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Seabirds and Shorebirds

Oceanus®

The Magazine of Marine Science and Policy
Volume 26, Number 1, Spring 1983

Paul R. Ryan, *Editor*
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Elizabeth Miller, *Editorial Assistant*
Polly Shaw, *Advertising*
William H. MacLeish, *Consultant*

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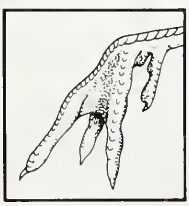

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Introduction:

Birds and the Sea

by Richard G. B. Brown

Evolutionarily speaking, we vertebrates are a paradoxically inconsistent group of animals. Our amphibian ancestors first crawled out of the primeval waters more than 300 million years ago, and ever since then we have been trying to get back in again. We have tried it as reptiles of various kinds, from the extinct ichthyosaurs and plesiosaurs to modern turtles and sea snakes. We have tried it as mammals: whales, seals, otters, manatees, and polar bears. And we have tried it as seabirds. Families from all of these classes have become, to some degree, readapted to life in the sea. All of them differ from the ancestral fishes in the traces they show of their previous adaptations to life on land — lungs, for example, circulatory systems, and skeletal changes.

In terms of number of species, the most successful of these groups today is the seabirds. There are at least 284 living species (the actual figure depends on how you define "seabird" and "species"), whereas there are about 115 living species of marine mammals, five sea turtles, one marine iguana, and about 50 sea snakes. "Seabird" is actually a catch-all term that covers birds from several families, each of which has adapted to marine life independently. The process began very early on. Birds as a class diverged from the reptiles 100 to 150

Red knots in flight. (Photo by David Twichell) million years ago, and fossil remains from the early Eocene Epoch (about 60 million years ago) show that the four principal groups of what we call "seabirds" were already in the process of evolution.

These evolutionary lines are:

*1) **Pelecaniformes:** boobies, gannets, cormorants, tropicbirds, and frigatebirds, as well as pelicans.*

*2) **Lari-Limicolae:** the ancestral shorebird stock that evolved into the auks (murres, murrelets, dovekies, and puffins — also known as alcids), jaegers, skuas, gulls, terns, and skimmers.*

*3) **Tubinares** (named for their tube-shaped nostrils): albatrosses, fulmars, shearwaters, prions, and petrels.*

*4) **Sphenisciformes:** the penguins, an offshoot of Tubinares.*

Roughly speaking, the gull/shorebird stock seems to have evolved in the Northern Hemisphere and the albatrosses and penguins in the South, although their distribution today is wider than that. Outside these four main groups, "seabirds" also includes members of other families: loons; grebes; ducks, geese, and swans; herons; and even a hawk, the osprey.

Variations

The extent of marine adaptations in this heterogeneous assembly varies considerably. Many of the birds, literally and figuratively, have done little more than dip their toes into the water again and cannot even swim. Examples include the herons, the osprey, and almost all shorebirds. Others, such as ducks, cormorants, loons, grebes, and most of the gulls and terns, keep to the shallow inshore zone and seldom or never go out of sight of land; the majority of these species divide their time between fresh water and salt. But the most highly adapted seabirds, such as the auks, albatrosses, petrels, penguins, and gannets, have no representatives on land or fresh water. They are true oceanographers' seabirds, and they spend much of their lives far out at sea. Once a young albatross has fledged, for example, it may be another 5 years or more before it sets foot on land again.

Seabird species have evolved a variety of techniques for living in their newly reacquired marine environment. Some of them plunge from the air into the water to catch their prey, head-first like the gannets and terns or feet-first like the osprey. Some, like the eiders and other ducks, dive deeply and feed at the bottom on benthic organisms. Others, like the auks, penguins, cormorants, and some of the shearwaters, actively pursue their prey underwater, using their wings and feet for propulsion. Frigates, skuas, and jaegers feed partly by pirating food from other seabirds. Skimmers and prions feed in flight, skimming their bills along the surface of the sea. Many species dip in flight to catch food at the surface, or sit on the water and feed on living or dead prey there. Small phalaropes, the only swimming shorebirds, pick at the zooplankton trapped in tide rips and along convergences. Giant albatrosses, at the other end of the scale, feed at the surface on squid. Many of these surface feeders — especially the gulls and fulmars — have learned to

Cormorant pursuing fish underwater. (Photo by Doc White, Nicklin & Associates)

scavenge on the debris left behind by fishing and whaling vessels. In many cases, the same feeding technique has evolved independently in different stocks of seabirds. The dovekie of the Arctic and the diving-petrel of the Sub-Antarctic both hunt by diving for zooplankton, and the two have become almost identical in foraging behavior, size, bill-shape, and even plumage; everything except the minor anatomical details that prove they are basically quite unrelated — a classic case of convergent evolution.

The anatomy of seabirds has evolved along with these foraging techniques. Birds that plunge down from the air have thin, streamlined bodies and pointed beaks and, in the case of the gannets, skeletal features that absorb the shock when they strike the water. The forms of the legs, feet, and bills of the various shorebirds allow them to specialize on preys of different sizes, at different depths in the sand or underwater. The phalaropes, for example, have a flat fringe of skin on the outside of each toe that acts as a simple web for swimming. Unlike other hawks, the osprey's foot has two toes pointing forward and two behind, and these, along with the roughened "sole" of the foot, give it a good grip on a fish. The most specialized divers, the auks and penguins, have compact, streamlined bodies with the legs and feet set well back for steering and propulsion; their short wings act as paddles, and, in the penguins and the extinct great auk, the birds have gone further and altogether lost the power of flight. By contrast, the albatrosses and frigates have long wings adapted for gliding, allowing them to cover long distances with a minimum expenditure of energy. More fundamentally, since seabirds ingest a large quantity of salt when they eat or drink, they have developed a gland that extracts the salt from the bloodstream and excretes it through the nostrils. For this reason most seabirds have perpetually runny noses.

The Halcyon Factor

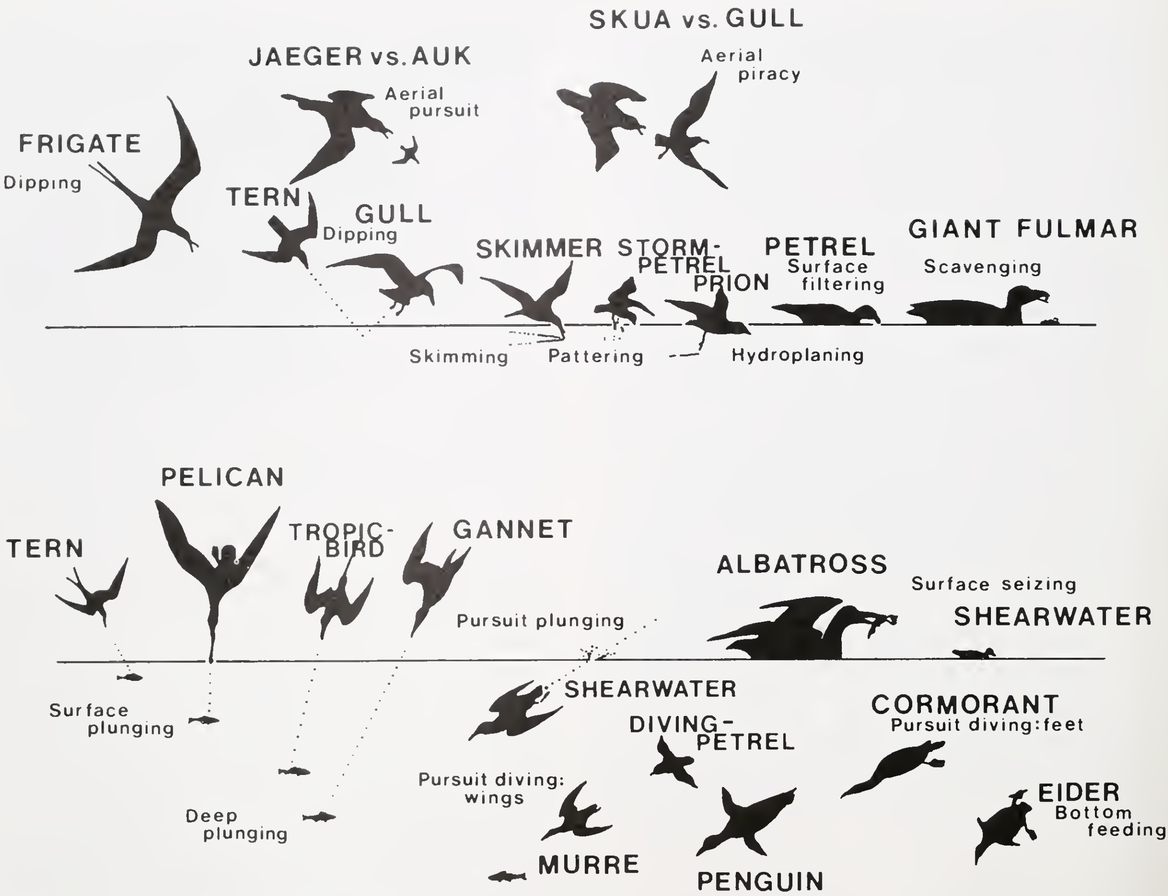
In other words, seabirds are marine animals, and the more specialized groups like the penguins are as well adapted as most of the higher marine vertebrates for their lives at sea. There is, however, one important difference. Seabirds can feed at sea, but they cannot breed there. Like seals, sea turtles, and some sea snakes, they thus are always to some extent tied to the land. The ancient Greeks had a pleasant fantasy about a seabird called the halcyon, which never came to land at all; it laid its eggs on the sea in a nest of foam during the "halcyon days," the calmest season of the year. In sober fact, the nearest any specialized seabirds have come to this, the last logical adaptation to a marine life, are certain murrelets in the North Pacific. These auks incubate their eggs for six weeks and then take their chicks away to sea only two days after they have hatched. Young murres leave their colonies three weeks after they hatch, and often travel several hundred kilometers before they can fly. But this is an exceptionally short time for a seabird chick to stay in its nest, and the feeding strategies of most species require the parents to bring the food to their young, and not the other way around. The young of the larger penguins and albatrosses, for example, may remain at their nesting sites on land for a year or more.

The reasons for this link are plain to see. Seabirds are warm-blooded animals whose eggs require incubation at temperatures of around 40 degrees Celsius, and the newly hatched chicks require brooding and feeding as well. Clearly the birds cannot cast their eggs into the sea and leave them to develop there, like the eggs of most fishes. Marine mammals are viviparous. Many of the reptiles which have become adapted to life at sea, like the extinct ichthyosaurs and most of the modern sea snakes, have solved this problem by becoming ovoviviparous, retaining the eggs in the mother's body until they hatch. But seabirds' eggs are quite large, about 10 percent of the mother's body weight in the murre, for example, and one may doubt whether a flying bird could carry such a weight for the four or more weeks needed for incubation. Conversely, the smaller the egg the more helpless the chick when it hatches and so, presumably, the less its chances would be of surviving birth at sea. On the face of it, seabirds have no alternative but to retain the pattern of their terrestrial ancestors and lay and incubate their eggs on land. The fact that no seabird has become a halcyon has placed important restrictions on the evolution of the group as marine animals.

The most obvious restriction is on their movements. The great advantage that flight gives seabirds over other marine animals is that it allows

Skua attacking an adélie penguin. Aggressive birds, skuas rob penguins of eggs and baby chicks. (Photo by William R. Curtsinger, courtesy of the National Science Foundation)

Black skimmer. (Photo by Phyllis Greenberg, Photo Researchers)



Seabird feeding methods (after Ashmole, 1971).

them to travel widely in search of food and suitable climatic conditions. Terns and red knots from the Canadian Arctic spend the winter off South Africa and in Patagonia, respectively, and the immature terns move on to Antarctica. Conversely, greater shearwaters from the South Atlantic and Wilson's storm-petrels from Antarctica "winter" in our summer in the North Atlantic, from Georges Bank northward. The shearwaters are able to exchange the cool-temperate oceanic zone off Tristan da Cunha for the corresponding one off eastern North America, 10,000 kilometers away. Once they are off our shores, they can follow the course of capelin spawning along the Newfoundland coast, move on to catch the later capelin season off southern Greenland, and then come back to the euphausiid swarms off Nova Scotia on their way back south again.

But only nonbreeders can exercise such options. The peak demand for food is during the breeding season, when the adult seabirds must find food for both themselves and their chicks. At this season, they are restricted to whatever they can find within economical cruising range of their colonies. As an additional complication, the seas may be rich in food but, as in the waters around Antarctica, there may be no land nearby where the birds can nest. The halcyon factor, in other words, is a restriction on the birds' distributions and, as a corollary, on their population sizes as well.

The need to breed on land has had an even wider effect on the adaptive radiation of seabirds as marine animals. A diving bird that must travel long distances from its colony to find food must retain the power of flight. It therefore cannot reduce its wings to the penguin-like paddle shape that is the most efficient form of propulsion underwater. This in turn sets limits on the depths it can reach and the efficiency with which it can chase its prey. The speed of swimming vertebrates is also related to their size; there is a limit to how much a bird can weigh and still be able to fly, and so a lighter bird is limited underwater in both its speed of pursuit and the size of prey available to it.

Penguins, of course, are not restricted in this way. They are the seabirds most highly adapted to the marine environment. Emperor penguins, the biggest species, can reach depths of 265 meters and speeds of 9.6 kilometers per hour and can remain submerged for 18 minutes — a performance fully comparable with that of seals. On the other hand, the flightlessness of penguins undoubtedly restricts their foraging range. For example, there have been recent declines in the populations of many seabirds breeding in South Africa, related to overfishing. The species affected worst is the jackass penguin, the one with the narrowest foraging range. It appears that these penguins now no longer have an abundant, predictable source of food within range of their colonies, whereas the flying seabird species are able to respond more flexibly to this new situation.

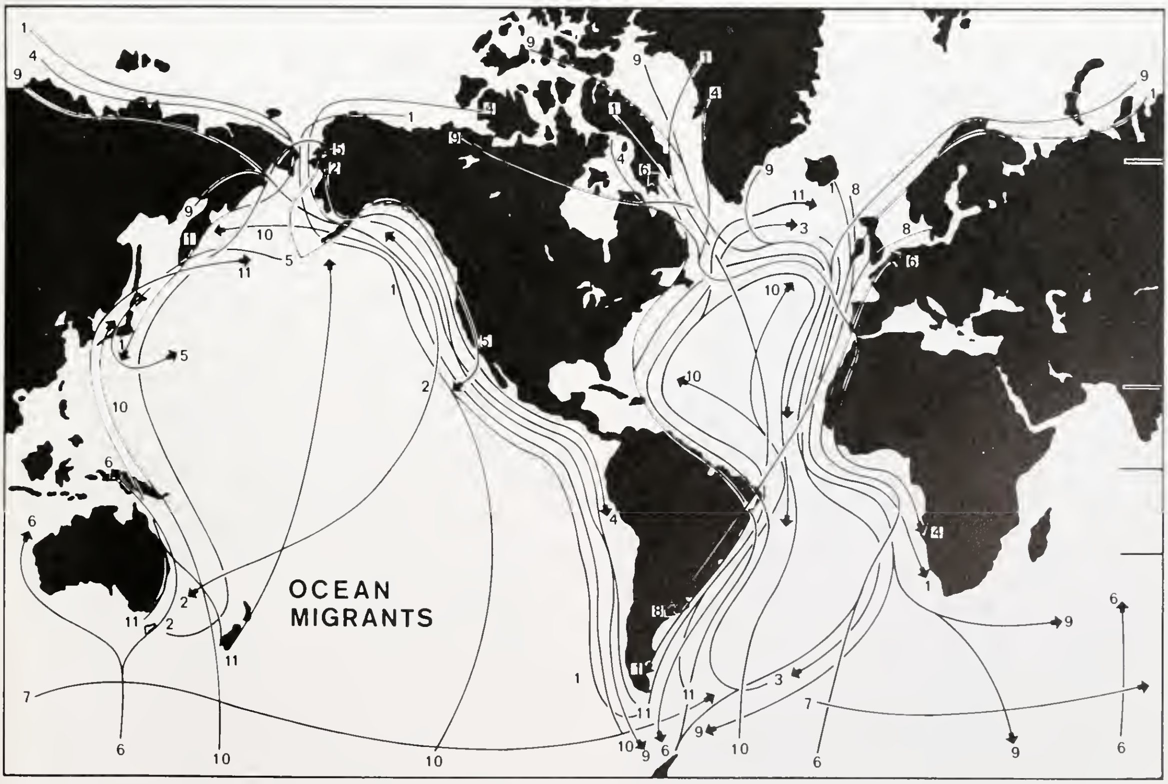
Vulnerability

Lastly, and most immediately, seabirds on land are exceptionally vulnerable animals. Their anatomical specializations for life at sea have in many cases made it difficult for them to walk about, to take off, and to avoid or defend themselves against land predators. The radiation of penguins in the Southern Hemisphere has undoubtedly been assisted by the absence there of such northern predators as polar bears, foxes, rats, and raccoons, all of which would have been devastating to flightless seabirds. Even flying seabirds tend to nest in trees, on cliffs, or on offshore islands free of ground predators, or a combination of the three, to minimize risks. We know all too well what happens when this strategy breaks down. Cats, rats, foxes, mongooses, pigs, and goats, deliberately or accidentally introduced by man, have for one reason or another all ruined seabird colonies. But the greatest devastation usually comes about when man himself is the predator.

The fate of the great auk, the flightless "penguin" of the North Atlantic, is a case in point. This seabird's last sanctuary in the New World, on Funk Island, 30 miles off the Newfoundland coast, was free of every ground predator until the colony was first discovered by European man in 1534. From that point on, men came to slaughter the great auk for three separate reasons during the last 300 years of its existence.

First came the fishermen from the Grand Banks, hunting for fresh meat like any other ground predator. They pillaged the Funks so regularly that it is surprising to learn that they were still able to kill a "boatload" of birds there as late as 1785. But that was before the New England merchants took to putting crews ashore to kill the birds and boil them down for their feathers and oil. In the face of this industrial fishery, the colony collapsed. The only great auks then left anywhere were on a small rock off the southern coast of Iceland, and museum ornithologists finished them off; the rarer a species was, the more necessary it became to collect it. The birds' inaccessible rock sank in an earthquake — another of the perils of land for a breeding seabird —

Some seabird migration routes. (Adapted from the National Geographic Society)



1. Parasitic jaeger
2. Short-tailed shearwater
3. Greater shearwater
4. Sabine's gull
5. Fork-tailed storm-petrel
6. Wilson's storm-petrel
7. Wandering albatross
8. Manx shearwater
9. Arctic tern
10. South polar skua
11. Sooty shearwater

and the alternative site was far less secure. The last great auks were killed on June 3, 1844, and that was the end of a very promising evolutionary experiment in the specialized adaptation of a marine bird to its marine environment.

New Predators, New Dangers

The moral of this tragic history is that in the last 400 years, and especially in the last 40, there has been a radical change in the factors that control the survival of seabird populations. Evolutionary strategies depend on long-range probabilities: that the breeding colony will not be invaded by ground predators; that the food supply will remain predictably close and abundant; that mortality from such "random" events as winter storms and cold breeding seasons is on average low. No species is immortal, and these probabilities are bound to break down in the very long run, of course. But recent events suggest that the tempo of such events has increased drastically, and that seabirds are faced with novel sources of mortality which are quite outside their 60 million years of evolutionary experience.

For example, it is unlikely that ground predators have ever reached predator-free seabird colonies at quite the rate that man and his commensals did during the age of European exploration. The seabird populations of Peru have always fluctuated irregularly, following population

Spilled or dumped oil creates a problem for birdlife. This oil-soaked gannet on a North Carolina beach could not fly and soon died. (Photo by Jack Dermid, U.S. Fish and Wildlife Service)

"crashes" of their main food, the anchoveta, after intrusions of warm water along that coast (known as the El Niño phenomenon — see *Oceanus,* Vol. 23, No. 2, pp. 9–17). But excessive fishing has added another dimension, and it is feared that this, combined with the El Niño of 1976, has left the populations of both anchovetas and seabirds at a permanently low level. The modern emphasis on harvesting the anchovetas, capelin, and krill that are the seabirds' own food, instead of the large predatory fish that are the birds' competitors, is also likely to work to the birds' disadvantage — as it already has for the jackass penguins of South Africa.

There are many direct sources of mortality as well, and they occur more regularly. The effects of oil pollution are well known; our mythical halcyon and its floating nest would be hard-put to survive in the polluted Mediterranean of today. Pesticide residues, working their way up the food-chain and accumulating in the bodies of seabirds, have affected the fertility of the eggs of ospreys, pelicans, gannets, gulls, and even the cahow petrel of Bermuda, already on the brink of extinction because of introduced ground predators. Monofilament gill-nets, almost invisible and virtually indestructible, have drowned large numbers of auks off Greenland and Newfoundland and in the North Pacific.

Less specialized marine birds, such as shorebirds and waterfowl, are perhaps more endangered on migration and in the winter than they are during the breeding season. The market-hunting that brought meat to the markets of Boston and New York during the 19th century put an end to the Labrador duck, which became extinct around 1875, and has virtually wiped out the eskimo curlew as well. But the main risk is the loss of their feeding habitat. It is a paradox that although marine birds can and do travel long distances outside the breeding season, along the coasts and out at sea, the number of places in which they can find the right kinds of food in the right quantities is actually very limited.

Migrating red knots move down to Patagonia and back along a track marked by a few well-defined pit-stops — beaches and mudflats where they can rest and build up their fat reserves for the next leg of their trip. At the end of the breeding season most of the semipalmated sandpipers and northern phalaropes in the eastern Canadian Arctic leave the tundra and migrate, probably nonstop, down to the Bay of Fundy. The sandpipers go to half a dozen very restricted mudflats at the head of the bay, while the phalaropes feed in the tide-rips off the Maine and New Brunswick coasts.

Greater snow geese breed only in the region of northern Baffin Island, and they have only two feeding sites farther south: in winter in Chesapeake Bay, and in spring and fall at Cap Tourmente, a salt marsh just outside Quebec City. These birds are clearly as vulnerable in their way as was the great auk on its isolated breeding rocks. Cap Tourmente has already been menaced at least once by an oil spill. There are plans to use the Fundy tides to generate electrical power, and if carried out, this project would eliminate at least one of the semipalmated sandpipers' stopovers. If these or any of the other marine birds lose their preferred feeding habitats, it is an open question whether they can find alternatives.

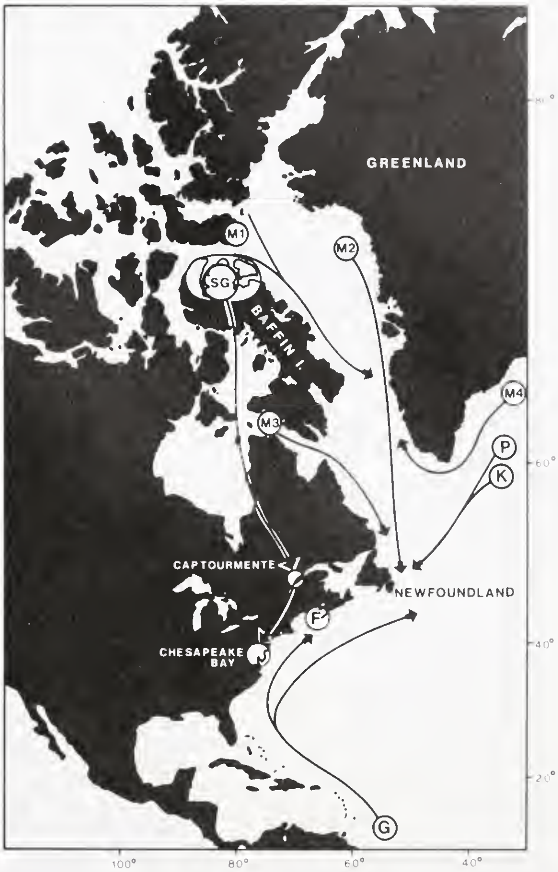
What of the Future?

What, then, can we say about the future of seabirds? If we think only in evolutionary terms and leave man completely out of the picture, how much further can birds go in their adaptations as marine animals? Their next step depends on whether they can solve the riddle of the halcyon, and evolve a means of breeding out at sea.

Could a seabird nest on one of the enormous Antarctic icebergs and drift along with it through the dense swarms of krill? Nonbreeding seabirds already use these as bases for their foraging, and ivory gulls have been known to breed on ice islands up in the Arctic. Could a murrelet lay its eggs on a mass of sargassum weed and hunt for lumpfish and sargassum fish among the fronds below?

What would happen if a penguin became ovoviviparous? Dougal Dixon has "preconstructed" a world 50 million years in the future in which the Southern Ocean is populated by ovoviviparous "pelagornids" — penguin descendants that have taken over the ecological roles of the whales, from dolphin-like fish-eaters to giant birds that feed on krill, as baleen whales do today. It is a fantasy, but on the evolutionary scale of time, who can tell?

Of course the biggest fantasy of all is to leave man out of the picture. We have changed the situation far too much to do this, and the immediate future of marine birds undoubtedly depends on how well they can adapt to our changes. It is not too difficult to make predictions from what we already know about their reproductive strategies. There are two basic patterns, named for the mathematical constants that define them. "*K*-selected" species lay only one egg in a season and have a long period of adolescence before they start to breed and a very low annual mortality as adults. This is the strategy that has been evolved by the seabirds most highly adapted to marine life: auks, penguins, and albatrosses and their relatives. It has proved effective in the past because the sea was normally a safe and predictable place to live, and the birds' life on land was confined to a largely predator-free environment. By contrast, "*r*-selected" species lay several eggs in a season and usually have short adolescent periods and relatively high annual rates of adult mortality. The species least adapted to marine life, such as ducks, geese, shorebirds, and, up to a point, gulls and cormorants, tend to show this pattern. Clearly an "*r*-selected" species, with its higher annual rate of reproduction and population turnover, will be better placed than a "*K*-selected" species to absorb and recover from man-induced mortalities, such as net-drownings or oil spills. For example, the short-tailed albatross of the Bonin Islands off Japan was persecuted almost to extinction by feather hunters until the early 1930s; its population is only just showing signs of revival. Herring gulls, similarly persecuted in New England, received protection in the early 1900s, and by 1930 the population had expanded so rapidly that the birds were becoming a menace to terns and other birds.



Post-breeding migrations of some birds in the northwest North Atlantic. SG: greater snow geese to Chesapeake Bay, via Cap Tourmente, Quebec. F: Bay of Fundy; a migratory stopover for most of the semipalmated sandpipers and northern phalaropes breeding in the eastern North American Arctic. M: migrations of thick-billed murres — (M1) from the eastern Canadian high Arctic to western Greenland; most of these birds later move on to Newfoundland waters; (M2, M3) from western Greenland and Hudson Strait to Newfoundland; (M4) from Spitsbergen and Novaya Zemlya to western Greenland. P, K: Atlantic puffins (P) from Iceland, and black-legged kittiwakes (K) from northwestern Russia to Newfoundland. G: greater shearwaters from the South Atlantic Ocean, initially to Georges Bank and the Grand Banks.

However, reproductive strategies are not the only key to a seabird's chances of survival. The adaptability of its feeding and nesting habits is also important. The herring gull expansion was, literally, fueled by the availability of edible garbage during the winter, which increased the chances of survival of the first-winter birds, the age-class with the highest natural mortality. Herring gulls also have shown an astonishing versatility in their choice of nest sites: cliffs, sand dunes, moors, salt marshes, and now, in Britain, the roofs of city buildings. The kittiwake, a more specialized and oceanic gull, is exploiting fish offal and other human wastes at sea, and in England is even nesting on waterfront warehouses instead of its more usual island cliffs. And who would have believed that as specialized a bird as the osprey could learn to nest on man-made structures, such as power pylons, and is on its way to becoming a bird of the suburbs?

Odds and Omens

The odds are therefore quite good for many species of marine birds, especially species with "*r*-selected" reproductive strategies that can not only absorb the increased mortalities caused by man but can go even further to take advantage of the new opportunities we have created for feeding and nesting. It is encouraging that populations of ospreys and pelicans are recovering from the damage done to them by chemical pollutants. Much of what happens next depends on man, of course. We must be careful to monitor the chemicals we spill into the sea and quick to put a stop to them if their effects are dangerous. We also must preserve the pieces of shoreline habitat that are crucial feeding areas for many of the birds.

But the omens are not nearly as good for the more specialized seabirds. I hope our species has gone beyond the direct, deliberate slaughtering of a species into extinction. But the effects of our commensal animals continue, and we are still living with the effects of direct exploitation and other man-made mortalities in the not-so-distant past. Hunting, egg-collecting, and net-drownings have caused recent, drastic declines in murre colonies in the Canadian Arctic, western Greenland, northern Norway, and Novaya Zemlya. Murres and other auks were once hunted in Britain, and suffered losses from oil pollution, too. It is encouraging that their numbers there are slowly starting to increase again, though it is too soon to say how far this trend will go, or if or when it will extend to the northern populations.

We still seem quite prepared to countenance the extermination of seabird populations, and even species, by indirect means. Abbott's booby breeds only in the treetops of the virgin forest on Christmas Island, in the Indian Ocean, but the whole island is rapidly being excavated for its phosphate deposits. Competition with the fishing industry would be slower, but just as drastic in the long run. The puffins in the biggest colony in Norway have had only a single successful breeding season since 1969. There is a scarcity of their principal food, immature herring, attributable to over-fishing of the Norwegian herring stock in the previous two decades.

The developing new industrial fisheries therefore will have to be monitored very carefully. The latest of these is for krill, the euphausiid shrimps that are central to the food webs of seabirds and all the higher marine predators in Antarctic waters. We must limit our catches so that the stock of krill is not damaged and enough is left for our competing marine predators. This will not be easy because man, as a fisherman, is under enormous pressure to find enough protein for fellow members of our own rapidly increasing, and increasingly hungry, species.

In the last analysis, we ourselves, through our technological achievements, have joined the ranks of higher vertebrates that have tried to go back to the sea again. Our trouble is that we have done this so recently that we are still trying — unsuccessfully, so far — to find our place in a balanced marine ecosystem.

Abbott's booby, with chick. (Photo by J. B. Nelson)

Richard G. B. Brown is a research scientist with the Canadian Wildlife Service's Seabird Research Unit at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia.

Suggested Readings:

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How Seabirds Adapt to Ocean Processes

by Kevin D. Powers

Albatrosses, fulmars, shearwaters, and petrels all have external tubular nostrils through which excess salt is expelled, giving these birds the nickname "tubenoses." This is Leach's storm-petrel. (Photo by Joseph Van Os, Nature Tours, Vashon, Washington)

Naturalists recognize, moreover, that the ranges of fishes and of innumerable marine invertebrates can be readily correlated with temperature and chemical content of sea water. But oceanic birds seem, in the main, to have been regarded somewhat naively as aerial rather than aquatic animals, notwithstanding that their relationships to sea and land, as concerned with feeding and breeding, respectively, are precisely the same as those of the seals among mammals or the sea turtles among reptiles. Members of none of these groups have escaped the necessity of using the land as a cradle, but their true medium, and the source of their being, is, nevertheless, the sea.

Robert Cushman Murphy, 1936,
Oceanic Birds of South America

Seabirds have adapted to their marine environments in a variety of ways, both physiologically and behaviorally. The species we usually call seabirds come from a wide variety of families: penguins; tubenoses (including albatrosses, shearwaters, and petrels); pelecaniforms (including gannets, boobies, and cormorants); gulls and their relatives (including jaegers, skuas, terns, and skimmers); and alcids (including puffins, murres, and dovekies).

All of these birds, in different ways, have had to solve the paradox which Murphy describes: how to make their living at sea while needing to breed on land. Yet another paradox exists concerning the study of these avian mariners. Their adaptation to the terrestrial part of their lives has been the subject of many important studies during the last 70 years; however, they spend 50 to 90 percent of their lives at sea. It is this portion that is still poorly understood. The study of seabirds at sea is one of the last frontiers in ornithology, and the integration of this science with oceanography has, in recent decades, greatly enhanced our knowledge.

The survival of seabirds and their young in breeding colonies is influenced by such factors as the availability of food and nest sites and the presence or absence of land predators. But seabirds at sea have few predators. Their survival depends mainly on their ability to find food in sufficient quantities, when their prey is often irregularly and patchily distributed over a wide and seemingly featureless ocean.

Adaptations

The great variety of feeding abilities in seabirds has allowed them to exploit most sources of food available near the surface in the world's oceans. Fish, crustaceans, and squid are types of prey most commonly taken by seabirds, but carrion and offal are important and often underestimated sources of food. It has been through competitive interaction between seabirds and their marine environment that important adaptations have evolved to partition these available food resources. The most obvious of these adaptations for efficient foraging are the differences in bill form and wing structure.

Variation in bill form is a structural adaptation that corresponds to differentiation in feeding abilities. Plankton-feeders, like dovekies and auklets, have short but relatively wide bills with flattened palatal surfaces and fleshy tongues. This form is most efficient in capturing small, soft-bodied organisms. Fish-eaters, like murres, have longer, narrower bills with palatal grooves and less-fleshy tongues. Similarly, gannets and boobies have long, strong, deeply serrated mandibles, which are well-suited for holding larger fish. Finally, the powerful and sharply hooked bills of skuas are most useful in tearing apart carrion or other seabirds which they often snatch from nests. This diversity in bill form has probably evolved from an overall evolutionary pressure to divide up the food resources among members of seabird communities.

Wing structure and flying ability are also related to feeding and hunting strategies. The complete dependence on flight by albatrosses and the complete flightlessness of penguins are the two extremes. Seabirds in tropical waters must forage over large areas because their prey is sparse, and scarce near the surface in daylight hours. They are able to do so economically because they have long wings relative to their body sizes. Such wings are structural adaptations toward energy-efficient gliding, as opposed to energy-expensive flapping flight. Thus, seabirds inhabiting tropical or equatorial waters feed at the surface by dipping over schools of predatory fish such as tuna, snatching the smaller prey that are being chased to the surface and into the range of the birds. Other tropical seabirds feed on larger and more dispersed prey by plunging from the air, using momentum gained during descent to carry them down below the surface.

However, the wing structure that allows energy economy in flight is not conducive to the underwater pursuit of prey. Underwater swimming broadens the selection of available prey, but only at the expense of flight mobility; short and narrow wings require a flapping rather than gliding flight. Many seabirds in areas of upwelling and in the higher latitudes of both hemispheres are pursuit-divers. A greater abundance of potential prey in these areas permitted the evolution of this strategy; pursuit-diving birds need not range as far as tropical seabirds.

