Feeding ecology of seabirds nesting at the Abrolhos Islands, Western Australia

Daniel Gaughan (Principal Investigator), Christopher Surman,
Michael Moran, Andrew Burbidge and Ron Wooller

Final Report for FRDC Project 1998/203

Department of Fisheries

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Fish for the future

Feeding ecology of seabirds nesting at the Abrolhos Islands, Western Australia

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OBJECTIVES

1. To determine the quantity and species composition of the diets of Abrolhos seabird species for which there is inadequate information.
2. To determine the relationships between diet and nesting success.
3. To extend the time-series of dietary and oceanographic information for seabird species whose diets have already been studied to gain an understanding of oceanographic effects on prey availability and the ability of the birds to respond.
4. To model the fishery-fish stock-seabird interactions to estimate the sustainable yield from the fishery that does not significantly affect the Abrolhos seabird populations.

NON TECHNICAL SUMMARY

OUTCOMES ACHIEVED

The main findings of this project will play a key role in educating those involved in managing fisheries and ecosystems on the mid-west coast of Australia. Because ecosystem-based management, rather than management of only targeted species, is a concept that the fishing industry has yet to adequately embrace, the knowledge gained has yet to be used in mainstream fisheries management, thus explaining the predominantly educational use of the data to date. The results from this study have been extended so that management of all purse seine fisheries in Western Australia now have a higher awareness that their target species form part of important ecosystem food chains. Although specific management actions relating to the prey species not targeted by purse seining have yet to flow directly from this research, securing data that provides hard evidence for the links between seabirds and the reef shallows at the Houtman Abrolhos Islands will highlight the need to provide an adequate level of protection to the shallows around the islands. These key results will flow through to the relevant industry groups, individual fishers, Government Departments and other interest groups.

Over one million pairs of seabirds breed annually on the Houtman Abrolhos island group, 60 km off the mid-western coast of Australia, the largest seabird breeding station in the eastern Indian Ocean. This report describes in detail the diets and breeding patterns of six key seabird species that nest at the Abrolhos Islands.

Lesser Noddy	*Anous tenuirostris melanops*
Common (Brown) Noddy	*Anous stolidus*
Sooty Tern	*Sterna fuscata*
Crested Tern	*Sterna bergii*
Roseate Tern	*Sterna dougalli*
Wedge-tailed Shearwater	*Puffinus pacificus*

The primary management goal of this report is to ensure that fishing activities off the mid-west coast do not adversely affect seabirds on the Abrolhos Islands. The main commercial fishing operations in the region target western rock lobster with traps, scallops with demersal trawls, a tropical sardine (but known locally as scaly mackerel) with purse seine and a variety of reef-associated and large pelagic fish species with hook and line.

Diets were examined from the five most numerous tern species and the wedge-tailed shearwater from 1998 to 2001. Around the Houtman Abrolhos Islands fish (e.g. wrasses) and squid of the reef shallows, small pelagic fish in the broader region inshore and offshore of the islands and larval stages of several species, of which beaked salmon and goatfish are particularly important, each form an integral part of the diets of the islands' seabirds. The dominant small pelagic fish in the region is the scaly mackerel, which is also fished commercially.

The largest tern species studied, the crested tern, foraged mainly for reef fish over shallow reef flats near the breeding islands, as well as for small pelagic fish over coastal shelf waters. The smallest species, the roseate tern, also foraged within sight of its colonies, but over deeper waters than crested terns. Larvae of three fish species (beaked salmon, a goatfish and a bellowfish) were prominent in the diets of the brown noddy, lesser noddy, sooty tern and roseate tern. The sooty tern and the wedge-tailed shearwater also ate large amounts of squid. Scaly mackerel featured only in the diets of wedge-tailed shearwaters and crested terns. These species consumed scaly mackerel between 100-220 mm standard length (SL); this sardine species comprised 22.5 % and 11.1 % by volume for crested terns and wedge-tailed shearwaters respectively. The other fish prey consumed by the smaller terns were either larval or juvenile forms between 2-110 mm SL.

Dietary data (e.g. composition, average size of meal, number of meals per day etc) were used with details of breeding behaviour and estimates of population sizes of the seabirds to determine the quantities of prey consumed, as summarized here:

Parameter	Lesser noddy	Brown noddy	Sooty tern	Crested tern	Wedge-tailed shearwater
Total nestling and post fledging care (days)	60	60	90	60	75
Time in on islands (days)	365	240	240	365	240
Population size	136,000	324,000	906,600	5000	2,000,000
Annual food consumption (tonnes)	1129	3173	8721	136	32,925 - 34,252
Scaly mackerel component of the total (tonnes)				30	3655 - 3770

TOTAL CONSUMPTION (tonnes)	**46,000 – 47,400**

In terms of the overall seabird population there was a strong positive relationship between diet and nesting success of seabirds at the Houtman Abrolhos. The diets of seabirds varied from one year to the next, and influenced both the timing of breeding and reproductive performance; breeding success was strongly influenced by the abundance of the key prey types in the diet. Significantly, during 1997 when scaly mackerel abundance in the fishery was low, the wedge-tailed shearwater did not attempt to breed.

