

# Seabird-fishery interactions: a manager's guide

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## SUMMARY

Fishing activities by humans can affect seabirds either directly, through death and drowning, or indirectly, through effects on prey of marine birds. Interactions are diverse, with outcomes that range from beneficial to detrimental for birds. Outcomes for humans are similarly diverse. Three different ratios—Horn ratio (dietary overlap), Evans ratio (prey mortality due to birds, relative to stock size) and Wiens ratio (prey consumption relative to production)—have been developed to diagnose the potential effect of birds on commercially important species. The Shaefer ratio (catch by birds relative to catch by fisheries) and the Bourne ratio (avian consumption relative to lateral resupply) can also be used to diagnose the potential effect of fisheries on seabirds. Decisions about the conservation of seabirds are necessarily taken in an economic and political context; and because of limited information decisions typically must be made where uncertainty is great. We examine the consequences of Type I uncertainty (believing that interaction occurs when none is present) and Type II uncertainty (believing no interaction occurs when it does). Many interactions detrimental to seabirds are incidental rather than directed at birds; this suggests that enlisting fishermen as allies would be an effective alternative to regulatory steps.

Human fisheries can affect seabirds directly or indi-

rectly in a wide variety of ways. Most attention has been directed at accidental deaths (e.g. King 1984, Ogi 1984, Atkins and Heneman 1987) and at competition (e.g. Furness 1982, Furness and Monaghan 1987). However, fishing activities affect seabirds in many other ways, both positive and negative. This paper reviews the diversity of seabird-fishery interactions, discusses practical means of detecting and estimating them, and assesses available management options. This review is aimed at the wildlife and fishery manager attempting to make wise choices when resources and information are limited. The approach is rather different from that used in traditional academic research, which seeks conclusions based on high levels of confidence that the results are correct. In management, decisions must be made in the face of considerable uncertainty (Walters 1984). Bross (1987) has called this difference an 'information gap', stating that 'it is not generally perceived that data collected within the rigorous academic tradition in which the scientific community operates are well in excess of the accuracy and predictive power sufficient for the commercial sector'.

We suggest managerial approaches that limit damage even when the wrong decision is made, rather than methods that are optimal or correct at 95% confidence limits, and we examine some of the economic and political limits to management. Finally we examine some possible means of escaping these limits.

**S**EBIRD-FISHERY interactions described in the literature are extremely diverse (Table 1). From a seabird perspective, they range from the strongly negative, such as the use of birds for bait and the death of birds in fishing nets, to the positive, such as the provision of offal to birds or the removal of competitors. For humans, negative interactions include piracy of bait, encircled prey and landed fish, and the fouling of boats, while positive effects include the use of seabirds to guide fishermen to schools of fish. Many seabird-fishery interactions

are more subtle, involving competition between humans and birds for the same prey species. These interactions may be negative for both birds and the fishery, although the two are unlikely to be affected to the same extent. This paper focuses on those interactions likely to produce serious negative consequences for either seabirds or the fishery. We do not examine positive or neutral interactions such as scavenging by seabirds, removal of seabird competitors, seabird fertilization of inshore waters or use of birds to guide fishermen to schools (Table 1). We

also ignore negative interactions by roosting and seabird

## PRACTICAL ASSESSMENT

It is most useful to divide seabird-fishery interactions into two groups: (1) those that are directly detrimental through use and (2) those that are indirectly detrimental because of their effects on the reproductive success of seabirds for commercial fisheries.

## Mortality

Most mortality is caused by direct interactions, such as single reproductive failure or foundering.

Table 1. Examples of the diverse seabird-fishery interactions. The table lists the interactions between seabirds and marine prey.

also ignore what appear to be rare or only mildly negative interactions such as fouling of fishing boats by roosting seabirds, seabird piracy on landed fish, and seabird 'wrecks' endangering fishing vessels.

### PRACTICAL MEANS OF DETECTING AND ASSESSING INTERACTIONS

It is most useful to divide seabird-fishery conflicts into two groups: (1) those causing direct mortality, through use of seabirds as bait and through net kills; and (2) those that may result in changes in seabird reproductive performance or population dynamics because of competition between birds and fisheries for common prey.

#### Mortality

Most mortality in seabird-fishery interactions is one-sided, caused by the fishery on seabirds, although a single report of a fishing vessel in Alaska almost foundering because of auklets landing on it (Dick

and Donaldson 1978) suggests that the converse might occasionally occur. Mortality can be caused by a variety of means: drowning in nets, drowning while taking baits, direct predation by fishermen to use birds as bait or as food, or to reduce perceived competition from birds (Table 1).

Mortality can best be measured directly at fishing operations (Wild in Jones and DeGange 1988). Measurements can be biased if the presence of observers restricts the behaviour of fishermen or if fishermen are actively hostile to observers. Observations of fishing operations from adjacent vessels can be used, as can counts of birds floating dead behind fishing vessels or washed up dead on beaches. The latter represent only a minimum count because many more birds may float out to sea and/or sink.