Ecology

Seabirds are found throughout the world's oceans, but they are more abundant in some areas than others. This is related to the fertility of the oceans; most animal life in the sea ultimately depends on primary production of plant matter — phytoplankton — through the process of photosynthesis. The nutrients that fertilize the growth of phytoplankton come from inorganic and organic sources, such as silt and the bodies of decaying marine organisms. In stable, permanently stratified, tropical waters these nutrients sink to depths far below the euphotic zone (the layer that receives enough sunlight for photosynthesis). The primary production of plants in such waters is usually very low, except at local areas of upwelling where vertical circulation in the water column returns the nutrients to the euphotic zone. In seasonally colder climates, on the other hand, winter gales ensure that the water column is well mixed each year.

Southern skuas. (Photo by M. F. Soper, National Audubon Society/PR)

Least auklet. (Photo by Karl W. Kenyon, U.S. Fish and Wildlife Service)

Thick-billed murre. (Photo by D. H. S. Wehle)

Dovekie. (Photo by Allan D. Cruickshank, National Audubon Society/PR)

The seas over shallow continental shelves, such as on Georges Bank off the New England coast and the Grand Banks off Newfoundland, are exceptionally rich in nutrients, though primary production in these regions is limited somewhat by reduced amounts of sunlight during the winter months. Growth in stocks of phytoplankton stimulates production in the higher trophic levels. Thus, there is a greater abundance of zooplankton, fish, and higher predators, such as seabirds and marine mammals, over boreal continental shelves than in most tropical seas.

The relationship of bird life to a marine environment can be observed off the northeastern United States (Figure 1). To the south of the Gulf of Maine is Georges Bank, a submerged plateau 40 to 100 meters beneath the water's surface. Water depth on the northern edge of the Bank drops rapidly from 40 to more than 300 meters into the Gulf of Maine. The southern flank of Georges is the edge of the continental shelf, where the depth quickly drops to 2,000 meters. Two distinct water masses meet there. Water within the 200-meter isobath at the outer edge of the continental shelf is known as shelf water. The deeper, warmer, saltier water just off the shelf is called slope water.

In winter months (December to March), shelf waters are well mixed vertically because of cold air temperatures and frequent strong winds from storms. In contrast, during summer months (June through August) shelf waters generally are well stratified; the layers of water cannot mix because of a seasonal thermocline from increased solar radiation. The exception to this pattern is Georges Bank, where tidal currents prevent the formation of a thermocline and allow water from off the Bank to mix with surface layers throughout the year.

Seasonal differences in the hydrography of the marine environment are reflected in the distribution and abundance of seabirds, in that the structure of the bird communities (species composition, density, biomass) is related to stratification of surface waters. During winter, the total abundance and species composition of birds is similar among the various regions of the shelf (Gulf of Maine, Georges Bank, and Middle Atlantic Bight). Average density ranges from 13 birds per square kilometer in the Middle Atlantic Bight (the waters over the continental shelf extending from Nantucket Shoals, southeast of Nantucket Island, Massachusetts, to Cape Hatteras, North Carolina) to 21 birds per square kilometer on Georges Bank

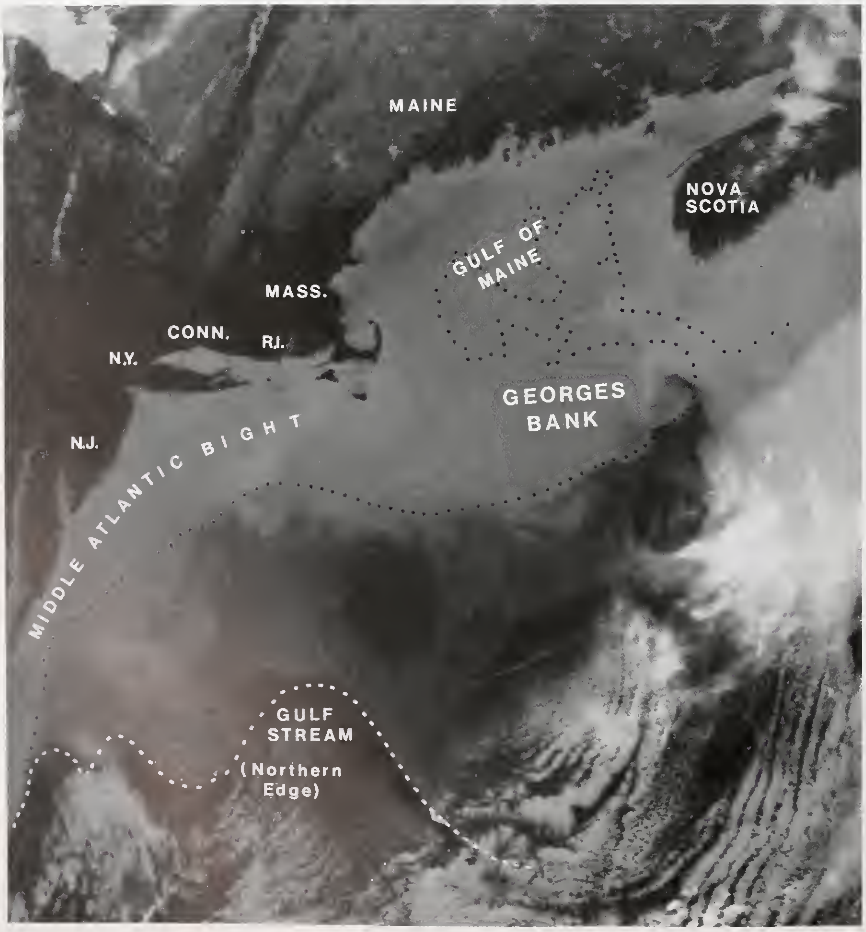


Figure 1. This satellite photo taken in March of 1979 shows the shelf/slope front off the northeastern coast of the United States. The cooler temperature of the shelf water shows up as pale grey along the coast and includes Georges Bank. Paler grey and white areas to the south and east are clouds. The dark circle directly south of Cape Cod is a warm core eddy. (Courtesy of NOAA, Satellite Data Services Division)

Gannet. (Photo by William Curtsinger, PR)

(Figure 2). This is in marked contrast to slope water, which averages only two birds per square kilometer at this time. Fourteen species occur regularly in shelf water during winter, including surface-feeding fulmars, gulls and kittiwakes, plunge-diving gannets, and pursuit-diving razorbills, murres, and puffins. Only four species are found in slope water, all of which are surface-feeders.

In summer, total bird abundance and species composition on Georges Bank contrast with those of surrounding waters. Total bird density on the Bank increases to its yearly maximum, 50 birds per square kilometer. Similar summer peaks in bird abundance do not occur in the Gulf of Maine, in the Middle Atlantic Bight, or in slope water. High rates of primary productivity are found in summer months in all shelf waters off the northeastern United States, but the large numbers of greater and sooty shearwaters and Wilson's storm-petrels in this region, all winter migrants from the Southern Hemisphere, concentrate only on Georges Bank and its perimeter. These species are surface and subsurface feeders that perhaps exploit the zooplankton, fishes, and squids that migrate up into surface waters at night.

Productive Mixing

One might expect a direct correlation between productivity and bird density; that is, large concentrations of phytoplankton should go with high densities of birds. The summertime discrepancy between bird densities on and off Georges Bank might best be explained by mixing regimes and how the energy of primary productivity is transferred to the rest of the food chain.

As summer progresses in stratified waters, surface concentrations of phytoplankton die out because of nutrient depletion. Stratified shelf waters are quite productive in summer, but the layer of maximum primary productivity is 30 to 40 meters below the surface, where the water is richer in nutrients. Therefore, herbivorous zooplankton graze at these greater depths, and their energy is potentially available to benthic and pelagic food webs. This in turn means that carnivorous zooplankton, fishes, and squids stay too deep for birds to reach them.

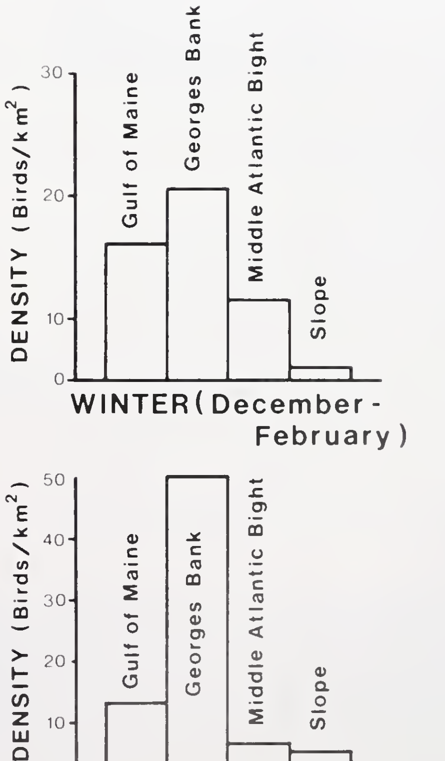


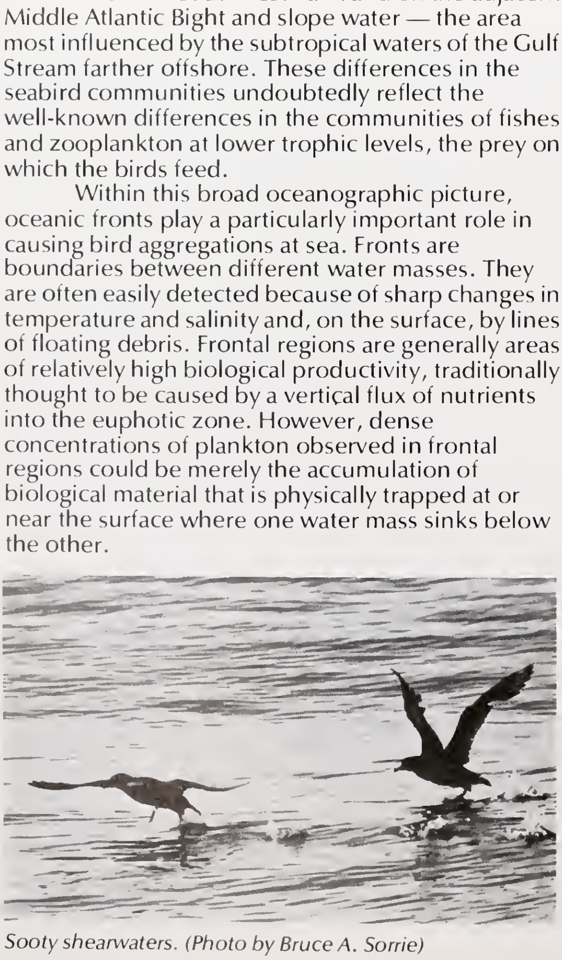
Figure 2. The seasonal abundance and distribution of seabirds are directly related to the degree of mixing in selected water masses off the northeastern coast of the United States.

However, water on Georges Bank is continually mixed vertically by mechanisms that include strong tidal currents running over shallow shoals. This mixing enhances the level of surface productivity, because deep nutrient-rich waters around the perimeter of Georges Bank are continuously injected into the surface layer.

Bird abundance in slope water is low because productivity there is low. Limited availability of nutrients in the surface layers prevents the growth of any large stocks of phytoplankton. Further nutrient depletion during spring and summer and the low rate of mixing in fall and winter set slope water apart from the shelf system. Bird density is permanently lower in equatorial waters, for the same reasons.

The fact that the mixing regime of the water masses adjacent to Georges Bank is more typical of equatorial waters, and the Bank itself is more characteristic of the well-mixed regimes found over boreal shelf regions, is especially interesting since the summer seabird communities in the area reflect both types of regime. Cool-water species, such as the greater, sooty, and Manx shearwaters and Wilson's and Leach's storm-petrels, are most common on the northern and eastern flanks of Georges Bank and in the Gulf of Maine. Subtropical species, such as Cory's and Audubon's shearwaters, are more common on the southwest flank and on the adjacent Middle Atlantic Bight and slope water — the area most influenced by the subtropical waters of the Gulf Stream farther offshore. These differences in the seabird communities undoubtedly reflect the well-known differences in the communities of fishes and zooplankton at lower trophic levels, the prey on which the birds feed.

Within this broad oceanographic picture, oceanic fronts play a particularly important role in causing bird aggregations at sea. Fronts are boundaries between different water masses. They are often easily detected because of sharp changes in temperature and salinity and, on the surface, by lines of floating debris. Frontal regions are generally areas of relatively high biological productivity, traditionally thought to be caused by a vertical flux of nutrients into the euphotic zone. However, dense concentrations of plankton observed in frontal regions could be merely the accumulation of biological material that is physically trapped at or near the surface where one water mass sinks below the other.



Sooty shearwaters. (Photo by Bruce A. Sorrie)

Greater shearwater. (Photo by Kenneth C. Parkes, Cornell University Laboratory of Ornithology)

One such frontal region is at the edge of the outer shelf in the Middle Atlantic Bight, at the boundary between the shelf and slope water masses. In spring (April-May), the shelf/slope front is nearly vertical, stretching from the surface to the bottom and separating well-mixed shelf water from weakly stratified slope water. At this time the maximum concentration of chlorophyll is on the shoreward edge of this front, and the peak abundance of small grazing-type zooplankton occurs in the outer region of the shelf. During late summer to early fall (August-September), the shelf and slope waters are fully stratified so that the surface thermal expression of the front is obscured by the strong seasonal thermocline. Likewise, there is no surface expression in chlorophyll; instead it peaks at the base of the euphotic zone, approximately 30 meters deep. Under such conditions there is no mixing in the surface layers, and the offshore populations of zooplankton are far below their spring peak.

The timing and routing of seabird migrations are apparently influenced by these seasonal variations. Red phalaropes feed at the surface on small zooplankton. They breed in the Arctic and spend the winter at sea. Fronts, with their locally high densities of surface zooplankton, are known to be important feeding areas for nonbreeding phalaropes. When these birds migrate north in April and May, their distribution in the Middle Atlantic Bight is clustered along the shoreward edge of the shelf/slope front, where local densities commonly exceed 100 birds per square kilometer (Figure 3). Both the distribution and the timing of migration suggest that the birds are exploiting the spring zooplankton peak there. By contrast, there is no comparable concentration of red phalaropes off the northeastern United States when the birds move south again in August and September; the mean density is less than 0.1 bird per square kilometer, and the maximum rarely exceeds 10 birds per square kilometer. This is not too surprising, given the scarcity of zooplankton in the shelf/slope frontal

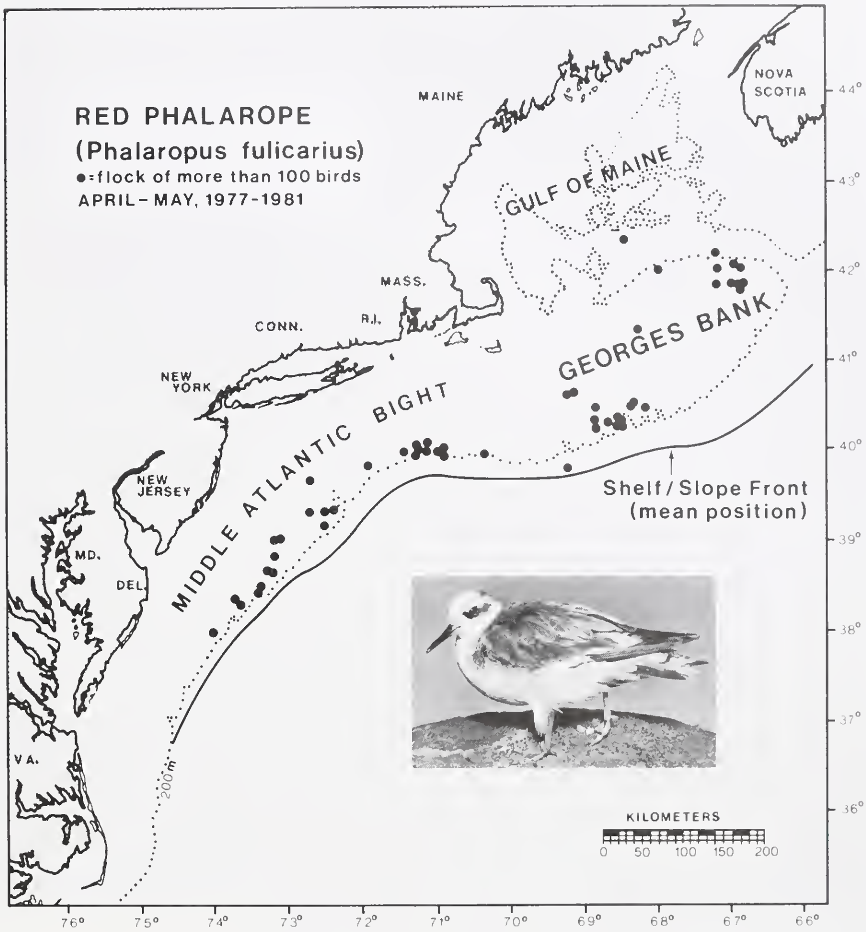


Figure 3. On their way north in April and May, red phalaropes (inset) cluster along the shoreward edge of the shelf/slope front to take advantage of the annual peak in zooplankton abundance there. (Photo by Karl W. Kenyon, PR)

region at this time of year. However, the migrating birds do visit well-defined surface fronts farther north, off eastern Canada. In other words, it appears that the phalaropes' migration patterns have evolved to take advantage of the local concentrations of food provided at different points along their route by the mechanisms associated with oceanic fronts.

An increased awareness and a better understanding of how seabirds interact with their marine environment offer new avenues of research to both ornithologists and oceanographers. Seabirds are effective hunters in a seemingly faceless environment and are well suited to exploit a variety of food resources in surface and subsurface waters. It makes sense that the traditional areas used by such predators have something to tell us about the structure of seabird habitats; in this case, certain oceanic features indicate those areas and times when a food web is developed to higher levels. A comparison of the characteristics of these areas to areas adjacent but not used by seabirds offers interesting research potential to marine biologists.

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Above, part of a colony of macaroni penguins on Bird Island, off South Georgia Island. (Photo by P. A. Prince)

Left, a courtship display by wandering albatrosses. (Photo by P. A. Prince)

Antarctic Penguins and Albatrosses

by J. P. Croxall and P. A. Prince

Albatrosses and penguins are the most characteristic and spectacular birds of the Southern Ocean. Both groups have their greatest number of species and individuals between 45 and 60 degrees South latitude, with vast breeding concentrations at sub-Antarctic islands or south of the Antarctic Convergence.* They are the two most marine of all families of birds, yet, in terms of their adaptations and ecology, they are at opposite ends of the seabird spectrum (Table 1).

Albatrosses have light bodies on vast wings, supremely adapted for apparently effortless gliding over storm-swept seas, while penguins are entirely flightless, with heavy, compact bodies superbly adapted for swimming and diving. Furthermore, albatrosses typically delay breeding until they are more than 10 years old, lay a single egg per breeding pair, and live for 30 years on average. Most penguins start breeding at age 3, lay two eggs per nest, and rarely survive long into their teens. The details of these very different life-styles provide insight into the relationships between seabirds and their environment.

Penguins

Six of the 16 penguin species are characteristically Antarctic. These belong to two main groups — the large emperor and king penguins and four smaller species. Emperor penguins breed on the ice of the Antarctic Continent, king penguins on beaches at sub-Antarctic islands. It takes a pair of these large birds a long time to raise their single offspring, which must fledge and become independent in the Antarctic summer, when food resources are most abundant. King and emperor penguins have solved this problem in very different ways.

Emperor penguins lay in autumn and rear chicks throughout the Antarctic winter, under the most extreme conditions faced by any bird, with *average* temperatures of −20 degrees Celsius and winds of 40 kilometers per hour (sometimes reaching 200 kilometers per hour). To survive this, heat-conserving adaptations are crucial. These include very small flippers and bills for birds of their size, excellent insulation from long, double-layered, high-density feathers, and highly efficient systems for minimizing heat loss. The nasal passages, for

An emperor penguin with chick. (Photo courtesy of Sea World)

*A frontal system around the Antarctic continent, between the latitudes of 50 and 60 degrees South, at which cold waters from the Antarctic and warmer waters from the middle latitudes converge and sink.

Table 1. Some characteristics of Antarctic penguins and albatrosses.

Species	Weight (kg)	Breeding age First	Breeding age Mean	Breeding success (%)	Annual survival (%) First yr.	Annual survival (%) Adult	World annual breeding population (pairs)
PENGUINS:							
Emperor	30	3	5	64	25	95	200,000
King	13	4	?	57	?	82	750,000
Adélie	4	3	6	40-50	50-60	70-80	5-10 million
Chinstrap	4	3	?	c. 50	?	?	6-8 million
Gentoo	6	3	?	40-60	?	c. 80	250,000
Macaroni	4	5	7-8	c. 50	65	86	8-10 million
ALBATROSSES:							
Wandering	9	7	11	60	45	95	20,000
Grey-headed	4	9	13	50	40-50	95	80,000
Black-browed	4	8	11	40	40-50	92	600,000
Light-mantled sooty	3	9	13	40-45	?	95	15,000

example, recover 80 percent of the heat added to cold inhaled air.

However, even all these adaptations cannot keep individuals alive through extended fasts: 110 days for males during courtship and incubation (when they may lose 45 percent of body weight) and 40 days for brooding females. Therefore emperors huddle tightly together in large groups, reducing individual heat loss by a further 25 to 50 percent. Such social behavior is unique among penguins and is only possible because the male can move around with his egg balanced on his feet and covered with a pouch-like fold of abdominal skin.

Despite the extremely cold climate, breeding success is high (60 percent), but emperor chicks become independent in summer at only 60 percent of adult weight. All other penguins rear their chicks to 90 to 100 percent of adult weight. Presumably, emperor behavior differs because adults need to molt (change all their feathers) and return to breeding condition before winter, and cannot devote any more time and effort to their offspring. Only 20 to 30 percent of the young survive the first year on their own. However, an early start at breeding (age 3 to 4) and good annual survival of breeders (95 percent — much higher than for other penguins) enable population levels to be maintained.

King penguins lack the extreme physiological adaptations of emperors, and, although the two species may shuffle around incubating their eggs in a similar fashion, breeding king penguins maintain a constant distance between each other. Only the chicks huddle to keep warm in winter. King penguins lay from November until mid-April, with marked peaks in the number of eggs produced at the beginning and near the end of this period. Incubation duties are shared by the parents, typically in five-day shifts. Early breeders raise their chicks to 80 percent of adult weight by June and feed them sporadically until September, when regular feeding resumes. By this time, most chicks have sustained a weight loss of about 40 percent. The chicks depart in mid-summer. The adults then molt and usually lay again in February or March. When winter arrives, the new chicks are smaller than their older siblings were the year before, and many die. Those that survive finally fledge late in the Antarctic summer. Parents with this timetable cannot breed again until the following year. Pairs that fail to produce a chick in summer usually molt and breed again as soon as possible. The variety of breeding and molting schedules means that in any colony at most times there are adults, eggs, and chicks at many stages of molt, incubation, and growth.

Large penguins dive to considerable depths in search of fish and squid (Figure 1). Emperors, with dives lasting 18 minutes and reaching 265 meters, hold all the records for single dives, but in work with Drs. G. L. Kooyman and R. W. Davis of Scripps Institution of Oceanography, we found that on four-to-eight-day feeding trips, king penguins rearing chicks each made 500 to 1,200 dives. More than half the dives we observed exceeded 50 meters, and two reached 235 meters. We calculated that only about 10 percent of the dives resulted in prey capture. Despite all this diving activity, the average daily energy cost of these trips was only about twice that of incubation — testimony to the superb hydrodynamic design of penguins.

King penguins near Schliper Bay, South Georgia Island. The cylindrical device is a dive recorder. (Photo by R. W. Davis)

The other four typically Antarctic and sub-Antarctic penguins — adélie, chinstrap, gentoo, and macaroni — are all smaller and similar to each other in weight and stature. Three are basically circumpolar in distribution, adélies mainly around the continent and gentoos and macaronis at sub-Antarctic islands. Chinstraps are virtually confined to the Antarctic Peninsula and Scotia Sea, where all four species coexist, and have vast colonies in the South Sandwich Islands. The shrimp-like crustacean *Euphausia superba* (krill), the hub of the Southern Ocean food web, is the main food of all these penguins.

Krill-eating penguins are not deep divers. Of 1,100 dives made by chinstrap penguins, 70 percent

Krill, Euphausia superba. *(Photo courtesy of British Antarctic Survey)*

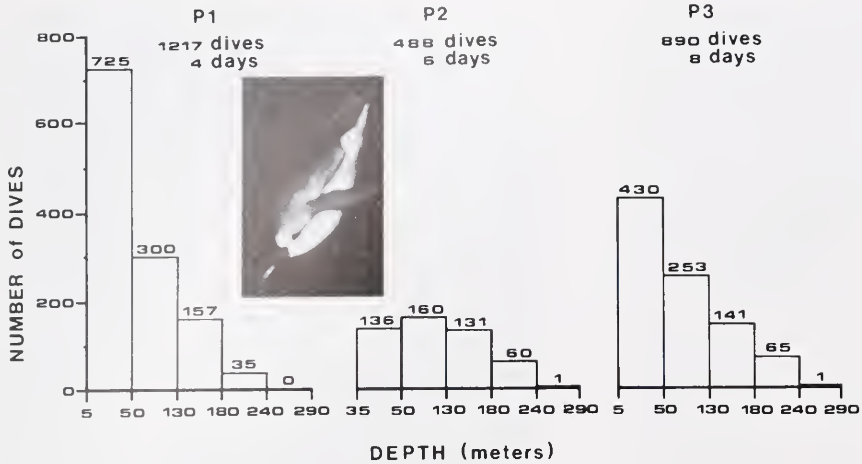


Figure 1. Frequency analysis of the diving depths of three king penguins (P1, P2, P3). All three birds departed and returned to the colony within four to eight days. The minimum threshold of the depth recorder for P2 was higher than for the other two penguins. (From G. L. Kooyman, R. W. Davis, J. P. Croxall, and D. P. Costa. 1982. Science 217, p. 726. Copyright 1982 by the American Association for the Advancement of Science.)

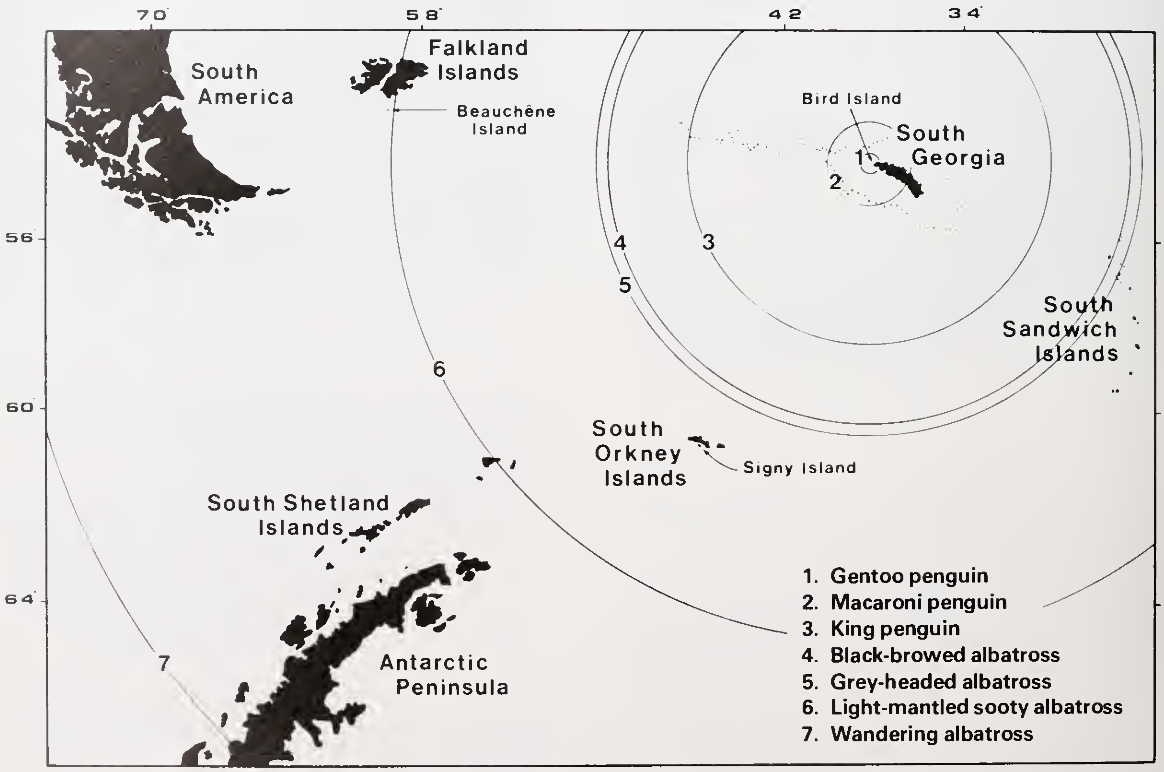
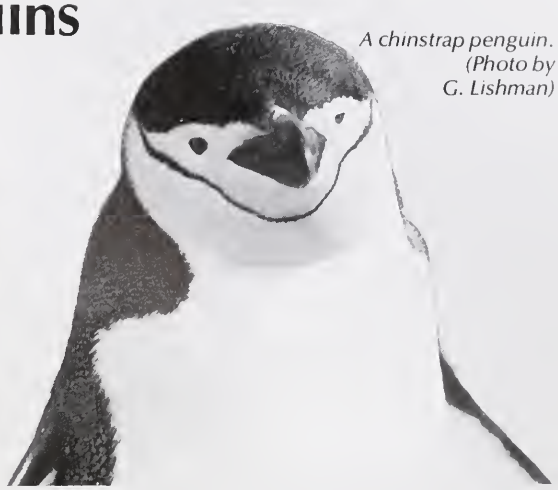


Figure 2. The foraging ranges of seven species during chick-rearing. The dotted lines are shelf boundaries.

were shallower than 20 meters and none exceeded 70 meters. Large krill are almost certainly caught individually. Penguins diving at night may be helped by the krills' bioluminescence and perhaps by a simple form of echolocation relating to the birds' swimming movement. Much feeding, however, is done during daylight. When raising young, penguins are greatly restricted in feeding range by the need to provision their chicks regularly (Figure 2). Our research leads us to believe they are effectively confined within 100 kilometers of the colony and probably stay over continental shelves and shelf/slope areas, places where krill concentrations are frequently located.

Although similar in diet, these small penguins are by no means identical in their ecology and reproductive biology; gentoo and macaroni penguins represent the two extremes. Gentoos lay two similar eggs, exchange incubation duties daily, make foraging trips lasting less than 10 hours, take nearly 100 days to rear their chicks, and accumulate fat reserves for molt relatively slowly. Their foraging range rarely exceeds 30 kilometers, and they supplement their krill diet by taking fish from the

The Evolution of Penguins



A chinstrap penguin. (Photo by G. Lishman)

A gentoo penguin. (Photo by P. A. Prince)

A macaroni penguin. (Photo by G. Lishman)

Penguins are birds: creatures whose bodies are covered with feathers — special skin outgrowths no other animals possess. Penguins are especially adapted for "flying" underwater.

Birds, as a class, are thought to have arisen sometime in the early Mesozoic Era — more than 150 million years ago — from reptilian ancestry. Among modern birds, penguins are relatively ancient; they were well established by the close of the Eocene Epoch, 40 million years ago.

The structure of the penguin's flipper is the key to the bird's evolution. The flipper has all the elements of a flying bird's wing. This means that, for its structure to make sense, the penguin had to evolve through an aerial stage. The penguin wing is now highly specialized for moving through water, a denser medium than air.

Because they differ so from other modern birds, penguins are considered a separate order. Three functional factors differentiate penguins from the flying birds that are most like them structurally or ecologically. They are: the penguin method of swimming underwater; terrestrial locomotion in an upright position; and insulation — feathers (which are down-like and extremely numerous in penguins) and blubber. A look at the classification of a modern penguin provides a brief synopsis of its evolution.

The Modern Penguin

Kingdom:	Animalia
Phylum:	Chordata (notochord)
Subphylum:	Vertebrata (a backbone of vertebrae)
Class:	Aves (the birds)
Subclass:	Ornithurae (modern birds with no teeth)
Superorder:	Carinatae (birds with a particular type of breastbone)
Order:	Spheniciformes (penguins)
Family:	Spheniscidae
Genus:	*Aptenodytes* (king and emperor)
Species:	*forsteri* (emperor)

inshore kelp beds. In years of high krill availability, both chicks are reared; in seasons when krill do not appear close to shore, a gentoo colony may experience complete breeding failure, as in 1978 at South Georgia Island.

Macaroni penguins also lay two eggs, but only the larger, second egg usually hatches. Incubation and brooding duties are completed in two long shifts (one by each sex), during which 30 percent of body weight may be lost. Foraging trips last 30 to 40 hours, allowing macaronis a much greater feeding range than gentoos. This increases the chances of finding krill, and breeding success is fairly constant from year to year. Chicks are reared in 55 days, after which parents depart immediately for two weeks of intensive feeding, nearly doubling their body weight in order to survive a three-week fast ashore during molt (Figure 3).

Adélies and chinstraps are intermediate between these extremes. They are rather similar ecologically but probably different physiologically. Adélies are basically adapted to the regions of the Antarctic continent, and chinstraps to the southern sub-Antarctic. In some places where their territories overlap, on and near the Antarctic Peninsula, chinstrap populations are increasing nearly twice as fast as adélies. It may be that the chinstrap is the superior competitor in these areas, but is unable to colonize the continent effectively.

Because we have been able to measure the energy costs of incubation, molting, and foraging for penguins and have detailed information on their breeding timetables, activities, and diet, we are in a good position to assess their consumption of krill. For example, at South Georgia, macaroni penguins eat about 4 million metric tons each year, about 70 percent of the krill consumed by all seabirds and significantly more than the amount taken by present-day seal and whale stocks in the area. Not enough is known about the biomass of krill (and its replacement rate) around South Georgia to assess the effect of this substantial predation, but the impact on the krill population may be magnified by the birds' peak demand coming in February, when female krill are in reproductive condition.