The data collected in this study has built on early work that commenced in 1991. There is now a 10 year time series of data relating to the breeding success of seabirds at the Houtman Abrolhos. Seabird breeding behaviour on the Houtman Abrolhos indicates that the marine environment and prey availability in waters adjacent to the Houtman Abrolhos are highly variable. This agrees with oceanographic observations that the flow of the dominant current, the Leeuwin Current, is strongly influenced by the activity of El Nino. It is unclear whether the warmer water associated with the Leeuwin Current affects the spawning of adult beaked salmon, or whether the stronger southwards current flow may displace the larval stages beyond the foraging range of seabirds. It is also unclear how vagaries of the Leeuwin Current influence the abundance of scaly mackerel near to the Houtman Abrolhos. However, the return to good catch rates of scaly mackerel for the purse seine fishery in 1999, following the very low availability to the seabirds in late 1997 and the lack of purse seine fishing in 1998, suggests that there was a change in the distribution (i.e. availability) of scaly mackerel rather than a change in the size of the stock.

Modelling fishery-fish stock-seabird interactions was not undertaken as planned due to failure of the scaly mackerel fleet to expand beyond one vessel during the period of this project. The unexpectedly small size of the purse seine fleet therefore did not warrant research expenditure sufficient to generate the fishery data required to model the scaly mackerel population. Even without further investment in the fishery, the nominal total allowable catch (TAC) of 2,700 tonnes should not be increased without further good evidence that this would not impact on the seabirds. This precautionary measure applies predominantly for those times when availability of scaly mackerel near the Abrolhos Islands is very low. This caution is suggested under the assumption that the current fishing grounds remain the same and that no further information becomes available to provide a robust stock assessment of scaly mackerel.

If fishing operations were to move beyond the current region adjacent to the Abrolhos Islands and if reliable estimates of stock size became available, with appropriate acknowledgment of uncertainty in both data and underlying assumptions, then an expansion of the purse seine fishery would be possible.

The importance of scaly mackerel and other small pelagic fish such as sprats to the seabirds has now been shown unequivocally, and will be reported to the management committee for purse seine fisheries in Western Australia. The critical importance of the reef shallows to seabirds at the Houtman Abrolhos has not previously been reported – risk assessments for any current or future activities involving the reef shallows at the Houtman Abrolhos must now consider this information. The importance of beaked salmon and goatfish is potentially relevant to trawling activities since these types of fish live on soft-substrate bottoms which are amenable to towed fishing gear. Because the locations of the populations that give rise to the larval stages of beaked salmon and goatfish are unknown there is a risk that any future bycatch of these species in other regions could adversely affect larval supply in the vicinity of the Houtman Abrolhos.

2 Acknowledgements

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3 Background

3.1 Project Background

The mid-west purse seine fishery is a developmental fishery based mainly on the tropical sardine (*Sardinella lemuru*), known locally as scaly mackerel. This purse seine fishery covers all Western Australian (WA) waters between the latitudes of 26° 30'S and 31° S. The fishery began in 1989 and has been managed very cautiously (there are only three boats licensed) due to inadequate knowledge of the size of the stock and no knowledge of the interaction of the fish stock with the seabird population of the Abrolhos Islands, by far the largest of any seabird rookery in WA. There are a number of species which are considered globally endangered and the Abrolhos populations are of worldwide significance.

The WA Government acknowledges its responsibilities in relation to the seabird populations, some of which are determined by international wildlife conservation treaties, and will not permit further expansion of the fishery without adequate knowledge on which to judge the likely effects on the seabird populations.

The government's catch limits have not constrained the development of the fishery to date. The operators spent some years coming to grips with the scale of boats and gear required to fish the scaly mackerel stocks. These problems are now better understood. Large vessels are required to effectively undertake purse seine fishing in the region because of the frequent strong winds, but the fishing season remains limited to about 6 months per year. There is currently only one active operator and thus only one boat that has consistently fished in recent years. The landing capacity of this vessel indicates that the addition of a similar vessel to the fleet would undoubtedly allow the catch limits to be reached (assuming sufficient processing facilities and markets). Increased catch limits for the existing operators, or expansion of the fishery to include more boats, will not be permitted without a sound knowledge of the stocks and the dietary requirements of the seabirds.

It is possible that the effect of the fishery on the seabirds is negligible. For example if the birds feed only on the late larval or early juvenile stages of the scaly mackerel, the fishery could take a much greater catch without significantly affecting food supply to the birds than if they feed on adult fish. If the population sizes of the birds and fish and the dietary requirements of the birds are known, a predator-prey population model can be used to predict the effects of various levels of fish catch on food availability to the birds and hence on nesting success.

FRDC Project 1995/037 (*The biology and stock assessment of the tropical sardine,* Sardinella lemuru, *off the mid-west coast of Western Australia*) has addressed the fish stock size and other aspects of biology. Following this study, ongoing monitoring of the mid-west coast purse seine fishery, will be required for population modelling of scaly mackerel. A PhD project at Murdoch University has investigated diets of some bird species, including those of the most vulnerable conservation status, but for logistic reasons has not investigated the diets of the most abundant species including the wedge-tailed shearwater, which is the species most likely to have a dependence on scaly mackerel. This previous work suggested that the bird species studied may have an ability to modify their diet in relation to oceanographic effects (e.g. Leeuwin Current strength) on the distribution and abundance of their prey but more data are required to clarify this.

