PERSPECTIVES ON THE MARINE ENVIRONMENT

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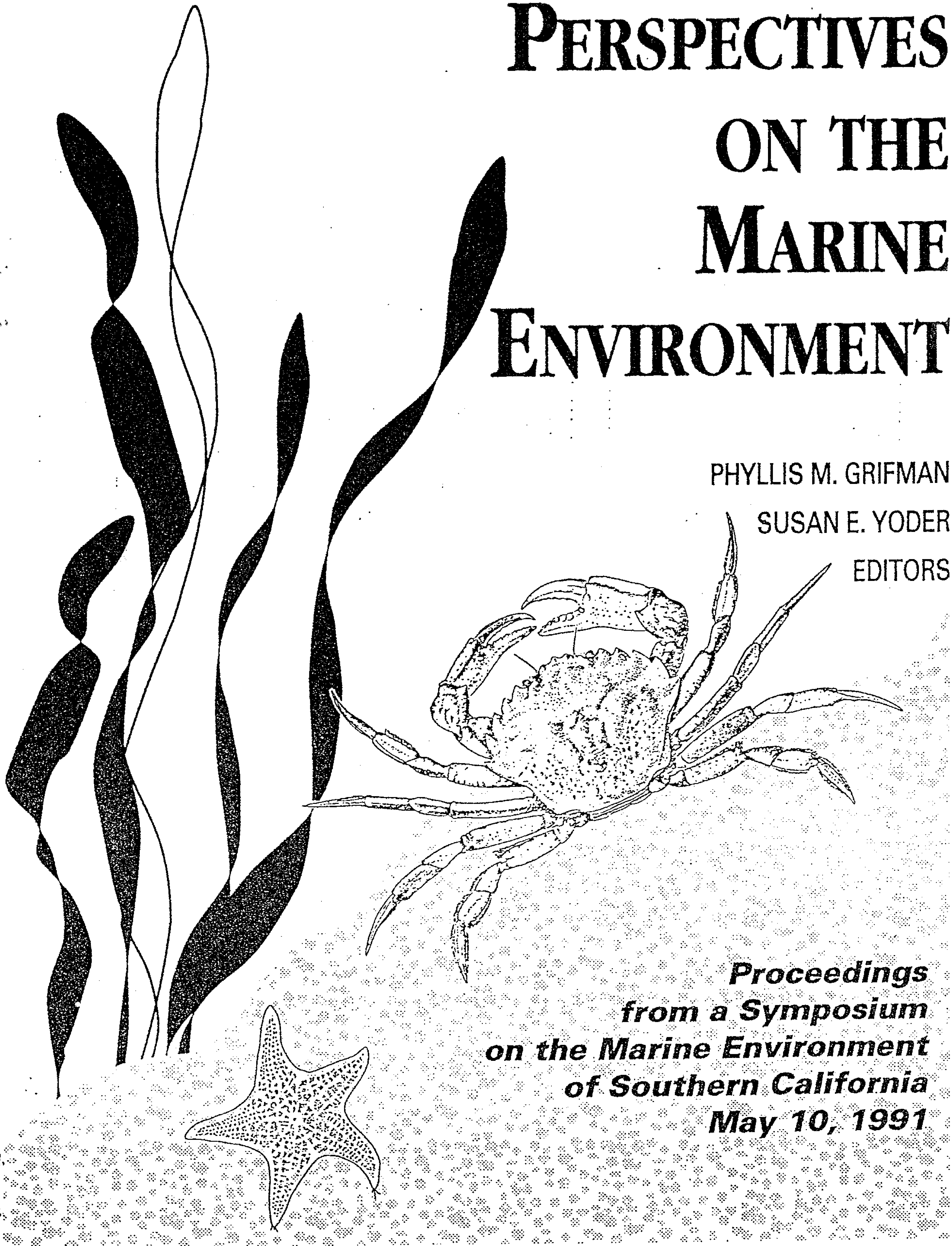

Proceedings from a Symposium on the Marine Environment of Southern California May 10, 1991