Albatrosses

Four species of albatross are characteristically sub-Antarctic. The wandering albatross, with a 10-foot wingspan, is the largest of all seabirds. It breeds in loose colonies on flat areas that are convenient for its spectacular pair and group

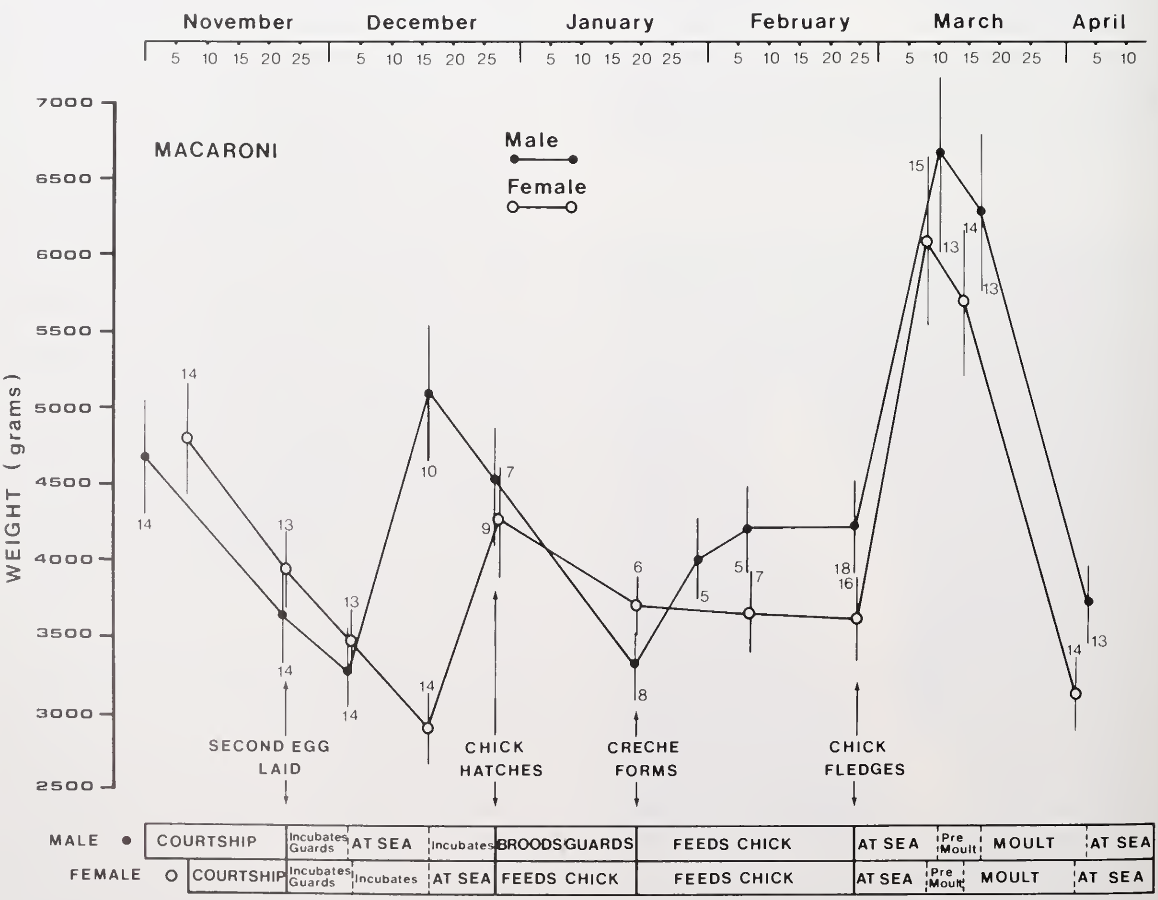


Figure 3. Weight changes of macaroni penguins during breeding season. [From R. M. Laws, ed., Antarctic Ecology, *Academic Press, in press. Copyright: Academic Press, Inc. (London) Ltd.]*

displays. The all-brown, light-mantled sooty albatross breeds singly on cliffs; its displays mainly involve synchronized aerobatics. In between are two "mollymawks,"* the grey-headed and black-browed albatrosses, identical in size and structure, breeding in large (often intermixed) dense colonies, and performing most displays at the actual nest site. There are, however, more fundamental differences between these four species.

The breeding cycle of wandering albatrosses lasts a full year, eggs being laid one summer and chicks fledging the next, having been reared through the winter. The three other species lay in spring and finish rearing by autumn. Only black-browed albatrosses breed annually; for the rest, success in one year means a year off before the next attempt. Loss of eggs or young chicks, however, is usually followed by breeding the next season. It is hard to see why the two mollymawks should be so different from each other. There are two main questions: How do black-brows manage to breed annually? and Is this advantageous?

Black-brows complete a breeding season about a month sooner than other albatrosses, mainly because their chicks become independent more rapidly. We found that the size and frequency of meals brought to the two species of mollymawk chicks are the same but their quality is not. Grey-headed chicks receive much more squid, which contains only 60 percent of the energy (and much less of the calcium so important for bone growth) provided by krill and fish (Figure 4). To see if the diet difference could account for the different growth rates, eggs were exchanged and the growth of fostered chicks was compared with that of chicks raised by their real parents. As predicted, grey-headed chicks thrived on the rich krill diet, whereas black-browed chicks languished on squid meals.

Raising chicks quickly has two probable advantages. First, parents use up body reserves (up to 30 percent of their body weight) while rearing chicks, so in a shorter period less reserves are consumed. Second, food supplies in the sub-Antarctic diminish rapidly after April. Black-browed chicks fledge in April, and adults presumably can partly regain condition while food is plentiful. But grey-headed chicks do not fledge until May, so adults may be unable to replenish their reserves adequately until the next summer, too late to breed in the spring. Grey-headed albatrosses elect to stay in Antarctic waters in winter (when they must continue to feed on squid, fish being very scarce), but black-brows migrate north to South African waters, where they can find fish (and also scavenge behind fishing vessels).

Light-mantled sooty albatrosses, being appreciably smaller than the other three species,

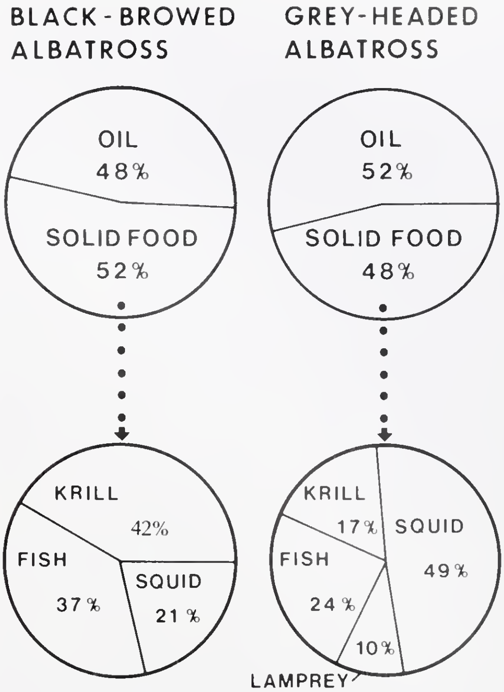


Figure 4. The diets of two albatrosses, by weight of the solid food contents of the stomachs of sampled birds. Albatrosses pass partly digested food to their chicks. Their stomachs also produce oil which the chicks can obtain by placing their bills across their parent's partly opened bill. (After P. A. Prince. 1980. Ibis 122.)

theoretically should be able to raise chicks faster. However, they feed mainly on squid and feed their chicks only about half as often as do mollymawks. Consequently, fledging is not until mid-May, and it is no surprise that the species breeds biennially.

Breeding annually would seem to favor increased reproductive potential. However, black-browed breeding success is variable, and during the last six years has averaged 10 percent less than that of grey-heads. This is mainly because of events in 1978 and 1980, seasons when commercial and research fishing vessels found very few krill swarms near South Georgia. Few black-brows (or gentoo penguins) raised chicks, but grey-heads fared much better, probably because squid were still available. But true reproductive success can only be measured over a bird's entire lifetime. In comparing the average annual survival of breeding birds of the two species, we find that it is 95 percent for grey-heads, but only 92 percent for black-brows. This difference does not sound like much, but a 5-percent difference would be equivalent to *doubling* life expectancy. Therefore grey-heads can expect to live at least half again as long as black-brows, and the extra breeding attempts in this time may largely compensate for their reduced frequency of breeding overall.

The two mollymawk species thus have rather different survival strategies. Grey-headed

*One of several spellings for a nickname given to various oceanic birds. Originally given by Dutch sailors to the fulmar, it was later applied to petrels and the smaller albatrosses.

A light-mantled sooty albatross, as sketched by E. A. Wilson on the British Antarctic ("Terra Nova") Expedition in 1910. (Courtesy of the British Museum)

A Black-browed albatross on its nest. (Photo by P. A. Prince)

A pair of grey-headed albatrosses during courtship. (Photo by P. A. Prince) albatrosses adopt a conservative approach; they eat a relatively poor-quality but regularly available food, breed less often but with more consistent success, and live longer. Black-browed albatrosses eat a high-quality diet of less-predictable availability, breed annually with variable success, and may not live as long.

Does breeding then impose a strain on albatrosses that may even affect their survival? Evidence from wandering albatrosses at South Georgia (but probably applicable to the other species) suggests that this may be so. These birds are physiologically capable of breeding at 3 to 4 years of age but do not start for several more years. They lose weight during a breeding attempt. Those that start breeding earliest (7 to 8 years old) survive slightly less well than those that start later (at ages 9 to 11). Birds starting very late (14 to 16 years) survive well, but the "missed" seasons may reduce their lifetime reproduction potential. In a group of birds of equal age, more die in the first few years of breeding (ages 7 to 11) than in later years. When immature birds return to the colony, they do so in autumn and stay only a few days. In succeeding years they return earlier and stay longer, until they become paired and appear in the weeks before egg-laying. Birds that return at the earliest ages (3 to 4 years) are more likely to die than those returning later (from age 5 onward). All this suggests that there is survival value in acquiring experience of shore life gradually, and that those breeding earliest may not do best in the long run.

For a young bird, the most important task ashore is to choose or attract a suitable mate. Much time, covering several seasons, is spent displaying with other youngsters in large groups before there is any real sign of pair formation. Once this happens, and a nest site is established, breeding usually starts within a year or two. "Divorces" are rare, normally following several seasons of failure, and illustrate the importance of an appropriate initial choice of partner if a successful breeding career is to be achieved.

Time spent on land is, of course, at the expense of foraging at sea, and young birds may not stay longer ashore because successful feeding may not be an easy skill to acquire. Recently we obtained at-sea activity budgets for adult grey-headed albatrosses. Of more than 7,000 hours of foraging while rearing chicks, 75 percent were spent flying and only the four hours spent on the sea at night were likely to involve attempts to feed. Young birds may have to spend even more time locating suitable feeding areas and catching prey, and this may restrict the time left over for finding a partner ashore.

The life of albatrosses may look effortless, unhurried, and carefree, but it seems that they have many skills to acquire and decisions to make in order to realize their full potential as the longest-lived of seabirds.

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In The Rime of the Ancient Mariner *by Samuel Taylor Coleridge, the killing of an albatross brings bad fortune to a ship's crew. (Drawing by Gustave Doré, from* The Annotated Ancient Mariner *by Samuel Taylor Coleridge with introduction and notes by Martin Gardner. Copyright © 1965 by Martin Gardner. Used by permission of Clarkston N. Potter, Inc.)*

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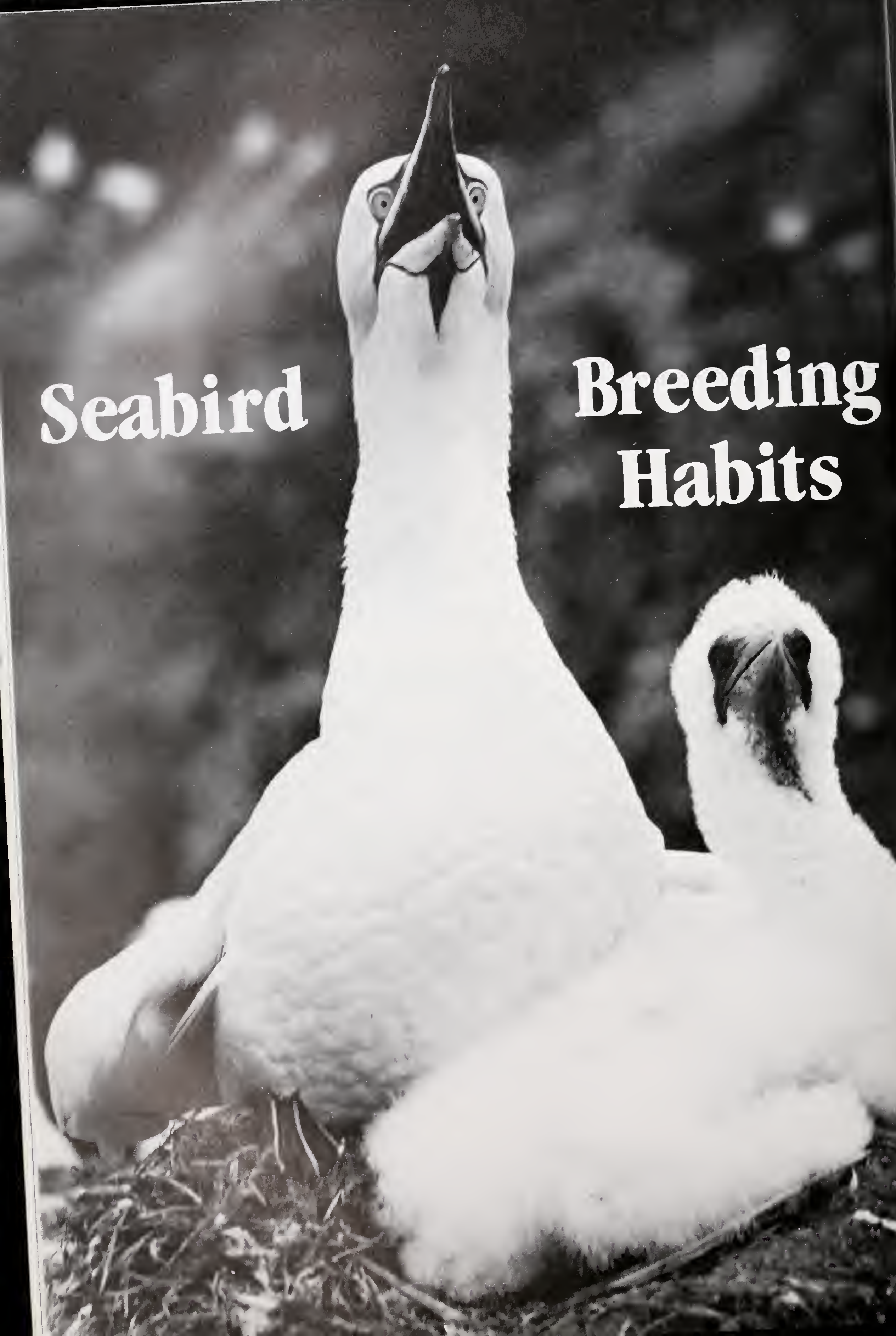
Seabird
Breeding
Habits

by Warren B. King

Whoever said that seabirds only come to land because eggs do not float was not far from the truth. The most inveterately pelagic birds, such as the albatrosses, their diminutive relatives the gadfly petrels, and the tropicbirds, are far more in their element on the water than on firm ground and can pass months or even years without touching down on land. Others — including boobies, shags, cormorants, and most gulls and terns — return to their land-based roosts nightly.

The activity that unites all seabirds in their dependence on land, however, is reproduction. Each seabird species arranges its affairs so that it can visit its nesting site on a regular enough basis to lay and incubate eggs and rear young to fledging, even though it continues to be dependent on the sea for food.

Location of Nest Sites

A number of factors influence the choice of a nesting site. Perhaps the most important is the availability of food, but also significant are competition from other seabirds for sites, the threat of predation or parasitism, certain social factors, the kind of site a species is adapted to use, weather, and disturbance by humans.

Most seabirds select their nest sites close to the ocean, which is their food source, but a few nest well out of sight of the sea. The grey gull, for instance, nests in the Peruvian desert, miles from any water. The greatest concentrations of nesting seabirds are found near ocean areas richest in food. For example, the presence of the Humboldt Current, with its immense schools of anchoveta close along the western coast of South America, enables colonies of piquero boobies, guanay cormorants, and brown pelicans to nest by the millions on the nearby sun-baked coastal islands.

Sea cliffs, relatively free of predators, are utilized by seabirds of many species, but each of these has adapted to a particular part of the cliff. This partitioning evidently reduces interspecific competition for nest sites. Puffins, petrels, and some storm-petrels require soil in which to dig burrows and a slope or cliff edge from which to launch themselves; they usually nest on the grassy slopes above a cliff. At the edge of the cliff or on prominent ledges near the top, gannets may be found. Fulmars nest in rock crevices along the steepest pitches. Long, narrow ledges are often jammed with murres, razorbills, and kittiwakes. Farther down, on rocks closer to the water, shags and cormorants typically nest, with black guillemots, several small auklets, and some storm-petrels making their homes in the rock talus at the base of the cliff.

Similarly, the flat, sandy, shrub-covered surface of a tropical atoll can be partitioned like a city apartment building. White terns and black noddies nest in the tallest trees, red-footed boobies and great frigatebirds build their stick nests in the shrubs, red-tailed tropicbirds nest on the ground under the shrubs, sooty terns and brown noddies nest on nearby bare ground, petrels dig scrapes between grass tussocks, and wedge-tailed shearwaters honeycomb the entire "basement" with their burrows.

Seabirds tend to be conservative in their choice of sites, and are apt to select a site similar to, and in the same colony as, the one their parents used. Numerous morphological and behavioral adaptations reflect the precise accommodation each species makes to its habitat. Murre eggs are markedly conical in shape; if an egg is jarred, its movement is likely to be limited to a small circle, an obvious advantage to a cliff-ledge nester.

Weather can influence the choice of nest sites by seabirds. In the Antarctic and Arctic the presence of snow and ice can prevent or delay nesting by ledge- or burrow-nesting petrels and alcids (members of the family Alcidae, which includes razorbills, murres, puffins, auklets, and murrelets). Sites where the snow melts early are often preferred. Flooding of nest sites because of rain or storm tides can cause wholesale desertion of colonies and, if repeated frequently enough, abandonment of a traditional nesting area.

Human disturbance is a factor that increasingly affects nest-site selection. Repeated human disturbance of nesting colonies or a single disturbance during a crucial period in the breeding cycle can result in abandonment of colonies in favor of some place less frequently disturbed. On the other hand, several species, including least terns, herring gulls, and fulmars now nest on man-made structures like roof-tops and stone walls.

Colony Nesting

Seabirds may forage or travel at sea in flocks or they may be solitary, but when they come to shore to breed they are with few exceptions gregarious. Seabirds usually nest in colonies, which can range in size from a few pairs, like the famous royal albatross colony on Taiaroa Head, New Zealand, to many thousands or even millions of pairs. The sooty tern colony on Christmas Island, in the Pacific Ocean, has been estimated to contain 10 million birds. Some adélie and chinstrap penguin colonies may exceed 5 million birds.

There are both advantages and drawbacks to colony living. On the one hand, colonial nesting offers protection against predators, at least for those toward the center of the colony. Predators can be detected more quickly and often can be driven off. On the other hand, a conspicuous colony can actually attract predators. Coloniality promotes social stimulation, leading to synchronous nesting, which reduces interference from other birds at different stages in their breeding cycles. It also facilitates pair formation and allows inexperienced breeders to learn by example from more experienced birds nearby. A colony may even function as an information center — birds that see a bird returning with food sometimes fly off in the direction from which it came. Colonies can result

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Gannet and young on nest. (Photo by Grant Haist, National Audubon Society/PR)

Razorbills. (Photo by Eric Hosking, National Audubon Society/PR)

from limited suitable nest sites in an area or from an abundant but briefly accessible food resource, and this means there can be excessive competition for food, nest sites, and potential mates. Parasites or diseases may sometimes spread throughout a colony. On the whole, however, the benefits of coloniality seem to outweigh the disadvantages.

Breeding Strategies

The schedule followed by a seabird during its breeding season depends largely on the availability of food within a realistic foraging distance of its colony. Food availability, in turn, is strongly influenced by the seasons. If a colony is located close to a food source, foraging time is minimized and chicks can grow quickly. The less predictable the food source, and the farther it is from the colony, the greater the proportion of time breeding seabirds must devote to foraging. As a consequence, the chicks get fed less frequently and, to survive, will have to be able to put up with periodic fasts. Chicks of species that forage some distance from the colony or depend on relatively unpredictable food sources are generally adapted to slower growth and development.

In the Arctic and the Antarctic, and in temperate latitudes, where there is a strongly marked change of climate from one season to the next, seabirds breed on an annual cycle. Arctic conditions dictate precisely when breeding should begin. Delay of a week or even a few days could mean the loss of those few days later in the season of good feeding

Cormorants on cliff in southern California. (Photo by Victor B. Scheffer, U.S. Fish and Wildlife Service) weather, before winter storms set in, making the difference between successful rearing of a chick and starvation. Thick-billed murres, for instance, begin laying eggs on their breeding cliffs on Novaya Zemlya, in the Arctic Ocean, between June 10th and 15th, and the peak in egg-laying comes only four or five days later. There is usually a certain time span between the laying of the first egg and the last, to provide for unusual events. Late layers, while under a disadvantage most years, might well be the only ones to succeed in the event a serious storm strikes just after the peak of egg-laying. Studies have shown, however, that most experienced, successful breeders return earlier and lay sooner than less-experienced breeders.

Subtropical seabirds are less constrained by the seasons. Breeding seasons stretch out, and an alternative strategy is possible: nesting in the winter so that chicks fledge in the spring. This winter-breeding strategy is in fact employed by several species, including black-footed and Laysan albatrosses and Bonin petrels in Hawaii, Solander's petrel of Lord Howe Island, and the cahow of Bermuda.

It is in the tropics that seabirds display the widest range of breeding strategies, even within a species. Each strategy is designed to deal in its own way with the relative poverty and ephemeral nature of tropical food resources. For example, sooty terns can breed every six months in the Line and Phoenix Islands, but they breed every nine months on Ascension Island, and they are roughly annual breeders at other sites. On Wake Island, breeding is continuous, new colonies forming before older ones have finished. Frigatebirds and Abbott's booby nest only once every two years; young are dependent on their parents for food well past their first year of life.

Pair Formation and Territorial Defense

At the start of a new breeding season a seabird is primarily concerned with finding two things: a mate and a nest site. Some species first find a mate and then prospect for a site; in others the male secures a site and then advertises for a female. Murres, pigeon guillemots, and common puffins apparently select mates while sitting on the water in rafts; most other seabirds form pairs on land.

Nest site defense assumes great importance in colonies where good sites are limited in number, or where nesting material is in short supply. Frigatebirds, cormorants, gannets, and adélie penguins steal nesting material from neighboring nests that are unguarded. Shearwaters invest considerable effort in digging burrows and defend them every year thereafter. Pair formation probably takes place in front of or in these burrows.

Defense of a site normally involves a set of stereotyped displays exchanged between the occupant and the intruder. These displays convey, without resorting to fighting, the level of commitment each bird has to a site and how fit and determined each is to remain. In most cases, displays are sufficient to resolve a conflict. Sometimes, however, neither bird can intimidate the other by ritual means and a fight ensues. Most birds grapple with intruders bill to bill. Penguins accost each other with flailing flippers. In general, the greater the fidelity of a species to individual nest sites from year to year, the greater is the tendency of a bird of that species to defend its site, violently if necessary. There are exceptions to this: Abbott's booby apparently returns to the same site, high in the crown of a forest tree, each time it breeds, yet because falling through the canopy poses an unacceptable risk, this species has evolved territorial displays that keep the disputants separated, reducing the chance that either will be dislodged accidentally. Birds that make no nest, like emperor penguins, have no territorial displays and do not fight.

Courtship

Courtship refers to all activities that establish and reinforce the pair bond and ensure receptivity to copulation. The display behavior associated with courtship in seabirds is particularly colorful and diverse. The heavy commitment of time and energy to these activities underscores their essential function in the difficult business of breeding. The components of courtship behavior are derived in large measure from aggressive and submissive displays. In fact, courtship functions to depress aggressive drives so that members of a pair can tolerate each other's presence in situations that otherwise elicit strong aggressive behavior.

Unlike seabirds that court communally, penguin courtship is always between two individuals. Males normally initiate displays. High pointing with the bill is widely used, as is head-flagging, flipper-waving, and bowing. Loud calling accompanies these displays and evidently serves in individual recognition.

Courtship display in albatrosses is perhaps more complex than that of any other seabird species. Birds normally display in pairs but sometimes threesomes or foursomes form when two or more males advertise to one female. Individual behaviors include bill-circling and clappering (in which the bill is opened and shut repeatedly very rapidly,

Rafting murres. (Photo by D. H. S. Wehle) producing a hollow, clacking sound), ritualized preening of the flanks, sky-pointing, and mooing (remarkably cow-like in tone). Certain displays by one bird trigger complementary displays in the other, for example when one bird clappers, the other automatically preens its flank. Royal and wandering albatrosses sky-point dramatically with spread wings, which span 11 feet or more.

Shearwaters, petrels, and storm-petrels display far less dramatically than albatrosses. Courtship involves little more than preening and synchronized vocalizing, but the life-long pair bonds these birds normally form are probably reinforced by the long periods mates spend together preening and billing in their burrows.

Boobies have highly ritualized greeting and advertising displays that involve sky-pointing, honking, hissing, and exaggerated parading around nest sites.

Tropicbirds are ungainly on the ground; their courtship displays are aerial, involving pinwheel flights of two or more birds, amid sharp raucous squawks, usually above or near a prospective nest site.

Frigatebird males attract females to a spot, later to become a nest site, by waving their bills over the tops of their red inflated gular pouches, all the while softly hooting in a wavering falsetto voice. Frigatebirds evidently do not establish lasting pair bonds.

Cormorants and shags advertise for mates from their nest sites by rapidly raising and lowering or fluttering their folded wings; waving their necks or laying them flat along their backs, thereby displaying their colorful gular skin to best effect; and fluttering their necks and throats, which are also brightly hued.

Gulls have evolved elaborate courtship displays that involve head-bobbing, choking behavior, and several stereotyped calls often performed in unison.

Terns court in the air. Males attract potential mates by flying low over the colony in a distinctive manner. When one is joined by a female, the two spiral up high in the sky, sometimes out of sight. Another aspect of tern courtship involves the passing of fish from the male to the female, providing her with some of the extra food she needs to produce eggs. This courtship feeding can become ritualized to the point where nonexistent fish are passed. Courtship feeding also occurs in gulls and skuas.

Bonin Island petrel at the mouth of its burrow. (Photo by William O. Wirtz)

Alcids display communally, either on water or land. Some species have courtship flights in which the wings are held in a distinctive manner. On water, different species form characteristic groupings, often straight lines or rings, in which chases along the surface are interspersed with dives or short flights and bouts of bill-grasping. On land these birds engage in bill-rubbing, often as a prelude to copulation, and, at least in puffins, communal head-nodding.

Copulation

Aside from its obvious primary function in reproduction, copulation helps to reinforce the pair bond and in some species seems to stimulate the development of the female reproductive organs. In the gannet, copulation can begin weeks or even months prior to egg-laying. Murres begin copulating four or five days before egg-laying but can continue up to 12 days after egg-laying.

Most birds copulate on or close to their nest site. Burrow-nesting shearwaters usually do so in front of their burrows. Puffins, which also are burrow-nesters, invariably copulate on the water, however. Murres often nest packed together on ledges and have been known to copulate promiscuously with several nearby birds, but species with life-long pair bonds show strong mate fidelity.

The male usually nibbles the female's neck feathers while mounting, or, as in gannets, he may actually bite the skin at the nape of the female's neck. Wing beating also takes place, either for balance, in the case of murres, or for added tactile stimulation, as seems the case with adélie penguins.

Copulation elicits diverse responses in a colony. In common terns, copulation in one pair is likely to trigger the act for other nearby pairs. In other species, king penguins for instance, copulation can trigger aggressive charges from nearby males.

Egg-Laying and Incubation

Seabirds lay relatively few eggs, but invest a considerable amount of time and effort in their care. Both sexes incubate. The number of eggs in the clutch and the period of incubation vary from family to family.

King and emperor penguins lay only one egg. The smaller penguin species generally lay two, occasionally three, spherical eggs per pair. Rockhopper and macaroni penguins' first eggs are substantially smaller than their second eggs. If the first egg hatches, the chick normally dies within a day or two. In contrast, most seabirds that lay two or more eggs lay their largest egg first. Some penguins nest in shallow burrows. Most, however, clear a shallow scrape, sometimes lined with pebbles, and incubate lying down. King and emperor penguins stand hunched and carry their single egg on the tops of their inturned feet, a thick belly-fold covering it from above like a tea cozy.

All members of the order Procellariiformes, which includes albatrosses, fulmars, shearwaters, and petrels, lay a single egg, with no replacement. The smaller members of the order lay the largest

Blue-footed boobies. The male, at right, is sky-pointing. (Photo by Irene Vandermolen, PR)

Male frigatebird displaying for female. (Photo by Irene Vandermolen, PR)

A blue-faced booby guards its egg on a bare nest scrape. (Photo by author)

eggs, in proportion to the female's body weight, of any seabirds. British and black-bellied storm-petrel eggs weigh 26 percent of the female's weight.

Gannets and red-footed and Abbott's boobies lay one egg; brown and blue-faced boobies lay two or three; and the piquero booby lays up to four. Brown and blue-faced boobies' second or third eggs are merely insurance against infertility or loss of the first egg — chicks hatching from them are almost invariably expelled from the nest to die.

Tropicbirds lay one egg on a scrape on the ground or in a rock crevice, cliff hole, or tree cavity, depending on the species. Frigatebirds lay a single egg on a loose nest of twigs, either in a tree or shrub or on the ground.

Cormorants and shags lay three or four eggs to a clutch as a rule. Nests can be in trees or shrubs, on cliff ledges, or on rocks or bare ground and are built of sticks, leafy vegetation, grass, seaweed, and debris of almost any sort, including small man-made objects. Some nests, for instance those of the pelagic cormorant, become enormous mounds of vegetation up to 6 feet high, and may be reused year after year.

Gulls lay two or three eggs, rarely one or four. Kittiwakes nest on cliff ledges, and mew and Bonaparte's gulls can nest in stick nests in trees, but most gulls nest on the ground, either on a scrape or in a nest constructed loosely of whatever vegetation is at hand.

Oceanic terns and noddies have small clutches, usually containing a single egg. Coastal terns lay two or three eggs, occasionally one or four. Some species, for example black noddies, build elaborate nests of vegetation; most, however, lay on a scrape. The white tern lays its egg on a bare tree branch, a novel way to avoid the problem of parasites in your nest.

Most members of the alcid family lay a single egg, but guillemots and several murrelets lay two. Eggs are laid in chambers at the end of burrows (puffins, some auklets), in rock crevices, small caves, or among boulders (some auklets and murrelets, guillemots), or on cliff ledges (murres, razorbills).

Care of Young

Once a seabird's clutch has hatched, the parents run a nonstop race to keep their chick supplied with enough food to keep it healthy and developing on schedule. Each species develops at a different, characteristic rate, according to the accessibility of food.

Seabirds usually pass whole or partly digested food to their chicks. Booby chicks reach up into their parents' throats to get their food. Tropicbirds reverse the process: the adult places its bill into the chick's gape. A herring gull regurgitates when its chick pecks at the red spot on its lower mandible. Procellariiformes, many of which forage far from the nest, reduce food to a concentrated oil, which the chick obtains by placing its bill across its parent's partly opened bill. Auklets feed their chicks by dribbling planktonic soup from their bill-tips. Puffins and some terns often carry one or more whole fish crosswise in their bills. Controlling a second or third slippery fish after one is already in place is a trick that defies explanation.

The length of time seabirds guard their young varies greatly. At one extreme are the murrelets, in which the young leave their nest two to four days after hatching. They continue to receive parental care on the water for some time. The other extreme, frigatebird young, are still dependent on their parents for food more than a year after hatching. Booby chicks hatch naked and helpless. They must be carefully shaded by their parents for more than a month to prevent overheating or, in storms, chilling.

Shag. (Photo by D. H. S. Wehle)

A white tern carrying fish. (Photo by Roger Pocklington)

White terns lay eggs on bare tree limbs. (Courtesy of Pacific Ocean Biological Survey Program)

Gulls and Procellariiformes hatch with thick, fuzzy down; the former can successfully thermoregulate shortly after hatching.

There can be no doubt from this brief survey that the paths leading to independence for young seabirds are manifold and variable. Each represents one species' or one population's solution to the environmental problems inherent in being a seabird. The solutions take into account the way each species feeds; where it feeds; when food is available on a predictable basis; and where a bit of land with the right vegetation, substrate, and slope can be found close enough to the feeding grounds. Reproductive failure is always close at hand, yet the abundance of seabirds we see about us today, in spite of the widespread effects of human disturbance of coastal and island habitats, attests to seabirds' highly successful adaptations to their environment.

Warren B. King is Chairman of the U.S. Section of the International Council for Bird Preservation.

Common puffin holding fish. (Photo by Phyllis Greenberg, PR)

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Woods Hole Birdwatchers:

The "formal" studies of seabirds by ornithologists have long been augmented by the "informal" observations of scientists and crew members aboard research vessels. Such observations are a popular way to pass a watch or off-duty time.

Records of bird sightings were begun on the early cruises of the Atlantis, *the ketch that served as the Woods Hole Oceanographic Institution's (WHOI's) first vessel. Among the first participants were Harold Backus, Alfred Redfield, Alfred Woodcock, Dean Bumpus, and William Metcalf. In later years, the list of WHOI birdwatchers included Michael Palmieri, Richard Backus, Robert Risebrough, John Kanwisher, Roger Pocklington, Paul Willis, William Butcher, Colin Summerhays, David Masch, Hank Tyler, Per Scholander, John Teal, and others.*

A few biologists carried out funded seabird studies, but most of the others watched birds for the fascination of it, on their own time. The list includes crew members as well as scientists. Harold Backus, for instance, was Chief Engineer on the Atlantis. *And in 1965, Third Mate (later Captain) Michael Palmieri was named Honorary Research Collaborator by the Smithsonian Institution. This was a volunteer post that entailed the shooting and shipping (frozen) of seabird specimens for the Smithsonian.*

"I think we fall into a long tradition of natural history observations made by just ordinary people, not just the so-called scientific staff," says Paul Willis, pointing out that many important sightings have been made by seamen and fishermen, whose eyes are trained to notice small objects at sea.

Willis, a former Navy medic, landed a job at WHOI in 1963 and was assigned as medic aboard the Atlantis II. *The ship spent most of the next three years in the Indian Ocean, where Willis, Palmieri, Robert Risebrough, and Roger Pocklington observed seabirds while on watch, correlating bird concentrations with certain water masses. One of their most important sightings was Matsudeira's storm-petrel,* Oceanodroma matsudeirae, *in the Red Sea, the Indian Ocean, and the Arabian Sea. It was partly through these observations that this species was discovered to have an unusual migration pattern. Breeding on the Japanese islands, the birds apparently fly 5,000 to 6,000 miles to the areas where Willis and the others saw them — one of the longest east-west migrations known.*

Now Parks Director for the town of Brookline, Massachusetts, Willis still spends as much time as he can observing seabirds. This past winter he took a leave of absence from his job to go on a 34-day cruise aboard the C.S.S. Hudson, *a Canadian research vessel. Last summer he was off the coast of Newfoundland observing gannets. A correspondent with several ornithologists, he knows the gaps in existing data. After writing up his observations, he passes them on to scientists who might find them useful. "It's like fitting pieces of a puzzle together," says Willis. "I'll continue to do it as long as I have breath."*

Pocklington, now an oceanographic chemist at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia, recalls that the Indian Ocean was "feast or famine" for seabird sightings. As the ship approached the Persian Gulf, a large flock of Jouanin's petrels "glided over the water as far as the eye could see," he remembers. Other days there were no birds, or perhaps only a few tropicbirds, "whose shrill, rasping call as they circled over the vessel, long 'marlin-spike' of a tail streaming behind,

Ships and Dip and Research, Too

was the only thing to break the monotony of blue sky, blue sea."