To illustrate the possible variations in prey availability, in late 1997 scaly mackerel could not be found in the Geraldton region but appeared to be unusually common in the Perth region. This situation was almost certainly not caused by overfishing but was likely to have been a response to oceanic conditions. A study in one year only could find atypical results.
A multi-year study would span a range of oceanographic conditions and give a greater understanding of the variation in bird diets, which could assist in understanding the responses of the small pelagic fish.

Researchers of the WA Department of Conservation and Land Management (CALM), with support from the Fisheries Department, have developed population estimation techniques for seabirds with all the different nesting strategies (mangrove branches, on ground, burrows).

There is currently the expertise in WA to study all the components and to model the fishery-seabird-scaly mackerel complex. It is very timely, with the fishery poised for further expansion, to gain an understanding of this system, with a possible outcome being that a degree of expansion can be allowed without prejudice to the seabird populations.

3.2 Seabird feeding background

Seabirds are marine organisms. They spend much of their time over the sea, gathering food and migrating from breeding areas to foraging grounds. Indeed, most seabirds are tied to land only as a place to safely deposit an egg and raise their young. In some cases, the time spent on land is minimized to the extreme, with the young of guillemots (*Uria aalge*) and razorbills (*Alca torda*) leaping off steep cliffs well before fledging, to be raised by their parents on the open sea (Nelson 1980).

As top order marine predators, seabirds respond rapidly to changes in the marine environment (e.g. Croxall et al., 1999). High latitude species, such as kittiwakes (*Rissa tridactyla*) and guillemots (*Uria aalge*), have exhibited dramatic variation in breeding performance in response to measured changes in food availability (e.g. Uttley et al., 1994). When lesser sandeel (*Ammodytes marinus*) catches declined in the North Sea, reflecting a less than average recruitment year, those species of seabirds whose main prey was sandeels, suffered delayed breeding, very poor reproductive success and fewer adults attended nesting sites (e.g. Uttley et al., 1994). The size and frequency of meals delivered declined and the amount of time spent foraging increased, reflecting an increase in effort by adults as a direct result of a decline in their favoured food (Monaghan et al., 1994). Recent research has indicated that the reverse is also possible when food supplies are artificially increased through fishing vessel discards. Gulls, kittiwakes, skuas, fulmars and gannet populations have soared as a direct result of an increase in discards (Montevechii, 2001).

Unlike their temperate counterparts, tropical seabirds tend to have a more relaxed breeding regime. Whereas many high latitude species complete a breeding attempt (defined as the time of laying until when the young leave the nest) within three months (Nelson, 1980), many tropical species, such as sooty terns, exhibit more protracted and more flexible breeding periods throughout their range. At some locations, sooty terns breed sub-annually (Ashmole, 1963), whilst at others (Galapagos) the timing of breeding may vary according to food supply rather than any cue from the calendar year (Harris, 1969, 1977).

At the Houtman Abrolhos islands, off Western Australia, seabirds appear to breed annually commencing laying each September (Surman, 1994, 1998; Tarr, 1949; Warham, 1951). However, a recent investigation into the breeding and feeding ecology of three sympatric terns found that breeding times and reproductive performance may vary by as much as three months from one year to the next (Surman 1997). This variation in the timing of breeding had dramatic effects on reproductive performance, with later breeding years being defined as 'poor' years with few young raised, a similar finding to other areas (Uttley et al., 1989; Rindorf et al., 2000; Kitaysky et al., 2000; Monaghan et al., 1992; Crawford and Dyer, 1995; Regehr and Rodway 1999).

In years when breeding commenced early at the Houtman Abrolhos, noddies had more beaked salmon, their main prey, in their diet compared with later years. Similarly, both the supply of beaked salmon and the timing of breeding appear linked to the flow of the Leeuwin Current, with far fewer beaked salmon eaten during years when the Leeuwin Current flows more strongly. It was hypothesized that this may prevent the regular supply of beaked salmon from their adult habitat in the south-west to the foraging range of noddies at the Houtman Abrolhos (Surman and Wooller, in press).

4 Need

To determine the degree of expansion in the mid-west purse seine fishery that can be accommodated without untoward effects on the seabird populations, information is required on fish and seabird populations sizes, the amount of food required for successful rearing of a nestling, the fish species required by different bird species, the effect of oceanographic events on availability of different fish species to the birds and the ability of the birds to respond to such events by switching prey.

5 Objectives

1. To determine the quantity and species composition of the diets of Abrolhos seabird species for which there is inadequate information.
2. To determine the relationships between diet and nesting success.
3. To extend the time-series of dietary and oceanographic information for seabird species whose diets have already been studied to gain an understanding of oceanographic effects on prey availability and the ability of the birds to respond.
4. To model the fishery/fish stock/seabird interactions to estimate the sustainable yield from the fishery that does not significantly affect the Abrolhos seabird populations.

