Beach patrol records indicate a substantial decline in sooty shearwater (*Puffinus griseus*) numbers

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Abstract Between 1961 and 1999 the number of adult sooty shearwaters found dead on beaches in northern New Zealand declined by about 64.4% and the number of fledglings by about 77.7%. Only 2 factors that we know about have been acting on the sooty shearwater population during the period studied and could have caused such a dramatic decline; a rise in sea temperature perhaps as a result of movement of the Sub-Antarctic Front and increase in harvest. Two other more recent phenomena, north Pacific fisheries mortality and climatic variation (El Nino Southern Oscillation and Pacific Decadal Oscillation), may be involved, but we cannot find any direct evidence of their impact in our data. The impact of this decline has been recently found on the breeding islands. More study is required to fully understand how weather, patrol frequency, deposition rate, persistence rate, and live bird numbers vary and interact. Deposition and persistence experiments similar to those reported from overseas need to be done in New Zealand.

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INTRODUCTION

Monitoring of the number of beach-wrecked seabirds has recently become a valued conservation and monitoring tool (Camphysen & Heubeck 2001). New Zealand has been a pioneer of such "beach patrols". Long before the monitoring of seabird numbers in response to increased levels of human induced mortality, members of the Ornithological Society of New Zealand (OSNZ) walked beaches out of enjoyment and curiosity, recording the number of beach-wrecked birds encountered. The reports of the OSNZ (e.g., Taylor 1999) over the past 50 years, summarised the distances covered, species and numbers of beach-wrecked seabirds observed on patrols. Often these reports included comments on interesting points. However, a few (e.g., Powlesland & Pickard 1992) have concentrated on providing data that others can use.

Many overseas studies involving beach patrols have been incident-based and result in detailed analyses. For example, Van Pelt & Piatt (1995) examined murre (*Uria* spp.) casualties after an oil spill in Alaska and counted carcasses on nearby beaches periodically for several months. Their main objective was to develop a way of estimating total mortality from such a localised catastrophe using beach-wrecked bird numbers. Broader studies have attempted to connect beach casualties with live bird populations, local oceanographic conditions, and particular causes of mortality. A particularly thorough example is that by Page *et al.* (1982) in California. For several years they took air- and land-based counts of live birds in conjunction with recording the numbers of beached birds. One of their main objectives was to see if beached bird numbers could be related to bird deaths from oil pollution and gill net fishing, and whether these deaths were affecting population numbers.

The sooty shearwater (*Puffinus griseus*) breeds on the islands off New Zealand, Southern Australia and South America. There are no accurate estimates of its total population, but, based on the work of Warham & Wilson (1982), it is likely that the population numbers in the tens of millions. The largest documented colonies are in southern New Zealand most notably on The Snares and the Titi Islands surrounding Stewart Island (Warham & Wilson 1982) but there is

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evidence that colonies in South America may be larger (Clark *et al.* 1984; RPS, unpubl. data). In New Zealand, sooty shearwater population sizes have been examined twice using beach patrol data (Powlesland & Pickard 1992; Hamilton *et al.* 1997), but no trend was found. Hamilton *et al.* (1997) hypothesised that various stochastic processes could obscure any trend. Here we examine whether there are long-term patterns in the numbers of sooty shearwaters found dead on New Zealand beaches by reducing the data set to biologically functional units. Further, we explore whether the decline in numbers, first reported by (Veit *et al.* 1997) in the northern hemisphere, and now detected on the breeding grounds (Lyver *et al.* 1999; Scofield & Hunter unpubl. data), is discernible in the beach patrol data, and, if so, when the decline first became apparent.

METHODS

Data

OSNZ beach patrols are simply walks along the high tide line to identify, and record what birds have been washed ashore. All birds are normally removed during a patrol to prevent the same birds being reported on subsequent patrols. As well as the numbers and species found, information is recorded on the date of the search, how long the patroller thinks each corpse has lain on the beach, the length of beach searched, whether a storm had preceded the patrol and other debris found. All data are entered on standard record cards and collated by the OSNZ. The methods of the New Zealand beach patrols scheme are outlined in Powlesland & Imber (1988). On the west coast of the North Island, regular patrols have been organised on Dargaville and Ninety Mile Beaches in Northland, on Muriwai, Kariotahi and Sunset Beaches near Auckland, and on beaches in the Kawhia region. On the North Island's east coast various beaches near Whangarei in Northland have been regularly patrolled. Pakiri and Mangawhai Beaches in the Auckland region were patrolled regularly in the 1970s and 1980s but not in the 1990s because of problems of access. Many other beaches have been patrolled intermittently.