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Proceedings from a Symposium on
the Marine Environment of Southern California
May 10, 1991
Los Angeles, California

100th Anniversary Meeting of the
Southern California Academy of Sciences

Sea Grant Program
University of Southern California

USCSG-TR-01-92

Seabirds as Indicators of the Oceanic Environment

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Abstract. Oceanic ecosystems are difficult to study. Even with the most advanced equipment, measurements of fish and invertebrate populations are hard to make because of their temporal and geo graphic patchiness. Additionally, changes in patterns of abiotic factors can affect the entire food web, and these changes often alter both abundance and distribution of important commercial species as well as species on which many other members of the food web depend. Two major questions that managers need to answer are: can these changes be predicted, and what is an indicator measure ment of these changes?

The importance of seabirds to humans, besides their aesthetic or food values, is that they are among the best biological indicator species of the health of the ocean. They are colonial; therefore they are visible. They return to the same sites each year to nest, and in this way are not geographically or temporally patchy as are other oceanic organisms. At seabird colonies, long-term studies can easily be conducted. Annual numbers of breeding birds, and measures of reproductive success such as laying, hatch ing, or fledging success, or chick growth are good indices of population trends and stability as well as those of their prey. Other indicator measurements are: weights of adults, of eggs, and fledglings, or species composition of the colony. Seabird populations can be measured in this way to predict events such as an El Niño or a collapse of a fishery. With a greater investment of time, various measurements of seabird prey can be made, and the subsequent charting of prey numbers, frequency and weight will give a good indication which changes are occurring in the prey base and thus in the surrounding oceanic environment.

The quest for understanding the interactions among abiotic and biotic factors in the oceanic ecosystem has been ongoing since humans started thinking about the sea. Today, many thousands of dollars are spent on monitoring oceanic parameters and although much is now known, much is not. Unlike terrestial ecosystems, the oceans remain hidden from easy study. Indeed, until this century, study and analysis of much of the ocean remained rudimentary at best. The measure of abiotic factors seemed to be the simplest data to obtain. Measurements of sea temperature and salinity, as well as above-ocean measures like rainfall and air temperature helped to provide details of the stability and change of physical factors over a period of time. However interpretation of these data on more than a local scale was lacking.

With the arrival of electronics, the study of other abiotic parameters like currents, tides, and deep-ocean temperatures were possible. With the advent of satellites, global assimilation of data gathered from techniques such as photo-interpretation of data like ocean temperatures became achievable (e.g. 1). Events like El Niño and trends like global warming were able to be detected more accurately and rapidly via state of the art computer modeling (2).

The measurement of abiotic factors in the ocean is important because these factors can influence biota from plankton to whales (e.g. 3, 4, 5, 6, 7, 1, 8, 9, 10). Likewise, distribution and abundance of prey populations influence distribution and abundance of other marine organisms. Abiotic factors often covary with distribution of animals, yet there is rarely geographic or temporal stability of these factors. From a practical standpoint, the identification and measurement of critical levels of abiotic or biotic factors that may control population numbers of certain commercial species becomes important for management of these populations.

Oceanic biotá are inherently difficult to sample because the ocean is a fluid medium. They are not only patchy, they move, and are therefore unpredictable. A fish school present in the morning probably will not be in the same area two hours later. Finding the same school again is a much more difficult problem than locating a flock of birds in a deciduous forest. Humans are terrestrial beings and our senses are most tuned into terrestrial cues.

The oceanic sampling of biotic parameters probably started out as simple counts. Recently, more advanced techniques such as aerial detection of fish schools, analysis of water samples for grams of carbon per cc, or bioaccoustics, where sonic pictures enable researchers to follow movements of fish, gave researchers a more complete picture of the oceanic ecosystem.

Many of the techniques developed for following fish schools were introduced because the species for which they were developed were of commericial value. These techniques were often later refined and used for scientific applications such as analysis of predator- prey interactions or for correlations between distribution of phytoplankton or invertebrate prey and seabird populations (11, 7, 12, 13, 14, 15). Yet these measures still depended on first finding, then measuring the concentrations of plankton or fish. Sampling was still a problem. Even with the use of electronics to find oceanic creatures, we may either wrongly sample them or miss them altogether.