With Willis and Palmieri, Pocklington published several scientific papers on seabird sightings in the Indian Ocean. Most of them contained conclusions drawn from linking the sightings to the temperature and salinity of the water surface and to the water's chemistry, which Pocklington was studying for WHOI. The three men also published a paper describing the species they found nesting on a small island in the Cargados Carajos Shoals (a corruption of "Coroa dos Garajos," Portugese for "Reef of the Terns"), about 215 miles northeast of Mauritius. In 1979, Pocklington pulled all the Indian Ocean data together in a detailed article on water masses and bird species distribution, in which he concluded: "Seabirds are not exempted by their mobility from the constraints of the marine environment."

The first to gather WHOI seabird observations together for publication was probably Susan Scholander, who, in the 1950s, went through the logs kept by birdwatchers and summarized them in a single document. In 1966, William Butcher, Jonathan Butcher, and R. P. Anthony prepared 48 charts to show the distribution of the many species sighted in the North Atlantic.

John Kanwisher, a former WHOI biologist who studied seabird metabolism, shattered the commonly held belief that the heartbeat of diving birds slowed dramatically when the birds went underwater. Previous researchers had tested this hypothesis by attaching a bird to a heart-monitoring device, tying it to a board, and thrusting the board underwater. "All they were measuring was fear," says Kanwisher, who proved them wrong when he raised pet cormorants from eggs and fitted them with radio transmitters to measure the heart rates of the birds as they dove after fish. The heartbeat stays the same, he found.

Kanwisher could call his cormorants to him with a whistle. To demonstrate this training, he once blew his whistle at an elegant Woods Hole cocktail party. The bird flew in the window and left tracks through the cheese dip.

Michael Palmieri, binoculars at the ready, off Madagascar in 1965. (Photo by Paul Willis)

Above left, a white-tailed tropicbird. (Photo by Frank Schleicher, PR) At right, a brown booby. (Photo by Jen and Des Bartlett, PR)

The Food and Feeding

by David Schneider

Migratory shorebirds (sandpipers and plovers) are the smallest birds that depend on marine habitats for food. Most are about the size of sparrows, some are as large as the common pigeon, and only a few species attain the size of a crow. One consequence of this small size is a high surface-to-volume ratio. Since heat production is a function of weight or volume, while heat loss is a function of surface area, a shorebird (like any other small bird or mammal) must maintain a high metabolic rate in order to maintain a constant internal temperature. Shorebirds are the smallest warm-blooded animals that make a living from the sea, and as such they have the highest metabolic rates of any marine animals.

We sometimes use the expression "eats like a bird" to describe a poor appetite, but, relative to body weight, it is we who have the puny appetites and birds that consume gargantuan quantities of food. The king penguin, *Aptenodytes patagonicus*, a relatively large bird, weighs 13 kilograms (almost 30 pounds). In order to maintain its weight, this penguin must take in 2,470 kilojoules (590 kilocalories) a day. This is just to support the resting (basal) metabolism; it does not include the energy needed for everyday activities, such as foraging for food. Recent work by Gerald Kooyman of Scripps Institution of Oceanography has shown that free-living penguins need about 2.8 times their basal metabolic requirements per day. From this, Kooyman calculated that these penguins eat about 2.5 kilograms (about 20 percent of their body weight) of squid per day (see page 21). To have a comparable appetite, a 180-pound man would have to consume 36 pounds of meat every day.

Smaller birds have even larger appetites. Physiological studies have shown that the metabolic rate of birds at rest is proportional to their weight raised to a power of around 0.73. That is, a bird species with half the body weight of a heavier species will have a resting metabolic rate that is 60 percent of that of the heavier species. Research on a 15-gram honeycreeper, *Vestiaria coccinea*, in the Hawaiian Islands by Richard MacMillen and Lynn Carpenter of the University of California at Irvine has shown that daily energy expenditure of this species is 2.2 times higher than its resting metabolic rate. In another study, Wesley Weathers and Kenneth Nagy of the University of California at Los Angeles found that daily consumption of mistletoe berries by free-living Phainopeplas, *Phainopepla nitens*, in southern California amounted to 2.6 times the resting metabolic rate of this 23-gram bird. The energy requirements of free-living shorebirds have not been measured, but from measurements of the metabolic rates of shorebirds at rest, and by assuming that a factor of 2.5 applies to shorebirds, we can expect food consumption to be on the order of 33 percent of body weight per day for a 190-gram bird, such as a large plover, and 55 percent of body weight per day for a 30-gram bird, such as a small sandpiper. To have a comparable appetite, a 180-pound man would have to eat 100 pounds of meat every day!

Ruddy turnstones. (Photo by Allan D. Cruickshank, National Audubon Society/PR)

These are minimum estimates and do not apply to birds engaged in activities such as territorial defense, feeding young, or gaining fat in preparation for long-distance migration. Rough calculations suggest that energy requirements for these activities may range up to four times the energy needed to support the resting metabolism. Shorebirds, especially at stopovers prior to long-distance migration, have the largest daily food requirements, relative to body weight, of any marine predator.

How do such small birds obtain these relatively prodigious quantities of food? First, many species migrate, often over long distances, and take advantage of seasonal pulses in the abundance of marine prey. Secondly, many species, especially the smallest, aggregate and feed in areas of locally high prey abundance. Thirdly, shorebirds, like other birds, select the largest prey that they can handle. Finally, each species shows a number of distinctive behavioral and morphological adaptations for finding and capturing food rapidly and efficiently.

Different Techniques

There are as many feeding adaptations as there are species, but all of the adaptations can be viewed as variations on a few themes: detection of prey by touch or sight, speed required to capture prey, and special techniques for handling or extracting prey. Plovers specialize in visual detection, sudden dashes, and quick stabs to subdue their prey. To do this, plovers have large eyes and short, strong bills. Turnstones and oystercatchers are also visual predators, but use their chisel-sharp bills to remove less active prey from burrows, shells, or sea urchin

# of Migratory Shorebirds

tests. Sandpipers have relatively small eyes, and use their longer bills to detect and capture prey that is beneath the water surface, wedged into crevices, or buried in sand or mud.

The bills of sandpipers are so flexible that a bird can open the tip of its bill to grasp prey without opening the base of the bill. Combined with an abundance of special sensory organs in the bill, this flexibility allows sandpipers to feel, grasp, and remove buried or hidden prey. The bills of many sandpipers show some degree of curvature, either upward (recurved) or downward (decurved). Recurved bills provide mechanical advantages in finding prey; decurved bills provide mechanical advantages in extracting prey from the substrate. Three types of foraging techniques are found within the sandpiper group: pecking at the substrate surface; probing into the substrate; and stitching like a sewing machine, with motions too rapid to follow with the eye. Some species use pecking or probing to the near exclusion of stitching, while other species use distinctive combinations of the three behaviors. Not all sandpipers feed on stationary prey. Some species use their long legs and bills to pursue and capture mobile prey, such as fish and fiddler crabs.

The morphology and feeding behavior of shorebirds are relatively easy to describe, but as yet no one can predict what prey a species will take, knowing only its foraging behavior, bill length, and a list of prey species in the area. Knowledge of prey taken in one habitat (such as a migratory stopover) is of little help in predicting what prey will be taken in another habitat (such as a tropical wintering area). The food choice of shorebirds remains an unsolved puzzle. For this reason, the following description of shorebird feeding emphasizes the contrasting functional adaptations of shorebirds. Prey are mentioned only to give some idea of the variety of marine organisms these birds eat.

Running and Stabbing

The plovers of the genus *Charadrius* are small birds (15 to 28 centimeters long) distinguished by one or two dark collars around the neck. The best examples of the run-and-stab foraging technique are found in this group. The Wilson's plover, *C. wilsonia,* has the heaviest bill in the genus, and it uses this bill to stab crabs. The semipalmated* plover, *C. semipalmatus,* is a similar-looking bird with a slimmer bill, which it uses to stab softer prey such as brachiopods and polychaete worms. The snowy plover, *C. alexandrinus*, is a smaller, paler bird of the west and gulf coasts of North America. It feeds by stabbing at flies in algae stranded on the beach, or by running down the beach after small organisms that tumble in the wake of retreating breakers. Its counterpart on the Atlantic coast, the piping plover, *C. melodus*, feeds on a variety of organisms, mostly insects, that it finds in the seaweed left by spring tides. The collared plover, *C. collaris*, confined to low latitudes, feeds on insects such as ants and beetles that are found near the high-tide line in the tropics.

The black-bellied plover, *Pluvialis squatarola*, is larger — 26 to 34 centimeters long. It is a conspicuous bird of the shoreline and, perhaps as a consequence, extremely wary of people. This bird uses the same foraging technique as the smaller plovers, but stands watching for longer periods, dashes longer distances, and catches larger prey. On intertidal flats in New England it catches a wide variety of prey, ranging from nereid polychaetes to nemerteans (round worms) and shrimp (*Crangon septemspinosa).* Black-bellied plovers also eat large gem clams, but one suspects that these birds capture clams that make a sudden movement, since the flats are littered with gem clams and there is no need to go dashing several meters to capture one. This plover will forage on muddy flats if active animals, such as nereids (worms), are present, but it is more regularly found on sandy flats or exposed beaches inhabited by active burrowers, such as certain worms and mole crabs. Sometimes the black-bellied plover adds a flipping motion after the initial stab, possibly to reveal a prey item that has retreated into the sand.

Chiseling, Hammering

Turnstones are smaller birds (20 to 25 centimeters long) that use their bills as chisels. This technique serves them in a variety of habitats. In Florida, ruddy turnstones, *Arenaria interpres*, excavate coquina clams from the sand, then use their bills to chisel them open. When periods of low wind expose reef platforms in the tropics, turnstones appear and begin feeding on small urchins. After flipping an urchin over, the bird uses its bill like a can opener to cut the

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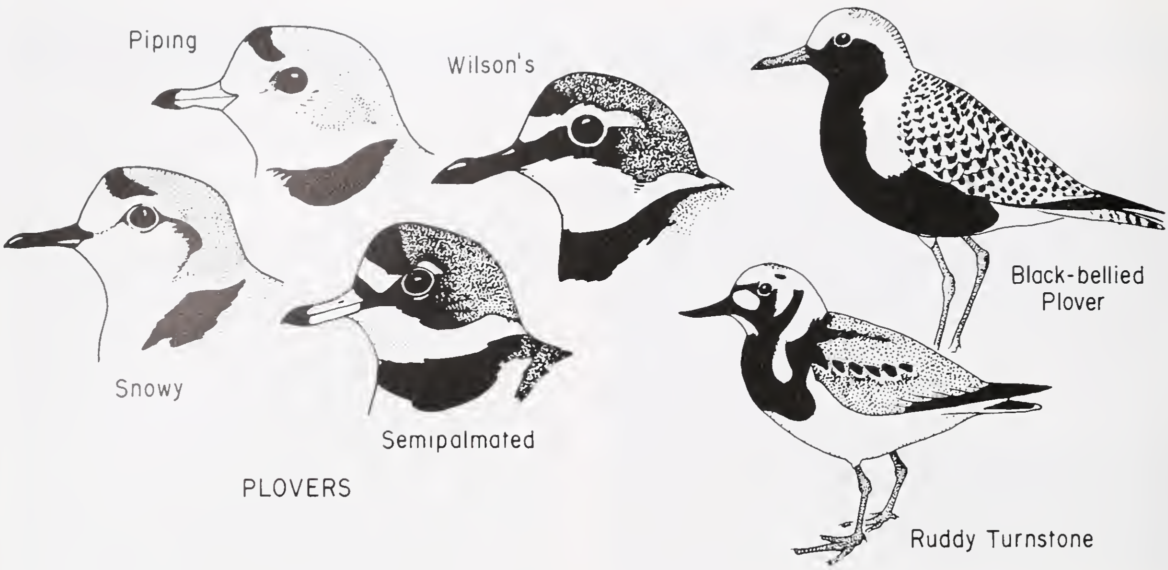
*Semipalmated: having partly webbed front toes.

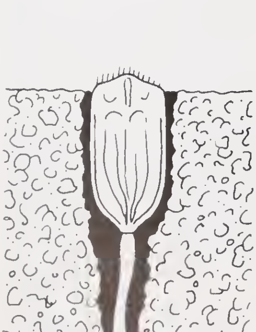


All drawings by Karin Christensen.

mouth and jaw structure free of the test. The entire contents of the test are then picked out, leaving the test intact with spines still set rigidly outward. Turnstones also excavate holes in stranded jellyfish (feeding on the gonads), in seal corpses (feeding on maggots), and in mud (capturing infauna). The tossing motion used for excavating is also used to reveal prey by flipping over seaweed and stones, hence the bird's name.

Oystercatchers are larger birds (43 to 53 centimeters long) with larger chisels. In Europe, the common oystercatcher, *Haematopus ostralegus*, uses two different techniques to open large shellfish. Some birds wade into shallow water and thrust the bill into the gape of a mussel or cockle, then saw through the adductor muscle and pick out the flesh. Other birds use the bill to hammer holes in mussel shells, then to sever the adductor muscle. An individual oystercatcher learns only one technique during its life, requiring more than a year to perfect its technique, and in the meantime must subsist on smaller prey. The capture of large shellfish with this foraging technique is important for breeding, as the oystercatcher is one of the few shorebirds that bring food to their young.

On the Pacific coast of North America, where rugged coastlines prevail, the black oystercatcher, *H. bachmani*, hammers a small hole in the ventral rim of a limpet shell, prying the shell off its rock. Another inhabitant of this coast is the surfbird, *Aphriza virgata*, which bobs over the wave-splashed rocks, capturing mussels small enough to swallow whole and crush in its gizzard.



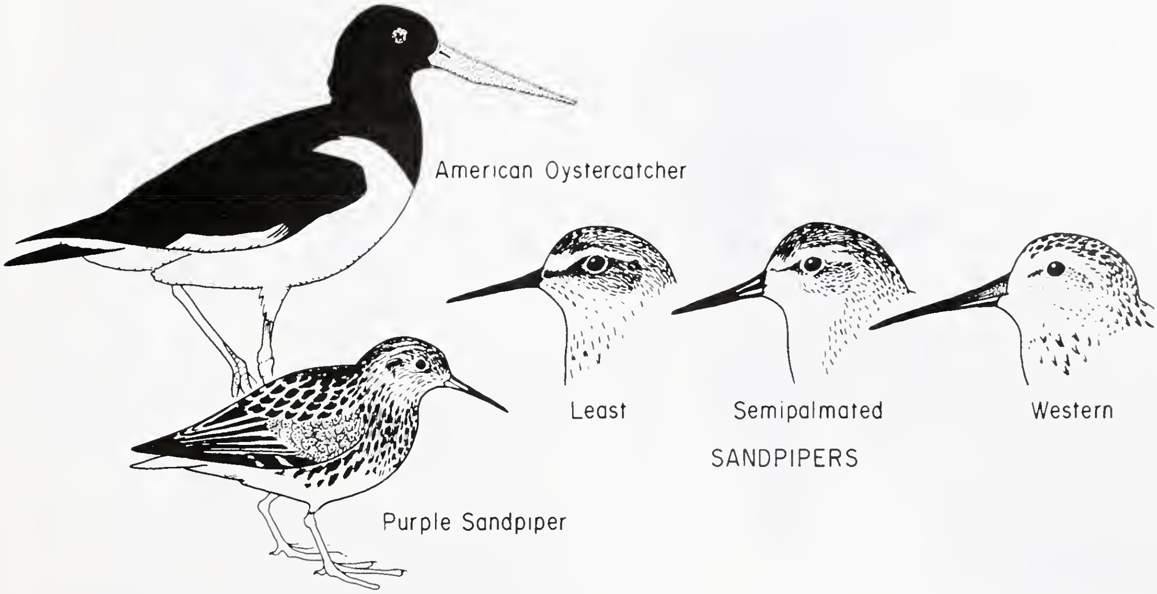
Brachiopod

Crangon

Pecking, Probing

Rocky coastlines also are inhabited by a few sandpipers, which peck and probe for prey in crevices and among the fronds of rockweed. The Aleutian, or rock sandpiper, *Calidris ptilocnemis*, ranges from Alaska to Oregon, feeding on animals living in crevices or stranded by the tide. Its counterpart in the western Atlantic, the purple sandpiper, *Calidris maritima*, is largely restricted in winter to the rugged coasts of Maine and eastern Canada, where it feeds on amphipod crustaceans and other animals in the rockweed.

Most other sandpipers seek out the inhabitants of softer substrates, the shifting sands and muds that make up most of the Atlantic coastline south of Maine. Many of the shorebirds seen along this coast are small sandpipers, belonging to the genus *Calidris.* Often the best clue to identification is the distinctive foraging style of each species, ranging from the fast-paced pecking of the smallest, the least sandpiper, *C. minutilla*, to the more leisurely



probing of the largest, the red knot, *C. canutus*. The diets of these species are varied and extremely difficult to categorize. The least sandpiper (13 to 16 centimeters long) feeds on animals at the substrate surface, rarely probing the substrate. Least sandpipers often forage in the algae growing on intertidal flats in late summer, capturing amphipods. The semipalmated sandpiper, *C. semipalmatus*, a slightly larger bird, uses a mixed repertoire of pecks, probes, and stitches to obtain prey at or just beneath the sediment surface. Prey include small animals visible at the surface (such as snails) and shrimp that bury themselves in sand if stranded by the receding tide. This sandpiper and its Pacific Coast counterpart, the western sandpiper, *C. mauri*, both probe for fresh prey in seaweed left behind by the falling tide.

The sanderling, *C. alba*, is a still larger sandpiper whose specialty is running down the beach in the wake of a retreating breaker to catch any animal revealed by the rolling water. Mole crabs and coquinas small enough to swallow whole are often important items in this bird's diet. Sanderlings, like semipalmated sandpipers, pounce on shrimp that they flush from the sand by using a rapid and shallow stitching motion. Other important sources of food are freshly stranded algal clumps, inhabited by still-moving amphipods and snails.

The dunlin, *C. alpina*, is a larger bird (20 to 23 centimeters) with a slower pace and a down-curved bill. The shape of the bill helps this bird maintain a grip on the worms it pulls from the substrate. The red knot is even larger (25 to 28 centimeters), with a still slower pace. The knot uses its straight bill to probe for amphipods and certain clams in soft substrates. Knots also feed on mussels small enough to swallow whole (about 1 centimeter long).

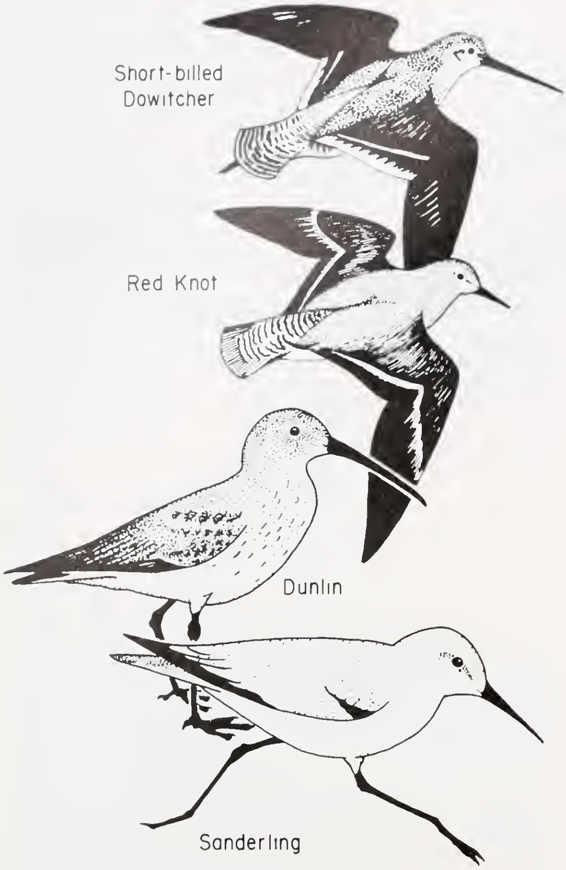
Dowitchers are about the same size as red knots, but have much longer bills. The short-billed dowitcher, *Limnodromus griseus*, uses its flexible bill to probe for infauna, such as the bamboo worm. Probes are sometimes accompanied by a shaking motion that can liquefy the sand, aiding the bird in detecting prey such as clams and amphipods. Dowitchers also wade in shallow water, using their long bills to find prey in the underlying mud.

Wading

The habit of wading to find prey is best developed in a group that includes the greater yellowlegs, *Tringa melanoleuca*, the lesser yellowlegs, *Tringa flavipes*, and willets, *Catoptrophorus semipalmatus*. The lesser yellowlegs is often seen wading, using its bill to find food at the sediment surface. The greater yellowlegs uses its long legs and bill to capture more mobile prey, such as minnows, in the shallow water at the edge of intertidal flats. The willet uses a high-stepping gait to search for food in the sheets of water running down the beach after a breaker. On tropical mud flats the long legs are used to chase ocypodid crabs that have come out of their burrows to display to each other at low tide.

Godwits, *Limosa* spp., are a group of large sandpipers whose long bills are heavily reinforced at the base, giving the bill a slight upward tilt. The skull musculature is modified for vigorous probing, which enables these birds to capture large and deeply buried infauna such as lugworms and razor clams. Curlews differ from godwits in having more flexible bills, curved downward. The whimbrel, *Numenius phaeopus*, uses its downcurved bill to drag crabs out of their burrows. The decurvature allows the bird to apply more pulling force on a resisting crab than it could if it had to clamp down on the crab with a straight bill. The decurved bill is also useful in probing for crabs in labyrinthine burrows, and allows the bird to probe beneath rocks without having to push its head into the mud.

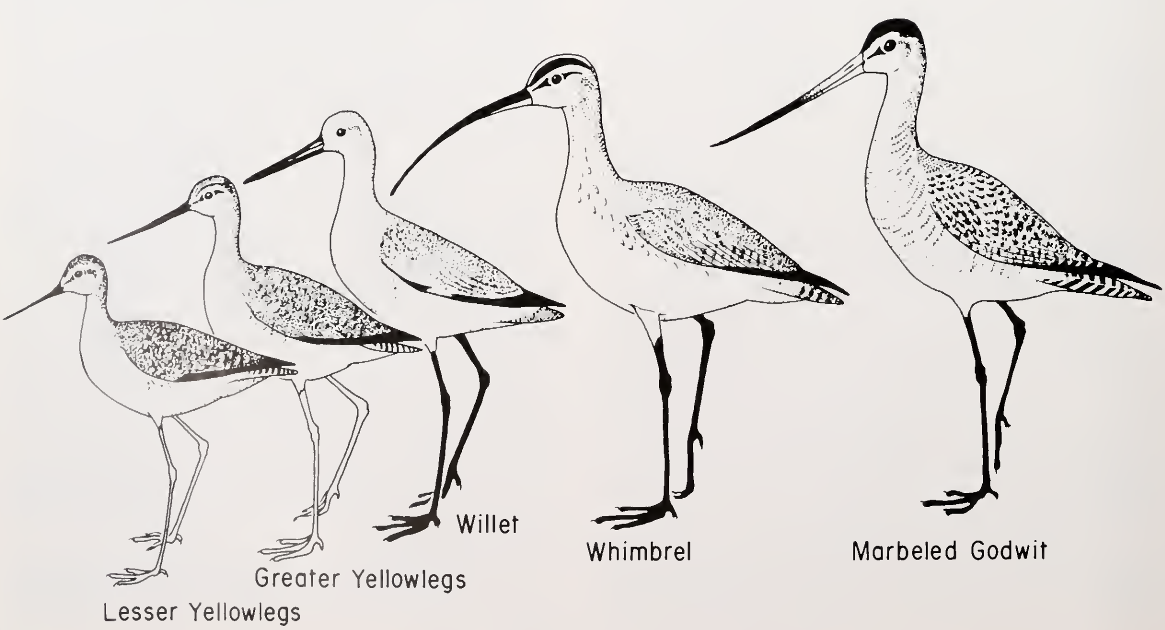
No description of shorebird feeding would be complete without mention of two highly specialized groups, the phalaropes and the avocets. Phalaropes

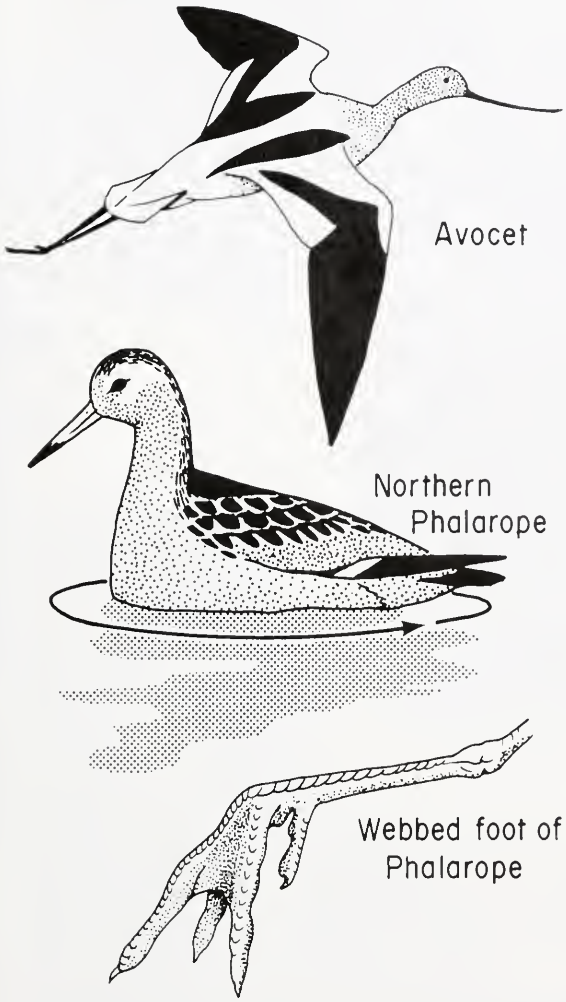


swim in tundra pools, salt lakes, or the open ocean using a whirling motion that concentrates crustacean prey, which are snatched up by rapid pecking. Avocets use their upturned bills to skim the surface of soft muds with a sideways scything motion. The functional significance of this behavior is still a mystery, for the stomachs and fecal castings of avocets contain little in the way of identifiable prey. Snagging small worms seems unlikely, since these are not visible on the bill after a sweep. The bird may simply be skimming the surface layer of mud, which in some seasons is rich with the larvae of benthic organisms.

The variety of specialized foraging techniques of shorebirds suggests that these birds competed for food during their evolutionary history and still may be competing. Shorebirds at a migration stopover in Massachusetts removed between 50 percent and 90 percent of the adult population of benthic invertebrates in less than six weeks. The effect on small patches (10 to 50 meters across) was even more pronounced than the effect on total abundance, for the greatest losses were from patches with the highest pre-migration densities of invertebrates. The earlier a bird arrived in Massachusetts, the richer the food source it encountered. These results suggest that migrating shorebirds face a competitive scramble to arrive early at migratory stopovers. Shorebirds also may compete for food with fish, based on the results of a study in southern California by Millicent Quammen of the University of California, Santa Barbara.

These results also tell us something about community structure of benthic invertebrates, for it is becoming clear that mobile predators, such as





birds and fish, can reduce invertebrate numbers within high-density patches, where competition among invertebrates would otherwise be intense. Further study of mobile predators promises to tell us something about the dynamics of invertebrate communities in sand or mud.

The impact of birds on prey densities is an important key to the conservation of birds. By knowing where in its life cycle a species faces the most intense problems with food depletion, we are able to pinpoint the locations where that species is most sensitive to reduction in the amount of food as the result of pollution or alteration of the habitat. Migratory shorebirds are one of the success stories of environmental legislation. Shorebirds were scarce during the early decades of this century, after a period of intensive shooting in the latter part of the 19th century. Today, under the protection of treaties signed more than 50 years ago, nearly all North American shorebird species have managed to stage comebacks. As these birds repopulate, the most serious problem they face is continued reduction in the amount of intertidal wetlands.

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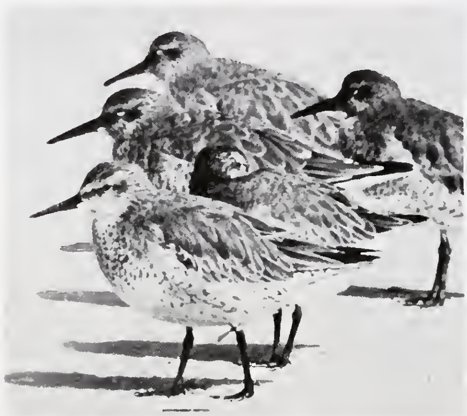
Semipalmated sandpipers. (Photo by Allan D. Cruickshank, National Audubon Society/PR)

The Migration of the Red Knot

by Brian Harrington



On first consideration, the study of bird migration may seem far removed from the realms of oceanography and marine biology. But with seabirds this certainly is not the case. Indeed, the most often-cited example of a "champion migrant" is the Arctic tern, for most of the year a creature more of oceans than of land. Less well known, but even more spectacular when it comes to migration, are the shorebirds — plovers, sandpipers, red knots, and their cousins.

Shorebirds are a relatively large group of birds, worldwide in distribution. All but a few of them are associated with open lands and shorelines. Some are sedentary and others extremely mobile. Among the latter are the highly migratory species that nest in the Arctic regions of Greenland, Canada, Alaska, and eastern Siberia, and when winter comes to the Northern Hemisphere, penetrate to the farthest reaches of South America, southern Africa, and New Zealand.

Though these remarkable travel distances are matched by some seabirds and approached by a very few land birds, the extraordinary aspect of shorebird migration is that great stretches of land and sea are traversed nonstop at high altitudes. Many details of these migrations remain obscure, but there is now sufficient evidence to say that at least seven North American shorebird species, and probably twice that many, habitually follow an over-water route from eastern Canada to the northern coast of South America, a span of 2,500 to 3,000 miles. The largest of these birds, the Hudsonian godwit, is about the size of a small crow; the smallest, a stint sandpiper, is the size of a sparrow. Radar observations show that much of the flying is at 12,000 to 18,000 feet, depending on weather conditions, with some flocks, presumed to be plover, at more than 20,000 feet. Speeds, influenced by wind, are estimated to be 35 to 60 miles per hour, with 50 miles per hour a working average for estimating duration of flight.

Other long-distance migrants, including seabirds such as shearwaters, petrels, and Arctic terns, pursue their travels in a leisurely fashion, feeding as they go, for periods of weeks or months. Migrating landbirds, with very few exceptions, fly either by day or by night and then put down to feed and rest. The Arctic-nesting shorebirds, covering long distances nonstop, at great altitudes and at relatively high speeds, are unique.

Given the extraordinary nature of shorebird migration, it is not surprising that these birds have some remarkable physiological adaptations. The chief of these is an ability to gain, in a few short weeks before an extended migration, a substantial amount of body fat — many individuals nearly double their weight. This fat supplies energy for long-distance flight, and thus may be largely used up in just 60 to 70 hours. For the birds to accumulate the necessary fat between nesting and migration, food supplies must be abundant and accessible, and this partly explains why shorebirds tend to gather in great numbers at the most favorable feeding places. On an evolutionary scale, shorebirds' long migrations are a

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Map, at right, by Charles Beier, New England Aquarium. (Photos by David Twichell)


...an
incredible
journey

way of exploiting very rich but widely separated, seasonably available food resources, many of which are marine.

The whole annual cycle, with its interlocking phases of nesting, accumulation of fat for southward migration, dissipation of fat during migration, molting, reaccumulation of fat, and spring arrival in the North to nest again, is of great scientific interest. For some species, the details of this cycle are yet to be discovered. What we do know is best illustrated by example.

Incredible Journey

The red knot is an Arctic shorebird known to breed in Greenland, Siberia, Alaska, and on Canadian islands from Victoria to Ellesmere. Roughly the size of robins, red knots annually commute as far south as New Zealand, South Africa, and Tierra del Fuego (Argentina), some of the longest migrations known. The American subspecies, *Calidris canutus rufa*, nests on islands of the central Canadian Arctic — Victoria Island, Jenny Lind Island, and perhaps as far south as Southampton Island at the northwest end of Hudson Bay. Using information from sources including a six-year banding program; a network of 300 volunteer bird-counters in 35 nations and commonwealths of North, Central, and South America; aerial and ground surveys in Argentina, Surinam, Venezuela, Florida, and New England; and the literature, we have pieced together a picture of *rufa's* migration route to Tierra del Fuego. We also have studied the foraging habits of red knots at points along the route, giving us some ideas as to why they travel such extraordinary distances and how they complete their migrations.

The major wintering grounds of *rufa* are along the southern Argentine coastline between Chubut province and Tierra del Fuego. This windswept coast is characterized by 30- to 40-foot tides and an intertidal zone with a densely pitted shelf called a *restinga*. The *restinga* harbors a wealth of marine life, including dense beds of mussels whose spat (young) are a favorite food of red knots. But the presence of spat alone is not the only attraction for knots, because with their soft, typical sandpiper bills, the birds are often unable to pry mussels away from rocks. The *restinga*, however, has the consistency of hard-packed clay, being formed from dust carried off the land by the famous winds of Chubut. As such, the substrate does not have the strong holdfast characteristic of mussel beds in many other parts of the world, and the soft-billed knots can pick off spat easily.

The northward migration of knots normally gets under way during the first half of March. At Peninsula Valdez in northern Chubut, one of the first stopover areas, peak migration is in mid-April. Large flocks of knots forage along immense tidal sandflats in sheltered bays, probing for thumbnail-sized tellin clams and polychaete worms. In 1981, we estimated that about 20,000 knots visited Peninsula Valdez. There we captured knots we had banded nine months earlier in Massachusetts. We know of at least one other major staging area for northbound knots in South America — the sandy coasts of Rio Grande do Sul in southern Brazil. The highest numbers of *rufa* are found there in late April and early May, apparently foraging on mussel spat.

From southern Brazil, we temporarily lose track of the knots' migration route, but soon after their numbers peak in Rio Grande do Sul, a major flight arrives along the southeastern coast of the United States. We know little of this passage, save a description by Judge Herman Coolidge of Georgia in 1971: [On May 22] . . . "we rode the beach (of Wassaw Island) in a jeep and quickly realized we were seeing the largest flock of knots we had ever seen. Wave after wave of these birds in their cinnamon-colored plumage passed us . . . stopping frequently to feed or rest . . . I am confident we did not exaggerate when we concluded we had seen at least 12,000 . . . ." This account, along with other fragments of information, suggests that knots do not tarry on the southeastern U.S. coast but move steadily northward toward Delaware Bay, their next major staging area.