Once the mortality per fishing operation is known, it can be extrapolated to the fishery as a whole (Jones and DeGange 1988). Care should be taken to consider variations because of bird migrations or nesting seasons and because of varying fishing activity

	Marine ecosystem	References
<b>A. Remove seabird predators through fishery mortality:</b>		
	Benguela Current	Shaugnessy 1984
	Southern Ocean	May <i>et al.</i> 1979
	Humboldt Current	Schweigger 1964
<b>B. Increase food for seabirds from fishery offal:</b>		
	North Atlantic	Fisher 1952, Oliver 1983
		Hudson and Furness 1988
	Benguela Current	Abrams 1983
	North Pacific	Wahl and Heinemann 1979
<b>C. Seabirds almost sinking fishing vessel:</b>		
	North-west Pacific	Dick and Donaldson 1978
<b>D. Reduce seabird food through fishing:</b>		
	California Current	Baldrige 1973, Ainley and Lewis 1974
	Humboldt Current	Jordán and Fuentes 1966
	Benguela Current	Burger and Cooper 1984
<b>E. Reduce seabirds through direct mortality from fishing:</b>		
<i>Use as bait</i>	North Atlantic	Collins 1884
	Straits of Magellan	
<i>Nets/lines</i>	North Atlantic	Tull <i>et al.</i> 1972, Piatt <i>et al.</i> 1984
		Piatt and Nettleship 1987
	Humboldt Current	Jordán and Fuentes 1966
	Southern Ocean	Brothers 1991, Croxall 1990
	North Pacific	Carter and Sealy 1984
	Mediterranean	Guyot 1988
	California	Atkins and Heneman 1987
<b>F. Increase fishery through locating prey:</b>		
	Pacific	Au and Pitman 1986
	Caribbean	Erdman 1967
	Oceania	Johannes 1981
<b>G. Increase fishery via fertilizing waters by guano run-off:</b>		
	Peru	MacCall 1984
	South Africa	Bosman and Hockey 1988
<b>H. Reduce fishery landings through seabird consumption:</b>		
	Humboldt Current	Schaefer 1970
<b>I. Reduce fishery landings through piracy or consumption by seabirds:</b>		
	Ecuador	Buckley and Tilger 1983
	Shetland	Ewins 1987

**Table 1.** Examples of the diversity of interactions between seabirds, humans and marine prey.

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(i.e. closed seasons, shifts in fishing effort or target species).

The mortality must then be compared to the size of the bird population and to its annual reproduction. A problem is likely to be severe or a crisis level if mortality from the fishery is approximately equal to reproduction. Even if mortality is perhaps 10% of the estimated reproduction, a strong possibility of a problem exists, as other sources of mortality also occur. Comparisons are easily made for species such as the Galapagos Flightless Cormorant *Nannopterum harrisi*, which has a small, local population and easily monitored breeding success (Harris 1974), but it may be impossible in practice for abundant, wide-ranging migrants such as terns or shearwaters where mortality can occur a hemisphere away from reproduction and where the population may range into the millions.

### Competition

Three methods have been used to identify the potential for competitive interactions between seabirds and commercial fisheries: (1) ratios of prey consumption by birds and the fishery relative to prey standing stock and turnover; (2) population studies, i.e. inferences of changes in bird numbers linked to changes in fisheries; and (3) studies of seabird reproduction and diet in relation to changes in fisheries and fish stocks. None of these indices are entirely satisfactory, but they are feasible. Used cautiously, they are adequate for indicating when competition between fisheries and seabirds may be occurring. Used even more cautiously, population and reproductive studies may help assess the strength of the competition. Finally, all three sorts of studies, used together, may be of help in understanding the actual, undoubtedly complex, mechanism of competition.

### Ratios of prey consumption

A number of ratios have been developed to measure the potential for interaction between seabirds and fishery vessels. We have taken the liberty of naming them after some of their original proponents, as an aid to memory. Three of them, the Horn, Evans, and Wiens ratios, may be especially useful in judging whether seabirds are reducing commercial fishery harvests, as fishermen often claim. Conversely, the other two ratios, Schaefer and Bourne, may be more useful in determining if the fishery is affecting seabirds. Further development of these indices from a fluid dynamics perspective can be found in Schneider *et al.* (1992). Taken together (Figure 1), the ratios allow a reasonably objective way of detecting seabird-fishery conflicts.

These ratios are calculated from environmental measurements such as estimates of bird numbers

(e.g. Sowls *et al.* 1978), seabird food intake or daily energetic requirements (e.g. Furness 1978, Ellis 1984, Wiens 1984, Furness and Monaghan 1987, Birt-Friesen *et al.* 1989), seabird diet (Duffy and Jackson 1986), seabird foraging ranges (e.g. Stahl *et al.* 1985, Fasola and Bogliani 1990, Wanless *et al.* 1990), fishery landings and effort (Ricker 1975) and prey population and production (Ricker 1975).