Data analysis

We extracted all sooty shearwater records from the complete OSNZ computer database. Knowledge of the biology of sooty shearwater and preliminary analyses suggested that recoveries represent 2 cohorts. Birds recovered from October to the following March are presumed to be returning from their north Pacific migration. The mortality peaks in November and is likely to contain birds of all ages. Because bird age cannot be identified in the hand we refer to all these birds as adults. Birds found from April to September are mostly fledglings from the previous breeding season (Stonehouse 1964) and the mortality peaks in May. For convenience, all recoveries are referred to by breeding season. For example, all birds found between 1 October 1984 and 30 September 1985 would be grouped under the 1985 season. The first complete season to include both adults and fledglings was 1961; the most recent data are for 1999.

We believe that sooty shearwaters travel along both the east and west coasts of the North Island when the adults return to the breeding grounds and also when the fledglings make their first northward migration. However, what determines the route taken by each migratory pulse is unknown. We hypothesise that the route taken may vary from year to year as a result of the predominant wind direction at the time. In our analyses, we estimated the recovery rate for the east and west coasts separately for each year, in addition to estimating a rate for both coasts combined.

Data were available from throughout New Zealand, but the most extensively patrolled areas where both the east and west coasts are represented is the northern part of the North Island. The OSNZ initially classified this area into Northland West, Auckland West, Northland East, and Auckland East. Since 1995, however, these areas have been further divided, to include Northland East and Northland West. For this paper, we combined Auckland West and Northland West as a single group and Auckland East and Northland East as another. This arrangement allowed the data to be analysed consistently over a longer period. Taylor (1997: 202.) provides a map of the beach patrol districts.

Using the above criteria we identified 4 groups for analysis, East coast (Auckland East, Northland East, 1961-1999) adults (reported October-March); East coast (Auckland East, Northland East, 1961-1999) fledglings (reported April-September); West coast (Auckland West, Northland West, 1961-1999) adults (reported October-March); and West coast (Auckland West, Northland West, 1961-1999) fledglings (reported April-September).

To account for the variable effort, data were normalised by dividing the number of birds found by the distance patrolled to give a recovery rate km^{-1}. The number of recoveries in a given year may depend on several variables, including the number of live birds in the area, weather, and ocean conditions. All these factors may differ seasonally and from year to year. We assumed that recovery rate in a particular month and year would equal a yearly level $\times$ a monthly factor.

This relationship weights the patrols made in different months, and the data can be viewed as a multiplicative time series. Such data are usually log-transformed, i.e.:

Log(recovery rate) = log(yearly level) + log(monthly factor).

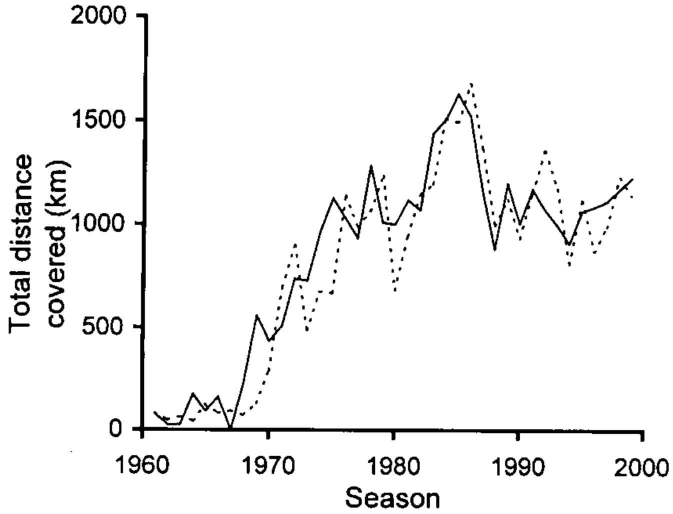

Fig. 1 Distance covered each year by Ornithological Society of New Zealand beach patrols for both northern North Island coasts combined. Adult (solid line) and fledgling (broken line) refer to recoveries in October to March and April to September, respectively.