"The Beach is Alive"

"Is this real or imaginary? I can't believe my eyes. My gosh, the beach is alive!" These remarks came from a first-time beholder at the peak of spring shorebird migration along the shores of Delaware Bay. The spectacle is caused by unimaginable numbers of horseshoe crabs coming ashore to lay their eggs, each one bumping against competing crabs, struggling to secure a spot to dig and lay its eggs. There are so many crabs that nests are repeatedly dug up by successive waves of crabs arriving with each new tide, and this causes millions of the tapioca-sized eggs to be washed up onto the beach. This, then, provides a feast table for whatever animals can use it, including hundreds of thousands of shorebirds, each one needing to find enough food to fuel the remainder of its journey from South America to the Canadian Arctic. The scene is primeval — thousands upon thousands of horseshoe crabs, gulls, and sandpipers move busily on beaches too small for the melee, each animal scrapping for space in the windrows of eggs. Among them are more than 100,000 red knots, roughly a third to half of the world population of this subspecies.

From Delaware Bay, the knots apparently fly directly to their breeding grounds, though a few individuals stop briefly on the shores of James Bay and Hudson Bay. The fat that the knots gained at Delaware Bay not only fuels their remaining northward flight, but also could be a crucial reserve for the first few days after the birds return to the nesting grounds. Often, knots reach their breeding areas before the ground is clear of snow, and must resort to eating roots, presumably a "hardship food." Even so, this is a season of intense activity: establishing and defending territories, courting potential mates, and preparing to nest. The four-egg clutch, laid promptly after arriving, normally weighs about 75 grams, or about 60 percent of the female's fat-free weight. Imagine giving birth to a 60-pound baby within a week or two of completing a 6,000 mile hike!

Knots' southward migration starts before the young are fully developed. Adult females leave their broods soon after hatching, to arrive at a few favored spots along James Bay and the New England coast in late July. The males follow about 10 days later, leaving the young to fend for themselves, and finally the juveniles leave the nesting grounds, in late August. According to our surveys, more than 80 percent of the knots that visit the Atlantic coast at this season stop at just six locations, three in Massachusetts and three in New Jersey; elsewhere the birds are scarce.

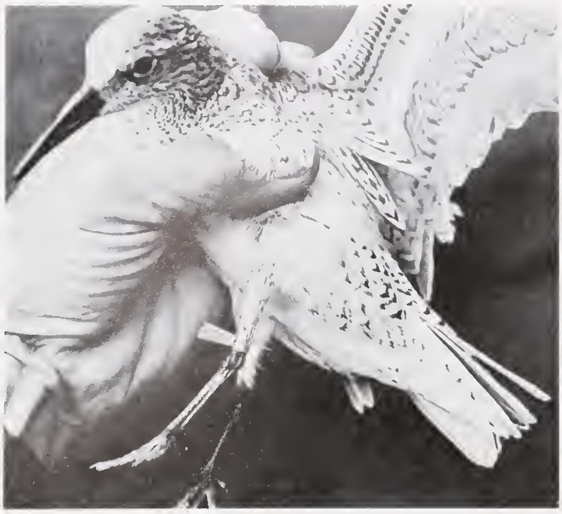
A feature common to knots' Atlantic stopover areas is the "sodbank," old salt marsh peat exposed where inlets have cut through beaches that, in past decades, buried salt marshes.

Why should old sodbanks be attractive to knots? Although we are not yet sure, we believe it is because the banks offer a substrate from which the knots can readily remove mussel spat. In any case, the migrating knots feed very intensively, sometimes eating practically all the spat on a sodbank. Our work in Massachusetts leads us to "guesstimate" that about 2,000 knots removed 10 to 20 million spat from a 10-acre sodbank in just three weeks. Alas, as we all know, a consequence of gluttony is obesity. During about 20 days of intensive foraging, the average knot's weight went from 130 to 185 grams, a 42-percent gain. This is equivalent to a 150-pound human gaining more than 60 pounds in two weeks, impossible in my experience, even at Thanksgiving! Knots do it several times a year.

One knot banded in Massachusetts was found at Anegada Island in the British Virgin Islands just 16 days later; another was shot in Guyana, also 16 days after banding. This and the lack of knot sightings elsewhere suggest that knots fly directly over the ocean from Massachusetts to South America.

Once in South America, we again lose track of the knots' migration route. Five banded birds have been found in the Guianas, all before September 10th. Three or four others were seen about a month later on the central Argentine coast. Apparently knots visit staging areas somewhere in northeastern Brazil in September, then fly nonstop across Amazonia to the central Argentine coast. Few are

Researchers from Manomet Bird Observatory extract red knots from a rocket-fired net. The birds were banded and released. (Photos by David Twichell)



To facilitate study of its migration, this red knot has been given a numbered band with a tiny colored flag that allows identification in flight. (Photo by David Twichell)

seen, at this season, along the coasts of southern Brazil (Rio Grande do Sul) and northeastern Argentina.

The Shorebird Pattern

The knot migration story, extraordinary as it is, may not be an unusual pattern among shorebirds; its theme is common to a dozen or more species. Essentially, this theme is one of amazing flights, used to connect a series of seasonally predictable and highly abundant food resources. In late spring and summer, these shorebirds are in the Arctic, taking advantage of a massive emergence of insect and aquatic life that flourishes for only a few months each year. Their first move is to marine intertidal areas in northeastern North America during July and August, just when the local invertebrate populations are at their peak. They then move on to harvest a wealth of the austral summer's marine production in the Southern Hemisphere. Thus shorebirds are indeed marine animals for most of the year.

The life-style of the genre of shorebirds represented by red knots is a "movable feast" following a seasonal chain of productivity at widely separated points of the globe. The chain is not without its weak links, however, as a number of species depend heavily upon fattening at localized marine staging areas, where much of their population may be concentrated at one time and thus vulnerable to hunters. This behavior led to near extinction of *rufa* and a variety of other shorebirds in the late 1800s and early 1900s. Some, such as the eskimo curlew, have never recovered. Happily, though, with the cessation of market and sport hunting, most shorebirds have regained their numbers.

Today there are new threats. Tidal power schemes, pollution, uncontrolled recreational use of beaches, and habitat loss in both North and South America threaten many of the major staging areas shorebirds must have in order to complete their phenomenal migration. There are no simple answers to these complex problems, but recognizing how they relate to shorebird migration and biology is a good starting point.

Brian Harrington is a shorebird biologist at the Manomet Bird Observatory in Manomet, Massachusetts.

Red knots and man —going in opposite directions. (Photo by David Twichell)

A young osprey on its nest above a Massachusetts salt marsh. (Photo by Alan Poole)

An Osprey Revival

by Alan Poole and Paul Spitzer

During the first half of this century, some of the densest concentrations of ospreys in the world were nesting in the narrow, productive coastal zone of the contiguous United States. By the late 1960s, significant portions of this huge population had disappeared, victims of the widespread organochlorine pesticide DDT (dichloro-diphenyl-trichloro-ethane), which kept many of these birds from producing hatchable eggs. Because of their conspicuous position as top predators in estuarine ecosystems and their ability to live near people, ospreys generated remarkable human concern during their decline. This concern was a factor in the decision to ban DDT. Today, coastal ospreys are thriving again, and it now seems safe to say that they will do more than merely survive. Like the mythical phoenix, ospreys are rising from the ashes of their own demise and rapidly gaining in numbers.

The osprey, *Pandion haliaetus*, is a fish-hawk; its diet is exclusively live fish. Few birds are more cosmopolitan. Breeding throughout the Northern Hemisphere, as well as in Australia and Southeast Asia, ospreys have adapted to a wide variety of freshwater and saltwater habitats. But since temperate waters are only seasonally productive, many ospreys must migrate to equatorial wintering grounds where food is more available. Populations along the eastern coast of the United States spend their winter in northern South America and throughout the Amazon basin. Only subtropical ospreys, such as those nesting in southern Florida or Baja California, remain year-round on their breeding grounds.

Ospreys are unusual among large birds of prey, not only because they eat live fish but also because they often nest in colonies. These two behavioral features are not unrelated. Since fish are very mobile and patchily distributed, ospreys are not able to defend exclusive feeding territories. Instead, loose breeding colonies form where feeding conditions are good and nest sites are available; sometimes nests are only 15 to 20 meters apart. The fertile, shallow bays and estuaries of the eastern U.S. coast have encouraged the growth of osprey colonies by allowing the birds to concentrate where anadromous and near-shore fish are particularly abundant. Ospreys can dive only about 1 meter deep, so they are restricted to bottom fish in shallow water and surface-schooling fish in deeper water.

The U.S. Fish and Wildlife Service recently estimated the current U.S. osprey population at approximately 8,000 nesting pairs. About two-thirds

Table 1. Distribution and abundance of nesting ospreys in selected regions of the U.S. coastal zone, 1981. (Data from C. J. Henny, U.S. Fish and Wildlife Service)

Region	Number of Pairs Nesting
Maine[1]	approx. 1000
New York City to Boston	168
New Jersey	87
Chesapeake Bay (coastal Maryland & Virginia)	1569
North & South Carolina	600
Florida[1]	approx. 1500–2000
Pacific Northwest[1]	approx. 850

[1]Includes ospreys nesting inland. For rough estimates of coastal populations, subtract a third for Maine and the Pacific Northwest; subtract a half for Florida.

of these are coastal nesters. Since osprey nests are easily spotted, and since numerous state and local wildlife agencies provided data, there is reason to believe that this survey was complete. Table 1 shows the 1981 distribution of nesting ospreys in the U.S. coastal region (excluding Alaska and Hawaii). More than three-fourths of them are clustered along certain portions of the Atlantic coastline. The foremost population center is Chesapeake Bay. There, vast areas of shallow, productive estuarine waters and a host of natural and artificial nest sites have fostered many dense colonies of ospreys. Further north, the spruce islands of Maine and eastern Canada have attracted a more diffuse but still significant breeding population, as have the mangrove estuaries of southern and western Florida.

Although the osprey population in the coastal region between New York City and Boston may not rank high in numbers, despite several large colonies, this population is important for several reasons. Here historical changes in the osprey population size have been particularly well studied and documented. This population was as severely affected by pesticides as any, and today gives us great insight into how a population can recover its numbers. And here ospreys must adapt to particularly dense human concentrations and disturbed habitats, providing a glimpse of the ability of these birds to move into the 21st century alongside us. For all of these reasons, and because this is a population that we have studied for the last 12 years, our report will focus on these ospreys nesting along the coasts of southern New England and New York.

Abundance and Decline

Historically, few people bothered to count ospreys, but their abundance was often noted. By the 1940s, however, the major osprey nesting concentrations in the New York City to Boston coastal region were known, and people had estimated their size (Table 2). Despite the fact that some colonies had undoubtedly declined because of egg collecting, shooting, and the destruction of key nesting habitats, ospreys were still abundant there; about 800 to 1,000 pairs were returning to nest each spring. According to banders who checked nests during the 1930s and 1940s, reproduction was excellent in those years, averaging one to two young per active (containing eggs) nest, and colonies generally showed considerable stability.

Such stability in the face of altered landscapes and increasing disturbance from human populations along this coast underlines the osprey's behavioral flexibility. No doubt, nesting ospreys had been growing accustomed to the presence of people ever since native North Americans first camped alongside fertile estuaries to harvest their abundant fish and shellfish. But the 20th century saw considerable clearing and settlement of coastal habitat. Except when directly persecuted, ospreys continued to thrive in good numbers, unlike a shyer bird of prey that once occupied the same range, the bald eagle. One factor in the ospreys' adaptive success was the fact that people enjoyed their presence and did not feel economically threatened by them. By 1900, for example, a curious symbiotic relationship had

Table 2. Change in number of active osprey nests in coastal areas between New York City and Boston that were censused around 1940, and then in 1970.

Area	Year of census	Source of data	Active nest count	1970 active nest count
Gardiner's Island, N.Y.	1940	S. LeRoy Wilcox	306	38
"North Fork" of Long Island, N.Y.	1940	Roy Latham, S. LeRoy Wilcox	79	10
Shelter Island, N.Y.	1940	S. LeRoy Wilcox	41	16
"South Fork" of Long Island, N.Y.	1940	S. LeRoy Wilcox	68	10
Rhode Island	1941	Carlos Wright and the R.I. Ornithological Club	120	8
Connecticut River estuary and surrounding areas, Conn.	1938	John Chadwick	200 +	8
		Totals	814	90

sprung up between farmers and ospreys; it is described below in a passage from E. H. Forbush's *Birds of Massachusetts* (1927):

> *Most of the conveniently located, large, isolated trees were already occupied [by osprey nests], and some of the birds were forced to use telegraph poles or even chimneys for nest sites. . . . Here and there someone has erected a tall pole in the dooryard with a cartwheel fixed horizontally across its top. This makes a convenient and safe location of which the osprey is not slow to take advantage. . . . It seems that while these birds are incubating and rearing their young, they will not allow other birds in the vicinity of their nests, and, as the young chickens are allowed to run at large at that season, the ospreys protect the chickens from the forays of other hawks.*

No doubt ospreys were quick to take advantage of these artificial nest sites because, as Forbush suggests, adequate natural sites were limited. The historical distribution of ospreys in our study region also suggests nest-site limitation. The two areas with the densest concentrations of nesting ospreys in 1940 were both islands (Gardiner's Island, New York, and Great Island, at the mouth of the Connecticut River), free of mammalian predators such as raccoons, foxes, and skunks. Ospreys are quick to adapt to predator-free areas by nesting on the ground, which opens up a vast source of potential nesting sites obviously unavailable to most mainland colonies.

In the 1950s, a decade after the introduction of DDT for the control of mosquitos and agricultural pests, several naturalists noted serious reproductive failure in osprey populations, as well as significant declines in the numbers of occupied nests. This attention sparked the pioneering study by Peter Ames and Charles Mersereau of osprey reproduction in the Connecticut River estuary. There, from 1960 to 1963, osprey reproduction was only 5 to 40 percent of what it had been before DDT, and the population was declining at the catastrophic rate of 31 percent annually. The research revealed that the poor nesting success of these birds was not because of predation or human disturbance. Nests failed because a high percentage of eggs failed to hatch. Significant amounts of DDT metabolites were found in the food and eggs of these ospreys.

Evidence from continued studies of ospreys in this area and from numerous field studies of other birds of prey in the Northern Hemisphere soon made it clear that the osprey's position as a top carnivore in estuarine food webs makes it vulnerable to the now well-known process of "biological magnification." In this process, the residue concentrations of organochlorine pesticides can increase as much as 10 times with each level of the food web in a given ecosystem. Like other avian predators, the osprey suffered eggshell thinning, and many eggs broke before hatching. There were some embryo deaths in whole eggs as well. By 1970, the first year of our survey, it was obvious that the poor hatching rates of the previous 20 years had severely reduced recruitment into the population, with drastic consequences for breeding colonies throughout the area.

An osprey alights on its nesting tree on Long Island, New York. (Photo by Alan Poole)

Only 90 of the more than 800 nests counted around 1940 in the New York City to Boston region remained active in 1970, a decline of roughly 90 percent (Table 2). Most other osprey populations in the coastal United States appeared less severely affected by pesticides. Although their historical records are sketchy at best, areas such as Maine and Chesapeake Bay probably lost about 30 to 50 percent of their nesting ospreys during the DDT era. Florida lost few birds, but coastal populations in New Jersey declined as precipitously as those in southern New England and New York. These varied declines fit well with what we know about levels of DDT residues in these regions. Eggs of Chesapeake ospreys, for example, contained approximately one-third to one-fifth less DDT residue than eggs from coastal New York, New Jersey, and southern New England; Florida ospreys produced eggs with only trace levels of contaminants. Since all East Coast ospreys share a common South American wintering ground, the different population declines emphasize the relatively local effects of DDT residues, though traces of this pollutant have been found in marine food webs throughout the world.

Reproductive Recovery and Population Increases

The way a species recovers from disaster, man-made or natural, can tell us much about that species, its interactions with the habitat supporting it, and the potential for recovery of endangered species with similar population characteristics. The DDT era in effect functioned as a massive osprey-removal experiment in our study area. Monitoring the ospreys' recovery there allowed us to address several key questions: 1) How quickly would DDT residues flush from coastal ecosystems? 2) How quickly would the ospreys respond, through reproductive success, to a decline in pollutant concentrations? and 3) How would increased reproductive success affect subsequent changes in the population's numbers?

An effective Environmental Defense Fund lawsuit against Long Island's Suffolk County

Mosquito Control Commission in 1967 led to a federal ban on DDT in 1972. While the total number of ospreys nesting in the study region continued to fall until the mid-1970s, their reproductive success was increasing by the early 1970s. This rise in hatching rate followed the gradual decline in the use of DDT in the region. Average organochlorine residue levels measured in osprey eggs from Connecticut and Long Island showed a five-fold decrease between 1969 and 1976, while levels of PCBs (polychlorinated biphenyls, industrial pollutants) remained virtually unchanged, indicating that the contribution of the latter to the reproductive failure of ospreys probably had been negligible. The osprey's major problem, it appeared, had been a specific one: DDT's shell-thinning effects. Once the use of this pesticide stopped, the stage was set for the recovery of reproductive potential and population numbers.

By the mid-1970s, northeastern ospreys were again reproducing near the "break-even" point: the birthrate needed to balance the death rate, thus maintaining the stability of the population (Figures 1 and 2). A dramatic surge in reproduction took place in 1976, an indication that contaminant levels were falling low enough to allow the population to approach the range of its pre-DDT productivity. By 1981, productivity had climbed to 1.55 young per active nest, well within this range. A single decade had proved to be enough time to totally restore the viability of osprey eggs.

Large numbers of fledgling ospreys, as well as some adults, had been banded in northeastern coastal populations during the 1960s and 1970s. Thus it was possible to recognize individual birds in later years. Sightings or recaptures of banded ospreys during the 1970s yielded data critical to an understanding of osprey population dynamics. For example, we learned that most young birds not only spend their first winter in South America, but stay at the wintering grounds 1½ to 2½ years before returning to nest close to or in the colonies where they were born. About 50 percent of the ospreys in our population first breed as 3-year-olds, 30 percent as 4-year-olds, and 20 percent as 5-year-olds. Males appear to select the nest location, and they are more likely than females to return to their original nesting areas. This has the effect of tying regional reproduction even more closely to changes in population size. Because of the generally short dispersal distances, and because other significant populations of breeding ospreys to the north and south are at least 200 kilometers away, immigration into the New York City to Boston population probably was not an important factor in its recent recovery.

Banding data also has shown that established breeders make up a very stable portion of the population. These individuals typically return to the same nest site, or to one within 2 kilometers of it, for many years in succession. The scarcity of nest sites probably plays a key role in limiting the movements of established breeders. Ospreys returning to traditional sites are likely to find their old nests remaining from the previous year, while birds pioneering new sites run the risk of nest failure or not getting a nest built in time to breed.

Given the nest-site fidelity and short dispersal distances of ospreys, it is obvious that the recovery of depleted osprey populations has been largely dependent on local reproduction. If one examines quantitatively the relationship within our study population between change in breeding population in 1980, for example, and the production of young in the years 1977, 1976, and 1975 (weighted for the percentages of birds returning to breed for the first time as 3-, 4-, and 5-year olds), one sees a dramatic increase in the number of pairs breeding, as reproductive success rose during the 1970s (Figure 2). This relationship also allows the calculation of a "break-even" point for this population. At the 1980 reduced population density, the production rate of about 0.8 young per active nest provides enough new birds to balance the mortality of established breeders. With recent rates of production, averaging

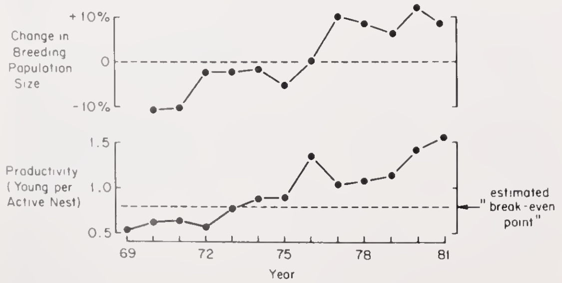


Figure 1. Yearly changes in the productivity and population size of ospreys nesting in the coastal region between New York City and Boston, 1969 to 1981. In 1976, the breeding population was at its low point for the 20th century: 109 nests. Rising productivity reflects declining levels of DDT residues in eggs, with accompanying increases in eggshell thickness and egg viability.

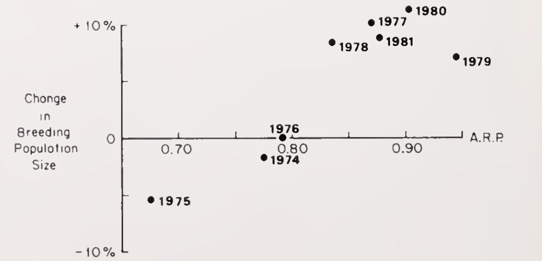


Figure 2. The relationship between "Adjusted Recruitment Productivity" (ARP) and the annual change in the number of breeding ospreys in the population under study, 1974 to 1981. The relationship emphasizes that growth of this population has come from local production of young, and it allows us to calculate a reproductive "break-even" point for the population. ARP for any particular year is an average young-per-active-nest figure for the three years in which the new breeders were born, weighted to allow for percentages of the three age-classes (3-year-olds, 4-year-olds, and 5-year-olds) returning to breed for the first time.

1 to 1.5 young per active nest, the 7-to-11-percent yearly population increases we now see are gratifyingly predictable. Until the nesting habitat becomes more saturated than it is, perhaps a decade or two from now, we should be able to count on continued yearly population increases of around 8 to 10 percent. At that rate, our population could recoup about 60 to 70 percent of its losses by the year 2000. Whether ospreys in our region will ever reach their pre-DDT population density is still an open question.

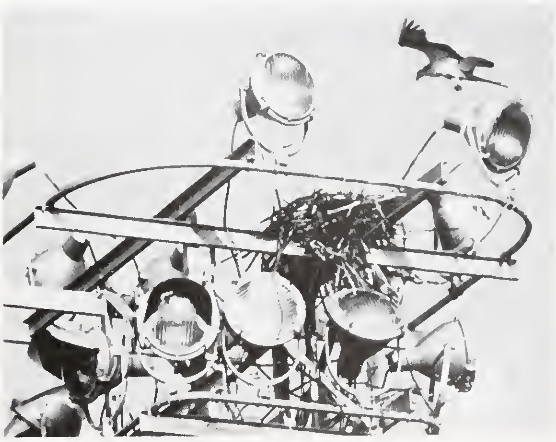
21st Century Ospreys

Having narrowly survived the DDT era in some regions, coastal ospreys in the United States now appear to have excellent prospects. But if the recovery is to continue, and if stable, unreduced populations are to retain their numbers, three conditions must continue to be met: 1) no new chemical pollutants detrimental to osprey reproduction or survival can become prevalent in coastal ecosystems; 2) food must be abundant and available; and 3) there must be enough adequate nest sites. Current evidence suggests that although the availability of nest sites and food may limit some populations, there is still much unexploited habitat for ospreys along our coasts and, equally important, a great many people determined to help these birds make use of it.

Today it seems very unlikely that a massive reproductive failure would go undetected for more than a few years. The interest these birds generated during their decline has made them one of the more intensively monitored wildlife species in the country. A major argument for such careful monitoring has been that, since ospreys have proved to be such excellent indicators of a specific environmental contaminant, their reproduction will continue to reflect levels of other coastal pollutants as well. Here one must be cautious, however. Many contaminants appear to have negligible effects on the reproductive success of ospreys, at least at present concentrations. To accurately monitor these contaminants, eggs and/or small amounts of blood plasma must be analyzed. Almost no studies of this sort have been done on ospreys since the mid-1970s; money and interest are lacking for studies of a species that now appears to be thriving. Unfortunately, we may be missing the chance to use ospreys to monitor shifts in chemical pollutants that may prove detrimental to other facets of coastal ecosystems.*

If the contamination of ospreys warrants continued monitoring, so does their food supply. When raising young, ospreys need a lot of food — about 200 to 250 grams of fish per family every two daylight hours. Generally ospreys have been opportunistic in their hunting, and have not been seriously affected by the impact commercial fishing has made on many coastal fish stocks. They are such opportunists that they inevitably start appearing with trout one or two days before the opening of "fishing season" — soon after the hatchery trucks have pulled away from stocked streams! Yet in two areas — Florida Bay, Florida, and Gardiner's Island, New York — there are colonies showing symptoms of food stress. Recent changes in fish stocks, due to overfishing in New York and to habitat alteration in southern Florida, may be responsible. Such symptoms should remain local, but nonetheless bear watching.

Historically, we have suggested, osprey populations were limited by the availability of nest sites. Present and future ospreys have a distinct advantage over their ancestors because of a dazzling and rapidly proliferating array of artificial structures that seem to satisify a nest-hunting fish-hawk. Telephone/power poles, channel markers, offshore duck blinds, lighting and radio towers — all these have lured the birds away from their natural, but less stable, dead-tree sites. In effect, we are building up a population of suburban, even urban, ospreys.



Significant numbers of osprey nests are now being built on man-made structures, such as this light tower in Connecticut. (Photo by Paul Spitzer)

The osprey "nest of the future" now exists in downtown New London, Connecticut; here a pair of birds has nested successfully for five years atop a lighting tower for a 300-car parking lot. The lot serves a nearby amusement park/bathing beach complex, so the ospreys are treated to well-lit softball games, the call of the hot-dog vendor, and even the clatter of a nearby roller coaster.

And people are finding that ospreys still respond to the old pole-with-a-cartwheel trick, even when the "cartwheel" is a simple wooden platform. Although most people no longer worry about protecting their chickens with ospreys, they do enjoy having the wild birds around, not to mention the status that goes with ospreys nesting in the backyard. Significant nesting concentrations are being created with such platforms from New England to the Florida Keys. More than 90 percent of the ospreys now breeding in coastal Massachusetts nest on poles,

*Equally important, we may be missing contamination that ospreys are picking up at their wintering grounds. Increasing amounts of pesticides (including DDT) are used in South America. At this point, we can only guess as to whether these pollutants will become concentrated enough to affect the reproduction of ospreys breeding in the United States.

Table 3. Average reproductive success of ospreys nesting in natural and artificial nest sites at selected colonies in Florida and New York. Results are combined totals for the years 1979, 1980, and 1981.

	Numbers of nests	% nests with young	average brood size
Florida [1]			
Natural Sites	45	41%	1.74
Artificial Sites	49	69%	2.14
New York [2]			
Natural Sites	38	29%	2.00
Artificial Sites	50	64%	2.16

[1] Data from M. Westall

[2] Data from M. Scheibel, New York Department of Environmental Conservation.

while about half of the nests in New York and New Jersey are on some sort of artificial structure. In the Chesapeake Bay area, radical changes in the distribution of nesting ospreys have occurred during the last three to four decades. More than two-thirds of the ospreys there nest on channel markers, duck blinds, or platforms. Since most of these structures are over water or on islands, the birds have essentially moved *en masse* off the mainland and out onto the water, taking advantage of both the long-term stability of these artificial sites and the protection they offer from climbing predators. As Table 3 shows, the advantage of nesting on man-made platforms is real.

By creating artificial nesting colonies of ospreys, we are shouldering some major management responsibilities. Young ospreys who fledge in these nests are likely to return to the same area to search for nest sites of their own. When do we stop building platforms? How dense can they be? Who maintains them? How dependent on humans do we want ospreys to become? Who pays a power company to modify a pole so a nest won't short out power in a rainstorm? How many young ospreys will die from colliding with wires? These are only a few of the questions we are starting to grapple with. Perhaps the grappling is a small price to pay for having such a magnificent raptor revived, and living in our midst.

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Suggested Readings

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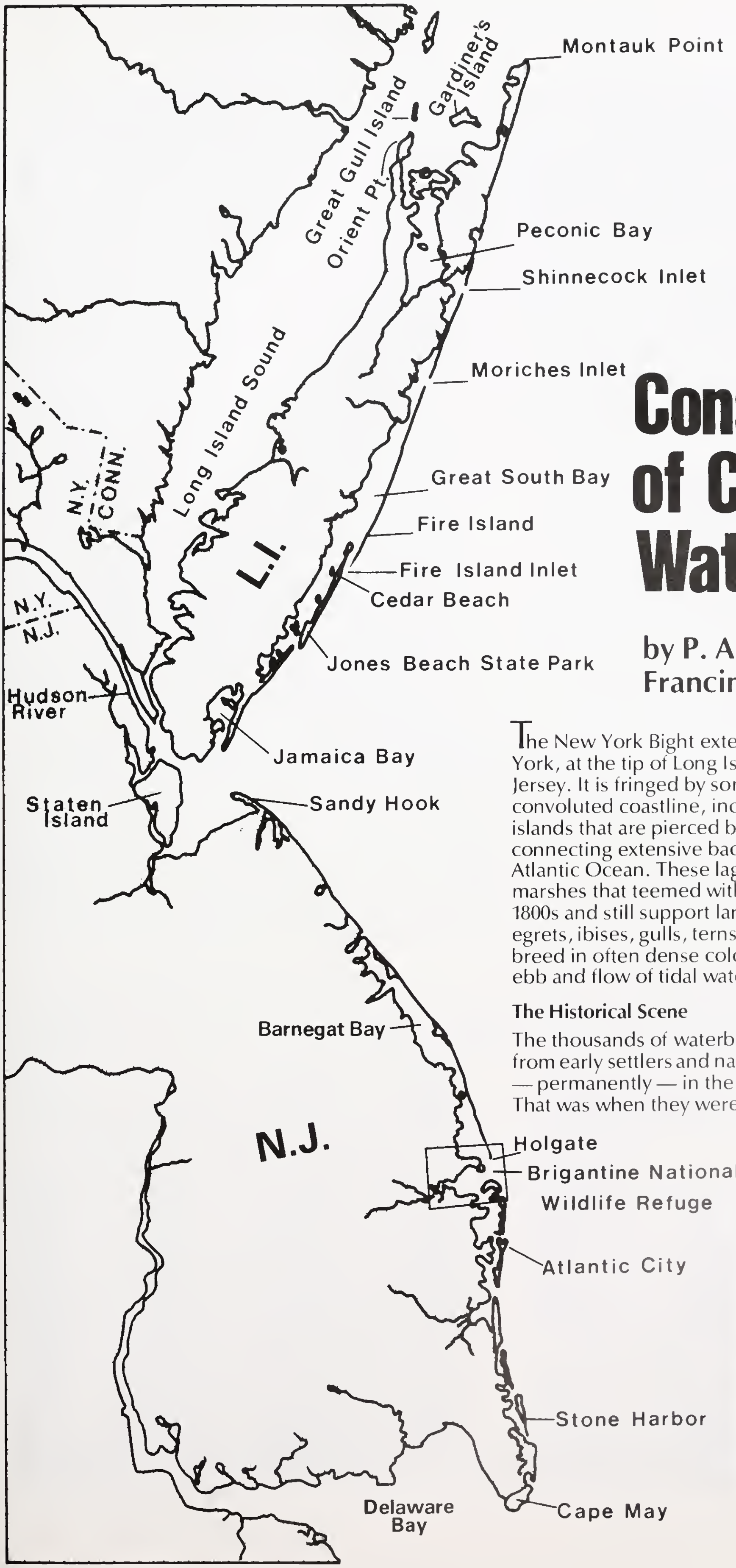

Conservation of Colonial Waterbirds

by P. A. Buckley and Francine G. Buckley

The New York Bight extends from Montauk, New York, at the tip of Long Island, to Cape May, New Jersey. It is fringed by some 280 miles of highly convoluted coastline, including 160 miles of barrier islands that are pierced by a number of inlets connecting extensive back-bay lagoons with the Atlantic Ocean. These lagoons contain vast tidal salt marshes that teemed with waterbirds in the early 1800s and still support large populations of herons, egrets, ibises, gulls, terns, and skimmers — birds that breed in often dense colonies and depend on the ebb and flow of tidal waters.

The Historical Scene

The thousands of waterbirds that attracted comment from early settlers and naturalists almost disappeared — permanently — in the late 1800s and early 1900s. That was when they were discovered, almost

Cattle egret. (Photo by authors)

simultaneously, by the market gunners who shot them by the thousands for food for the big cities, and by the plume hunters, who killed them, also by the thousands, for decorations for women's hats and clothing. It is nearly impossible today to comprehend the rate at which waterbirds were slaughtered and, more's the pity, what their pre-slaughter populations had to have been.

The terns retreated to small colonies on very hard-to-reach islands and salt marshes, the herons to isolated colonies in southern states. There they hovered on the brink of extinction for many years. Gradually they came back; first the terns, then the herons. If it had not been for moral outrage leading to stringent laws, augmented by the work of the vigilant Audubon Society, these birds would indeed be gone forever.

With the recolonizers came a few strangers. From the Old World, by way of Florida, and probably the West Indies and northern South America before that, came the glossy ibis, and then the cattle egret. Before 1950, the former was restricted to a few hundred pairs nesting in Florida, and the latter was unknown in North America. Today these two species are among the most numerous waders in the United States, and the cattle egret has even reached Alaska. From the north came the herring gull (to Long Island in 1931, to New Jersey in 1946) and the great black-backed gull (to Long Island in 1942, to New Jersey in 1966).

Recent Censuses

In 1974, we began a five-year series of complete survey-censuses of the entirety of Long Island in order to assay its colonial waterbird breeding population. No one had ever done it before: the total numbers were simply unknown. Our goal was to obtain, using helicopters, a "snapshot" of the island's breeding waterbird population in as short a period of time as possible, to minimize or eliminate the factors of early and late nestings, renestings, colony movements, and so on. We were able to survey all of Long Island's coastline, including all salt marshes, in three long days each year. We took the same kind of census of New Jersey's Atlantic coastline in 1977. The information we obtained was startling.

Our data are still being analyzed, but several major discoveries emerged quickly and clearly from both censuses: 1) There were far greater numbers of birds, and many more colonies, than anyone expected (Table 1); 2) the importance of dredge spoil islands had been vastly underestimated; and 3) an enormous population of common terns was breeding (and apparently flourishing) in tidal salt marshes. It was clear our data merited detailed analysis, and here, too, our findings were surprising. Two examples make the point.

Census data from other parts of the country during the renaissance in colonial waterbird work that occurred in the early and mid-1970s, had suggested a relationship between numbers of wading birds and salt-marsh acreages (Figure 1). Data from a major 1977 effort to take a census of the Atlantic coast, of which our studies formed a part, confirmed and extended this relationship.