Certain cues can be used to locate biota. Commercial fishermen have tried to solve the dilemma of finding what they want to catch, by sighting on a predator species, usually marine mammals, which hunt the same prey they seek. Marine mammals, unlike the majority of fish, spend a comparatively large amount of time at the surface of the water, and are thus visible to humans. For example, some commercial fishermen sight on dolphins to find yellowfin tuna, a common prey of dolphins. Sometimes fishermen also look for flocks of seabirds to find swarms of krill. Timing, however, is still a problem, for these predator species also must be located, and they too are patchy and unpredictable.

If we continue to sample fish or invertebrate populations the way we do at present, we may not detect early deleterious or critical decreases in their populations. Subtle incremental changes may be additive and we might have no way of knowing whether or not we should be alarmed at these changes until perhaps the populations have already reached critically low levels. We need to be able to anticipate changes in the ecosystem and to predict what effect these changes will have: from the smallest prey to the largest commercially desirable species. We need early warnings.

Three recent events that might have been predicted but were not are: 1) the collapse of the herring fishery off of Norway in the 1960's (16), 2) the collapse of the anchovy population off Mexico in 1990 (D. Brewer, pers. comm), and 3) the radical decrease of the pollock fishery in Alaska to 25% of its normal levels (17). Could these collapses have been foreseen? Were there any predictors of these potential collapses that could have been monitored instead of the fish populations themselves, which clearly did not predict their own demise?

One way to get at the problem of predictability is to understand that changes in the food web are often magnified through higher trophic levels. Even small changes in the prey populations will be reflected in concomitant changes in the associated predator populations. Thus, repeated counts of large predators may be a good indicator of biotic and abiotic changes in the ocean. Good predators to measure would be top carnivores like salmon and tuna that feed on common species like capelin, sandlance, herring, smelt and anchovies, on which many other species feed. The problem in prediction here is that these fish carnivores are difficult to locate because for the most part they remain invisible to researchers. Even using feeding assemblages of marine mammals or birds to locate these fish does not help because the prey themselves are still unpredictable in place and time. Clearly, something that is stable, preferably stationary and present year after year, as well as being easy to measure needs to be found.

Ocean transects are stationary and repeatable and have been used to sample everything from physical and chemical parameters to seabirds and mammals. If enough of an area is covered on a regular basis, ocean transects are a good way to monitor long-term changes and variations (14). However they are expensive and thus are often not conducted regularly throughout the year over a large enough area and often not over a long enough period of time. Infrequent or incomplete transect sampling probably does not give accurate information on natural variation and abundance and certainly does not yield good predictive values. The biota found in these transects are transient and the transects only provide a snapshot of what is present. Data gleaned from them are useful to correlate carbon or temperature or salinity with population abundance of predators or prey species (5, 7, 1, 8 , 14), but not to count the same fish population from month to month.

However, there are some marine-associated species that are not only visible but are also predictable and stable in place in time. These are seabirds breeding at colonies. Seabirds return to nest, usually annually, to their natal colonies. Their populations frequently do not change drastically over a number of years. Since seabirds are long-lived, any increases or decreases in the overall colony numbers will probably not reflect a short-term output or decrease of chicks during a single breeding season. Seabirds are wide-ranging upper trophic level consumers and their colonies are often found near areas of high oceanic productivity (18). They are visible and easy to monitor because they are stable in space and in time.

Abiotic and biotic changes in the oceanic environment will often be reflected in certain changes at seabird colonies. Since many seabirds are also top predators, they are strongly affected by changes not only in their prey base but also in prey species a few trophic levels below them. Additionally, their populations are affected by changes in abiotic factors which influence all aspects of their food web (19, 20, 21, 10, 3, 22, 23, 43, 24, 25, 11, 26, 27).

