularly young students, we hope to reduce plastic pollution in the long-term.

Conclusions and Recommendations

Concurrent increases in human activities and marine pollution in the world's oceans continue to negatively impact seabird populations. Floating plastic debris is particularly harmful to surface feeding seabirds, some of which are listed as endangered (e.g., Short-tailed Albatross *Phoebastria albatrus*; world population less than 2,000 birds). The subtle effects of plastics on oceanic and coastal seabirds, such as stomach impaction and the consequences of leaching pollutants, are difficult to document. In our field study, we were not able to attribute the primary cause of death in Northern Fulmars and Red Phalaropes to plastic ingestion, as has been found in some cases of clear stomach obstruction (Sievert and Sileo 1993, Pierce et al. 2004). However, the high incidence of plastic ingestion (71 to 100%) may have contributed to the reduced body condition (body mass) found in all the specimens collected during a large-scale seabird die-off documented off California, as suggested previously for other species (Connors and Smith 1982, Ryan 1987, Spear et al. 1995). The inability to clearly ascribe detrimental effects from plastic ingestion at the individual-level (e.g., deteriorated condition) and population-level (e.g., lower reproductive success) poses a great challenge for seabird conservation. Our review of the literature and research findings suggest that marine debris pollution affects many North Pacific seabirds, but further systematic research is necessary to determine spatial and temporal trends, and to quantify species-specific impacts. In the North Sea, an international consortium of scientists initiated a program to monitor trends in marine pollution, using the incidence of industrial plastics in the stomachs of beached fulmars collected throughout eight countries (Van Franeker and Meijboom 2002, Van Franeker 2004). This effort provides a working model upon which the North Pacific community could develop a system to quantify marine pollution impacts, and to determine the effectiveness of mitigation actions aimed at reducing marine pollution in coastal communities. Our preliminary data from Northern Fulmars recovered in California indicate a high incidence of ingested plastics (71 %) similar to those found in the North Sea. We suggest an annual systematic effort following the approach taken by Van Franker (2004) to document the incidence of plastic ingestion by fulmars along the west coast of North America. Currently, beach survey programs operate throughout the region, in collaboration with national marine sanctuaries, and university research laboratories. Beach-cast specimens could be obtained from these programs and analyzed following standardized techniques, thus providing a coast-wide perspective of the incidence of plastic ingestion and the condition of fulmars at-sea. In addition, we advocate the increased support of marine stewardship educational programs, as a way to reduce marine pollution impacts on North Pacific seabird populations.

Acknowledgements

Beach COMBERS was supported by a grant from the Science Integrated Monitoring Network, Monterey Bay National Marine Sanctuary to Moss Landing Marine Laboratories. We thank the many dedicated COMBERS volunteers who conduct systematic beach surveys every month and without whom this work could have not been possible. K. Starbuck, C. Gibble, and M. Frieberg assisted with stomach content analysis. Teacher workshops were supported by the California Coastal Commission's Whale Tail grant. Education program was additionally supported by Algalita Marine Research Foundation, Oikonos Ecosystem Knowledge, Cordell Bank National Marine Sanctuary, City of Benicia, Seaturtle.org, SignalsofSpring.net, Duke Marine Laboratories, and Moss Landing Marine Laboratories. J. Adams provided helpful comments that greatly improved this manuscript.

Cited and Reviewed Data Resources

Ainley, D.G., L.B. Spear, C.T. Tynan, J.A. Barth, T.J. Cowles, and S.D. Pierce, S.D. 2005. Factors affecting occurrence patterns of seabirds in the northern California Current, spring and summer 2000. Deep-Sea Research II 52: 123-143.

Auman, H.J., J.P. Ludwig, C.L. Summer, D.A. Verbrugge, K.L. Froese, T. Colborn, and J.P. Giesy. 1997. PCBs, DDE, DDT and TCDD-EQ in two species of albatross on sand island, midway atoll, North Pacific Ocean. Environmental Toxicology and Chemistry 16: 498-504.

Auman, H.J., E.J. Woehler, M.J. Riddle, and H. Burton. 2004. First evidence for ingestion of plastic debris by seabirds at sub-Antarctic Heard Island. Marine Ornithology 32: 105–106.

Baltz, D.M., and G.V. Morejohn. 1976. Evidence from seabirds of plastic particle pollution off central California. Western Birds 7:111–112.