Looking only at 1977 data, from both Long Island and New Jersey, another approach is also illuminating. If one takes actual breeding heron, gull, tern, and skimmer counts and multiplies them by literature-derived figures for mean clutch size, weight at fledging, and adult weight, one finds not only that both Long Island and New Jersey salt marshes are producing or supporting a large avian biomass each year, but even more intriguing, that average biomasses of young produced, or total adult plus young supported, per mile of coastline (and by extension, acre of salt marsh) are remarkably similar for both states, despite widely differing species compositions in the various colonies (Table 2). Thus,

Table 1. Breeding pairs of colonial waterbirds on Long Island, New York, from 1974 through 1978 and along the coast of New Jersey in 1977.

	LONG ISLAND					NEW JERSEY
	1974 pairs/ sites	1975 pairs/ sites	1976 pairs/ sites	1977 pairs/ sites	1978 pairs/ sites	1977 pairs/ sites
Great Egret	252/7	410/13	298/14	311/13	216/12	397/13
Snowy Egret	730/9	932/17	1398/18	1401/15	1228/21	2094/24
Cattle Egret	16/3	14/4	21/2	15/1	66/3	431/6
Little Blue Heron	34/4	20/5	11/4	9/3	25/5	232/17
Louisiana Heron	13/3	14/5	8/3	10/4	18/4	151/14
Black-crowned Night Heron	455/11	516/16	430/18	509/19	760/23	627/28
Glossy Ibis	465/11	644/14	741/16	892/17	574/18	1543/23
Great Black-backed Gull	1838/21	1307/22	1243/24	1702/27	1503/36	103/21
Herring Gull	16764/27	20768/28	15691/28	14428/35	10985/45	4202/40
Laughing Gull					1/1	35241/31
Gull-billed Tern		2/1	1/1	0/0	2/1	18/3
Common Tern	11128/34	12329/39	14972/40	13918/43	14005/54	4667/52
Forster's Tern						349/6
Roseate Tern	1854/9	1694/11	979/9	924/8	618/7	0/0
Least Tern	1719/31	2628/34	2491/38	2188/29	2237/47	691/15
Black Skimmer	339/13	458/10	495/12	342/10	458/12	1352/14
Totals	35607	41736	38779	36649	32693	52205

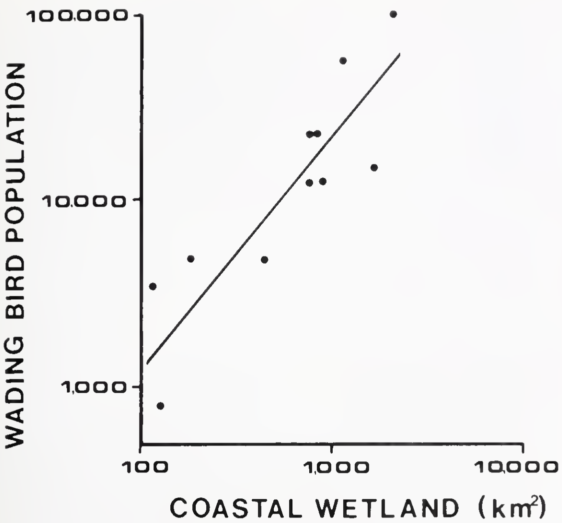

Figure 1. The relationship of habitat availability to the number of nesting wading birds. The populations of nesting wading birds in states along the Atlantic coast of North America are plotted against the area of coastal wetlands. States with less than 100 square kilometers of coastal wetland habitat are not graphed. (Redrawn from Kushlan in Sprunt, *and others, 1978)*

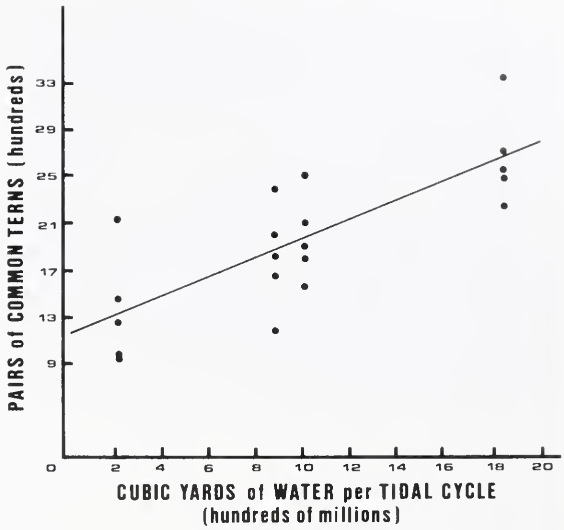

Figure 2. The relationship of tidal prism (the total amount of water that flows through an inlet or out again with the movement of the tide, excluding fresh water flow) at four Long Island, New York, inlets to numbers of pairs of common terns breeding near these inlets, 1974 through 1978.

Table 2. Estimated biomass of breeding colonial waterbirds supported, and biomass produced, along barrier island portions of New Jersey and Long Island, New York, in 1977. Data are kilograms of avian biomass per linear mile of beach.

	Total Biomass Supported		Biomass of Young Produced	
	New Jersey	Long Island	New Jersey	Long Island
Herons and Ibises	133	81	68	39
Gulls	459	437	182	219
Terns and Skimmers	37	53	14	20
	629	571	264	278

the continued health of our heron and ibis populations depends not only on the existence but on the very size and productivity of our back-bay tidal marshes.

Another relationship that showed up in the Long Island data concerned the location of major terneries at or near bay-to-ocean inlets. New Jersey inlets were too developed to support any terneries, with one exception. The four Long Island inlets least surrounded by development (Jones, Fire Island, Moriches, and Shinnecock) annually support great numbers of breeding terns (between 50 and 59 percent of the entire Long Island population) in their immediate vicinities. These are some of the largest and most persistent terneries on Long Island. Plotting data on tidal prisms (the amount of saltwater flowing into each inlet per tidal cycle) against our annual breeding censuses at each inlet yielded a strong and highly significant positive relationship (Figure 2). We interpret this to show the importance of tidal inlet interchange in supplying the fishes on which the terns feed themselves and their young.

The relationship between colony size and tidal prism is too strong to be the result of chance, underscoring the importance of these inlets to Long Island's breeding tern population. It is likely that a similar pattern would emerge upon analysis of herring gull and great black-backed gull populations, were one able to satisfactorily factor out the role of garbage dumps as food sources. Thus, the presence of these colonies becomes an important ecological consideration during any analysis of the environmental impacts of inlet opening, closure, or "stabilization."

Environmental Threats

The populations of herons, gulls, and terns breeding along the New York Bight are holding their own or increasing, are reasonably varied, and seem to be adapting to severe changes in their environment. But what *are* some of the threats these birds have been facing and how have they reacted to them?

Doubtless the single most pervasive threat to these birds is pressure from people. This pressure takes many forms, ranging from development of beaches and filling in of marshes for establishment of communities to off-road vehicles (ORVs), marina construction, and "shore-protection" structures, such as jetties, groins, seawalls, "artificial dunes," and the other devices that purport to stop the

A common tern protecting its chick from rain. (Photo by Arthur Swoger, National Audubon Society/PR)

inexorable landward advance of barrier islands in response to sea-level rise (on the order of 1 foot per 100 years — not inconsequential in low-lying coastal areas).

Coastal engineering works may have the most devastating, long-lasting impacts on colonial waterbirds, for when jetties and seawalls are constructed natural inlet migration is stopped; oceanic overwash, with its fans of fresh sand that eventually become new, productive salt marshes, is severely restricted. Breeding, feeding, and roosting areas disappear, and with them go the birds. Fortunately, severe, episodic storms like the 1938 hurricane and the 1962 Ash Wednesday storm can restore lost habitat in a very short time, but often with loss of property and human life.

Black-crowned night heron. (Photo by authors)

As inlets have been jettied, and flat, gently recurving spits on their updrift sides have been eliminated, the common terns that used to nest there have been forced onto spoil islands, which proliferate near inlets due to repeated navigational dredging. If the natural beaches they prefer are heavily used by people and no predator-free spoil islands are available, terns will move into salt marshes. We take this for granted now, but were surprised when we found that between 17 and 24 percent (1,900 to 3,600 pairs) of the Long Island breeding population of terns was nesting in salt marshes between 1974 and 1978. In New Jersey in 1977, the figure was an astounding 83 percent (3,874 pairs) of the entire breeding population. But then New Jersey is the most densely populated state in the country, and many of its inhabitants spend the summer at the beach. The terns have to go somewhere, and they are managing quite well in the marshes, exhibiting behavior strongly suggesting a long exposure to salt-marsh breeding.

In days gone by, herons nested mainly in undisturbed native maritime forests along the barrier beaches of the Bight. Development has now all but precluded that option: none of Long Island's wading birds presently nest in such habitat. In New Jersey in 1977, 28 percent (1,562 pairs) were still hanging on in native maritime forest, though several of those sites were threatened. Where have the herons gone? They, too, for the most part, have moved to spoil islands, where their habitat requirements of reasonably dense stands of shrubs, trees, or reed grass have placed them at odds with rotational dredging regimes that deposit spoil whether the site is inhabited or not. Spoil islands now constitute the single most important breeding colony site for colonial waterbirds along the New York Bight.

Urbanization of the eastern United States has led to many problems with wildlife exposed to contaminants, ranging from DDT (dichloro-diphenyl-trichloro-ethane) sprayed for mosquitoes in coastal salt marshes to PCBs (polychlorinated biphenyls) dumped illegally in manufacturing processes. Nonetheless, biomagnification of pesticides in waterbirds has not been as bad along the New York Bight as on other coasts. While significantly high levels of DDT residues have been found in black-crowned night herons from Long Island and southern New Jersey, decreases in eggshell thickness barely exceeded 10 percent, generally acknowledged as the break-point for reproductive failure from cracking eggs. While black-crowns on Long Island in the 1970s (mean annual population: 534 pairs) were certainly fewer than at their known peak (at least 3,400 pairs in 1935) it was being suggested even in the pre-DDT 1930s that urbanization was responsible for heron declines. The true causes may never be known, but probably human development and biocides are both responsible.

In the early 1970s, a series of anatomical anomalies in common terns from eastern and western Long Island were reported, and although it was suggested that mercury and PCBs may have been the villains, the connections were weak at best. Thin-shelled eggs were not reported in significant

Off-road vehicle tracks through a traditional least tern colony site near Shinnecock Inlet, Long Island. (Photo by authors)

numbers in New York Bight terns, nor, for that matter, in gulls or herons, so biocide effects in these populations may have been only indirect, sublethal, or synergistic. In any event, most workers seem to agree that the biocide threat is diminishing in importance in this area.

Probably more of a threat to waterbirds today comes from direct human interference with colonies, whether by bathers who wander into terneries or by ORV drivers who unwittingly crush eggs and chicks. Indeed, the mere presence of people can prevent colonies from forming. Least terns are especially vulnerable in this regard, as they require fresh, shell-strewn sand of the type normally found on natural beaches but also typical of freshly dredged spoil. Unfortunately, such habitat is for many reasons ephemeral, so least tern colonies typically move and re-form from year to year. So far, they have been reasonably successful in accommodating to man, despite repeated reports of annual fledging success per pair on the order of 0.5 young, and despite their apparent inability to nest in salt marshes. The best evidence indicates that their post-plume-trade numbers have never been higher than they are now, though they could possibly be only a tenth of their population in the mid-1800s.

Habitat Management

Habitat manipulation or management especially designed to attract colonial waterbirds is in its infancy. To our knowledge, no such attempts have been made with wading bird or gull colonies along the New York Bight, although there have been at least two major studies of the habitat preferences of laughing gulls in New Jersey. Other studies have examined various aspects of breeding habitat selection by common terns, especially in salt marshes, but to date these findings have not been used in an effort to induce new marsh colonies to start, or existing ones to move or grow. Such work is probably not far off, however, and has been successful elsewhere in the United States.

An effort to create nest-site habitat for black skimmers by planting beach grass in strips alternating with bare sand was successful at Jones Beach, as were efforts elsewhere on Long Island to induce roseate terns to use the artificial shade provided by berry boxes turned on their sides. On Faikner's Island in Long Island Sound, the breeding success of roseate terns increased after old rubber tires were half-buried in the sand. Clearing massive amounts of vegetation from another island in the Sound, Great Gull Island, has worked wonders, opening up large areas for common tern nests. Stephen Kress of Cornell University's Laboratory of Ornithology and his co-workers successfully induced Arctic terns to recolonize certain islands in the Gulf of Maine. After eradicating herring gulls from these islands, Kress used taped courtship vocalizations and life-like models of Arctic terns in courtship display postures to attract this species. These same techniques have lured least terns to new sites along Long Island's Great South Bay, and they hold promise for use elsewhere.

Male and female black skimmers, with young. (Photo by A. A. Francesconi, National Audubon Society/PR)

Undesirable, inadvertent habitat management has been provided to gulls by the U.S. Army Corps of Engineers in New Jersey. Dredge spoil island construction practices have included the erection of dikes to contain spoil slurry. When dredging is completed, the dikes remain, and the islands are often flat or incompletely filled. These islands are rapidly invaded by reed grass, and gulls have been quick to follow. With more talk of herring gull control following a recent upsurge of bird-strike accidents at airports, it is ironic that public works dredging practices have added to the numbers of breeding gulls. Undiked islands, on the other hand, have proved a boon to terns and skimmers, in their early successional stages, and to herons and ibises later on.

Thousands of pairs of herons and ibises nest in the Stone Harbor Heronry (center), the last sizeable patch of maritime forest on this stretch of New Jersey coast. Tourists view the birds from observation platforms along the bayside boulevard. (Photo by authors)

Land Protection

Without doubt, the most direct way to protect colonial waterbirds is to purchase major breeding areas, including all rights and easements to the property. This has proven most effective at two important waterbird complexes in the Bight, Jamaica Bay Wildlife Refuge (part of Gateway National Recreation Area) in New York City, and Brigantine National Wildlife Refuge, with its splendid wilderness area protecting the last remaining ORV-free natural barrier island in New Jersey — and within sight of Atlantic City's casinos. Protection on a smaller scale has come with the town government's purchase of the remaining piece of maritime forest at Stone Harbor, New Jersey, site of the largest heronry in the state and a roadside tourist attraction for most of the year. Many colony sites and adjacent feeding areas get some protection from New York and New Jersey wetlands laws, and both states in the last few years began intensive efforts to locate and protect their major colonies. In New Jersey, the effort has been paid for by the recent passage of a non-game tax check-off. The state's income tax forms include a box that taxpayers can check if they want a portion of their taxes to help fund the management of birds other than game birds.

Also effective under certain conditions, particularly with herons, which tend to desert sites for many years, are certain alternatives to outright acquisition of the land. In these days of dwindling dollars, conservation easements should be considered, as should multiple-use arrangements whereby the landowner agrees to post "No Trespassing" signs around breeding sites or islands so long as they are occupied by birds, or only during certain times of the year. At other times, the same lands may be used for public recreational purposes such as hunting, fishing, and so forth, provided the resource is not physically impaired. Novel approaches must be developed to give tax benefits to individuals or corporations willing to provide such habitat protection. Another idea that has proved very effective is "adoption" of important sites by local natural history or conservation organizations, which then supply volunteer wardens to post, patrol, and maintain sites. Often just these simple kinds of caretaking will protect a colony through the breeding season. And under carefully controlled conditions, enormous educational benefits can be reaped by allowing the public to view active waterbird colonies (see *Guidelines for the Protection and Management of Colonially Nesting Waterbirds*, 1976, in reference section).

A diked spoil island in Great South Bay, Long Island, New York. (Photo by authors)

Our enumeration of the successful management efforts on the shores of the New York Bight must be qualified by the reminder that, although colonial waterbirds are numerous, they still have not nearly regained their former, pre-slaughter numbers. Their highly social breeding habits place them at greater risk than were they distributed throughout the region in a singular fashion.

The roseate tern is a good case in point: this species' total North American population is now down to about 2,000 pairs, probably 95 percent of which are concentrated in just *two* colonies, Bird Island off Marion, Massachusetts, and Great Gull Island. Our 1978 analysis of the North American population, which has been declining since the early 1930s, predicted extirpation of the species from North America in 20 years. Investigation by Ian Nisbet of the Massachusetts Audubon Society and his colleagues revealed no productivity or food-gathering problems for roseate terns. Rather it seemed that mortality from a number of causes, perhaps including human predation, on their South American wintering grounds was the culprit. While the rate of decrease seems to have slowed since 1978, it remains to be seen if the long-term trend will be halted in time. Catastrophe has but to strike one of the two remaining colonies, and this species would even more quickly disappear from North America.

The situation is less critical for the other birds along the Bight, but the principle is the same. Moreover, some groups of birds move their colonies with unexpected frequency. It is not uncommon to find that half of their colony sites have been abandoned and new ones established each year. This movement is apparently not pathological, so if we were to manage properly for these animals, we would have an adequate number of suitably protected but vacant colony sites available for them. To accomplish that, we need to know what features render sites suitable or unsuitable, and if needed, manage for those features. In addition, we need regular aerial surveying and censusing to measure the frequency with which sites are used, abandoned, or reoccupied, thereby enabling us to calculate the number of reserve breeding sites that are necessary. Otherwise, even the most carefully crafted management practices may be ineffective. Regrettably, we are a long way from having such a comprehensive overview, although we are perhaps closer to it on Long Island than anywhere else.

Conclusions

We have only touched on the subject of colonially breeding waterbirds and the pressures they face in the urban northeastern United States. Nonetheless, we offer some firm conclusions and recommendations:

- The numbers of marine-dependent waterbirds breeding along the New York Bight are impressive indeed. Most of their populations are in reasonably good health, the roseate tern being a conspicuous exception.
- When compared to their counterparts in more natural, less-manipulated areas, New York Bight waterbirds are nesting to a possibly alarming degree on spoil islands, in marshes, or at otherwise unusual sites. Many of these sites are in short supply when one considers such requisites as freedom from predators and proximity to food. Programmed management of the appropriate substrate and stage of plant succession is essential, because of these animals' species–specific requirements.
- The New York Bight has the potential for enormous, still-to-come pollution. Because of the potential for biomagnification in these top-of-the-food-chain predators, they need to be monitored for contaminants on a regular basis for the foreseeable future.
- If we are to protect these animals and their sites, we need to know where they are, and in what numbers. We need to look for them in places where they are not usually expected so we can provide alternate breeding sites for them to move to when needed. This means regular, intensive surveying and censusing, by experienced personnel and certainly by air.
- We need to develop alternatives to outright purchase of land for sanctuaries. However, we also need to identify those "seed colonies" that serve year after year as recruitment centers for regions and subregions, and give them extra protection by permanent acquisition.
- We need to pay more attention to what happens to our migrating waterbirds when they leave our domain, in which, after all, they spend less than half of each year. The lesson of the roseate tern is an especially poignant one. If we need stronger international treaties, protocols, and conventions to enforce the protection of certain species, then negotiations for them should be given high priority.
- We need to consider the future, to imagine threats to these animals that are as yet unrealized, and plan for them before they become crises. In this category would fall the planned sand-launce-for-fishmeal fishery that could, if overworked, deprive terns of their main food source. Other possible hazards include the re-release of DDT, PCBs, and other pollutants that are now buried on land or under water; the eventual leaching of contaminants from the mountainous tideland garbage dumps that characterize the New York City area; and even new recreational fads such as the relatively inexpensive two-man Hovercrafts that are now disturbing birds in the Netherlands' wetlands.
- Last but not least, we need to tell people about these animals, and the ways we can learn to live with them, even within sight of the Empire State Building, with Concorde thundering in our ears.

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For the Gullible

A young marine biologist has developed a diet that keeps porpoises alive almost indefinitely. The vital ingredient is seagulls. Returning to his lab one day with a bag of them, he found a lion asleep on the doorstep. He stepped over the beast, only to be arrested and charged with transporting gulls across a staid lion for immortal porpoises.

Brown Pelicans – *Can They Survive?*

by James O. Keith

The appearance of a bird reflects little more than the external adaptations that help it to survive. Often beauty is a by-product of this evolutionary process. In other cases, nature has produced some rather bizarre creatures; the brown pelican, *Pelecanus occidentalis*, is a good example of such a bird. Its long neck and bill contrast sharply with its heavy body, short tail, and short legs to create a most unorthodox and ungainly creature. In appearance, such a bird does not seem to be one of nature's successes. But the old adage that looks can be deceiving is certainly true for the pelican.

Success in living organisms is gauged by the ability to survive. Pelicans are winners; their ancestry dates back to the early Miocene Epoch, 15 to 22.5 million years ago. Their survival is clear testimony to the utility of their form for the lives they lead. So, while pelicans have an appearance that seems strange to us, they function quite efficiently. This becomes evident as they fly in graceful formations or plunge from heights in their fishing dives. The brown pelican is one of the birds best known and appreciated by humans.

A bit of luck was also involved in the success of pelicans. Pelicans evolved to feed on schools of small fishes at the ocean's surface. These fishes also have been successful, and their survival has ensured that of pelicans. Species usually become extinct because they overspecialize and fail to adapt to changing environments, but the coastal marine environment has been a rather stable one. It is ironic, therefore, that just within the last several decades the ancient pelican has become threatened. The ocean and the fishes are still there, but things are different now due to the activities of man.

Problems

Pelicans are so specialized in feeding that they are capable of taking fish only at certain times and in specific ways. Commercial fishing is disrupting natural conditions, and this is interfering with the pelican feeding process. Over much of their range, pelicans are having problems getting enough food to produce a sufficient number of young.

Brown pelicans have other problems, too. As with most life on earth, pelicans have not evolved mechanisms to adequately detoxify the synthetic chemicals with which man is polluting the earth. Pelicans are especially vulnerable to certain insecticides. One of these, endrin, was most likely responsible for the demise of the Gulf Coast population of more than 50,000 pelicans. By 1962, the birds had disappeared from Louisiana, and only a remnant population remained in Texas. In 1968, conservation agencies began cooperative efforts to re-establish pelicans in Louisiana. Each year young pelicans were transported from Florida and released. By 1975, after considerable effort, a population of about 465 birds was established, and adults were producing young. But that year, 300 of the pelicans died. Birds analyzed contained residues of seven

Brown pelicans gather at a nesting area. (Photo by Allan Cruickshank, PR) chlorinated hydrocarbons, but levels of endrin alone were high enough to have caused the deaths.

The coastal environments of pelicans are being polluted throughout most of their range. Threats exist to pelicans, but usually effects are not discovered until after disasters have occurred. Although North American pelican populations have been severely damaged by insecticides, stricter regulation of insecticide use is possible. Regulatory agencies act slowly, however, and pelicans will be threatened by these chemicals for many years in the future.

Brown pelicans are found only in the Western Hemisphere. On the Pacific Coast their range extends from California south to Chile. There also is a resident population in the Galápagos Islands. Brown pelicans also live along the Atlantic and Gulf Coasts, throughout the Caribbean, and along the coasts of Central and South America to Guyana. A warm-weather species, the brown pelican thrives near coasts and islands in areas of cold water upwellings and at the mouths of large rivers. These waters are laden with organic nutrients that nourish food chains for the birds. Brown pelicans are not really seabirds. They must return to roost on land each night, as they cannot withstand setting in cold water.

The majority of brown pelicans follow the tradition of the species in feeding on fishes at sea. Some pelicans, especially young birds,

opportunistically feed on fish wastes at wharves and behind fishing boats, but these habits greatly reduce their chances of survival. Fish wastes are available only during seasons of commercial harvest. As most of these "scavenger" pelicans never learn to feed in their natural way, many die of starvation.

Experience helps pelicans feed successfully at sea, but an element of chance is also involved. Pelicans can learn to locate schools of fish, but whole schools are seldom available to them. Though their dives are impressive, pelicans can capture fish only to a depth of about 1 meter. Schools usually remain below this depth, and another factor is needed to push the fish nearer the surface. Other marine predators, such as dolphins and predatory fishes, attack schools from beneath, driving them to the surface where they become available to pelicans. This phenomenon is called a "pile-up."

The incidence and duration of pile-ups are critical factors for pelicans. In a given area, food availability depends not only on the size, number, and distribution of fish schools but also on the degree of pressure put on those schools by marine predators. Such conditions are modified each season by changes in the strength and direction of major ocean currents.

Pelicans generally move between areas where food resources are seasonally abundant. However, changes in currents, such as the Humboldt Current along the coast of Peru, are sometimes so extreme that brown pelicans cannot locate food, and they starve by the thousands. The birds usually flourish on the tremendous quantities of anchoveta in that current, but when the El Niño phenomenon (see *Oceanus*, Vol. 23, No. 2, pp. 9-17) stops the upwelling of cold, nutrient-rich waters, the fishery fails, and the birds do not have other options for feeding.

Breeding Behavior

Adult pelicans breed in areas and at times that have the highest probability of providing food resources to support reproduction. But there are no guarantees, and periodically food sources either do not develop sufficiently or decline during the nesting season. Such incidents can occur naturally. In the Gulf of California in 1973, conditions were clearly different from earlier and later years. Schooling fishes and their marine predators were scarce. Some birds attempted to breed, but most soon deserted their eggs and left to seek better feeding grounds.

To maintain population levels, reproduction must result in enough young birds entering the breeding population to replace adults lost through mortality. In other words, each adult must replace itself during its life span. Adult pelicans breed annually for eight to ten years. A pair can produce eight to ten young in a lifetime, but the death rate for young birds is high. Only about 20 percent of young survive to breed. Pelicans have been a successful species, but examination of their present population

Brown pelican diving for fish in Monterey Bay, California. (Photo by Al Lowry, PR) trends suggests that present-day birthrates will not maintain their abundance.

Reproduction in pelicans is an interesting and spectacular affair. Plumage and other breeding characteristics, such as the brilliant red pouches in the California brown pelican, show that birds are ready to breed for several months before colonies form. As the anticipated food supplies develop in breeding areas, adults must receive some environmental cues that trigger their gradual movement to traditional colonies, which have been practically deserted since the last breeding season.

Brown pelicans nest on islands and in estuaries. Most islands used for nesting in the Gulf of California are barren or covered only with scattered bushes. Apparently pelicans prefer to nest above ground, as they build bulky stick nests in all available bushes on islands and use mangroves to support similar nests in bays and estuaries. Most island nests, however, are on the ground and consist of vegetation, small sticks, bones, and feathers.

At colonies in the Gulf of California, brown pelicans gradually arrive in small flocks and gather along the shorelines of the islands. Groups of males occupy the canyons, ridges, and flats used for nesting and begin efforts to attract mates. While standing low with slightly spread wings, each male sweeps his extended head and bill in a horizontal, figure-eight motion. This display flashes the vivid red pouch to females in every direction. The males frequently lunge toward each other with their wings flared and their necks and bills extended. This aggressive feint is often followed by a display of what is called pelican posture, in which a standing bird arches its neck and points the tip of its bill between its feet while slowly twitching its half-opened wings.

Females fly into the colony and move demurely among the males. Males show little discrimination between females, always increasing their rate of display when one approaches. The female finally makes a choice and joins a male at his site. The male then proceeds to attack the female with his bill. If the female accepts this display of dominance, a pair bond begins. Sometimes a male is too vigorous in his attack, and the female will retreat and fly off; then both again try, but with other birds.

Each pair interacts for several days while moving about the nesting area. A bird will frequently display pelican posture and rub its head and neck against its partner. Mates join each other in lunging at other pairs, and both repel intrusions by other males. Copulation occurs during this courtship period and continues into the egg-laying period.

Grace and Affection

A nest site is finally selected, and a nest is built over a period of three or four days. Males fly out, gather nest material, and return to the nest, making 20 or more of these forays each day. As the completed nest contains little material, much of this behavior is ritualistic rather than functional. The nest material is presented to the female in a graceful display, and she carefully places it along the edge of the nest, in which she is setting. Three eggs are usually laid. Incubation, which takes about 30 days, begins with the first egg. The red pouches in both sexes change during egg-laying to a bright yellow. The yellow pouch fades during incubation to a dark gray, and stays that color until the next breeding season approaches.

Neither bird leaves the island to feed during courtship, nest-building, or egg-laying. Females depend on stores of lipids and nutrients to produce eggs. After the clutch is complete, the sexes take turns incubating, with spells of two days or so. If food is readily available, mates often return and stay at nests for some time before relieving their partners. Displays at nest exchange are usually graceful and appear to be steeped in recognition and affection.

Adults in colonies often travel more than 50 miles to feed. They leave the colony along the routes of returning birds. The direction from which birds return from feeding is an important cue to departing birds, as it indicates the location of food sources. All too frequently, the number of returning birds diminishes; birds at sea do not return until they have fed successfully.

Opportunities for pile-up feeding, in which almost every bird captures fish with each dive, seem essential to sustain reproduction. Most pile-ups are of short duration, lasting from 5 to 15 minutes. But when a large group of marine predators finds a large school of fish they will work the school until they are satiated. Such a pile-up may last eight hours or more, attracting thousands of birds of several species. Boobies and pelicans dive into the water from above, while cormorants pursue fish underwater. Gulls, terns, and shearwaters join the pile-up to feed on the remains of partially eaten fish.

If its mate is gone for more than five days or so, the bird on the nest will finally leave to feed. This desertion terminates the nesting attempt. Avian predators, such as western gulls and ravens, immediately take unattended eggs and small young.

Adult pelicans will not jeopardize their chance of survival by persisting with an attempt to reproduce. Their reproductive strategy is to continue with nesting as long as food is available, but to cease efforts if food becomes scarce. Over their breeding lives, they have many years to replace themselves in the population, if they ensure their own survival. This strategy provides the greatest success, given their variable and unpredictable food supplies.

As hatching approaches, nest exchange becomes more frequent. Often both mates are at the nest, especially when young become vocal within the eggs. Eggs and hatchlings are so closely brooded that it is difficult to observe events closely at hatching. However, several days after hatching is completed, most nests contain only two young. It would appear that most pelicans can rear only two young at most. The third egg may be only a form of insurance, a replacement in case either of the first two embryos or hatchlings dies. Still, some cue must stimulate adults to discard the last young, as some parents rear all three hatchlings. Long-term productivity in a normal colony averages about one young per nest per year.

Young are brooded constantly for several weeks after hatching, but thereafter are left alone at nests while adults forage for the ever-increasing amount of food needed by their growing young. Young pelicans have the ability to survive two weeks or more without food. During periods of food scarcity their rate of growth decreases and they use energy reserves for maintenance.

Abandoned

Young fledge at between 12 and 13 weeks of age. They appear hesitant to make their first flights from the uplands of islands, but it becomes a matter of urgency, as their parents abandon them just before they fledge. At fledging, young normally are heavy with energy reserves that sustain them during their first weeks of independence. At this time, fish resources around the colony are waning. The young must quickly learn to fend for themselves. Starvation is the main cause of death during the first year.

Adult and young pelicans disperse from colonies to seek areas where they can feed satisfactorily. Alone or in small groups, they sometimes feed near shorelines, where they either dive on individual fish or pursue small schools with short, low flights and oblique thrusts into the water. This feeding behavior is not very successful — only about 30 percent of all thrusts and dives result in the capture of a fish. Still, nonbreeding birds without duties at colonies have the time for this sort of feeding.

Poor Reproductive Success

Along the Pacific Coast and in the Gulf of California, pelicans have not produced adequate numbers of young for at least 15 years. Several factors are responsible for poor reproductive success, and these factors interact with each other to cause a variety of debilities.

Brown pelican feeding young at Pelican Island National Wildlife Refuge, Florida. (Photo by Jen and Des Bartlett, PR)

During the 1960s and early 1970s, California brown pelicans received, through the fish they ate, severe exposure to residue from the pesticide DDT (dichloro-diphenyl-trichloro-ethane). The primary source of this exposure was a DDT manufacturing plant in the Los Angeles area. Female pelicans laid eggs with very thin shells. These eggs were too fragile to withstand incubation, and most collapsed shortly after being laid. Very few young were produced at colonies along the coasts of California and Mexico during this period.

Many pelicans that nest in the Gulf of California migrate in autumn to the coast of California, and all of these birds accumulated DDT residues as well — some had levels as high as pelicans living in California year-round. Collapsed eggs were evident in colonies in the Gulf of California, and the average clutch of eggs incubated to hatching was smaller than normal. Also, breeding success was very low in certain years due to massive desertion of eggs and young during periods of food shortage. Success in these colonies was being influenced concurrently by both DDT and food stress.

In 1972, the source of DDT contamination in California was eliminated. During the next several years, residues in pelicans decreased and eggshells increased in thickness. Many more eggs survived incubation and ultimately hatched in Pacific Coast colonies. However, higher-than-normal rates of nest desertion (resulting in starvation of young) became evident in those colonies. As in Mexico, nesting failure occurred during periods of food shortage, but the birds still carried residues of DDT.

Food shortages are common in the lives of breeding pelicans. But pelicans in California and Mexico were showing severe effects of food stress. It seemed either that fish were unusually scarce, perhaps due to an increase in the commercial harvest, or that DDT residues were aggravating the effects of food stress. Research was begun to see if the residues in birds increased the effects of food restrictions on reproductive success. The results were very convincing. For example, in birds without DDT residues, a 10-percent reduction in food was sufficient to keep 50 percent of the experimental population from even attempting to breed. However, the effect of food stress was greatly accentuated in birds with residues: the same 10-percent food reduction kept all pairs from breeding. In trials where food was restricted during incubation, birds with DDT residues deserted nests at twice the rate as birds without residues. This experimental work was conducted with ringdoves, but it suggests a similar pattern in brown pelicans, for which DDT residues continue to be a factor in the Pacific Coast environment. Periodic food shortages continue, but as their magnitude is difficult to measure, it is not certain whether they are increasing in intensity and frequency.

If the commerical fish harvest is regulated properly, it will decrease neither the annual biomass of fish nor the potential food supply for pelicans.

However, throughout the world, exploitation of fishery resources has too often occurred without the constraints of quotas or other harvest restrictions. Data necessary for effective management seldom exist. Even with technical information, harvest is often dictated more by economic necessities than by biological principles. In many areas, harvests seriously threaten populations of pelicans and other marine birds.

A more immediate threat to pelicans in many areas is the actual mechanics of commercial fishing. Pelicans and commercial fishermen seek the same concentrations of schooling fishes. They both are most successful when the fish are at the ocean surface. It seems likely that the fishing activities of boats could disrupt the normal schooling habits and vertical distribution of fishes in the ocean. This disturbance could influence the frequency of pile-ups and decrease the availability of fish to pelicans.

Nonbreeding pelicans probably are not seriously influenced by commercial fishing activities. Given the freedom to move and search out pile-ups, pelicans can probably outfish the fishermen. Breeding pelicans, in contrast, have a limited foraging range, and time spent in seeking food is a critical element in their nesting process. Thus, the most effective way to eliminate the adverse effects of commercial fishing activities is to close waters within the foraging range of colonies to commercial fishing during the pelican breeding season.

The continued existence of pelicans demands that humans modify several of their activities. Pollution of marine environments must decrease, which means more strict regulations must be promulgated and enforced. Of equal importance is the need for more information on how changes in harvest quotas and fishing methods influence pelicans. Unless the needs of pelicans are more carefully considered, this species, which has been so successful for so long, may disappear in a relatively short period of time.