The simplest but not necessarily the most accurate method of tracking seabird populations and determining if subtle changes are affecting them is to census them on their colonies over a long period of time (28, 29, 30, 31, 32, 33, 34). This is easy and fairly inexpensive. They should be censused during the peak of the breeding season (early-to-mid nesting) when the largest number of birds are present on eggs (see 35). At least one but prefera bly several censuses should be made by several observers to increase the accuracy of counts, since nesting can be advanced or delayed by both biotic and abiotic factors (36, 37, 38). Annual counts should be consistent in a well-established colony. An oil spill or collapse of a major food stock or radical change in ocean temperatures will affect numbers quickly (e.g. 34, 16, 3, 39, 32, 40).

To predict when and what to census, the natural history of the species needs to be known. Black-legged Kittiwakes, for example, will sit on nests even if no egg is present to retain ownership of their scarce nesting site (36). Tufted Puffins often stand outside their burrows in the early morning, where at other times they are inside their burrows and are thus invisible for censusing. Pigeon Guillemots are best censused at both high tide and during the morning to obtain optimal colony attendance (41).

Many researchers have looked at population numbers over a period of years (28, 23, 31, 33, 34, 18). In these studies, the long- term effects of abiotic and biotic factors can be separated from short-term effects.

Another indicator of abiotic and biotic conditions is the reproductive success of marine birds (42, 15, 43, 40, 26, 44). There is growing evidence that abiotic factors like ocean temperatures, rainfall, and wind can influence abundance, distribution, and catchability of prey in some oceanic areas (45, 46, 47, 48, 3, 4, 21, 10, 49, 6, 50, 51, 52). Prey abundance and availability in turn influence reproductive success (53, 42, 3, 21, 10, 58, 50, 51, 43).

Thus, a better measure than population surveys of changes in abiotic or biotic parameters is reproductive output of seabird colonies over a long period of time (28, 40, 54, 55, 3, 43, 11, 44). Short-term fluctuations in reproductive output are the norm, with many of these long-lived species sacrificing egg or chick success in a scarce food year (e.g. 53, 55, 3, 15, 56, 23, 57, 12, 10, 58, 59). Yet, if studies are conducted over a period of years, any significant changes in output will be detected. Drastic changes in success from one year to the next could most likely be a reflection of concomitant changes in the prey base. This could mean either that prey are unavailable (have moved elsewhere due to abiotic factors, e.g. El Niño's bringing in warmer waters (60, 61, 55, 3) or are stratified at depths where they are uncatchable (10), or else that prey stocks are low. There are many examples of this (3, 21, 10, 36, 62, 63). Most recently, just before the anchovy collapse off Mexico, there was a breeding failure of Brown Pelicans that nest on the Cornado Islands close to the anchovy fishing grounds (D. Brewer, pers. comm.). Up to 80% of these nests were abandoned in March before the summer anchovy collapse. Brown Pelicans could have been used as a predictor of a decrease in an important commercial species, and perhaps if commercial harvesting of anchovy had been stopped at that point, the collapse may not have occurred.

The major problem with counting offspring is knowing at which stage to census them: at laying (e.g. number of eggs laid), at hatching (e.g number of eggs hatched), or at fledging (e.g. number of chicks fledged). There are accuracy problems with each stage.

If only eggs are counted, this census will reflect only abiotic and biotic events affecting the parents up till egg laying. Abundance of food is known to affect laying either by increasing the number of eggs or by increasing the eggs' weight (64, 65, 37, 26, 66, 10, 58). Thus egg weight should also be measured. Caution must be used if the species migrates back and forth between the breeding and wintering grounds, for egg counts or weights may reflect the conditions present on the wintering grounds. In addition, the census date is important to ensure accuracy (35). A knowledge of the chronology of the colony under study is thus needed.

Another cause of reproductive failure could be the presence of a pollutant, such as DDT (67) or petroleum (68, 69, 70, 71, 72, 73, 29, 34) which could affect the birds either directly (e.g. eggshell thinning) or indirectly (negative effect on the food web).