BirdLife International. 2004. Tracking ocean wanderers: the global distribution of albatrosses and petrels. Results from the Global Procellariiform Tracking Workshop, 1-5 September, 2003, Gordon's Bay, south Africa. Cambridge, UK: BirdLife International.
www.birdlife.net/action/science/species/seabirds/tracking.html

Blais, J.M., L.E. Kimpe, D. McMahon, B.E. Keatley, M.L. Mattory, M.S.V. Douglas, and J.P. Smol. 2005. Arctic seabirds transport marine-derived contaminants. Science 309: 445-445.

Blight, L.K., and A.E. Burger. 1997. Occurrence of plastic particles in seabirds from the eastern North Pacific. Marine Pollution Bulletin 34: 323–325.

Briggs, K.T., K.F. Dettman, D.B. Lewis, and W.B. Tyler. 1987. Bird communities at sea off California. Studies in Avian Biology 11: 1-74.

Burger J., and M. Gochfeld. 2004. Marine birds as sentinels of environmental pollution. Ecohealth 1: 263-274.

Collins, S. 2005. Albatrosses have had a gizzard full of plastics. New Zealand Herald. Published 7 February 2005. http://www.nzherald.co.nz/index.cfm?c_id=1&ObjectID=10009767

Connors, P.G. and K.G. Smith. 1982. Oceanic plastic particle pollution: suspected effect on fat deposition in red phalaropes. Marine Pollution Bulletin 13: 18–20.

Cooper, J., H.J. Auman, and J. Klavitter. 2004. Do the albatrosses of Midway Atoll select cigarette lighters by color? Pacific Seabirds 31(1): 2–4.

Day, R. H. and D.G. Shaw. 1987. Patterns in the abundance of pelagic plastic and tar in the North Pacific-Ocean, 1976-1985. Marine Pollution Bulletin 18: 311–316.

Ebbesmeyer, C.C., and W.J. Ingraham. 1992. Shoe spill in the North Pacific. Eos 73: 361.

Edwards, R. 2005. Seabirds ingest bellyfuls of plastic pollution. New Scientist 185:11. Published 8 January 2005.http://www.nmm.ac.uk/server.php?show=ConWebDoc.18821

Finkelstein, M.E., D.A. Croll, B. Tershy, B.S. Keitt, W. Jarman, T. Lowe, C. Bacon, and D.R. Smith. 2003. Regional, not trophic, foraging patterns substantiate differences in contaminant levels between two North Pacific albatross species. Toxicological Sciences 72: 192-192 930 Suppl.

Fry, D.M., S.I. Fefer, and L. Sileo. 1987. Ingestion of plastic debris By Laysan Albatrosses and Wedge-Tailed Shearwaters in the Hawaiian-Islands. Marine Pollution Bulletin 18: 339-343.

Furness, R.W., and C.J.Camphuysen. 1997. Seabirds as monitors of the marine environment. ICES Journal of Marine Science 54 (4): 726-737.

Gould, P.J., P. Ostrom, and W. Walker. 1997. Trophic relationships of albatrosses associated with squid and large-mesh drift-net fisheries in the North Pacific Ocean. Canadian Journal of Zoology 75: 549–562.

Hunt, G.L., Jr., H. Kato, and S. McKinnell. (Eds.) 2000. Predation by marine birds and mammals in the subarctic North Pacific Ocean. PICES Scientific Report 14. Sidney, Canada. pp. 165.

Hyrenbach, K.D., P. Fernández, and D.J. Anderson. 2002. Oceanographic habitats of two sympatric North Pacific albatrosses during the breeding season. Marine Ecology Progress Series 233: 283–301.

Jones, P.D., D.J., Hannah, S.J. Buckland, P.J. Day, S.V. Leathem, L.J. Porter, H.J. Auman, J.T. Sanderson, C. Summer, J.P. Ludwig, T.L. Colborn and J.P. Giesy. 1996. Persistent synthetic chlorinated hydrocarbons in albatross tissue samples from midway atoll. Environmental Toxicology and Chemistry 15: 1793–1800.

Kinan, I. and K.L. Cousins. 2000. Abundance of plastic debris and ingestion by albatross on Kure Atoll, Northwestern Hawaii Islands. Abstract. Second International Conference on the Biology and conservation of Albatrosses and other Petrels, Waikiki, Hawaii, 8-10 May 2000.

Kubota M.1994. A mechanism for the accumulation of floating marine debris north of Hawaii. Journal of Physical Oceanography 24: 1059–1064.

Montevecchi, W.A. 1993. Birds as indicators of change in marine prey stocks. In: Furness, R.W. and J.J.D. Greenwood (Eds.), Birds as Monitors of Environmental Change. Chapman and Hall, London. pp. 217–266.