James O. Keith is a Research Biologist with the U.S. Fish and Wildlife Service. For the last 12 years, he has been involved with research on the California brown pelican in the Gulf of California. He is presently working in Haiti.

Suggested Reading

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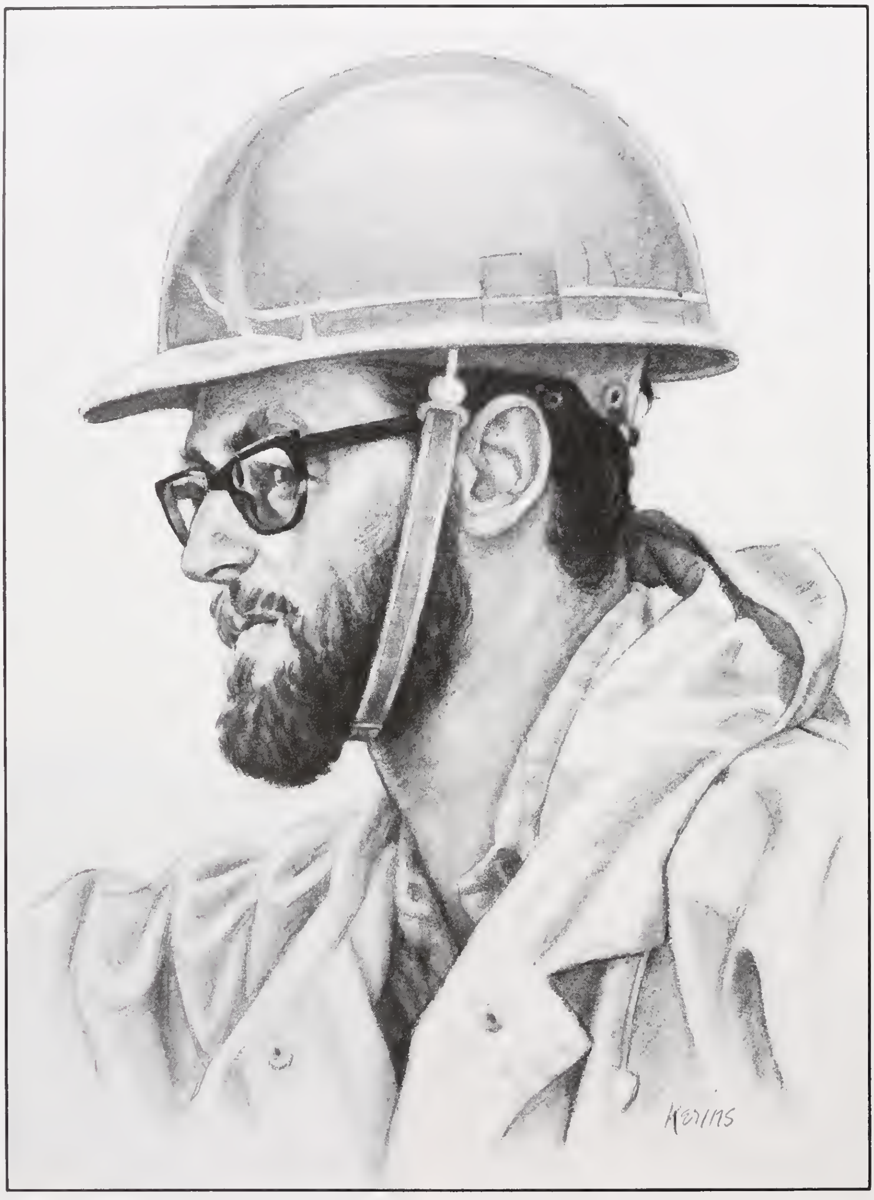
profile John W. Farrington



Portrait by Charles Kerins

Marine Geochemist

by William H. MacLeish

Gas chromatography–mass spectrometry is not a term to be bandied about. Not, that is, unless you happen to be in a science center like the village of Woods Hole, Massachusetts, where some people think nothing at all of saying it out loud several times a day. I have always had difficulty in pronouncing the words when sober, probably because I have always had difficulty conceiving of a process that to my lay mind combines the disparate magics of alchemy and cybernetics. But a half-hour spent recently in the company of a courteous and intense marine geochemist named John W. Farrington eased both tongue and understanding.

Consider yourself in an emergency room, Farrington said, giving me that slightly monkish look the true scientist reserves for the Other. If someone were wheeled in with a drug overdose, doctors would initiate a procedure something like what we do here to find out what the drug is, how much is in the victim, and how long it has been there. Farrington maneuvered me past transparent bubblings to a machine slowly spilling a roll of paper on the floor.

What happens, Farrington told me, is that components of what are often extremely complex compounds are identified by the nature of their passage through a glass tube containing silica coated with a chemical film. The identities appear as groups of spikes and peaks on the moving paper, the chromatogram (gas chromatography got its name from its initial usage — the separation of pigments). If further identification is needed, the mass spectrometer comes into play. The spectrometer bombards the chemical components with high-energy electrons. Specific chemical substances react in different ways to the bombardment, fragmenting into different particles. These performances are then matched against mass spectrometer analyses of known substances. "Then," Farrington said, "the computer gives you its best estimate of what the compound is you're looking at."

Farrington, 39, is a Senior Scientist at the Woods Hole Oceanographic Institution and Director of the Oceanographic's new Coastal Research Center. For more than a decade, he has spent a great deal of time looking at the confusion of peaks and spikes left as a signature on the chromatogram by one of the most complex substances in nature: oil. So skilled has he become in his analyses and in the broader business of studying what happens to petroleum hydrocarbons in the marine environment — rates and fates, he calls it — that he is constantly being sought out by politicians, bureaucrats, businessmen, environmentalists, and others caught up in this most emotional of marine issues. When the National Academy of Sciences decided to update its 1975 report on oil in the sea in a study to be released this fall, Farrington was named to the project's small steering committee.

Howard Sanders, a fellow scientist at the Oceanographic and a veteran of the oil-and-ocean wars, says that Farrington has two characteristics essential for a scientist involved in marine environmental work. "He demands quality first and always, and he speaks out. He fills the shoes of the man he came here to work with, Max Blumer. Max had a strong social feeling. He was a scientist first, but because he was being paid out of public funds, he felt he had a duty to inform the taxpayers of his findings. John's the same way."

"I went to a small local college that I could afford, working part-time, and I must admit that my grades were terrible and my interest in science zero."

Blumer died in 1977. Long-time readers of this magazine may remember an editorial (Fall, 1975) in which Blumer was quoted as saying that we were ignoring our ignorance of oil and its effects. He said that biological effects of chemicals are related to their fine structures in a way not yet fully understood and that petroleum is such a soup that "even the best combinations of analytical techniques, providing the highest degree of resolution, have not separated any crude oil into individual components. . . We must remain cautious in adopting tolerance levels as long as our analyses are so incomplete."

Blumer's successor now feels somewhat differently about the situation. First, Farrington feels, a great deal has been learned about rates and fates — about the pathways oil follows in sea and sediment and about the processes of its eventual degradation. "I think it's a good thing to recognize, as Max did, the complexities of nature and the limits to our knowledge. But we shouldn't get hung up on it so that our hands are tied. Neither should we cast our environmental decisions in concrete. There is an environmental equivalent to the Heisenberg uncertainty principle in physics, which is that the subject of our study is dynamic, changing continuously. So is our knowledge, imperfect as it is and must be, and decisions must change with it."

Farrington and his wife Shirley were both born in 1944 in the fishing port of New Bedford, across Buzzards Bay from Woods Hole. He roamed the docks near his uncle's sheet-metal shop, but a marine career wasn't part of his early plans. He received an appointment to the Coast Guard Academy, but a football knee ended that idea. "I went to a small local college that I could afford, working part-time," he says, "and I must admit that my grades were terrible and my interest in science zero." Jobs in textile chemistry were available nearby, and in turning in that direction, Farrington met a catalyst, a professor of physical chemistry who gave him the challenges he needed. He was accepted at the University of Rhode Island's Graduate School of Oceanography and went to work under a young scientist named James Quinn. "I was very much intrigued by his enthusiasm," Farrington remembers. "Quinn said 'I don't know a doggone thing about the ocean; maybe we can learn something about it together.' " They did.

Farrington and hydrocarbons got together when he was doing research for his thesis on sewage dispersion in Narragansett Bay. When it came to measuring and identifying his substances, he got blobs instead of peaks on the chromatogram. "In the beginning," he says, "that was attributed to my not knowing how to operate the machine properly." When he came across some papers describing chromatograms of weathered oil that also looked like blobs, he went over to Woods Hole to get Max Blumer's opinion — and ended up coming to work for Blumer as a post-doctoral investigator in 1971.

No single crude oil has yet been fully analyzed, down to the last of its tens of thousands of components. But Farrington and other workers in academe, industry, and government are piecing together its behavior in the ocean. "We now have tremendous insights into new constants, physical-chemical constants, and parameters to put into modelling equations about air-sea exchange, particle-solution interactions, sediment-water interactions, and what this means in terms of chemical structures." Insight has been gained into the problems of photochemistry, processes by which light can alter — and sometimes intensify the toxicity of — certain petroleum hydrocarbons.

Farrington feels that oil exploration and production can often proceed in relative safety, provided adequate monitoring and safeguards are in place.

Farrington himself was involved in field work — in the noisome effluent from the blow-out of the IXTOC–1 well in the Gulf of Mexico — which showed that under some conditions, highly toxic aromatics can be transported long distances inside rafts of oil-water emulsion called mousse. That same cruise also produced evidence that although bacteria can and do degrade oil they cannot do so effectively when certain nutrients are in short supply. On shore, he has worked with scientists who have demonstrated, with large tanks containing seawater, sediment, and benthic organisms, that — contrary to prevailing opinion — even extremely low levels of oil can, over a period of months, eventually get into sediments.

Farrington is not the type to get upset "every time a couple of polychaetes roll over and die." He feels that oil exploration and production can often proceed in relative safety, provided adequate monitoring and safeguards are in place. What interests him is more specificity and less generalization in addressing such problems. Some crude oils look remarkably like fuel oils, others don't. Oil pumped from a given well can change in composition during the course of a given day. To overlook these variables can be dangerous to sound policymaking. As another example, a good deal of public attention has been focused on aromatic components of oil, some of which are known carcinogens. But there are aromatics and aromatics. Those of low molecular weight tend to be evanescent. Those of heavier molecular weight are apt to be less toxic but more persistent. Which does more environmental damage? "It depends," Farrington says, "on whether your concern is for larvae, fish, a long-lived marine animal like a whale, or transfer back to man."

Equanimity is not always his strong suit, particularly when he senses that facts are being distorted or that freedom of research is being unnecessarily trammeled. When that happens, his face reddens and caution goes into his back pocket. A few years ago, he went before a Congressional committee and tore into federal requests for proposals "with ill-defined objectives and responded to by incompetent or marginally competent environmental research companies who are designated as competent by 'authorized contract officers' who would not recognize a hydrowinch on a research vessel if they fell over it. If the research scientists in the academic, government, and competent industry laboratories could receive more adequate funding of proposals that they propose and carry out, then we could make much quicker progress toward solving some of the pressing marine environmental problems."

Poor science, Farrington believes, is responsible for much of the confusion about marine pollution. As things stand, a determined reader can find references in the literature that will support arguments that the seas are dying or in good health.

"I kept hearing: 'We're drowning in data; if we only had more time to synthesize, to see the thing more in its totality.' "

As far as oil spill research is concerned, too much is done under emergency conditions. When a spill occurs, scientists, funding agencies, and others work around the clock to find a ship, load it with something approaching the right mix of men and equipment, and get it out to the scene of the accident. How much better to plan and stage a carefully controlled spill and study it with the proper rigor. The Canadians are doing just that, looking not only at petroleum but at substances used to disperse it at sea. Farrington thinks it would be difficult to do that kind of work in this country, environmental passions being what they are. In its absence, he favors continued use of controlled ecosystems, such as the one at the University of Rhode Island's Marine Environment Research Laboratory.

In time, experiments around the world, in the field and the laboratory, may well make environmental forecasting possible. Farrington thinks that fine gradations of man's environmental effects may escape our notice. Assessments of major damage to, say, a fishery over a period of 10 years or so, may not be far off. But he worries that such forecasts may not be given proper weight, particularly if decision-makers continue to rely heavily on economic forecasting. Why, Farrington wonders, do so-called solid economic arguments win out so often over scientific assessments of risk — especially when inflation and recession demonstrate how solid those arguments really are? The face reddens. "This is a ridiculous situation." For John Farrington, "ridiculous" is an expletive, one he rarely deletes when his dander is up.

A number of scientists investigating marine pollution are reaching the conclusion that perhaps too much attention is being given to oil in the sea, important as it is. Farrington is one. He told me that, though there was a suspicion that benthic organisms were impacted by IXTOC oil, it was impossible to sort out cause from cause — particularly since three hurricanes came tearing through the research area. Now, he says, everything has to be floating belly-up in order to prove a point in pollution. "What you ought to be able to do is go out to an area that has low nutrients, maybe some chlorinated hydrocarbons or petrochemicals from a plant on shore, maybe a little bit of oil from offshore drilling, and say what the net result is going to be. You're not going to be able to do that by studying oil all by itself."

That urge to broaden scope, to work out on the frontiers where physical and chemical and biological shade together, is one reason why the Woods Hole Oceanographic chose to announce on its 50th birthday three years ago that it was establishing a Coastal Research Center. The concept is rather novel, even in a place where the sound of physicists and chemists and biologists explaining things to each other is only slightly less often heard than the crying of the gulls. The Center employs only three people full-time. Scientists use it as a think-tank and as a base for joint experiments in coastal waters. It is more of a clubhouse than an office, a place of commonalities to be discovered and pursued, a place where men and women can step away from the exigencies of their disciplinary work and draw an interdisciplinary breath.

One major undertaking at the Center is an encyclopedic study of nearby Georges Bank, an unusually rich fishing ground that is being explored for gas and oil. The findings, edited by Oceanographic biologist Richard Backus, are scheduled to be published by the MIT Press, probably early next year. "We came to realize that people were spinning their wheels out there," Farrington says. "Scientists were being driven from pillar to post: preparing material for the environmental impact statements needed for the drilling; preparing material for one fisheries management plan after another, as required by the Fishery Conservation and Management Act; and preparing materials for the U.S.–Canadian dispute over Georges that is now at the World Court. I kept hearing: 'We're drowning in data; if we only had more time to synthesize, to see the thing more in its totality.' " The Center is providing the time, and the result — judging from early drafts of some papers — should more than justify that provision.

Farrington himself works half-time at the Center and half-time as a Senior Scientist in the Chemistry Department — and, it seems, another half serving on international committees and speaking at workshops on marine pollution. His own research is a reflection of the principle by which he runs the Coastal Research Center. Petroleum in the marine environment takes about half that time, depending on the year.

For the rest, he says, "if you really want to understand what's happening to the biogeochemistry of pollutant compounds in the environment, you have to be cognizant also of what's going on with naturally occurring compounds. And, to turn it around, you can use some of the man-introduced compounds to be tracers of biogeochemical processes that will tell you how the natural system works. I've tried to maintain that balance ever since I've been here."

William H. MacLeish is a former Editor of Oceanus. He is now writing a book about Georges Bank and serving the magazine as Consultant.

Oil and Gas Group Attacks Marine Sanctuary Program

The National Marine Sanctuary Program is presently engaged in a legal action with the Western Oil and Gas Association that questions the validity of the entire system. At present, there are six designated preserves and ten officially proposed ones. There are no oil operations in any of them, although such activities are not precluded.

The suit, brought under the National Environmental Policy Act and filed in Federal District Court in Los Angeles on September 28, 1982, specifically asks the federal court to nullify the Channel Islands National Marine Sanctuary off Santa Barbara so that further oil and gas operations can commence. The defendants are the Department of Commerce and its National Oceanic and Atmospheric Administration (NOAA), which runs the sanctuary program. The action states that in the view of the oil and gas group there was no adequate assessment of the prospective impact of oil operations on environmental values, nor of a drilling ban on the national energy supply. The suit also charges that the Final Environmental Impact Statement on the sanctuary was inadequate because it made no mention of the cumulative impacts of the Marine Sanctuary Program as a whole.

In late December, 1982, the Department of Justice filed a formal response to the suit in which it denied most of the charges brought by the oil and gas association. However, the Department of Justice acknowledged that the environmental impact statement for the sanctuary "contained no detailed assessment of the nationwide impacts of the marine sanctuary program." Further litigation in the suit is expected this spring and summer.

The Western Oil and Gas Association (WOGA) describes itself as a trade association whose members conduct more than 90 percent of the producing, refining, transportation, and marketing of petroleum and petroleum products in the

Marine Sanctuary System

western United States. WOGA maintains that nearly all of the companies that explore for and produce oil on the Outer Continental Shelf of the Pacific Coast are members of the association.

The "Complaint for Declaratory Relief" by WOGA alleges that the Commerce Department's and NOAA's actions in establishing the sanctuary were "inconsistent with statutory authority, arbitrary and capricious, and an abuse of discretion." It states that the sanctuary set a precedent of establishing "excessively large areas of the ocean as marine sanctuaries and prohibiting oil and gas operations therein. On January 26, 1981, regulations prohibiting oil and gas activities on new leases within the newly-created Point Reyes–Farallon Islands National Marine Sanctuary, also offshore California, were issued. Currently, there are seven additional sites offshore California which are being considered as marine sanctuaries. Numerous additional sites have been proposed nationwide. As much as 40 percent of the oil and gas resources of the United States is located in the Outer Continental Shelf.

"The Marine Sanctuary Program "the complaint continues," may ultimately result in a major reduction of the U.S. domestic oil output and a consequent equivalent increase in the use of coal, nuclear, or other sources, but in all probability, chiefly coal. This will likely result in an increase in sulfur dioxide and atmospheric particulate levels in most of the larger cities of the United States. Increased imports will bring an increased risk of oil spills of refined petroleum products by tankers. There will be other adverse environmental consequences which have not been considered."

In a separate action, the Union Oil Company of California has appealed a decision by the California Coastal Commission that in effect bars Union Oil from drilling two wells on old leases that fall within the Channel Islands Sanctuary. The notice of appeal was sent to the Commerce Department on December 16, 1982.

Some Background

The National Marine Sanctuary Program was established in 1972 under the Marine Protection, Research and Sanctuaries Act of that year. In 1975, two sanctuaries were designated — the site of the sunken *U.S.S. Monitor* off the coast of North Carolina, and a portion of the Florida reef tract off Key Largo, Florida. By January 1981, an additional four sites had been added (see map).

The stated mission of the program is "the establishment of a system of national marine sanctuaries based on the identification, designation, and comprehensive management of special marine areas for the long-term benefit and enjoyment of the public." The goals are to:

1) Enhance resource protection through the implementation of a comprehensive, long-term management plan tailored to the specific resources;
2) Promote and coordinate research to expand scientific knowledge of significant marine resources and improve management decision-making;
3) Enhance public awareness, understanding, and wise use of the marine environment through public interpretive and recreational programs; and
4) Provide for optimum compatible public and private use of special marine areas.

The sizes of the sanctuaries vary. In general, the smallest area possible is said to be designated in relation to management objectives. For example, existing sanctuaries range from the 1-mile diameter *U.S.S. Monitor* site to the 1,252-square-nautical-mile Channel Islands Sanctuary, which is probably the upper size limit for future sites.

The Marine Sanctuary Program is presently funded at $2.23 million. Each preserve has an on-site manager. The sanctuaries themselves may reach as far seaward as the outer edge of the continental shelf, in coastal waters where the tide ebbs and flows, or be in the Great Lakes and their connecting waters. Public participation in the program's site selection and evaluation process is encouraged.

In a recent reorganization of the National Oceanic and Atmospheric Administration, the Marine Sanctuary Program now falls under the Sanctuary Programs Division of the Office of Ocean and Coastal Resource Management within NOAA's National Ocean Service. NOAA is presently revising its procedures for identifying and selecting potential sanctuaries. Meanwhile, two House subcommittees — one on Oceanography and the other on Fisheries and Wildlife Conservation and the Environment — held a joint hearing in late February on reauthorization of the program, which is scheduled for legislative action later this year.

The sanctuary program developed in the 1970s along with a number of federal initiatives to protect the marine environment. For example, the use of the marine environment for disposal of industrial and municipal wastes led to the enactment of certain sections of the Clean Water Act and to the Ocean Dumping Act. Other pressures on the marine environment led to the Fishery Conservation and Management Act, as well as to amendments to the Outer Continental Shelf Lands Act (to control oil and gas development). Deepwater ports, liquified natural gas terminals, and plans for floating nuclear power plants led to legislation such as the Deepwater Ports Act and the coastal energy impact provisions of the Coastal Zone Management Act. Other ocean issues, such as thermal energy and mineral development, led to laws covering ocean thermal energy conversion (OTEC) activities and deep seabed mining.

The Sanctuary Program Development Plan issued by NOAA specifically states, however, that "while the Act and its legislative history clearly indicate that the Program was designed to protect significant marine areas, it is not intended to prohibit all uses, but rather to protect the recognized values of the site and emphasize compatible human uses."

In commenting in 1971 on Title III of the proposed Marine Protection, Research and Sanctuaries Act, Congressman Hastings Keith, Republican of Massachusetts, stated: "It provides a balanced even-handed means of prohibiting the resolution of one problem at the expense of the other. It guards against 'ecology for the sake of ecology.' It also guards against the cynical philosophy that the need for oil is so compelling that it justifies the destruction of our environment."

The Sanctuaries

The **Channel Islands Sanctuary** provides refuge for more than 80 species of resident and migratory seabirds, as well as pupping grounds for five species of seals and sea lions. In addition, the waters of the sanctuary encompass about 40 percent of all kelp beds in the Southern California Bight. And the area is a significant fishery resource, supporting some 200 or more species of fish, or 44 percent of all species known to occur in all southern California waters.

The sanctuary, which was designated in 1980 by President Carter, consists of waters 6 nautical miles wide (11.1 kilometers) around San Miguel, Santa Rosa, Santa Cruz, Anacapa and Santa Barbara Islands. The distance from the islands to the mainland is approximately 25 miles (40 kilometers). In 1969, this channel was the scene of a much-publicized oil well blowout. The oil spill that resulted caused extensive damage to marine life.

But spills are not the only source of oil in the Channel Islands region. According to the Final Environmental Impact Statement on the sanctuary, the area is characterized by a large number of natural oil seepage zones that are estimated to introduce from 40 to as much as 670 barrels of oil per day. Two seeps exist within the sanctuary, but the amount of oil being released has not been documented. The southern California offshore region from Point Concepcion south to the Mexican border also receives significant quantities of oil from other sources. Rivers and creeks introduce about 91 barrels of oil and grease per day. Discharges of treated municipal wastewater, which exceed 1 billion gallons per day, account for an additional 1,152 barrels per day.

The Western Oil and Gas Association has contended in its suit that the Sanctuary area may contain some 100 million barrels of oil, along with a large amount of natural gas. The association also contends that the resources could be extracted without ecological harm. The Final Environmental Impact Statement, however, stated that the U.S. Geological Survey estimated that there were 5.7 million barrels of oil and 8.9 billion cubic feet of gas underlying 24 tracts in the sanctuary that were withdrawn from Lease Sale 48 in creating the sanctuary. It added that there were no reliable data on the amount of petroleum underlying the entire sanctuary.

The sanctuary is characterized by a large number of seabird breeding colonies. In addition, many migrating species — protected under the Migratory Bird Treaty Act — congregate in the offshore region for brief periods throughout the year. Floating oil affects marine birds by fouling feathers and through ingestion, inhalation, and irritation of the eyes and membranes. Feather contamination is the primary cause of immediate death because of the resulting inability to fly, avoid predators, or forage underwater.

Among birds that are particularly susceptible to oil fouling are the endangered brown pelican, cormorants, murres, puffins, loons, grebes, and scoters. The western grebe was the one species most seriously affected by oiling in the 1969 well blowout off Santa Barbara. Shearwaters, albatrosses, petrels, gulls, terns, shorebirds, and some ducks and geese are also vulnerable to oil contamination.

The waters of the **Point Reyes–Farallon Islands National Marine Sanctuary** also support many diverse forms of sea life. They are rich in nutrients and promote thriving concentrations of marine life at all levels of the food web from microscopic algae and plankton to large predators, such as the killer whale and leopard shark. The rich fishing resources include salmon, abalone, flounder, clams, and herring, all of which serve as food for large populations of marine mammals and seabirds.

The sanctuary extends over 948 square nautical miles, ranging from Bodega Head to Rocky Point along the northern California coastline out to the Farallon Islands. Seals and sea lions are present throughout the year on both the mainland and the islands.

The Farallons are an important pupping area for many species, including the northern elephant seal, which can reach 20 feet in length and weigh as much as 2½ tons. The elephant seal was nearly exterminated by commercial hunting in the mid-19th century: however, as the result of improved protection, it is now re-establishing itself over its former range.

The Farallons also contain the largest seabird rookeries in the continental United States — 12 species totaling more than 2 million birds. Among the most numerous are petrels, cormorants, murres, and puffins. Rare birds, such as the brown pelican, peregrine falcon, southern bald eagle, heron, and egret also depend on this sanctuary for a place to live. Many other species of waterfowl and shorebirds frequent the area, which lies along the migratory route between the Arctic and Latin America.

NOAA and the U.S. Coast Guard, which is the primary law enforcement agency for the national program, recently cited the operators of a commercial container ship for discharging 95 tons of marine diesel fuel while passing through the sanctuary. The oil did not reach shore and NOAA believes that damage to marine life was minimal.

The **Key Largo and Looe Key Marine Sanctuaries** are underwater gardens that contain spectacular coral reef formations. Key Largo's reefs have survived through thousands of years of attack by natural enemies and buffeting by storms and hurricanes — and their structures have helped build the Florida Keys.

The reefs — major sources of beach sand (2.5 tons per acre annually) — are the result of construction by billions of tiny organisms called polyps, some no longer than a pinhead. They secrete a calcareous skeleton that is the basic structure of the reef. Reef-forming polyps have existed since the Ordovician Period (about 400 million years ago) and have dramatically changed during glacial periods when sea level may have changed by as much as 100 meters. The present reefs sit on top of what were once hills.

There are more than 100 different species of Caribbean coral polyps. New coral structures are constantly being built on top of the dead skeletons of older colonies, but the rate of growth is slow. Branching corals, such as staghorn and elkhorn, grow about 3 inches a year, but larger corals grow at a much slower rate.

The reefs — encompassing 100 square miles in the Key Largo Sanctuary — are home for many small rainbow-hued fish, while larger predators, such as sharks, barracuda, and grouper, prowl the area in search of food. In all, more than 500 different species of fishes populate the reefs, many of commercial value.

The Looe Key Sanctuary consists of a submerged section of the Florida reef tract located 6.7 nautical miles southwest of Big Pine Key in the lower Florida keys. It encompasses 5.3 square nautical miles of water surrounding a well-developed coral reef.

Several shipwrecks can be found within the sanctuary, including the remains of the

H.M.S. Looe, a British frigate that went down in 1744. These wreck sites are popular with divers, as the water is usually very clear during moderate sea conditions. The harm that divers were doing to the coral reefs was part of the reason for designating the sanctuaries in the first place. Many dive shops opposed establishment of the sanctuaries.

The **Gray's Reef Sanctuary** consists of an ecosystem that supports a diverse array of temperate and tropical species. It is located 18 nautical miles east of Sapelo Island, Georgia, and encompasses about 17 square nautical miles. The **U.S.S. Monitor Sanctuary** protects the wreck of the famous Civil War ironclad, located in the waters southeast of Cape Hatteras, North Carolina, and is the only site in the national system designated solely for the protection of a cultural resource.

The Road Ahead

It is clear that there will be continued legal pressure from oil interests on the West Coast to develop tracts within the Channel Islands and Point Reyes–Farallon Islands sanctuaries. For the oil companies, it is primarily a question of economics. It is far cheaper to explore for oil in the relatively warm weather off southern California than it is to make the same effort in the distant fields off Alaska. They also can state the fact that oil exploration in the tidelands of the Santa Barbara Channel dates from 1896, when the first offshore oil and gas development began in the United States. It was not until 1968, however, that the first federal lease sale was held for tracts in the deep waters of the channel. Industry has insisted that the channel area could produce some 400,000 barrels of oil a day by the mid-to-late 1980s, about 5 percent of the total domestic supply.

And so the lines of battle are drawn. Fourteen environmental organizations — including the Sierra Club, Friends of the Earth, and the National Audubon Society — collectively have intervened as opponents of the suit brought by the Western Oil and Gas Association. In addition, the California Coastal Commission, the leading state agency engaged in litigation with Secretary of the Interior James G. Watt over offshore leasing in California, has intervened.

We should also mention that there has been intense opposition from the oil industry to a marine sanctuary proposed for the East and West Flower Garden Banks off Louisiana and Texas. The chief environmental concern there has been the effect on coral of discharged drilling effluents. Then, too, Georges Bank, a rich fishery resource off Cape Cod in Massachusetts, was once nominated as a sanctuary but subsequently withdrawn in a complicated inter-governmental legal action widely viewed as a victory for oil interests.

The stakes in all this are very high. It is obvious that oil companies — reacting to new drilling discoveries off the coast of southern California — are moving to head off future battles by depriving environmentalists of one of their best weapons — the sanctuary designation.

Paul R. Ryan

concerns

Ocean Dumping Nations Vote Radwaste Suspension

LONDON — During the week of February 14–18, 1983, delegations from 36 nations, seven international organizations, and three nongovernmental groups participated in the work of the 7th Consultative Meeting of Contracting Parties to the London Dumping Convention (LDC). The major item for discussion and decision at the meeting was whether ocean dumping of low-level radioactive wastes should be immediately banned, phased out over several years, stopped pending scientific studies, or allowed to continue under stricter controls. After two days of intense debates, a two-year moratorium sponsored by the Spanish delegation was adopted by a vote of 19 to 6, with 5 abstentions (Table 1).

The resolution called for an immediate suspension of any ocean dumping of low-level radioactive wastes, pending presentation of a scientific and technical report on the subject at the 9th Consultative Meeting, scheduled for February 1985.

The LDC is the global treaty that addresses the prevention of marine pollution caused by the dumping of

Table 1. Spanish moratorium resolution.

In Favor			Against	Abstaining
Argentina	Kiribati	Papua New Guinea	Japan	Brazil
Canada	Mexico	Philippines	Netherlands	France
Chile	Morocco	Portugal	South Africa	West Germany
Denmark	Nauru	Spain	Switzerland	Greece
Finland	New Zealand	Sweden	Britain	Soviet Union
Iceland	Nigeria		United States	
Ireland	Norway			

wastes. The secretariat for the LDC is the International Maritime Organization (IMO). To date, 53 countries have ratified the LDC, which prohibits disposal of high-level radioactive wastes and other highly toxic substances at sea. In addition, other toxic substances, including low-level radioactive wastes, can only be dumped pursuant to certain special-care procedures and permits. Since the mid-1970s, Britain, Switzerland, Belgium, and the Netherlands have been the only countries dumping radioactive wastes at sea. Last fall, the Netherlands announced that it intends to phase out ocean dumping. But in recent years, both Japan and the United States have made public their interest in the ocean disposal option for certain low-level wastes.

Initially, the discussions at the recent meeting focused on proposed amendments to the treaty that would have placed all radioactive wastes and other radioactive matter on the Convention's "blacklist." The Pacific Island governments of Kiribati (formerly the Gilbert Islands, which gained independence from Britain in 1979) and Nauru (a former United Nations trusteeship that became independent in 1968) proposed an immediate global ban. The five Nordic countries — Norway, Sweden, Denmark, Finland, and Iceland — proposed a substitute amendment that would have banned all radwaste dumping as of 1990, with interim conditions that there be no new dumpers, no new dump sites, stricter controls, and a ceiling on existing dumping at current levels. As the meeting progressed, it appeared that neither amendment had the support of the two-thirds majority needed for adoption, so the sponsors agreed to defer a vote until the 1985 meeting so that their proposed amendments could be scientifically reviewed.

Those seven nations, and others, then gave their support to the Spanish resolution as the next-strongest alternative. Resolutions require only a simple majority for adoption. While such resolutions are not legally binding on convention members, several delegations said that, if adopted, they should be considered morally binding. Some delegations sought to modify or weaken the Spanish resolution to make it a "consensus" resolution, and in the final hours of the debate the United States and Britain unsuccessfully raised numerous procedural objections in an effort to block the vote on the moratorium.

During the first year of the two-year moratorium, the IMO and the International Atomic Energy Agency (IAEA) will request scientific and technical information pertinent to the proposed amendments. As part of that effort, IAEA will convene an interagency meeting of invited experts. A status report will be submitted to the 8th Consultative Meeting next year. Between the 8th and 9th Meeting, another meeting of specialists from international, intergovernmental, and nongovernmental organizations will be convened. The results of that meeting will be forwarded to the 9th Meeting.

On a related matter, delegates from several nations (including the United States) expressed the view that subseabed emplacement of high-level radioactive wastes (still in the development stage — see *Oceanus*, Vol. 25, No. 2, pp. 42-53) is covered by the LDC, and therefore prohibited. In an effort to resolve this question, an intersessional "ad hoc legal experts meeting" will be convened to clarify whether subseabed disposal would be contrary to the provisions of the Convention.

Clifton E. Curtis, attorney,
Center for Law and Social Policy,
Washington, D.C.

letters

To the Editor:

Recently you made some changes in your format, but it seems without drawing yourselves any distinct boundaries. Your article "Women in Oceanography" made this apparent. A lot of things about this article rankle me, but first and foremost is: I buy *Oceanus* for science, not sociology.

Who comprises your readership? I was not of the impression that it was largely of neophytes in the field, so what purpose did this article serve? What was the purpose of the statistics? To inform us that there aren't a lot of female oceanographers? So who didn't know that? Did anyone ever think that maybe most women just aren't interested in oceanography, or was the suggestion being made that with proper encouragement during schooling we would find an equal ratio of men and women in all jobs? Not being able to see that the statistics given provided proof for anything, the only thing left was to assume that they were there for propaganda. And there it was — handsomely manifested in your offer of research fellowships discretely placed in nice dark print within the text of this article to say: We Hire Women. And I'd like to lay the odds on your doing just that for the 1983-84 awards. (Has the Affirmative Action Program "given some men the impression that unqualified women have been hired just because of their sex?" Considering I know men who have been refused to *even apply* for Affirmative Action jobs because the jobs were open only to women, I should think that impression fairly accurate, for whether or not the women were qualified for the job, the men were unqualified for it by reason of sex.)