Many of these measurements are sensitive to the type of environmental method chosen, and can vary greatly both in time and space (Harrison and Seki 1987). It may be possible to estimate some of them only to the nearest order of magnitude. The precision of the ratios cannot be greater than the precision of the least-known variable. Thus, it would be of little use to know the daily consumption per bird to three significant figures (i.e. the nearest 0.1 kg) if the fishery stock or bird population is known only to the

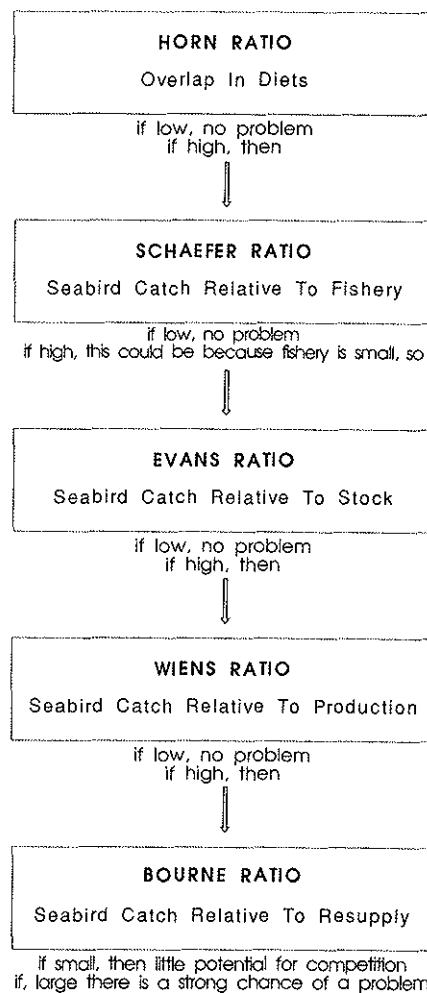


Figure 1. A flow chart for examining the potential for seabird-fishery conflicts.

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**Horn ratio.** Most attention to collection of data on seabirds as a whole is able, but the

If a fishery is small, then, usually valuable. If a fishery is small, then, usually valuable. If a fishery is small, then, usually valuable.

**Evans ratio.** This is the ratio of seabird catch to fishery stock. It is divided by the stock mass. Catch is calculated as bird population intake per unit time, the period of the diet percentage 10% g/T.

nearest order of magnitude. It is particularly important to collect data at comparable spatial and temporal scales. Comparing estimates of seabird food demand around a colony to prey densities across the prey's entire range might give the nonsensical result that seabirds cannot exist. The extrapolation of data on seabird diets from the breeding season to the year as a whole could also give erroneous results. In the absence of data, generalizations may be unavoidable, but they should be interpreted with care.

#### Horn ratio

Most attention has been devoted to examining competition within seabird communities (Lack 1970 and references therein). Relatively little attention has been devoted to measuring feeding overlap between seabirds and fisheries. Any study of potential seabird-fisheries conflicts should start by determining the degree of overlap in the diet of seabirds and fishery landings. We suggest the use of Horn's (1966) modification of Morisita's Index, used by Diamond (1983) where  $C$  is the degree of overlap ( $0 =$  no overlap,  $1 =$  complete overlap),  $x_i$  and  $y_i$  are the proportion of the same prey  $i$  in the diets of seabirds and in the fisheries landings:

$$C = 2 \frac{\sum x_i y_i}{\sum x_i^2 + \sum y_i^2}$$

If a fishery and a seabird species show low overlap, then, unless the prey taken by both is extraordinarily valuable as a commercial resource in its own right, the seabirds would not be seriously competing with the fishery.

Even when fisheries and seabirds overlap considerably in prey taken, they may differ in the sizes of prey (Idyll 1973). Wilson (1985) presented evidence that penguins and purse-seiners also differ in the size of anchovy schools they attack. The penguins favoured small, widely dispersed schools while the purse-seiners were most efficient when targeting large, dense schools.