Moore, C. 2003. Trashed! Across the Pacific Ocean, Plastics, Plastics, Everywhere. Natural History 112: 46-51.

Pierce, K.E., R.J. Harris, L.S. Larned, and M.A. Pokras 2004. Obstruction and starvation associated with plastic ingestion in a Northern Gannet Morus bassanus and a Greater Shearwater Puffinus gravis. Marine Ornithology 32: 187–189.

Robards, M.D., J.F. Piatt, and K.D. Wohl. 1995. Increasing frequency of plastic particles ingested by seabirds in the subarctic North Pacific. Marine Pollution Bulletin 30: 151–157.

Ryan, P.G. 1987. The effects of ingested plastic on seabirds – correlations between plastic load and body condition. Environmental Pollution 46: 119–125.

Ryan, P.G., A.D. Connell, and B.D. Gardner. 1988. Plastic ingestion and PCBs in seabirds – is there a relationship. Marine Pollution Bulletin 19: 174-176.

Ryan, P.G., and M.W. Fraser. 1988. The use of Great Skua pellets as indicators of plastic pollution in seabirds Emu 88: 16-19.

Ryan, P.G., and C.L. Moloney. 1993. Marine litter keeps increasing. Nature 361: 23-23.

Sievert, P.R., and L. Sileo 1993. The effects of ingested plastic on growth and survival of albatross chicks, pp. 212–217 In: Veermeer, K., Briggs, K.T., Morgan, K.H., Diegel-Causey, D. (eds.). The status, ecology, and conservation of marine birds of the North Pacific. Canadian Wildlife Service Special Publications, Ottawa.

Spear, L.B., D.G. Ainley, and C.A. Ribic. 1995. Incidence of plastic in seabirds from the tropical Pacific, 1984–91 – relation with distribution of species, sex, age, season, year and body-weight. Marine Environmental Research 40: 123-146 1995

Van Franeker, J.A., and P.J. Bell. 1988. Plastic ingestion by petrels in Antarctica. Marine Pollution Bulletin 19: 672–674.

Van Franeker, J.A. and A. Meijboom 2002. Litter NSV: Marine litter monitoring by northern fulmars (a pilot study). Alterra-rapport 401, ISSN 1566-7197. 72 p.

Van Franeker, J.A. 2004. Save the North Sea Fulma-Litter-EcoQO Manual Part 1: Collection and dissection procedures. Alterra, Alterra-rapport 672, ISSN 1566-7197. 38 p.

Vlietstra, L and J.A. Parga. 2002. Long-term changes in the type, but not amount, of ingested plastic particles in short-tailed shearwaters in the southeastern Bering Sea. Marine Pollution Bulletin 44: 945-955.

Wong, C.S., D.R. Green, and W.J. Cretney. 1974. Quantitative tar and plastic waste distributions in the Pacific Ocean. Nature 247: 30-32.

Table 1. Summary of plastic ingestion in seabird species which occur off California, including the foraging strategy (surface-feeding, piracy, diving) relative susceptibility to plastic ingestion (high = 50-80% incidence; moderate = 20-50%; low < 20%; ? = not enough information), foraging location (R = resident year-round; BR = breeding area; NB = non-breeding area), percent incidence of plastic ingestion (n = number of birds examined), and the source of the data, coded by the location of the study (AK: Alaska, CA: California, ENP: Eastern North Pacific, ETP: Eastern Tropical Pacific, HI: Hawaii).