6 Methods

6.1 Overview of methods

180 - 200 field days (4 field trips) were spent on the Abrolhos Islands in each year of the three year project for the bird diet studies. Regurgitates were collected monthly throughout each breeding season from the target bird species. The fish species in the diets were identified and measurements made of the size-frequency distribution of prey species. Feeding frequency was observed.

Population sizes of nesting birds of each species were estimated using specific techniques developed for each nesting-type, that is, ground nests, burrows, mangrove branches, etc. The timing of breeding of each species was determined using marked nests which were visited regularly throughout the breeding season to obtain the egg-laying chronology. Breeding success (the number of eggs that are laid and survive to produce free-living young) was determined at the same time.

For each bird species, the total quantity of each prey species was calculated from the bird population size, the feeding frequency, the length of the nesting season and the species composition in the diet. Total prey consumption is expressed as numbers of each life-stage of each fish.

Studies over three years, together with the existing information on a subset of the bird species, allowed comparison of diets between years and correlation with environmental factors such as Leeuwin Current flow and population sizes of commercial fish species. The ability of the birds to switch between alternative prey species was gauged from the variation in species composition in diets between years and between seasons within years.

Information for scaly mackerel population dynamics was to be derived from the results of FRDC project 1995/037 and ongoing monitoring, but this awaits a longer time series of catch, effort and age data since only one vessel has fished since 1997. The quantity of scaly mackerel and other species of prey consumed by seabirds was calculated and the importance of currently and potentially exploited fish species in the diet of each bird species assessed.

6.2 Detailed methods

6.2.1 Study area and species

The study was conducted on Pelsaert Island (28° 56'S, 113° 58'30"E), the southernmost and third largest of an archipelago of 120 islands (the Houtman Abrolhos), 60 km off the mid-western coast of Australia (Fig. 6.1). Pelsaert Island (120 ha) is 12 km long, only 50-500 m wide and very low, comprising coral rubble, limestone and sand. Of the 13 seabird species that breed regularly on the island, eight are terns and all of these breed annually over spring/summer (Surman, 1998). The largest species, the caspian tern (*Sterna caspia*; 700 g) has only 10-20 pairs and the smallest species, the fairy tern (*S. nereis*; 70 g) only about 200 pairs breeding on the island (Burbidge and Fuller, 1989). These two species, together with about 300 pairs of bridled terns (*S. anaethetus*; 130 g), were not included in the study. The five more abundant species were the crested tern (*S. bergii*; 1,000 pairs), roseate tern (*S. dougallii*; 1,000 pairs), sooty tern (*S. fuscata*; 250,000 pairs), lesser noddy (*Anous tenuirostris*; 35,000 pairs) and brown noddy (*A. stolidus*; 130,000 pairs). Populations of these species on Pelsaert Island represent about 80% of the totals for the whole Houtman Abrolhos island group (Fuller et al., 1994). The only other abundant seabird is the burrow-nesting wedge-tailed shearwater (*Puffinus pacificus*), of which about 4% of the two million birds breeding on the Houtman Abrolhos are present on Pelsaert Island (Fuller et al., 1994). The lesser noddy nests in the few mangrove trees on the island; the other terns nest on the ground or on low bushes (Surman and Wooller, 1995 and 2000).

6.2.2 Dietary samples

The Abrolhos Islands were visited regularly during the austral spring/summer-breeding season, between September and January from 1993 to 1999. Lesser noddies, brown noddies and sooty terns were induced to regurgitate without the use of emetics or stomach flushing. Although spontaneous regurgitations may not always empty the proventriculus (Duffy and Jackson, 1986), this method was judged minimally intrusive and is commonly used to determine diets (Cooper and Klages, 1995; Croxall et al., 1997), including terns (Shealer 1998). Adult birds recently returned from a foraging trip were captured at the nest-site by hand or using a small net, whereupon most regurgitated. They were marked individually with leg bands to ensure that no individual was sampled more than once during any single breeding season. A minimum of

10 regurgitations were collected from each species in each month, corresponding to the incubation, small nestling and large nestling stages in their breeding cycle.