#### Evans ratio

This is the catch by birds ( $C$  = catch in tonnes) divided by the average mass of the prey stock ( $S$  = stock mass in tonnes) during the period of interest. Catch is conveniently estimated as the product of bird population size ( $N$  = number of birds), daily intake per bird ( $I$  = grams ingested per bird per day), the period of interest ( $T$  = days) and the percentage of the diet made up of the prey species ( $D$  = the percentage of the diet during time  $T$ ), where  $K_i$  is  $10^6$  g/T:

$$\text{Evans ratio} = \frac{N \times I \times T \times D}{K_i \times S}$$

This measure was first used on birds by Schaefer (1970), who found a value of 0.16 for the ratio of Peruvian anchoveta *Engraulis ringens* consumed by birds compared to the total fish population. In the North Sea, Evans (1973) found a value of 0.06, similar to a later range of values of 0.05–0.08 estimated by Bailey and Hislop (1978). Similarly small values are believed to occur for birds in the California Current (MacCall 1984) and the Sea of Okhotsk (Shuntov 1986). Larger values may occur in small areas. In the southern Benguela Current, Furness and Cooper (1982) estimated a ratio of 0.23 within the foraging radius of seabird colonies at Saldanha Bay, South Africa. For the entire Benguela ecosystem, the ratio varied from 0.02 to 0.11 over an eight-year period (Duffy and Siegfried 1987).

#### Wiens ratio

Standing stock or a single measure of the population size of fish, used in the Evans ratio, may be the only information on prey populations available. Unfortunately, this value can be misleading for smaller, faster-growing, and short-lived species where production (biomass grown and reproduced) may be a substantial fraction of total biomass, compared to the biomass of fish in existence at any one time, based on calculations from equations by Banse and Mosher (1984).

Where estimates of total production are available, they can be used to produce estimates of consumption that are more informative than the Evans ratio. Production can be calculated either by application of cohort analyses and somatic growth curves for fish (Ricker 1975) or, much more crudely, by obtaining primary production values either from local studies or from atlases (e.g. Koblenz-Mischke *et al.* 1970) and assuming a 10% transfer efficiency to the third trophic level (seabird prey). For example, if a marine area has a primary production of 1.0 g carbon per m<sup>2</sup> per day, then at the third trophic level, this would be a production of 0.001 gC/m<sup>2</sup>/day. Multiply this by the area under study (either an ecosystem or the estimated foraging range of species around a nesting site) for the estimated total production. This is then compared with the estimated intake by seabirds, using methods described for the Evans ratio, so that:

$$\text{Wiens ratio} = \frac{N \times I \times T \times D}{K_2 \times b^3 \times P \times A}$$

where  $b$  is the transfer efficiency (typically 10%),  $P$  is the primary production (gC/m<sup>2</sup>/day) in an area ( $A$  = m<sup>2</sup>) by seabirds during a period of  $T$  days, and  $K_2$  is 0.11 g wet per gC. Time periods must be the same for both numerator and denominator, so:



$$\text{Wiens ratio} = \frac{N \times I \times D}{K_2 \times b^3 \times P \times A}$$

Wiens and Scott (1975) obtained a ratio of 0.22 for seabirds consuming small pelagic fish in the northern California Current. At a smaller spatial scale, Springer and Roseneau (1985) found a Wiens ratio of 0.37 for seabird consumption of pollock, based on primary productivity. This ratio appears to rise to 0.4–0.8 around one island colony (Springer *et al.* 1984). Furness (1978), using a 45 km foraging range and primary productivity values, found a ratio of 0.29 in the North Sea, whereas Bourne (1983) and Bailey (1986) found values of 0.054 and 0.05–0.08 for the entire sea. In the Benguela upwelling ecosystem, Duffy *et al.* (1987a) found a value of 0.058. Polovina (1984) and Harrison and Seki (1987) reported a ratio of 0.42 for seabirds at French Frigate Shoals, Pacific Ocean. Wingham (1989) suggested that the ratio of consumption by Australasian Gannets *Morus serrator* to fish production in the Hauraki Gulf, New Zealand, was 0.035–0.109 and that the gannets accounted for 'between a third to a quarter of all seabird predation of fish production' in the same area.

A simple plot of catch versus primary production (Figure 2) suggests that catch by seabirds is a log linear function of primary production, so that an expected value of the Wiens ratio can be calculated from the best-fit regression equation in Figure 2. However, the relationship is very imprecise for practical applications.

Low Evans ratios (<0.10) and Wiens ratios (<0.10) suggest that seabirds are relatively minor consumers in an ecosystem and thus unlikely to be important in determining the availability of prey for commercial fishermen. However, these ratios may be useful for evaluating situations where fishermen call for the destruction of bird populations to increase fishery yields. The converse does not hold: low ratios do not

necessarily indicate that seabirds are unaffected by commercial fishing. The following two ratios may be more useful in assessing this.

#### Schaefer ratio

Schaefer (1970) compared the catch of a prey species by birds ( $N \times I \times D$  = tonnes per day) to the catch by fishing vessels ( $F$  = tonnes per day):

$$\text{Schaefer ratio} = \frac{N \times I \times D}{F}$$

Values in upwellings include: 0.3 for Peru; c.0.5 for the Benguela ecosystem (Duffy *et al.* 1987a); and 0.25–0.5 for California, based on all commercial landings (Briggs and Chu 1987). In the central Pacific, Harrison and Seki (1987) found a Schaefer ratio of 87.0, but noted that there was little overlap in the prey taken by the birds and the fishery. In the North Sea, Bailey and Hislop (1978) found a ratio of 0.03 relative to all commercial landings; Furness and Barrett (1985) found a minimum value of 0.003 for the waters off northern Norway.