The log transformation has several advantages, such as changing the multiplicative series to an additive series, assigns similar weights to large and small numbers so that very large (but rare) wrecks do not swamp the analysis, and results in constant annual percentage changes appearing as straight line trends.

For each month from 1961 to 1999, we calculated the number of sooty shearwaters found on each coast as a function of the distance patrolled (in km). The equivalent log rate was calculated as:

$L = \log_{10}(\text{birds/distance} \times 100 + 1)$.

giving the equivalent of birds 100 km^{-1}. The unit is added to take account of months with no birds, and it also ensures that L=0 when no birds were found. All monthly values are expressed as percentages of the seasonal peak.

The best fitting yearly and monthly patterns were found using least squares regression on the log-transformed rates. The log-transformed yearly levels were back transformed and data from both coasts were combined to find total yearly levels for both fledglings and adults.

Finally, the best fit exponential (constant percentage change) trend for each group was determined for these yearly values using weighted regression. There were some problems with the data coverage, especially in the early years of the scheme, when there were no patrols in many months and sometimes entire seasons passed without a patrol of one or other of the coasts. It was not until the 1970s that the patrols reached even half their current (1990s) level. In finding the long term trend, the unreliability of the early years was allowed for by giving each yearly value a weight according to the distance patrolled in that year. The yearly distribution of beach distance covered is given in Fig. 1.

RESULTS

Monthly patterns

The monthly patterns for each of the 4 groups are compared in Fig. 2. There were marked differences in numbers of birds found between adults and fledglings and between east and west coasts. Fledgling recoveries showed a single, sharp peak and carcasses found in succeeding months were likely to be remains from the same event, corresponding to the 1st migratory flight. Adults showed a broader peak of strandings. It may be possible to reduce the variance of these peaks using the corpse age codes that are supposed to be recorded for each specimen. We did not do this, however, as there appear to be some inconsistencies in the use and application of these codes.

On the west coast, the carcasses disappeared more quickly than on the east coast. Within 2-3 months of the events thought to cause the wrecks, there were few to no recoveries made on west coast beaches. However on the east coast, the recoveries were more evenly spread and even after 4 months significant numbers of birds were still being found. Whether

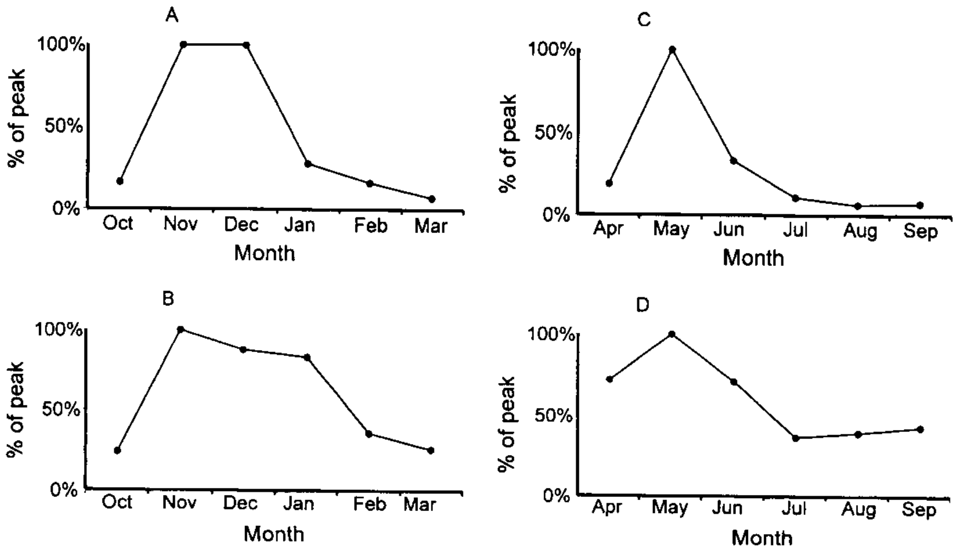

Fig. 2 Seasonal pattern of sooty shearwater (*Puffinus griseus*) recoveries for adults (A & B) and fledglings (C & D) on East (B & D) and West (A &C) coasts (as percentage of peak). Adult and fledgling refer to recoveries in October to March and April to September, respectively.