Weather and prey may also drastically change over the next stages, the incubating and chick stages, and thus the egg or chick success is also important to measure during these periods. The percentage of eggs hatched gives an indication not only of abiotic and biotic factors occurring during incubation or hatching, but also may give an indication of the presence of pollutant loading if hatching success is low but laying success is high (67).

If the population is regulated more by density independent factors like weather or denisity dependent factors like food availability and not by nest space, then the number of offspring that are produced in a colony may be the most accurate measure of population stability (81). However sometimes this is the most difficult stage for which to obtain an accurate count. Many chicks hide in vegetation away from the nest until they fledge, (49, 36, 38) and other chicks leave the colony before they can fly (e.g. Ancient Murrelets, murres) and the researcher has difficulty estimating survival of chicks who fledge at sea (36, 74). Weight gain by chicks has also been used as an indiator of marine resources in oceanic systems (47, 75, 64, 76, 3, 26).

If numbers of offspring produced are low, the next step is to try to determine the cause. If abiotic factors have been measured concurrently, corresponding changes may be found. If a correlation is found, we need to know if the abiotic parameter is of a direct or indirect nature. For example, does an increase in precipitation affect chick survival directly by soaking the feathers, or does it drive prey more deeply in the water where they are inaccessible? Do changes in temperature chill or overheat the eggs or chicks or do they drive the prey into other areas (3, 40, 10)? Might rain in the previous season affect chick output the next season by diluting the ocean surface where fish eggs (next year's prey) are laid inshore? On the other hand, might a large amount of precipitation wash fish eggs out to sea or kill them by the change in osmotic pressure? These factors all need to be determined.

If the effect of the abiotic factors can be established to be direct, then is this change just a brief deflection or does it herald a long-term overall change in oceanic conditions? A rain storm or cool temperatures during hatching may rapidly decrease the chick output of any given year. However, unless this abiotic pattern is repeated year after year, and seems to be an established change, then effects on the population as a whole will probably be small, barring other factors. Only measurements on long-term studies will provide an answer. Presence of DDT and lack of success of Brown Pelicans is probably the best known study on direct cause and effect (67). After DDT was banned in the United States, the success of Brown Pelicans there increased remarkably after having been on a decline since use of DDT began.

To obtain the best overall picture of what is occurring throughout various trophic levels in the oceanic ecosystem, a varitey of seabird species should be monitored. If several species at a colony are studied, each one may be an indicator of a different marine resource, depending on its prey preference and method of foraging. Thus the condition of many marine resources can be observed independently through sampling their seabird predators (42, 26, 9).

The determination of abundance and distribution of prey over a period of years is one of the most accurate means of sampling the long-term effects of oceanic parameters on all biota in the food web. Sampling for invertebrate or vertebrate prey directly is difficult, because prey are patchy. The best way to analyze this problem is to use seabirds as biological sampling devices. If quantitative data on fish populations are required to make predictions about their population trends, seabirds can also be used as the samplers. Seabirds are upper trophic level consumers, wide-ranging and diverse in their feeding habits. They are probably the best samplers of what available fish and invertebrate populations are present (77, 23, 24, 43, 11). By obtaining prey samples from seabirds, the presence of some abiotic factors, e.g pollutants, can be observed (79, 67, 78).

One method to sample prey would be to search for flocks of feeding seabirds and collect an adequate number of birds for analysis. Although seabirds are more visible than fish, they are still patchy and fairly unpredictable, and the problem of obtaining samples that reflect oceanic changes may still not be solved because of poor sampling techniques. Likewise, stomachs are often empty from seabirds collected in this way (P. Baird, G. Sanger, unpubl. data). The best way to sample prey is to obtain food from adults or chicks in the seabird colonies (36, 80). This way, information on seabirds' prey may be added to data on their populaton numbers and reproductive output. Thus one can obtain a more complete picture of what is occurring in the oceanic ecosystem.