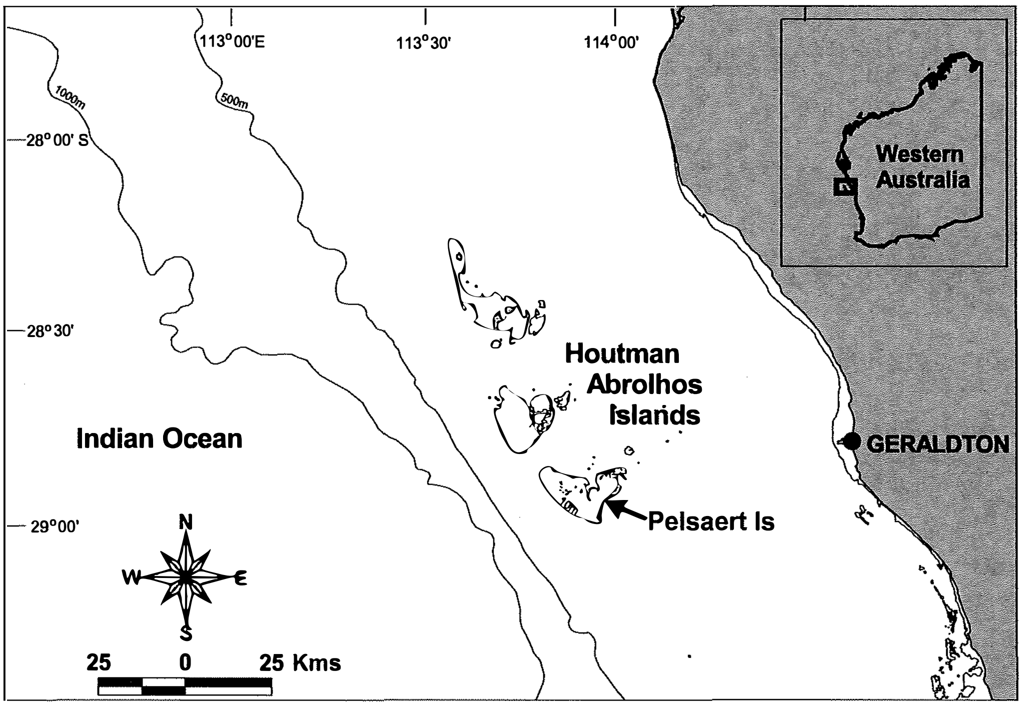


Figure 6.1 Location of Houtman Abrolhos Islands off the Western Australian coast in relation to Geraldton and the continental shelf (500 and 1000 m bathymetry lines shown).

Regurgitates were preserved in 70% ethanol, then rinsed and vacuum filtered to allow the percentage volumes of identifiable material to be estimated before obtaining the wet mass of each sample. The total number of individuals of each prey type in each sample was recorded. Prey items were identified using keys (Last et al., 1983; Smith and Heemstra, 1986; Leis and Rennis, 1983; Leis and Trnski, 1989; Gomon et al., 1994) and from reference specimens in the Western Australian Museum. Head parts were poorly preserved in most samples and tail counts were the most effective method of identifying each species. Of the three main prey species, beaked salmon (*Gonorhynchus greyii*) resisted digestion better than the more fragile black-spotted goatfish (*Parupeneus spirulata*); Hawaiian bellowfish (*Macrorhamphosus scolopax*) remained more intact than either. Fortunately, the tails of these three species proved particularly distinctive.

The importance of each prey taxon in the diet was assessed using three measures common to dietary studies of fish (Crabtree et al., 1991) and seabirds (Harrison et al., 1983). These are the percentage of individuals of each prey taxon, the percentage volume of each prey taxon and the frequency of occurrence of each prey taxon in all the samples for each seabird species. The overall importance of each prey taxon in the diet of a seabird was ranked using an Index of Relative Importance (IRI; Pinkas et al., 1971) that combines all three measures:

IRI = (% numerical abundance + % volume) x % frequency of occurrence

6.2.3 Meal sizes and feeding frequency

For the purposes of this study, we used only the positive mass increments as an indicator of the size of meals delivered to nestlings. This provides a good estimate of actual mass of food delivered but with a negative bias. The amount of food delivered to nestlings will also vary depending upon chick size and when they were last fed (Hamer et al., 1997; Nicholson 2002).

6.2.3.1 Wedge-tailed shearwaters

Wedge-tailed shearwaters feed their young at night, returning to the colony after sunset and departing before sunrise (Warham, 1990). To estimate feeding frequency and the quantity of food delivered to chicks by parents, frequent weighing trials were conducted over a minimum of five consecutive nights for two periods during 1998/1999, 1999/2000 and 2000/2001. The dates and numbers of chick- nights monitored are presented in Table 6.1.

Within each breeding season, an effort was made to monitor the same young when more than one monitoring period was conducted during each season. Weighing was conducted at dusk, and again at dawn. Chicks were weighed in the same sequence during each weighing episode.

The mass of food received by chicks' overnight was determined by the sum of positive mass increments between consecutive weighing (Ricklefs et al., 1985; Hamer et al., 1997). Meal size, as represented by positive mass increments, underestimated total food delivery by the mass lost through metabolism and excretion. Mass loss was estimated for each chick by subtracting the dusk-mass from the dawn-mass and dividing this by the total hours between the two masses.

6.2.3.2 Lesser and brown noddies

For each breeding season monitored during this research project, several young of lesser and brown noddies were monitored over several days to determine the frequency and size of meals for offshore foraging terns at the Houtman Abrolhos. The dates and lengths of monitoring periods are given in Table 6.1.

Up to 15 nests of lesser and brown noddies were marked permanently, and the nestlings banded with a unique, numbered incoloy (stainless steel) leg band. Chicks were weighed every three hours, commencing at 0600 and finishing at 2100 hours each day of the monitoring period. Research conducted between 1991 and 1997 indicated that most young of these two species were fed during dusk or shortly thereafter, so the final weighing at 2100h usually included the last feed for that evening (Surman, 1997). Lesser noddy and brown noddy chicks were weighed simultaneously, and each chick was weighed in the same sequence. Chicks were weighed on an electronic balance to the nearest 0.1g.