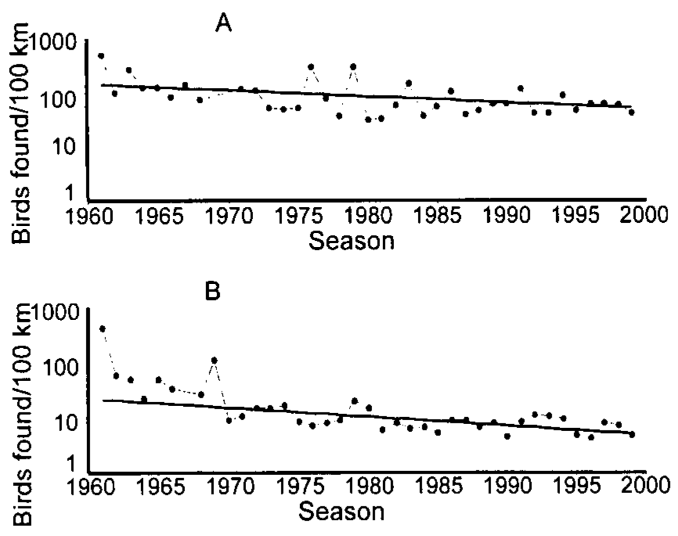

Fig. 3 The yearly level for adult (A) and fledgling (B) sooty shearwater recoveries 1961-1999 (birds 100 km^{-1}; note log-log scale) for both East and West coasts combined. Adult and fledgling periods refer to October to March and April to September, respectively. Thin line, yearly values; heavy line, best-fit exponential (constant percentage change) trend weighted by annual distance travelled.

this results from the pattern of patrols on the 2 coasts or differences in the natural conditions is unclear.

Yearly patterns

Fig. 3 shows the yearly level for adults and fledglings with the monthly pattern removed. A double logarithmic plot ensures constant percentage changes appear as a straight line. Data from early years in the series are not as reliable as those for later years. There was no significant serial correlation in the residuals of either group (Durbin Watson test statistic; $\alpha = 0.05$, $d_{\lambda} = 1.43$, $d_{u} = 1.54$; fledglings $d^{1}_{38} = 2.35$; adults $d^{1}_{38} = 1.53$).

For adults, the trend was for a decline of *c.* 2.6 % year^{-1} ($P = 0.03$; Table 1), which implies that from 1961 to 1999, the annual total of birds found has declined to 35.6 % of the 1961 level (95 % CI 14.2-89.2 % of 1961 total).

The fledglings declined at a slightly higher rate of 3.8 % year^{-1} over the study period ($P < 0.001$; Table 1), which, over the 39 years of the study equates to a decline to 22.3 % of the 1961 level (95 % CI 11.1-44.9 % of 1961 level) in the numbers of fledglings beach-wrecked.

The difference between the regression slopes of the 2 cohorts was not significant (slope = 0.0052, t (2-tailed) = 0.82, $P = 0.42$).

DISCUSSION

Do beach patrol counts reflect the population at sea?

In northern California, Page *et al.* (1982) made aerial and land-based counts of live birds in addition to recording the numbers of beached birds over a 14-

Table 1 Trends in numbers of beach-wrecked sooty shearwaters (*Puffinus griseus*) in northern New Zealand during 1971-1999; from the regression of log (yearly level) against year weighted by annual distance covered by patrols. Slope, slope of log-log regression line; 1999 level is expressed as percentage of 1961 level.

	Slope	Annual decline (%)	1999 level
Adults			
Upper 95% CI limit	-0.0013	0.3	89.2
Estimate	-0.0115	2.6	35.6
Lower 95% CI limit	-0.0217	4.9	14.2
Fledglings			
Upper 95% CI limit	-0.0089	2.0	44.9
Estimate	-0.0167	3.8	22.3
Lower 95% CI limit	-0.0245	5.5	11.1

year period. They confirmed that the number of beached pelagic birds correlated well with live bird numbers in the same area but found that a scaling factor, possibly specific to each area, was required. At least 24 studies have used marked dead birds or floating objects to estimate the proportion of birds that die that are picked up (Camphysen & Heubeck 2001). Four studies revealed no recoveries but in general 0.3-59% of all objects thrown into the sea were recovered.