Concurrent studies on prey and predators have been carried out on a variety of species including the Elegant Tern, Brown Pelican, Rhinoceros Auklet, Black-legged Kittiwake, Common Puffin, Glaucous-winged Gull, Tufted Puffin, and California Least Tern (81, 82, 11, 12, 63, 10, 58). The main drawback of analyzing prey is that it is more time consuming than censusing adults, eggs, or chicks. This defect, however, is overridden by the more accurate picture given by prey analysis, especially if concurrent measurements on abiotic factors have been made. Conclusions might then be reached of how the measured abiotic factors might be affecting both the prey base and the seabirds, (e.g. 10, 58). Likewise, care must be taken to measure the same age class and breeding stage of bird each year, for it has been shown that different age classes and different reproductive stages consume a different suite of prey species (59).

The natural history of the most important prey species of a seabird population is necessary to make inferences about how these prey might be affected by abiotic changes in the environment (18). Do they school? Do they stratify at depth at certain temperatures? Do they lay their eggs inshore where they might be heavily affected by runoff from an unusually wet year?

Common measurements of prey are frequency of occurrence, percent numbers, weight and length and overlap (77, 83). The natural history of seabirds must also be taken into account when analyzing prey data because it is important to know whether the birds are feeding over a large segment of the water column or if they forage only on the surface. Surface feeders are often more limited in their choice of prey than are seabirds that forage throughout the water column.

Whether a seabird is a specialist or a generalist must also be accounted for when analyzing prey from year to year. If a seabird is a generalist, there are alternate foods to choose from if a favored prey is absent one season. These species can turn to other prey to feed chicks and to raise a healthy crop of young. On the other hand, if the species is a specialist, then a crash in a particularly important prey will severely affect their output of young (e.g. 58).

Even for a generalist, a change in diet breadth is an indication that something has happened to the preferred prey (36). It is therefore best to study more than one species of seabird to obtain the best picture of which changes are occurring in the ecosystem. And it must be kept in mind that for the same effect, e.g. food shortage, different species react in different ways (42, 26, 9, 10).

If we monitor more than one species, say a generalist and a specialist, a surface feeder and a diver, a surface nester and a burrower, then we can narrow down the factors which might be affecting the reproductive output, population numbers or food. A year with a high rainfall may not only soak newly hatched chicks, it might also push the preferred prey into deeper waters where only divers are able to catch them (10). A typical finding in this situation might be: presence of preferred species in divers and not in surface feeders, expansion of the prey base by generalists, higher relative reproductive output by burrowers than by surface nesters, a low reproductive output by surface feeding specialists (10), or low adult weights and smaller clutches and even a change in numbers of extra-pair copulations in other species (58).

CONCLUSION

Seabirds, because of their highly visible and relatively stable colonies, can be used as indicators of the health of the ocean. Detection of changes in populations of fish or invertebrates is difficult because of their lack of visibility and their patchiness in space and time.

Observations of annual population numbers of seabirds, of their annual reproductive success, and of their prey can reveal patterns which are often correlated with food-rich or food-poor years, (53, 42, 55, 3, 21, 10, 63, 51, 56, 43, 57, 74). Prey abundance in turn can be correlated with abiotic changes in the oceanic environment (47, 48, 4, 50, 51, 52, 6, 10, 58). From these observations, predictions can often be made about trends in fish or invertebrate populations or even in long-term changes in abiotic factors. Thus much of the information about the oceanic ecosystem that appears hidden or obscured or at best difficult to obtain, can actually be found when seabirds are used as biological indicators.

ACKNOWLEDGEMENTS

The idea for this paper was first hatched in the summer of 1977 on a seabird colony off Kodiak Island, Alaska. These fledgling ideas were subsequently presented at a meeting of the Pacific Seabird Group in December 1977, and much discussion ensued with especially: Gerry Sanger, Alan Moe, and George Hunt. I thank numerous others who helped me refine my ideas for subsequent presentation at the Southern California Academy of Sciences meetings in 1991. I especially thank Dee Boersma and Kees Vermeer, who contributed excellent suggestions for improving a first draft of the manuscript. I also thank Sue Yoder, University of Southern California Sea Grant Program, for her forebearing and relentless encouragement and enthusiasm.

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