High values of the Schaefer ratio (>0.25) would seem to indicate considerable potential for competition, but such values can be misleading if not used carefully. For example, extreme values occur when the prey overlap (Horn ratio) is low, or when a fish species is only a marginal part of fishery landings. High values are also misleading if there is a low overlap in fishing zones between seabirds and fisheries (Schneider *et al.* 1987). For example, Walter *et al.* (1987) found a high overlap in the Schaefer ratio of anchovy taken by Crested Terns *Sterna bergii* and commercial fisheries in the Benguela upwelling, but the two predators operated in different areas. Wilson *et al.* (1988) found a similar situation for anchovy taken by the South African fishery and African Penguins *Spheniscus demersus*, with the penguins usually feeding inshore of the fishery.

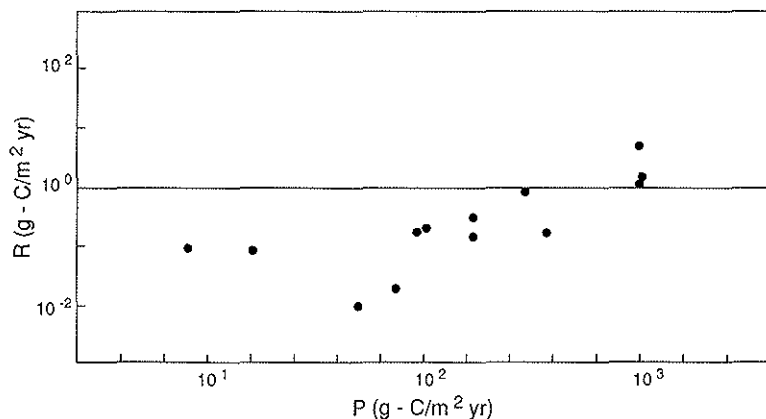


Figure 2. The relationship between annual primary productivity and avian energetic requirements from 14 studies in 12 ecosystems (Schneider 1992). All units are gC/m²/year.

#### Bourne ratio

The Schaefer ratio system, like a lake, is affected by currents, mating speeds of seabirds, one can prey species, ( $N$  : advective resupply. Resupply can be prey passing through the circumference  $r$  is the foraging

Bourne

At South Georgia, the krill collapsed the standing stock population with a typical current radius of 80 km. The resulting Bourne ratio indicates that resupply is low.

In Hudson Bay, a foraging range of 100 km and an average current speed of 1.9% per day in 30% of stock over loss is 0.3% per day.

In the Saldaña upwelling, Furness estimated an Evans ratio of 0.058 known to prey on the bay, so the Bourne ratio is a passive transpiration radius of 30 km.

A Bourne ratio of competition for fish is less likely, as focus is outside, but it does fishery and the stock, at a much

#### Population dynamics of seabird-fishery

Exploited fish populations in their life stages in their population; (2) a sure; (3) an abrupt population level seabird population fishery landings and strengt and fisheries. So with caution. Th

### Bourne ratio

The Schaefer ratio assumes that prey exist in a closed system, like a lake. In reality, the prey can be replenished by currents or voluntary movements. By estimating speeds of prey movement and the range of seabirds, one can calculate the consumption rate of a prey species,  $(N \times I \times D) / (K_f \times S)$ , relative to the advective resupply of that species (% per day). Resupply can be estimated as average velocity of prey passing through the area ( $v = \text{km/day}$ ) divided by the circumference of the foraging range ( $2\pi r$ ) where  $r$  is the foraging radius (km). The result is:

$$\text{Bourne ratio} = \frac{N \times I \times D \times 2\pi}{v \times S}$$

At South Georgia, Croxall and Prince (1987) estimated the krill consumption by birds as 80% of the standing stock per month or 2.7% per day. However, with a typical current speed of 0.3 m/s and a foraging radius of 80 km, the resupply rate is 16% per day. The resulting Bourne ratio is  $2.7/16 = 0.17$ , which indicates that resupply is far greater than consumption.

In Hudson Bay, Cairns and Schneider (1991) report a foraging range of 160 km in an area with an average current speed of 0.07 m/s. The resupply rate is 1.9% per day in this region. Assuming the catch is 30% of stock over a breeding season of 90 days, the loss is 0.3% per day and the Bourne ratio is 0.16.

In the Saldanha Bay area of the Benguela upwelling, Furness and Cooper (1982) originally estimated an Evans ratio of 0.23. This colony is now known to prey on an anchovy stock that moves past the bay, so the Bourne ratio would be 0.53, assuming a passive transport rate of 0.3 m/s and a foraging radius of 30 km.