Only those chicks which could be captured for the entire monitoring period were included in analysis. Lesser noddy young remain on the nest for at least 40 days, however brown noddy young may move off the nest site after nine days, and hide amongst dense *Nitraria billardierei* bushes (Surman and Wooller, 2000). Data were analysed using the same methodology as described for the wedge-tailed shearwater above.

6.2.3.3 Crested terns

It was not possible to determine meal size for crested tern chicks from repeat weighing visits as many young often regurgitate their meals when disturbed, and may become displaced from the breeding colony during investigator approach. However, during the 2000/2001 breeding season a hide was established adjacent to the crested tern colony on Pelsaert Island. On 28 November 2000, between 06:00 hours and 18:00 hours, we monitored continuously 11 nests containing crested tern young less than one week in age. Where possible, the type of prey (as species or as either reef fish or open water fish) bought back to each chick and the timing of feeding for each chick was recorded. In addition, all other prey delivered to the area of the crested tern colony that we could reliably observe in all lighting conditions were recorded.

Table 6.1 The timing of feeding frequency nest monitoring and the number of chick days observed between 1998 and 2001 on Pelsaert Island.

		Breeding Season		
Species		**1998/99**	**1999/00**	**2000/01**
Lesser noddy	Date	6-7 Dec	20-21 Oct	8-9 Nov
		16-17 Dec	19-20 Nov	
	Chick days	13	42	28
Brown noddy	Date	16 Dec	20-21 Oct	8-9 Nov
			19-20 Nov	
	Chick days	14	52	32
Wedge-tailed shearwater	Date	23-27 Mar	16-22 Mar	15-28 Mar
			8-15 Apr	16-26 Apr
	Chick days	75	181	330
Crested tern	Date			28 Nov
	Chick days			12

6.2.3.4 Sooty terns and roseate terns

During the period of this study, it was not possible to determine the frequency and size of meals for roseate and sooty terns. Sooty tern young become mobile at an early age (<5d) and crèche under dense *Nitraria billardierei* shrubs. Roseate tern young also become mobile and are highly cryptic, making regular monitoring impossible. Roseate tern colonies were deemed too fragile during this study to disturb. Few roseate terns bred successfully during the last two seasons of this study.

6.2.4 Timing of breeding and reproductive performance measures.

Eggs of unknown age were aged using the backdating technique described by Wooller and Dunlop (1980) for silver gulls (*Larus novaehollandiae*), and from water loss rates described in Surman and Wooller (1995) and Surman (1997). Laying patterns were analysed using both laying dates of known-age eggs and the estimated laying dates of other eggs. Eggs that were known to be relaid were excluded from calculations of the mean date of laying for each species. The laying pattern was considered the most practicable measure of the timing of breeding and allows the onset of laying and the peak periods of nestlings to be predicted from simple measurements at the nest. The numbers of marked nests monitored in each year of this study are presented in Table 6.2.

6.2.4.1 Lesser noddy, sooty tern and brown noddy.

Nest-sites monitored were selected at random and permanently marked. Their contents were recorded weekly during field trips from mid-September 1998 to mid-February 2001. These protocols allowed the percentage of nests that were occupied (participation rate), the percentages of eggs that produced nestlings (hatching success), the percentage of nestlings that became free-flying (fledging success) and the percentage of eggs that were laid that produced free flying young (breeding success).

6.2.4.2 Wedge-tailed shearwaters

62 burrows of the wedge-tailed shearwater were marked with 600 mm long wooden stakes at the start of the project. Burrows were monitored weekly to record occupancy between September and November, when visits increased to every second day to record the onset of egg laying. Burrows that were identified as occupied with egg were left undisturbed after this initial visit until January, when burrows were rechecked to determine the proportion of eggs that hatched. Similarly, burrows containing young during checks in January were left undisturbed until late February, when regular monitoring of burrows recommenced in order to determine fledging times and rates.

6.2.4.3 Crested terns and roseate terns.

Because of the transitory nature of their nesting sites, these species were monitored by surveying areas known to have had breeding colonies regularly until that season's breeding site was located. Thereafter, daily counts of breeding attempts were made during field trips to determine the sequence of breeding and breeding population size. Both species were left undisturbed until chicks had hatched, when a closer look at the colony was made. It was not possible to calculate accurate measures of nesting, fledging or breeding success for these species; however, indications of breeding performance were recorded.

Table 6.2 The number of marked nests monitored of each species on Pelsaert Island between 1998 and 2000.

Species	Breeding Season		
	1998	1999	2000
Lesser noddy	218	228	240
Brown noddy	130	134	138
Sooty tern	50	66	88
Wedge-tailed shearwater	61	62	62

6.2.5 Environmental factors influencing reproductive performance and diet

In order to determine the influence, if any, that the seasonal body of low-salinity tropical water known as the Leeuwin Current has on the timing of breeding of tropical seabirds at the Houtman Abrolhos, we compared the date that the first eggs were recorded and the mean lay date with the mean average sea level recorded at Fremantle (Flinders University), the average Sea Surface Temperature (SST) at 113.5°E and 28.5°S (Reynolds', CSIRO) and the Southern Oscillation Index (SOI). We also looked at any influence from lunar activity and meteorological events on the timing of breeding and reproductive performance of seabirds at the Houtman Abrolhos. Data for moon phases were obtained from the Perth Observatory. Moon phases were mapped on a calendar and compared with the breeding phenology of each seabird species to determine if breeding was timed to any particular phase of the moon.