The relationship between the number of birds at sea and the rate of recovery has not been examined in New Zealand, but it is likely that the rate of deposition of birds differs between east and west coasts. Deposition of sediments on New Zealand's west coast beaches is complex. Near-shore currents are dominated by waves and swell whereas farther out currents are influenced strongly by the wind (R. Bell, National Institute of Water and Atmospheric Research Ltd, pers. comm.). It is possible that on steep, high-energy beaches corpses would be buried faster than on low energy, flatter beaches but this has not been tested, nor has the relationship between substrate and burial time. We conclude that there is no evidence to believe that the decline in sooty shearwater numbers on New Zealand beaches does not accurately reflect a decline in their true abundance.

Potential influence of harvest on the decline

The Rakiura Maori traditional harvest of sooty shearwater chicks on the Titi Islands off Stewart Island may have started in pre-historic times but there is evidence that the practice began in earnest about 1800 (Anderson 1997). Noticeable declines in the number of breeding adult or fledgling sooty shearwaters in the 1960s probably indicates a population decline beginning at least 10 years earlier (Caughley 1977). An initial decrease in numbers is likely to initially be masked as more non-breeders are recruited into the breeding population and prebreeders begin breeding at a younger age.

Since European settlement and up until the Second World War, family groups visited the islands on large chartered fishing boats or on the New Zealand Government steamship *Hinemoa*. It took several days to get there, with each boat carrying *c.*80-100 passengers (Russell & Gaw 1998). This allowed neither flexibility in when people went to the islands or how long they stayed, nor how many people could go and how much they were able to bring back.

After the Second World War the manner in which the harvest was undertaken, and the scale on which it occurred underwent major changes (Wilson 1979). Many Maori returned from the war financially independent and this coincided with technological advances that led to a new availability of small fishing vessels. These factors provided an opportunity for individuals to pursue a livelihood more in tune with their Maori culture, and many southern Maori began to visit the islands. The appearance of numerous smaller, "family" owned fishing boats provided more flexible, faster, and less dangerous transportation to the Titi Islands. Families now had much greater control over when they went and returned from the islands and the amount of, and ease with which, they could transport gear each way. The new mobility may have led to larger numbers of people visiting the islands, and presumably resulted in larger harvests.

The use of helicopters for transport to the islands, which began in the 1960s (Wilson 1979), also greatly increased the ease with which equipment (and people) could be transported to and from the islands. Helicopters also increased the accessibility of previously unharvested areas of the larger islands, especially Taukihepa (Big South Cape). Increased accessibility resulted in a substantial increase in the number of family groups participating in the harvest (Department of Conservation, Southland region unpublished archives). The use of helicopters also increased the amount of work time available to birders during the harvest season due to quicker and more reliable transport of equipment within a shorter distance of the work/living houses. Helicopters also allowed larger numbers of harvested birds to be returned to the mainland.

Concurrent with, and partly as a result of, the use of helicopter transport were the development of quicker processing methods, changes in storage methods and the advent of large portable generators that could provide power and enable refrigeration. In particular, the use of wax for cleaning birds (first used about 1965 — Lyver & Moller (1999), and the transition from kelp bags (poha) (Richdale 1946) in the 1950s, first to metal (Wilson 1979) and then to plastic buckets, for storing birds reduced the time needed for processing allowing person to take a larger catch. The effect of some of this technology in reducing processing times and increasing profits is described in detail by Lyver & Moller (1999).

The rat invasion of Taukihepa

At 929 ha, Taukihepa (Big South Cape) is the largest of the Titi Islands. Sometime in the early 1960s, the ship rat *Rattus rattus* was accidentally introduced to Taukihepa and hence to its smaller neighbouring islands. The impact on the fauna was devastating (Bell 1978). The diet and ecological effects of rats arriving in a pristine environment are quite different to that on an established population (King 1990). Introduced rat populations quickly reach plague levels with not only animals being eaten but also trees are stripped of their bark, and invertebrate populations damaged.