A Bourne ratio less than 1.00 suggests that local competition for food between birds and fisheries is less likely, as food is continuously replenished from outside, but it does not reduce the possibility that the fishery and the birds are competing for the entire stock, at a much larger scale.

### Population dynamics, diet and reproductive performance as indicators of seabird-fishery interactions

Exploited fish populations frequently exhibit four stages in their history: (1) a large unexploited prey population; (2) a period of increasing fishing pressure; (3) an abrupt collapse; and (4) a continuing low population level afterwards. Historical changes in seabird populations can be related to changes in fishery landings as a means of evaluating the existence and strength of interactions between seabirds and fisheries. Such analyses must be approached with caution. They cannot be tested, and thus run a

real risk of being *post hoc* 'just so' stories, explaining everything. There is no guarantee that fisheries, as opposed to (or compounded with) other forces such as climatic events, are responsible for changes in fish stocks, or bird numbers, diet and breeding success (cf. Bailey 1989). Nevertheless, such studies can be quite valuable, as fish and seabird populations tend to vary greatly over short or long periods (Ainley and Lewis 1974, Cushing 1975, Duffy and Siegfried 1987).

Further caution is needed in analysing the data. Fish stocks and bird numbers from one year are unlikely to be independent of previous years. Annual measurements are not statistically independent of one another. Levels of statistical significance should be used only with caution. Owing to the short data runs, correlation values have to be very high to be significant, which increases the possibility of failing to detect competition when it is, in fact, occurring (Type II error). As in any study based on correlations, there is also the danger that fisheries and seabirds are responding independently to a third factor, such as climate.

Such studies may be most useful for generating predictions of seabird numbers and breeding performance in response to future conditions of the fishery, all other things being equal. For example, Furness *et al.* (1988) have suggested that increasing mesh size of nets and the consequent reduction in the percentage of small fish which are dumped as offal in the seas around the British Isles will make it harder for smaller seabirds to compete against larger ones. This may eventually lead to population decreases of the former.

Correlations can also be used to make predictions, although similar efforts based on past correlations have frequently proved unsuccessful when applied to fishery recruitment (Cushing 1975). Correlational studies generally require rather intensive measurements of both seabirds and the fishery at an annual or shorter time scale. Time-series analysis may be appropriate if the data series are long enough for the application of such methods (Box and Jenkins 1976).

In the best of all possible worlds, we could adjust bird populations and fishery landings between years, to calibrate regressions of bird and fish numbers and to conduct rigorous scientific experiments. In reality, environmental variability and sampling error are such that it might take centuries to get statistically significant results (e.g. Butterworth *et al.* 1988), even assuming that field experiments could be done at the right temporal and spatial scales. Modelling of predator-prey interactions may be more useful than field experiments and might generate predictions that can be tested in the field at realistic scales.

### Studies of seabird population dynamics in relation to fisheries

Ainley and Lewis (1974) have suggested that, following the cessation of direct human exploitation, populations of Double-crested Cormorants *Phalacrocorax auritus* and Tufted Puffins *Fratercula cirrhata* in the California Current ecosystem remained at low levels because of overfishing.

For the Benguela ecosystem off Namibia and South Africa, Crawford and Shelton (1978, 1981) and Burger and Cooper (1984) examined past abundances of seabirds in relation to changes in fish stocks. Numbers of some populations (Cape Gannet *Morus capensis*, Cape Cormorant *Phalacrocorax capensis* and African Penguin) decreased following the collapse of the sardine *Sardinops ocellatus* in the 1960s. However, several other local populations maintained themselves or increased after switching to anchovy *Engraulis japonicus capensis* or pelagic goby *Sufflogobius bibarbatus*.

### Studies of seabird diet in relation to fisheries

Diet data have been widely used because they are usually far easier to collect than are reproductive or population data (cf. Duffy and Jackson 1986). In the Benguela upwelling, Walter *et al.* (1987) found a positive relationship between the occurrence of anchovy taken by commercial fisheries and those of Swift Terns *Sterna bergii* on a one-week scale during one year; however, they found no relationship at all on an annual scale. Conversely, Berruti and Colclough (1987) found significant correlations on a monthly but not an annual scale for the pilchard *Sardinops ocellatus* taken by Cape Gannets and by the fishery in the same system.

Unfortunately, at annual scales, it is difficult to separate changes in diet of seabirds caused by fishing and by climatic events (e.g. Crawford and Shelton 1981, Blake 1984, Springer *et al.* 1984, Hislop and Harris 1985, Barrett *et al.* 1987, Montevecchi *et al.* 1987, Monaghan *et al.* 1989, Vader *et al.* 1991), just as it is difficult to determine if fishery collapses are caused by overfishing or climatic events (e.g. Radovich 1981).