Common Name *Scientific name*	**Foraging strategy**	**Plastic ingestion**	**Breeding / Foraging Locations**	**Incidence (%) (n)**	**Source**[1]
Black-footed Albatross	Surface	High	Hawaii, Japan (BR)	100 (3)	Blight & Burger 1997 (ENP)
Diomedea nigripes			North Pacific (NB)	100 (56)	Kinan & Cousins (HI) chick boluses
Laysan Albatross	Surface	High	Hawaii, Mexico (BR)	100 (106)	Kinan & Cousins (HI) chick boluses
Diomedea immutabilis			North Pacific (NB)		
Northern Fulmar	Surface	High	Boreal Pacific (BR)	100 (3)	Baltz & Morejohn 1976 (CA)
Fulmarus glacialis			Temperate North Pacific (NB)	84 (19)	Robards et al. 1995 (AK)
				100 (3)	Blight & Burger 1997 (ENP)
				71 (190)	Nevins et al., this study (CA)
Buller's Shearwater	Diver	High	New Zealand (BR)	100 (3)	Spear et al. 1995 (ETP)
Puffinus bulleri			North Pacific (NB)		
Pink-footed Shearwater	Diver	Low (?)	Chile (BR)	20 (5)	Baltz & Morejohn 1976 (CA)
Puffinus creatopus			North Pacific (NB)		
Short-tailed Shearwater	Diver	Moderate	South Pacific (BR)	100 (6)	Baltz & Morejohn 1976 (CA)
Puffinus tenuirostris			North Pacific (NB)	80 (5)	Robards et al. 1995 (AK)
Sooty Shearwater	Diver /	Moderate	South Pacific (BR)	43 (21)	Baltz & Morejohn 1976 (CA)
Puffinus griseus	Surface		North Pacific (NB)	75 (36)	Spear et al. 1995 (ETP)
				75 (20)	Blight & Burger 1997 (ENP)
Leach's Storm-petrel	Surface	High	North Pacific (BR),	100 (1)	Blight & Burger 1997
Oceanodroma leucorhoa			Tropical Pacific (NB)	20 (354)	Spear et al. 1995 (ETP)
				48 (64)	Robards et al. 1995 (AK)
Forked-tailed Storm-petrel	Surface	High	North Pacific (R)	86 (21)	Robards et al. 1995 (AK)
Oceanodroma furcata				100 (7)	Blight & Burger 1997 (ENP)
Pelagic Cormorant	Diver	Moderate	California (R)	20 (10)	Robards et al. 1995 (AK)
Phalacrocorax pelagicus					
Red Phalarope	Surface	High	Arctic (BR)	100 (3)	Nevins et al., this study (CA)
Phalaropus lobatus			CA Current (NB)		
Pomarine Jaeger	Pirate	Low (?)	Arctic (BR)	0 (2)	Spear et al. 1995 (ETP)
Stercorarius longicaudus.					
Mew Gull	Surface	Moderate		25 (4)	Baltz & Morejohn 1976 (CA)
Larus canus				25 (4)	Robards et al. 1995 (AK)
Glaucous-winged Gull	Surface	Moderate	Boreal N. Pacific (BR)	13 (8)	Baltz & Morejohn 1976 (CA)

[1] Collection location indicated in parentheses: AK = Alaska, CA = California, HI = Hawaii, ENP = Eastern North Pacific, ETP = Eastern Tropical Pacific Region.

Larus glaucescens			CA Current (NB)	0 (21)	Robards et al. 1995 (AK)
Heerman's Gull	Surface	Low	Mexico (BR)	7 (15)	Baltz & Morejohn 1976 (CA)
Larus heermani			CA Current (NB)		
Black-legged Kittiwake	Surface	Low	Alaska (BR)	13 (8)	Baltz & Morejohn 1976 (CA)
Rissa tridactyla			CA Current (NB)	8 (256)	Robards et al. 1995 (AK)
Common Murre	Diver	Low	North Pacific (R)	0 (1)	Blight & Burger 1997 (ENP)
Uria aalge				0.8 (134)	Robards et al. 1995 (AK)
				0.2 (772)	Nevins, unpublish. (CA)
Pigeon Guillemot	Diver	Low	North Pacific (R)	3 (43)	Robards et al. 1995 (AK)
Cepphus columba					
Xantus's Murrelet	Diver	Low (?)	California, Mexico (R)	0 (5)	Blight & Burger 1997 (ENP)
Synthliborhamphus hypoleucus					
Marbled Murrelet	Diver	Low (?)	E. North Pacific (R)	0 (96)	Robards et al. 1995 (AK)
Brachyrhampus marmoratus					
Cassin's Auklet	Diver	Moderate	E. North Pacific (R)	11 (35)	Robards et al. 1995 (AK)
Ptychorhamphus aleuticus					
Rhinoceros Auklet	Diver	Low	North Pacific (R)	4 (26)	Baltz & Morejohn 1976 (CA)
Cerorhinca monocerata				0 (1)	Robards et al. 1995 (AK)
				0 (6)	Blight & Burger 1997 (ENP)
Tufted Puffin	Diver	Moderate	North Pacific (R)	89 (9)	Blight & Burger 1997 (ENP)
Fratercula cirrhata		to High		24 (489)	Robards et al. 1995 (AK)
Horned Puffin	Diver	Moderate	North Pacific (R)	37 (120)	Robards et al. 1995 (AK)
Fratercula corniculata				50 (2)	Blight & Burger 1997 (ENP)