Climatic data, including wind speed, minima and maxima temperature and rainfall were obtained for Geraldton and the Houtman Abrolhos from the Bureau of Meteorology, Western Australia.

To test variability in the diet of seabirds we must assume the following null hypothesis: Seabirds forage non-selectively, that is they will feed on any prey of suitable size that they encounter within their foraging range.

Statistical tests were carried out to determine if breeding success was related to quantities of the five main prey species for each seabird species. This allows us to concentrate on those prey that make a significant contribution to the diet of those seabirds and so may influence the outcome of their breeding attempt. After testing for homogeneity of variance, mean parameters were compared using either ANOVA's or non-parametric Mann-Whitney U and Kruskall-Wallis Chi^2 tests.

Some data collected prior to the commencement of this project are also included in the analysis in order to better understand variation in diet. We also only analysed in any detail the volume that each prey contributed to the diet as this was thought to most accurately represent the contribution each prey makes to the diet of each species of seabird. We therefore pooled each year's dietary data for each species into a single annual pool to see if the supply of various key prey species changed from one year to the next.

6.2.6 Daily variation in diet

To examine daily variation in the diet of some of the main seabird species on Pelsaert Island, regurgitates were collected on three occasions during the 1998 breeding season. On each occasion we attempted to obtain 15 regurgitates from each seabird species (Lesser noddy, brown noddy and sooty tern) were collected on three consecutive evenings, weather permitting. No samples were collected on the evening of 15 October 1998 due to bad weather. Bird species were sampled in the same sequence, lesser noddies were sampled first, followed by brown noddies and finally sooty terns. This sequence was followed to maximize the rate of return of regurgitates, thereby minimizing the number of adults that needed to be captured to obtain the 15 regurgitates. The method of capture varied; lesser noddies were mist-netted, whilst brown noddies and sooty terns were captured by hand. However, birds were induced to regurgitate in the same way as described in Section 6.2.2. The dates of sampling, and number of samples collected from each species are presented in Table 6.3.

6.2.7 Seabird population size estimation

Estimates of population size of seabirds at the Houtman Abrolhos have been regularly undertaken by CALM (Fuller et al., 1994; Fuller et al., 2000). Estimates based on the most recent surveys carried out by CALM have been used to determine the quantities of marine prey consumed by seabirds. Breeding population sizes where possible were corrected using participation rates calculated during this study.

Table 6.3 The dates that regurgitates were collected and number of samples obtained for lesser noddies, brown noddies and sooty terns sampled on the same evenings during 1998.

	Number of samples		
Date	**Lesser noddy**	**Brown noddy**	**Sooty tern**
4 October	12	5	
5 October	15	1	
6 October	13	1	
13 October	20	20	
14 October	18	17	
10 November	18	15	13
11 November	21	15	16
12 November	18	14	15

6.2.8 Spatial overlap of seabird foraging and the purse seine fishery

The distributions and abundances of all seabirds in waters adjacent to the Houtman Abrolhos, from 29°25' to 27°35'S and 112°15' to 114°30'E, were recorded from an oceanographic research vessel on 1 April 1995, 24 March 1996 and 15 August 1996, as well as on two other cruises in smaller vessels adjacent to Pelsaert Island (Fig. 6.2; Surman and Wooller, in press). The bridges of these vessels were 10 m and 3 m above sea level respectively and all birds observed within an estimated 300 m radius semicircle forward of the bridge were identified and counted using binoculars. During each daylight hour, three consecutive ten-minute sets of observations were made, except in the area around Pelsaert Island where observations were continuous. The spatial extent of foraging areas for six seabird species was summarized from the data in Surman (1997) and Surman and Wooller (in press) and mapped along with the fishing grounds of the scaly mackerel purse seine fishery. Note that seabird data available for the 600 m wide at-sea transects have been extrapolated across data points provided in the above studies to provide an overview of the foraging range for each species.