### Studies of seabird reproductive performance in relation to fisheries

In the California upwelling ecosystem, Baldrige (1973) compared the reproduction of Brown Pelican *Pelecanus occidentalis* with sardine fishery landings and stock from 1933 through 1964. He found that breeding success corresponded roughly with landings of the local sardine *Sardinops sagax*: neither the fishery nor the pelicans were successful after 1944. During the 1970s, Hunt and Butler (1980) found an

association between the reproductive responses of two seabird species (Western Gull *Larus occidentalis* and Xantus's Murrelet *Synthliboramphus hypoleucos*) and the abundance of anchovies *Engraulis mordax* in the California Current ecosystem. Anderson and Gress (1984) found a correlation of 0.885 between anchovy biomass and pelican reproduction in the Southern California Bight and a correlation of 0.669 between percentage change in anchovy and pelican populations. We calculate a positive Spearman rank correlation of 0.624 between the anchovy catch and pelican nest productivity from Figure 1 in Anderson and Gress (1984).

In the Benguela ecosystem, Duffy *et al.* (1987b) examined the growth and diet of African Penguins at monthly intervals during 1980-1985 in relation to the size and composition of purse-seine landings and found a positive rather than negative correlation. The positive relationship between seabirds and fisheries in all these studies suggests that both the fishery and the birds were responding to food availability as opposed to competing for food.

The only apparent exception to this trend is a study in Peru (Duffy 1983) that reported a negative relationship between fishery landings in one year, and the percentage increase of the seabird population between that year and the next. During the study period, the fishery grew from negligible amounts to 14 million tonnes/year while the seabird population collapsed. This suggests severe competition.

### Measuring the intensity of interactions

As we have seen, it is not easy to demonstrate the existence of competition between a fishery and seabirds. It is even harder to measure the intensity of competition. One can measure the number of birds killed for bait or in nets, or the amount of offal and number of birds feeding on it. The impact of these on bird populations remains unknown, unless one knows the size of the bird population, its turnover rate, and how the fishery affects both of these. In assessing the impact of offal on bird populations, it may be relatively easy to record the number of birds feeding on offal around a particular ship (Hudson and Furness 1988, 1989), but it is difficult to use these data to extrapolate the proportion of the entire population exploiting offal, or the relative survival rates of individuals feeding on offal compared with other foods.

## MANAGEMENT OPTIONS AND REALITIES

### Deciding whether interactions occur

Given the estimates of these ratios, the past history of both the fishery and seabird populations, and perhaps a short-term intensive study, a manager must

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finally decide whether further action is warranted. It is highly unlikely that the correlation will be significant at the traditional 95% confidence level, given the great variability of seabird populations, marine environments, and fisheries. What is he or she to do?

The manager might well conclude that flipping a coin is the most effective management tool, but consideration of two other aspects of the data may help. First, what are the consequences of believing there is no interaction when there actually is (i.e. 'Type II error' to the statistician)? Are there endemic or endangered species that might be lost if nothing is done? Or are most of the species common and widely distributed? Are the foraging birds in a few areas, so that local food demand and thus competition might be localized and severe? Or are nesting colonies small and dispersed, so competition is likely to be diffuse? Second, what are the consequences if the manager believes an interaction is occurring when in fact there is none (i.e. 'Type I error')? What management actions are possible? Are the possible benefits of such actions for birds large relative to the costs to the fishery? Should the manager make a decision not to be right, but to minimize the cost of being wrong? Which type of error would cost more? Which is the 'least worst'?

#### Decision-making for the fishery resource

Even if the manager can show that populations of seabirds are threatened by commercial fisheries, this will be of secondary interest to decision-makers who see little value in seabirds and whose primary concerns are elsewhere. Seabirds have considerable potential or actual value for tourism (e.g. Tindle 1983), as environmental monitors (Vermeer and Westrheim 1984, Berruti 1985, Cairns 1987), as indicators of unfished stocks (e.g. Ricklefs *et al.* 1984) and even as buffers against overfishing (Duffy 1983). Their protection may be mandated by national law or international treaties (e.g. Gress and Anderson 1982, CCAMLR 1991, Harrison *et al.* 1992). However, these values and laws are often ignored when resources are allocated. Such decisions have little or nothing to do with biology; they are political.

Unfortunately, mechanisms to incorporate seabirds into regulatory decisions about marine ecosystems are frequently deficient, even when legally mandated. Bailey (1989) has suggested that seabird biologists imitate the mechanism used by fisheries biologists under the auspices of the International Council for the Exploration of the Sea (ICES) and regional fishery management bodies: 'it would be extremely helpful if the main bodies carrying out seabird monitoring could collaborate with a view to achieving a working consensus on population levels

and trends, and on food consumption'. Bailey (1989) suggests that such estimates be made for regions that match the ICES statistical-reporting areas, so that the seabird data are on the same spatial scale as fishery information.