R. rattus has been demonstrated to be a significant predator of burrowing procellariiforms (Atkinson 1985). Taukihepa and its surrounding islands account for about 40% of the total area of sooty shearwater breeding habitat in New Zealand. *R. rattus* is still present on these islands but is reported to be in smaller numbers than during the invasion (Bell 1978). The effect of the Taukihepa rat invasion on the sooty shearwater population of the island may have been significant. The Cory's shearwater (*Calonectris diomedea*) is considerably larger than the sooty shearwater (946 g v 787 g, Warham 1990), yet Fernandez (1979) found that this species was severely affected by *R. rattus* predation on eggs and small chicks. Harvesters on Taukihepa have reported falling takes in harvest (Lyver 1999).

Could climate change be affecting sooty shearwater survival?

The decline in sooty shearwaters reported here is similar in magnitude and has occurred over a comparable period to that described for the rockhopper penguin (*Eudyptes chrysocome*) on Campbell Island (Cunningham & Moors 1994), on Amsterdam Island (Guinard *et al.* 1998), and in the Falklands (Bingham 1998). All these authors have suggested that long-term changes in the sea surface temperatures around the islands related to the position of the sub-Antarctic convergence may be the cause of the penguin decline. Weimerskirch (1998) argued that sooty shearwaters on The Snares use a dual short-long foraging strategy to feed their chicks and maintain body condition. Short trips being primarily to feed the chick whilst longer trips to the sub-Antarctic convergence allow the adults to maintain body condition. Any movement of sub-Antarctic convergence would effect either adult condition or birds' ability to provision their chicks, and lead to a slow decline in numbers.

Lyver *et al.* (1999), using 20 years' records, postulated that the El Niño South Ocellation (ENSO) affected sooty shearwater chick production on Poutama, one of the harvested islands. The pattern of consistent decline reported by us is not consistent with either ENSO or the Pacific Decadal Oscillation (see below) both of which follow a broadly sinusoidal pattern.

Could climate change be affecting deposition rates?

The frequency of onshore winds is known to significantly affect the number of dead birds washed ashore on beaches (Stowe 1982; Camphysen & Heubeck 2001). It is possible that a major shift in the frequency of onshore winds could account for the declines shown here. Recently Salinger & Mullan (1999) have identified a long lasting shift, characterised by more persistent westerly winds, in New Zealand's climate that began about 1977. The inflection point coincided with an eastward movement in the longitude of the South Pacific Convergence Zone, and with more frequent El Niño events. It has been suggested that the shift resulted mainly from a Pacific-wide natural fluctuation that is being called the Pacific Decadal Oscillation (Mantua *et al.* 1997), which exhibits phase reversals every 20-30 years. In El Niño years, New Zealand tends to experience stronger or more frequent winds from the west in summer, while in winter the winds tend to be more from the south. During La Niña events, New Zealand tends to have experienced more northeasterly winds.

We consider that an increase in westerly winds since 1977 would tend to increase the likelihood of birds being deposited on the west coast. It is likely that any shift in wind direction would produce compensating differences on the other coast. Furthermore, the trends we identified are consistent throughout the period studied and do not change in 1977. Thus, it seems unlikely that the Pacific Decadal Oscillation could have been the proximate cause of our results. However we do not rule out wind pattern changes having been involved in the decline in sooty shearwater numbers as suggested by Lyver *et al.* (1999).

How has north Pacific drift-net fishing affected sooty shearwater survival?

Drift-net fishing in the north Pacific killed millions of sooty shearwaters between 1978 and 1992 (Uhlman 2001). Our data show no evidence that this mortality was reflected in the numbers of beach-wrecked sooty shearwaters during this period. However the long-term demographic effects of such high mortality on the population may take 1 or more generations to manifest themselves (Caughley 1977).