What happened at *Oceanus*? Did you receive a number of letters from women saying you were "prejudiced" because they didn't see enough female names with PhD's after them in your magazine and by printing this article you were hoping to fill a "need?" Well, if so, you're in for a surprise, because women make their judgments as strongly, if not more so, on the basis of sex, and all who wrote in with the above complaint are going to write back complaining that the article was written by a *man*. Horror of horrors.

Perhaps this article might have been better placed in a collegiate "jobs" brochure; it may have found an excuse for existence there. But there was no excuse for the pop psychology/sociological drivel of the last paragraph. If the possibility that ". . .such marriages will bring about societal changes that will allow people still more freedom to choose their own role, to live the lives they want to live" is of such interest, perhaps you should all come to where I work — a mental health facility for children — and see some of the handiwork such marriages have already produced.

Seeing an article such as this in *Oceanus* makes me fear that more are to come and soon I'll be reading an article in which the author uses (lest I offend) his/her study of slipper limpets to propound their personal beliefs regarding sexual preference and mating habits!

Decide your purpose and goals for *Oceanus*, so I may decide whether or not to resubscribe.

Diane C. Ging,
Pittsburgh, Pennsylvania

To the Editor:

I just received my first copy of *Oceanus* [Fall 1982]. Having written a term paper on manganese nodules while attending college, I found the magazine very interesting. I personally feel that the U.S. should not sign the [Law of the Sea] Treaty. We should go ahead and mine the nodules. If we did, we could tell the Russians, because of their covert operations in Africa, [where] to go. We would not need Africa's minerals.

Frank H. Kreysar
Steelton, Pennsylvania

book reviews

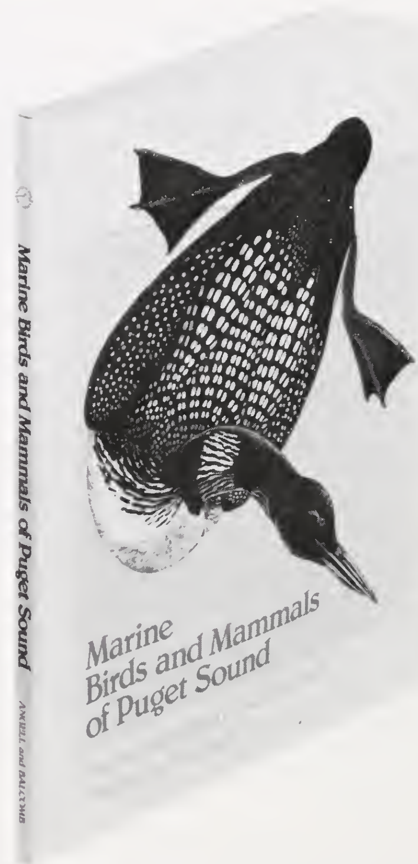
The Marine Birds and Mammals of Puget Sound **by Tony Angell and Kenneth C. Balcomb III; Drawings by Tony Angell. 1982. Puget Sound Books, Washington Sea Grant, University of Washington Press, Seattle, Wash. 160 pp. $14.50.**

At a time when field guides to wildlife are proliferating, it is a pleasure to find a book that picks up where conventional field guides usually leave off. Tony Angell and Kenneth C. Balcomb III have produced an account of the birds and mammals of Puget Sound that reflects the richness and diversity of that region's natural environment.

The Marine Birds and Mammals of Puget Sound is written for the naturalist-layperson, one of a series of books concerned with the ecology of Puget Sound and published with financial support from the National Oceanic and Atmospheric Administration. It lists local species but does not tell you how to identify them in typical field-guide style. Rather it provides a stimulating blend of natural and human history, personal experience, habitat assessment, conservation priorities, and superb drawings that should appeal to any naturalist with even the remotest interest in marine birds and mammals or the coastal Northwest.

Angell, supervisor of environmental education for the state of Washington and an accomplished illustrator with three published books of bird drawings to his credit, is a lifelong resident of the Puget Sound region. Balcomb is a whale biologist whose recent research has focused on the killer whales of Puget Sound. These two men have the broad knowledge of Puget Sound's wildlife and the well-developed sense of place that gives this book its strength and charm.

The book (softcover) begins with a brief history of Puget Sound's wildlife heritage, emphasizing human exploitation. It continues with short descriptions of primary coastal habitats, touching on their ecology and a few of the key species utilizing each one, then stresses ways in which these habitats have been degraded. The bulk of the book is taken up with species accounts, organized by family.



Sensibly, the authors have sketched broad categories of "marine birds and mammals," including species that depend heavily on the Puget Sound ecosystem but are not traditionally thought of as "marine": peregrine falcon, raven, river otter, and so on. One hundred and thirty birds and 15 mammals are considered residents or migrants in the Puget Sound region, and the authors discuss each of them. A good bibliography encourages further reading.

The text is very readable, often colorful, but distinctly anecdotal. This is primarily a book for the appreciative, curious naturalist, more than for the scientist or wildlife manager seeking facts (although there are some quantitative references of species abundances and specific breeding sites). The emphasis on pollution, particularly oil pollution, is often redundant; the subject would have been better discussed by family than by species. In addition, the individual species maps have no key and are too small to be of much use; an appendix might have made specific information on numbers and distributions of the animals more accessible.

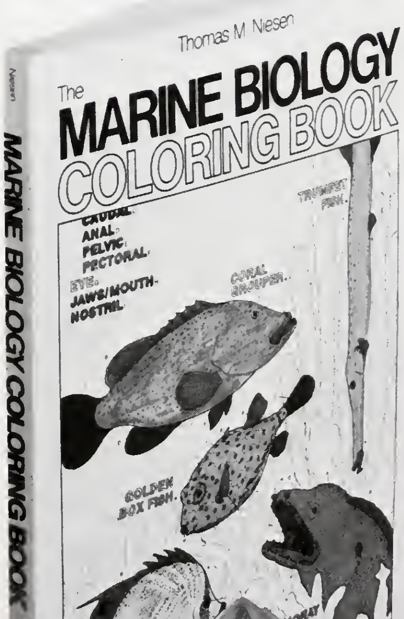
These are small quibbles, easily compensated by Angell's pen-and-ink scratchboard drawings. It has been said that one can learn how to paint, but one must be born knowing how to draw. However he acquired his talent, Angell has an obvious gift, as well as an observant eye and a delightful imagination. His illustrations are scattered generously throughout the text, often filling half a page; they add a truly aesthetic dimension. Angell is a master of birds in flight and of conveying the cohesiveness of bird flocks.

If you believe that conservation begins with an understanding of one's local ecosystem, then you will want a book like this for your own region. You also will agree with Paul Ehrlich in his preface: "We need similar works for all of the ecologically sensitive areas of our globe." For those who live there, this book is both incentive and information for providing Puget Sound (one of the fastest-developing areas of the United States) with a gentle transition into the 21st century. If you don't live there, this book will make you want to go!

Alan Poole,
Boston University Marine Program,
Marine Biological Laboratory,
Woods Hole, Mass.

The Marine Biology Coloring Book **by Thomas M. Niesen. 1982. Illustrations by Wynn Kapit and Lauren Hanson. Barnes & Noble Books, New York, N.Y. $8.95.**

This is a good beginning textbook on marine biology that is packaged as an adult coloring book. It's the packaging that makes the book different, and it obviously sells: this is one of a series which so far



includes botany, human evolution, and zoology. On each of the right-hand 9-by-12-inch pages is a pen-and-ink plate to color in. Depicted are specific animals and plants, showing their feeding habits, defense mechanisms, reproduction methods, or species distribution. The plates are skillfully drawn, with titles for everything. On the page facing each of the 96 plates is an interesting and clear explanation of the picture, with directions for how to color it in. All parallel structures, such as eyes, are to be colored with the same "magic marker" or colored pencil.

The reason given for the coloring-book format is that it will enable you, the user, to "very pleasantly create your own visual interpretations of marine life." The introduction continues: "Using the same color for a structure common to several organisms allows you to understand both the similarity and diversity of form and function in marine organisms." The second statement contains some truth: just as in maps that show a nation and its territories in the same hue, a visual link is made when all eyes, for instance, are the same color.

Color can be a powerful teaching tool and memory aid, all the more effective when the student does the coloring. It is especially enticing when a process of movement is involved; when one colors in the barnacle larva and its trail across rock and other barnacles in search of a place of its own, one becomes the larva, the trail. One tends to color very carefully around the pores on the cord grass where salt pours out, somewhat in fear of plugging them up. This sort of identification results in remembering the process better than if one had only read about it.

Few adults will have either the time or the inclination to actually color in much of this book. I think, though, that a sort of "ownership" feeling, of all the book's creatures, is established by making one's mark on a few of them; one then *imagines* coloring the others in, moving them here or there, probing.

I do not feel that this is "creating your own visual interpretation" of anything, but it does seem to be a way of learning some basic marine biology under the guise of fun and "creativity." The coloring-book format is just a selling gimmick, but the text is interesting and well written; the pictures are very good. Maybe this way of learning science will make it more accessible to people who otherwise regard it as beyond them, but I wonder why anyone needs all these trappings when the information is already inherently fascinating. How much do the "magic markers" obscure while they define?

Molly Bang, author,
Woods Hole, Mass.

The Management of Pacific Marine Resources: Present Problems and Future Trends **by John P. Craven. 1982. Westview Studies in Ocean Science and Policy, Westview Press, Boulder, Colorado. 105 pp + xix. $12.95.**

The work on this volume was sponsored by the Pacific Basin Project, a joint effort of the Aspen Institute of Humanistic Studies and the Hubert H. Humphrey Institute of Public Affairs. The book reports on a workshop, held in Tokyo in June of 1981, on marine resources in the Pacific Basin. As Harland Cleveland notes in the foreword, the text is neither a "consensus report" nor a "summary" of the proceedings of that workshop. This may be the major drawback to the volume.

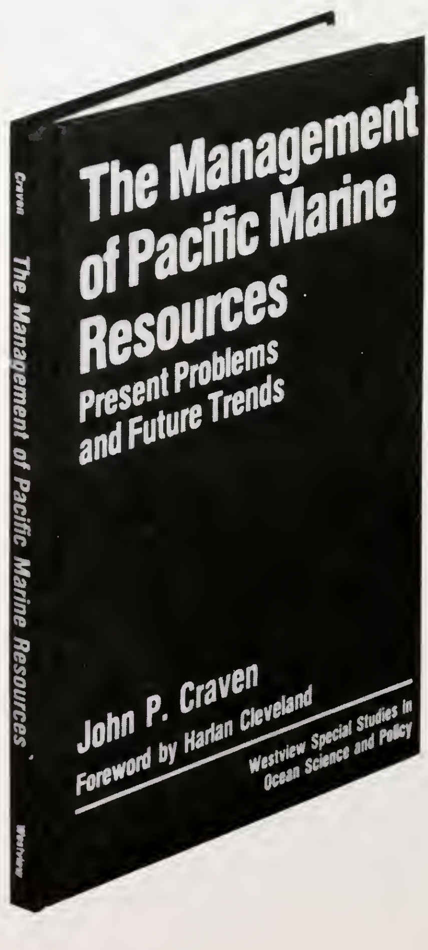
The three basic assumptions the workshop participants made in analyzing future management possibilities for Pacific marine resources are: 1) that the provisions of the United Nations Law of the Sea Treaty will become the norm; 2) that regional arrangements conforming with the treaty may nullify its intent; and 3) that there will be widespread attempts by "non-cooperative entities" to avoid the provisions of the treaty. Armed with these assumptions, the workshop's participants were to consider these questions: What action is required? and What countries are in positions to do something about it?

For those interested in the management of marine resources, particularly in the context of regional or subregional arrangements, a discussion of these assumptions and questions would be useful. What *are* the Pacific Basin countries now doing to manage resources? Are techniques or structures now being considered by Pacific Basin nations for regional or subregional management of marine resources? What management alternatives might be available in the future? Unfortunately, any connection between the assumptions declared at the book's outset and the operative questions is rarely made by Craven. Rather, he spends a great deal of his time considering how the idea of an "ocean commons" might be subverted by the Law of the Sea Treaty.

This is not to say that the issue of ocean commons is not important. However, as stated in the workshop assumptions, the Law of the Sea provisions will come into force — if not as international law, then as customary law. Therefore, it is an opportune time to evaluate the management alternatives presented by the impending change in ocean regimes. This is particularly true in areas of the world where there are many small, diverse nations, such as the Pacific Basin.

While Craven does not devote a great deal of attention to what the response of the Pacific Basin nations has been or might be to the imminent change in ocean regimes, one suspects that the workshop did. Excerpts from papers by workshop participants Gold and Chee let us surmise that the issue of marine resource management now and in the future was a major topic of discussion at the workshop. Thus, a more precise, fuller description of the workshop proceedings would have had more value for those interested in international perspectives on marine resource management and policy.

To this point, the response of this reviewer has been somewhat negative. This stems from the fact



that *The Management of Pacific Marine Resources* delivers something other than what is promised by the title. What you get is an interesting and speculative piece by Craven on what the future uses of the Pacific and its resources might be. For those unfamiliar with ocean thermal energy conversion and its potential as envisioned by proponents, Craven's chapter on ocean energy potentials provides an entertaining and worthwhile introduction. Additionally, his observations about the shrinking ocean commons are relevant and worthy of consideration.

Maynard Silva,
Marine Policy and Ocean Management Program,
Woods Hole Oceanographic Institution

Books Received

Aquaculture

Recent Developments in Aquaculture, **James F. Muir and Ronald J. Roberts, eds. 1983. Westview Press, Boulder, Colo. 453 pp. $20.00.**

The editors' goal, in this book, was to bring together a series of reviews of current developments in the field of aquaculture, both marine and freshwater, for practical study by those involved in the field. The subjects covered range from habitat study (mangrove swamps) through culture techniques (for crustaceans, snakeheads, carp, and tilapia) to specific aquaculture technology.

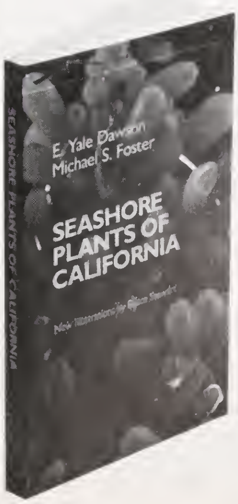
Biology

Encyclopedia of Marine Invertebrates, **Jerry G. Walls, ed. 1982. T.F.H. Publications, Inc., Neptune, N.J. 736 pp. $49.95.**

There are thought to be more than 500,000 species of marine invertebrates (compared to 20,000 species of fishes, marine and freshwater). In this book, each non-parasitic phylum of marine invertebrates is described, with liberal use of color photographs. Short summaries list the main characteristics of each phylum discussed and give an overview of its higher classification. Some notes are included on the suitability of the various groups for home aquariums.

Seashore Plants of California **by E. Yale Dawson and Michael S. Foster; new illustrations by Bruce Stewart. 1983. University of California Press, Berkeley, Calif. 226 pp. $15.95 hardcover; $7.95 paperback.**

This book is part of a series of California Natural History Guides, meant to be taken along on beach visits. The cover design even includes rulers, in inches and centimeters, to help eliminate guesswork. The plants presented, more than 240, are those most frequently encountered on the California coast, and are keyed for easy field identification. Most are seaweeds. The reader is introduced to plant distribution in the intertidal and subtidal zones, algal structure and reproduction, and identification of marine plants. Following that are the keys, and chapters on green, brown, and red algae, sea grasses, and salt-marsh and dune vegetation.



Jellyfish and Other Sea Creatures **by Oxford Scientific Films; photographs by Peter Parks. 1982. G. P. Putnam's Sons, New York, N.Y. pages not numbered; $8.95.**

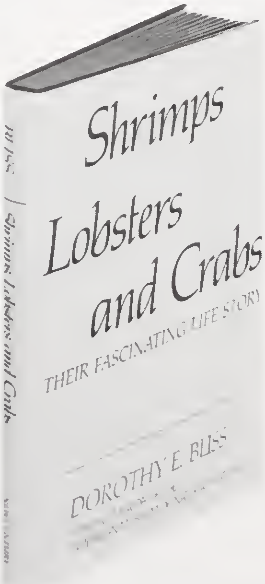
Coelenterates have in common a flexible, gelatinous, hollow "bag," the mouth of which is ringed with tentacles. The tentacles capture food and pass it into the stomach, inside the bag. In this small book, a four-page introduction describes physiology and life-cycle; the remaining pages are devoted to color pictures of jellyfish, sea anemones, man-o-wars, by-the-wind sailors, and other coelenterates. Captions explain the photographs.

Red Sea Coral Reefs **by Gunnar Bemert and Rupert Ormond. 1981. Kegan Paul International, Ltd., Boston, Mass. 192 pp. $45.00.**

The Red Sea is surrounded by arid lands — desert and semidesert — but within the waters of the sea itself are thousands of coral reefs, teeming with colorful life. This book is for those generally interested in natural history, as well as Red Sea Scuba divers. Geographical and historical summaries describe the Red Sea region. The major portion of the book is filled with photographs (taken by author Bemert), mostly underwater, of the coral reefs and the many creatures living on or near them, with text elaborating and explaining.

***Shrimps, Lobsters and Crabs* by Dorothy E. Bliss. 1982. New Century Publishers, Inc. Piscataway, N.J. 242 pp. $14.95.**

Written for the general reader and naturalist by an authority on crustaceans. The shrimp, lobster, and crab are three of the most popular shellfish, especially on the dinner table. Bliss describes the life-changes of these animals, and of the crayfish and the land crab, from mating and spawning to molting and anatomy. She also covers their natural distribution, fisheries, and culture.



Marine Policy

***Social Science Perspectives on Managing Conflicts Between Mammals and Fisheries,* Biliana Cicin-Sain, Phyllis M. Grifman, and John B. Richards, eds. 1982. Marine Policy Program, Marine Science Institute, University of California at Santa Barbara and University of California Cooperative Extension. 347 pp. $16.00.**

There is an ongoing conflict arising from a question of priority: how much effort should be directed to the protection of marine mammals when they compete or conflict with commercial and recreational fisheries? This book is the proceedings of a conference addressing that issue. The California sea otter/shellfish industry conflict is used as a case study, with an interdisciplinary approach exploring the web of philosophical, historical, economic, social, political, and administrative issues underlying the problem.

***Modernization and Marine Fisheries Policy,* John R. Maiolo and Michael K. Orback, eds. 1982. Ann Arbor Science, Woburn, Mass. 330 pp. + xii. $29.95.**

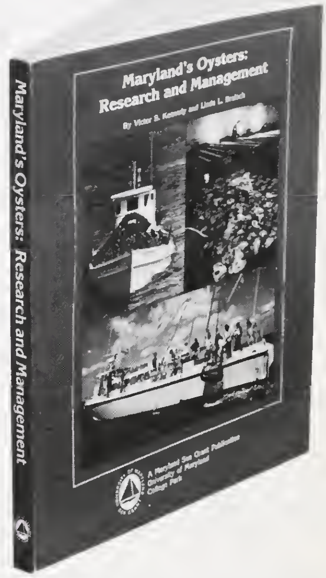
The papers in the first section of this book are about the process of modernization in fishing communities and the role of government policy in that process. Section Two, Social Dynamics and Technoeconomic Adaptations, focuses on the implementation of the policies whose formation is discussed in part one, using specific examples.

***The New Nationalism and the Use of Common Spaces: Issues in Marine Pollution and the Exploitation of Antarctica,* Jonathan I. Charney, ed. 1982. Allanheld, Osmun & Co., Totowa, N.J. 343 pp. $39.50.**

Part One of this book is about marine pollution, from oceangoing vessels and land-based sources, covering the legal, political, and economic aspects. Part Two examines the management of Antarctic resources, also approached from various perspectives. The collection, interpretation, and distribution of data are shown to be one of the most important (and often most limiting) factors in the development of international environmental law.

***Maryland's Oysters: Research and Management* by Victor S. Kennedy and Linda L. Breisch. 1982. Maryland Sea Grant, University of Maryland, College Park, Md. 286 pp. $8.00.**

A critical review intended to improve planning for research on and management of the eastern oyster. The Maryland (Chesapeake Bay) resource is emphasized. The authors delineate those areas of the oyster's biology and ecology that are not well understood and need further research. They then trace the historical decline of the Maryland oyster fishery, describe the oyster grounds today, and discuss current management practices. Finally, there is an annotated bibliography of Chesapeake Bay oyster literature.



Environment

***Industrial Waste.* Proceedings of the 14th Mid-Atlantic Conference. James E. Alleman and Joseph T. Kavanaugh, eds. 1982. Ann Arbor Science, Woburn, Mass. 612 pp. + xix. $39.95.**

Originally developed as a forum for regional environmental engineering issues, the emphasis of the Mid-Atlantic Industrial Wastes Conference now encompasses the national concern for industrial and hazardous waste treatment. These proceedings, in 59 chapters, cover hazardous waste handling, waste pretreatment, case histories, residue stabilization and fixation, and other relevant topics. The book intends to provide a state-of-the-art synopsis of environmental engineering practices.

***Pollutant Transfer and Transport in the Sea,* Gunnar Kullenberg, ed. 1982. CRC Press, Boca Raton, Fla. Volume I: 227 pp., $77.00; Volume II: 236 pp., $77.00.**

Volume I, consisting of four chapters, covers physical processes, models of dispersion, experimental techniques, and air-sea exchange of pollutants. Volume II, five chapters, includes biological transfer and transport processes; the concentration, mineralogy, and chemistry of suspended matter in the sea; sediments and transfer in and at the bottom interfacial layer; estuaries and fjords; and the effects of weather systems, currents, and coastal processes on major oil spills.

Marine Tailings Disposal, **Derek V. Ellis, ed. 1982. Ann Arbor Science, Woburn, Mass. 368 pp. $37.50.**

This book was produced from the proceedings of a symposium of the same name, held in Ketchikan, Alaska, in March of 1982. Much of the information comes from existing mines, especially those developed during the 1970s (at the same time major Canadian and United States environmental regulations were being implemented). There are four sections: engineering and scientific principles; case studies; regulatory action; and Quartz Hill. Within each section, the individual chapters are followed by selected parts of the discussions that went on at the symposium.

Educational Books

***A Guide for Writing Better Technical Papers,* Craig Harkins and Daniel L. Plung., eds. 1982. The Institute of Electrical and Electronics Engineers, Inc., New York, N.Y. 219 pp. $22.95.**

Writing is a natural part of the scientist's or engineer's work; reports and articles are used to communicate ideas and information to others. However, writing must be learned; to help that process along, this book, composed of articles by many authors, provides information about the writing process and suggests certain techniques and guidelines.

***Knowledge: Its Creation, Distribution, and Economic Significance. Volume II: The Branches of Learning;* by Fritz Machlup. 1982. Princeton University Press, Princeton, N.J. 205 pp. $17.50.**

In this book, the different parts of "intellectual knowledge" — that knowledge gained for satisfying one's intellectual curiosity, part of liberal education, humanistic and scientific learning, and general culture — are examined. Part One is a survey of the classifications of sciences, now called disciplines, as proposed by philosophers and encyclopedists. Part Two discusses the way subjects are arranged in academic institutions: academies of sciences, libraries, and universities.

***The Water Link: A History of Puget Sound As a Resource* by Daniel Jack Chasen. 1981. Puget Sound Books, Washington Sea Grant, University of Washington Press, Seattle, Wash. 192 pp. $8.95.**

Chasen traces the development, from the middle of the 19th century, of Puget Sound — its economic development and history of environmental conflict. This is the story of what happened once white Americans arrived in the Sound and decided to make use of it, first exploiting the magnificent timber resources there. It is a history of the evolution of a human community in an area of huge natural resources. The text is followed by a chronological table marking important events in the Puget Sound area since 1846.

***The Complete Book of Seafood Fishing* by Rob Avery; illustrated by Paul Dadds. 1982. Van Nostrand Reinhold, Inc., New York, N.Y. 162 pp. $16.95.**

Written as an introduction to small-scale fishing and imaginatively illustrated with pen-and-ink drawings, this book is for people who wish to be more self-reliant. The author approaches fishing with a matter-of-fact attitude, cheerfully explaining the benefits and drawbacks of different fishing styles and equipment. There are three sections: shore fishing, boat fishing, and what to do with the harvest (including seaweed).

***Descriptive Physical Oceanography: An Introduction* by George L. Pickard and William J. Emery. 1982. Fourth enlarged edition. Pergamon Press, New York, N.Y. 249 pp. $35.00 hardcover; $11.95 paperback.**

An up-to-date version of a popular text, with the addition of a selection of references to original literature. The major change is the inclusion of 45 new figures. The text is meant to be used by would-be oceanographers and others desiring an introduction to this aspect of science. The authors emphasize their approach to physical oceanography: observation; followed by preparation and concise description of data; finally, interpretation.

Reading for Pleasure

The Conch Book by Dee Carstarphen. **1982. Pen and Ink Press, Banyan Books, Inc., Miami, Fla. 80 pp. $6.95.**

Billed as "All you Ever Wanted to Know about the Queen Conch, from Gestation to Gastronomy," this little book, handlettered and illustrated, is just that. In a sprightly, story-telling fashion, the author introduces readers to the biology and evolution of the conch and to the ways man has used it. There are many other tidbits of information concerning this sea creature; at the end are 16 pages of conch recipes.

Ships of China by Valentin A. Sokoloff. **1982. Published by the author, 773 Cypress Avenue, San Bruno, Calif. 53 pp. $29.95 + $2.75 for shipping.**

The paintings in this book, reduced from original watercolors, are printed on 10-by-16-inch heavy paper. Each is a delicate, detailed painting of a Chinese junk, shown from various angles. Each boat is described briefly, including information on size, building materials, and history. The boats' names are given in Chinese characters as well as in English; all the writing is done in calligraphy. That a great deal of loving effort went into this book is very apparent.

Follow the Wild Dolphins by Horace Dobbs. **1982. St. Martin's Press, New York, N.Y. 263 pp. $15.95.**

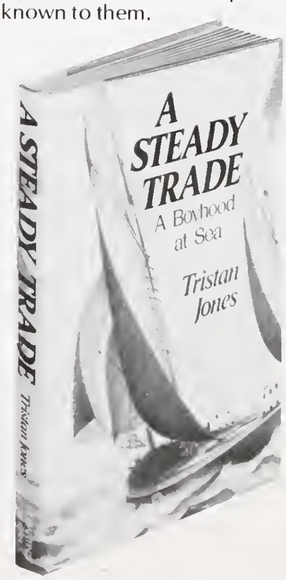
This is a book about dolphins and adventures with dolphins. The reader is soon acquainted with Donald, the bottlenose dolphin that the author met off the Isle of Man. Donald makes many human friends, entrancing them with his playfulness and intelligence. His personality, well described by Dobbs, dramatizes this book's message about dolphins: save these animals.

Books Policy

Oceanus welcomes books from publishers in the marine field. All those received will be listed and a few will be selected for review. Please address correspondence to Elizabeth Miller, editor of the book section.

A Steady Trade: A Boyhood at Sea by Tristan Jones; drawings by John Cayea. **1982. St. Martin's Press, New York, N.Y. 267 pp. $15.95.**

Partly an adventure story and partly a descriptive story of growing up in Wales some 50 years ago, this autobiographical tale recounts a life far different from most of our experiences. At age 13, the author apprenticed on a sail-in-trade barge, the *Second Apprentice*. Interspersed with soft pencil drawings, the chapters are introduced with sea chanteys and poems; this book will delight young and old readers, and many will discover a world previously unknown to them.



The Delicate Art of Whalewatching by Joan McIntyre. **1982. Sierra Club Books, San Francisco, Cal. 144 pp. $12.50.**

Joan McIntyre for five years headed a group working to increase public understanding and protection of cetaceans. Then she moved to a remote Pacific island, where dolphins and whales are seasonal visitors. She could see them often, and by observing and interacting with them, learned to look at other life as well. This book is really a series of sketches — one person describing her wonderment at the mystery and beauty of the natural world.

The Sea Fisherman's Bedside Book, Bill Nathan, ed. **1982. General Duckworth Co., Ltd., London, England. 155 pp. $12.95.**

This is a compilation of saltwater fishing stories from many sources, including some written by the editor himself. Some of the contributions are instructional, and a few are fiction, but most are true stories. Pencil drawings provide graceful illustration to this slim, readable volume.

The Voyage of the Armada: The Spanish Story by David Howarth. **1981. The Viking Press, New York, N.Y. 256 pp. $13.95.**

In 1588, the huge Spanish Armada was defeated off the coast of England by Sir Francis Drake's relatively small contingent of Elizabethan seamen. Howarth, in this historical narrative, tells what happened on this well-known voyage and what the Spanish soldiers knew of their mission. Based on discoveries made in the Spanish Royal Archives, the book is intended to be an unbiased presentation of the Spanish side of the story.

The Miracle of Dunkirk by Walter Lord. **1982. The Viking Press, Inc., New York, N.Y. 323 pp. $17.95.**

In the spring of 1940, Hitler's forces had pinned more than 400,000 Allied troops against the coast of Flanders, near the port of Dunkirk. In what is called by some "the greatest rescue of all time," some 338,000 of these men were evacuated safely to England. Written by the author of *A Night To Remember,* this tale of deliverance by sea is based on material researched from the British Archives, new material from France and Germany, and the reports of some 500 participants.

Nature Close Up: A Fantastic Journey into Reality by Andreas Feininger. **1981. Dover Publications, Inc., New York, N.Y. 160 pp. $8.95.**

This is a collection of photographs, some in color, most in black-and-white. Without "trick" photography, rocks, shells, landscapes, animals, and plants are depicted from unusual angles, magnified, or printed without context. The author is a former *Life* magazine photographer. His captions include thoughts from his imagination's ramblings. From this one learns how the artist, and oneself, can more fully see the things he is looking at.

Books for Children

***The Everglades Coloring Book.* 1982. Florida Flair Books. Banyan Books, Inc., Miami, Fla. 32 pp. $1.95.**

Ready-to-color drawings of some of the plants and creatures of the Everglades, including alligators, fish, mangroves, and many others. Each picture has a brief description, generally about the natural history of what is depicted.

***The Fisherman and the Bird* by Sonia Levitin; illustrated by Francis Livingston. 1982. Houghton Mifflin Co., Boston, Mass. 20 pp. $10.95.**

Rico is a lonely fisherman, without friends. His boat is chosen as a nesting site by a pair of beautiful birds, and the people of the fishing village convince Rico to let the birds stay, as the species is nearly extinct. Happily, two chicks hatch. The watercolor illustrations, in wet-looking blues, greens, and sunset tones, are lovely.

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regional councils, and the complex boundary disputes between the U.S. and Canada. Other articles deal with the electromagnetic sense of sharks, the effects of tritium on ocean dynamics, nitrogen fixation in salt marshes, and the discovery of animal colonies at hot springs on the ocean floor.

Sound in the Sea, Vol. 20:2, Spring 1977 — The use of acoustics in navigation and oceanography.

Issues not listed here, including those published prior to Spring 1977, are out of print. They are available on microfilm through University Microfilm International; 300 North Zeeb Road; Ann Arbor, MI 48106.

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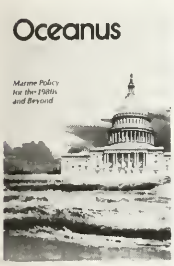

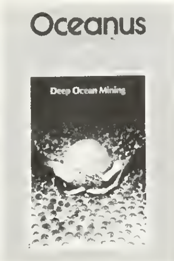

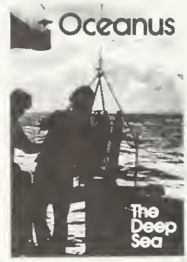

Marine Policy for the 1980s and Beyond, Vol. 25:4, Winter 1982/83 — This issue examines the role of government in human activities affecting the sea. Each author makes recommendations for the future. The articles focus on the problems of managing fisheries, the controversy over dumping wastes in the oceans, the lack of coordination in United States Arctic research and development, military-sponsored oceanographic research, the Law of the Sea, and the potential for more international cooperation in oceanographic research. Other features include essays on commercial whaling and women in oceanography.

Deep Ocean Mining, Vol. 25:3, Fall 1982 — Eight articles discuss the science and politics involved in plans to mine the deep ocean floor. Also included are a profile of a marine scientist (John Teal), book reviews, letters to the editor, and a concerns section (an article on the U.S. Navy's plans to dispose of old nuclear submarines and a piece on the future of big ocean science in the 1980s).

General Issue, Vol. 25:2, Summer 1982 — Contains articles on how Reagan Administration policies will affect coastal resource management, a promising new acoustic technique for measuring ocean processes, ocean hot springs research, planning aquaculture projects in the Third World, public response to a plan to bury high-level radioactive waste in the seabed, and a toxic marine organism that could prove useful in medical research.

Sharks, Vol. 24:4, Winter 1981/82 — Shark species are more diverse and less aggressive than the "Jaws" image leads us to believe.

Oceanography from Space, Vol. 24:3, Fall 1981 — Satellites can make important contributions toward our understanding of the sea.

General Issue, Vol. 24:2, Summer 1981 — A wide variety of subjects is presented here, including the U.S. oceanographic experience in China, ventilation of aquatic plants, seabirds at sea, the origin of petroleum, the Panamanian sea-level canal, oil and gas exploration in the Gulf of Mexico, and the links between oceanography and prehistoric archaeology.

The Coast, Vol. 23:4, Winter 1980/81 — The science and politics of America's 80,000-mile shoreline.

Senses of the Sea, Vol. 23:3, Fall 1980 — A look at the complex sensory systems of marine animals.

A Decade of Big Ocean Science, Vol. 23:1, Spring 1980 — As it has in other major branches of research, the team approach has become a powerful force in oceanography.

Ocean Energy, Vol. 22:4, Winter 1979/80 — How much new energy can the oceans supply as conventional resources diminish?

Ocean/Continent Boundaries, Vol. 22:3, Fall 1979 — Continental margins are being studied for oil and gas prospects as well as for plate tectonics data.

Oceans and Climate, Vol. 21:4, Fall 1978 — *Limited Supply only.*

General Issue, Vol. 21:3, Summer 1978 — The lead article here looks at the future of deep-ocean drilling. Another piece, heavily illustrated with sharply focused micrographs, describes the role of the scanning electron microscope in marine science. Rounding out the issue are articles on helium isotopes, seagrasses, paralytic shellfish poisoning, and the green sea turtle of the Cayman Islands.

Marine Mammals, Vol. 21:2, Spring 1978 — Attitudes toward marine mammals are changing worldwide.

The Deep Sea, Vol. 21:1, Winter 1978 — Over the last decade, scientists have become increasingly interested in the deep waters and sediments of the abyss.

General Issue, Vol. 20:3, Summer 1977 — The controversial 200-mile limit constitutes a mini-theme in this issue, including its effect on U.S. fisheries, management plans within regional councils, and the complex boundary disputes between the U.S. and Canada. Other articles deal with the electromagnetic sense of sharks, the effects of tritium on ocean dynamics, nitrogen fixation in salt marshes, and the discovery of animal colonies at hot springs on the ocean floor.

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