Unfortunately, at present, convincing decision-makers through biological arguments is often an exercise in futility. When a seabird-fishery conflict exists, the seabird biologist may find his or her most effective action is to involve local environmental groups and then allow the political process to generate some form of compromise, allocating sufficient resources for the seabirds.

Such compromises are most likely in countries that can afford them, because of their high standards of living, or because fishing has ceased to be a major part of their economies. Elsewhere, reserving resources for seabirds will be much more difficult. For example, small-scale fisheries account for 27 million tonnes of the total world catch of 49 million tonnes and employ 95% of the world's 10.5 million fishermen (Troade 1988). In such artisanal fisheries seabird conservation problems can only be dealt with locally, by enlisting the interest and support of local fishermen, and not by regulations drawn up by centralized bureaucracies detached from the lives of the fishermen.

Outside assistance, ranging from tourism to international expressions of interest, may help in such situations, but this can never be a substitute for the active participation of national scientists and conservationists, familiar with the local culture. Regrettably, such scientists are hamstrung by lack of resources (Cooley and Golley 1989). One of the fundamental contributions to international seabird conservation must be the steady building of infrastructure and support for scientists in developing nations.

#### Management options

Even if the battle is 'won' and decision-makers agree to allocate resources to birds, two questions remain: 'How is this best done?' and 'How much is sufficient?'. At present we have only a limited ability to answer these questions. A manager will rarely if ever be able to say that 1,000 tonnes more fish landed by a fishery will result in some number 'x' fewer birds being raised or surviving, while the fishing industry can easily show that 1,000 tonnes more fish will generate more jobs or more income for a fishing community. A manager may be on firmer ground with the mortality of birds caused by fishing activities, where estimated deaths can be compared to reproduction to get an idea of acceptable levels of mortality.

One solution to apparent competition is to limit the commercial catch, setting aside sufficient food to



A final possibility is to enlist the fishermen as allies. Conservationists have too often wanted fishermen to pay the price for seabird conservation. If conservation is necessary, its cost must be borne by everyone. This can occur through tactics such as subsidizing fishermen deprived of fish or fishing grounds, aiding them to convert to tourism or to other prey species, and supporting the fishermen's political efforts, whether these be against pollution, taxes, or competition. Supporting the creation of 'limited entry' or 'closed' fisheries, those that limit the number of boats or fishermen exploiting the resource, may be the only way to ensure the protection of common resources such as fisheries, as 'open' fisheries provide little incentive for the protection of resources (Gordon 1954, Berkes 1985, Keen 1988). Without such protection, seabirds that rely on fishery resources will always remain at risk. Unfortunately, the change to closed fisheries may be politically controversial in existing open fisheries (cf. Passel 1991).

Fishermen themselves may have the best ideas about which seabird populations are most at risk from competition and how such mortality might be reduced. For example, Brothers (1991) found that Japanese long-line fishermen have developed ways to reduce the mortality of albatrosses which their fishery causes. This has the potential of saving tens of thousands of albatrosses in the Southern Ocean and *millions of dollars* in fisheries landings. The technique would probably not have been developed if conservationists had used boycotts and confrontation. Cooperation convinced decision-makers that the price for conservation is increased fishing efficiency.

It is an unfortunate truism of scientific research, much bemoaned by managers, that scientists always call for further research. We have no wish to ignore tradition, so we will finish by identifying several topics that still need investigation.

- The managers, despite much good intentions, are typically, we argue, in a variable environment. Scientific 'proof' let alone their systems as do fish managers too of fishery interactions much less to a nation. In this view, conservationist action and short-term thinking to work have have any real incentives for conservation want to manage need to know regulating fish

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## CONCLUSIONS

The management of seabird-fishery interactions, despite much good work, is still in its infancy. Scientifically, we are faced with too few data and highly variable environments that restrict the available scientific 'proof' of the existence of these interactions, let alone their strength. Here we face the same problems as do fisheries biologists. Politically, seabird managers too often lack the expertise to put seabird-fishery interactions on national or local agendas, much less to achieve a politically sustainable solution. In this we face the same problem as many conservationists who have been long on confrontation and short on negotiation. Solutions that are going to work have to benefit both sides, but few of us have any real idea of the constraints on and opportunities for conservation in the fishing industry. If we want to manage and to conserve seabirds wisely, we need to know the economic costs of fishing and of regulating fisheries.

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## SUMMARY

Among the threats of a universal physical environment sufficient to influence behaviour. It is eggs, your products. breeding habits, or nesting chemicals, petrels for islands, section, economic to the preservation with

ALL birds are affected by weather, food, sites, diseases. Each of these ways, and they impact far greater weather, prey, seabirds breed are often more because of habitat, and factors.

In this paper, survival and reproduction, generally, continental seabirds