Why is the "adult" monthly pulse so much longer than the fledgling pulse

There are 2 possible causes to explain the difference in patterns observed between the adults and fledglings. First, there may be behavioural differences between adults and fledglings. Such differences could result in a difference in migratory dynamics. Non-breeders, pre-breeders, and failed breeders appear to leave the colony in mid March. It is believed that these birds migrate north before the breeders (Richdale 1963). All breeding birds have left the colonies by 3 May (Richdale 1963; RPS, unpubl. data). Fledglings leave between about 20 April and mid-May. It is believed that all fledglings immediately migrate to the north Pacific. Few sooty shearwaters remain in the southern hemisphere in winter (Richdale 1963). Thus, there are few sooty shearwaters in the area to be washed up on beaches from May-October except during the peak fledging period in May. Conversely, the "adult" pulse consists of birds of differing ages that arrive from the northern hemisphere at different times. Birds first return to prospect burrows on The Snares in late September (Warham *et al.* 1982). It is likely that these first birds are those that have bred successfully previously and have established burrows. Later waves include those that bred unsuccessfully the previous year, those that will attempt to breed for the first time, those that will prospect for breeding sites and those that will visit the colony but not prospect and finally the youngest birds that may not visit the colony that year but frequent New Zealand inshore waters. Therefore, the peak in early November is likely to be made up of inexperienced younger birds. Adults are passing offshore for a longer time than fledglings and it seems reasonable that a broader peak of beach-wrecked birds would therefore be observed.

Behavioural effects may also be related to site-related to differences in foraging biology. Preliminary satellite tracking has shown that in spring and early summer sooty shearwaters attending the Taiaroa Head colony feed in the waters of the Chatham Rise or in the Tasman Sea (Sohle 2001). If this pattern is also true of other populations, then sooty shearwaters from more southern populations that die during the breeding season may be recovered on North Island beaches in spring and early summer.

A 2nd possible cause might be a difference in persistence of dead birds on beaches between seasons. Differences may be weather induced. Van Pelt & Piatt (1995) reviewed studies investigating the persistence rates of birds found dead on beaches. However none of these studies appear to have examined the relationship between persistence and season. The beaches of northern New Zealand are subjected to higher winds and larger swells in the winter. It is likely that beach washed birds would be buried by the action of these storms and by wind-blown sand. This effect would appear to be especially marked on the west coast where persistence of the fledgling cohort is particularly short.

Alternatively, lower persistence could be related to increased levels of scavenging. Carrion feeding by feral cats *Felis catus*, and mustelids increases in winter because other foods are harder to find (King 1990). Carrion feeding could reduce the length of time birds would remain on beaches.

Why was the fledgling decline since 1970 steeper than the adult decline?

The sooty shearwater is a long-lived, monogamous, species with a low reproductive output. They take 1 or more seasons to develop a pair bond and lay 1 egg season^{-1} (Richdale 1963). The demographic consequences of a significant mortality of breeding sooty shearwaters in the north Pacific fisheries would be reflected in the adult recoveries and in the production of chicks the next season. Every breeding adult with a mate lost represents the loss of production of a chick for 1 or more breeding seasons. If the time to create a pair bond is >1 year and the cause of adult mortality persists, the result will be a steeper decline in chick production than in actual adult mortality. If a similar proportion of chicks die each year regardless of the number produced, the mortality would then be reflected in a decline in the number of beach-wrecked fledglings over time.

If conditions are becoming more difficult, for example if birds have to travel further to feed or there is less food, then it may also be more difficult to raise healthy young. If this results in fewer young produced, this may also contribute to the trend.

CONCLUSIONS

We conclude that there are only 3 long-term events that have been operating in the 2nd half of the 20th century that could have caused the decline reported here: a rise in sea temperature perhaps as a result of a southward movement of the Subantarctic Front; an increase in harvest rate; or a rat invasion of the largest colony.

Two other more recent phenomena, north Pacific fisheries mortality and ENSO and PDO climatic variation, may be involved but we cannot find in our data any direct evidence of their impact. It is possible that the decline shown was caused by a combination of some or all of these phenomena.

More study is required to understand fully how weather, patrol frequency, deposition rate, persistence rate, and live bird numbers vary and interact. Deposition and persistence experiments similar to those reported from overseas (Van Pelt & Piatt 1995; Camphysen & Heubeck 2001) need to be made in New Zealand on both east and west coasts.

Despite these concerns, the results here support the conclusion that since 1961 sooty shearwaters have declined significantly in New Zealand waters. The number of adult sooty shearwaters found dead on beaches has fallen by about 64.4% and the number of fledglings by about 77.7%. The impact of this decline has been recently found on the breeding islands (Lyver *et al.* 1999; P. Scofield & C.M. Hunter unpubl. data).

The OSNZ is fortunate to have begun beach patrols at a time when interest-based science was considered worthwhile. Given the likely effects of global warming, fisheries by-catch, and pollution, the importance of this historical data and the need for continued patrols cannot be too strongly stressed.

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