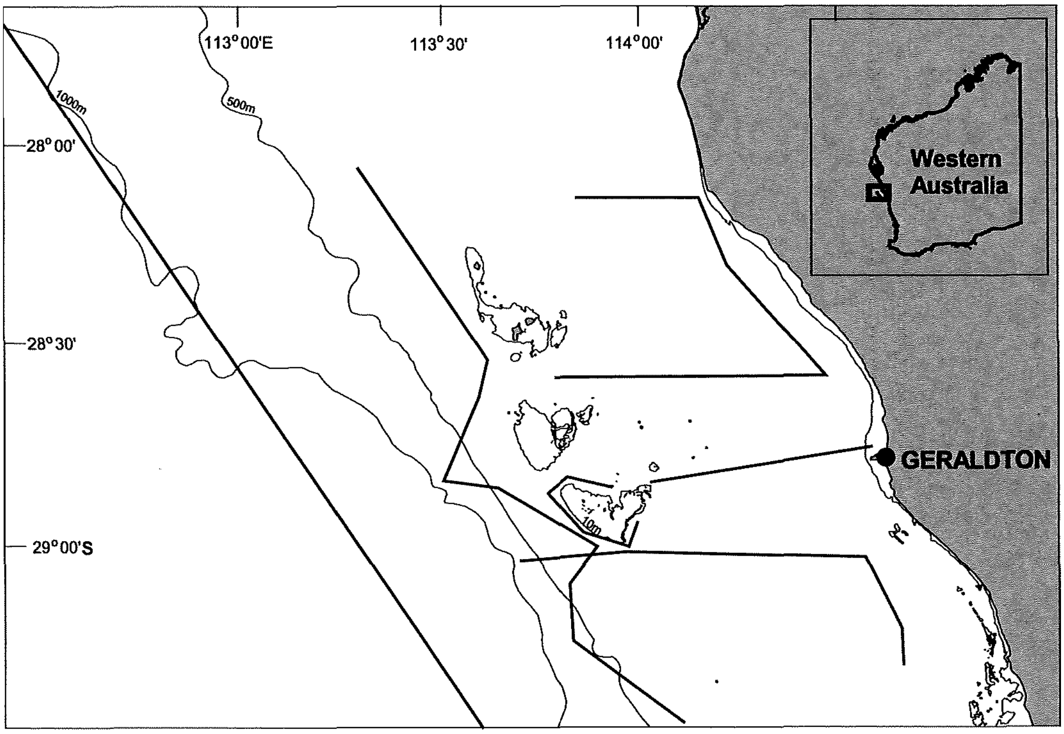


Figure 6.2 Seabird survey transects in the study area.

7 Results

7.1 Timing of breeding

All six species investigated on Pelsaert Island are annual breeders. Table 7.1 shows the mean and modal lay dates and date of first laying form 1998 to 2000. There was little variation in the mean lay dates of roseate terns and wedge-tailed shearwaters, but considerable variation (up to a month) in the mean lay dates of lesser and brown noddies and sooty terns.

Table 7.1 The mean and modal lay date and the date of the first egg for each species of seabird monitored during 1998-2000.

Species		1998	1999	2000
Lesser noddy	Mean	22 Oct	15 Sep	1 Oct
	Mode	15 Oct	10 Oct	20 Sep
	First	9 Sep	19 Aug	5 Sep
	n	77	93	91
Brown noddy	Mean	15 Oct	13 Sep	25 Sep
	Mode	13 Oct	20 Sep	24 Sep
	First	13 Sep	26 Aug	3 Sep
	n	111	94	96
Sooty tern	Mean	3 Nov	22 Oct	4 Oct
	Mode	20 Oct	18 Oct	4 Oct
	First	12 Oct	9 Oct	27 Sep
	n	50	40	56
Wedge-tailed shearwater	Mean	22 Nov	23 Nov	22 Nov
	Mode	16-21 Nov	18-24 Nov	17 Nov
	First	14 Nov	16 Nov	17 Nov
	n	39	43	32
Crested tern	Mode	27 Oct	15 Nov	27 Oct
	First	19 Oct	25 Oct	14 Oct
Roseate tern	First	8 Nov	11 Nov	6 Nov

7.2 Number of breeding attempts

The number of breeding attempts (participation rate) in monitored nest sites for lesser noddy, brown noddy, sooty tern and wedge-tailed shearwater are presented in Table 7.2. There were no significant differences in the number of breeding attempts for lesser noddy ($X^2_1 = 0.4$, $p > 0.5$), brown noddy ($X^2_1 = 2.2$, $p > 0.1$) or wedge-tailed shearwater ($X^2_1 = 1.6$, $p > 0.1$) between the three years of this study. However, there was a significant difference in the number of attempts made by sooty terns, with more attempting to breed during 1998 ($X^2_1 = 7.62$, $p < 0.01$).

Table 7.2 The participation rate (%) of lesser noddies, brown noddies, sooty terns and wedge-tailed shearwaters for monitored nests on Pelsaert Island between 1998 and 2000.

Species		**1998**	**1999**	**2000**
Lesser noddy	Participation rate	35.3	40.8	37.9
	Nests monitored	218	228	240
Brown noddy	Participation rate	85.4	70.1	69.6
	Nests monitored	130	134	138
Sooty tern	Participation rate	90.6	60.6	63.6
	Nests monitored	43	66	88
Wedge-tailed shearwater	Participation rate	65.6	69.4	55.6
	Nests monitored	61	62	63

7.3 Reproductive performance

7.3.1 Lesser noddy, brown noddy, sooty tern and wedge-tailed shearwater

The hatching success, fledging success and breeding success of lesser noddy, brown noddy, sooty tern and wedge-tailed shearwater are presented in Table 7.3. Breeding success and fledging success was not able to be determined for sooty terns due to the highly mobile nature of their young. Similarly, hatching success, fledging success and breeding success were not able to be determined for the roseate tern and crested tern. However, their general reproductive performance was determined from regular visits to their colonies.

There was no significant difference in the breeding success observed between 1998 and 2000 for brown noddies ($X^2_1 = 0.05$, $p > 0.8$) or wedge-tailed shearwaters ($X^2_1 = 3.1$, $p > 0.05$). However, breeding success in lesser noddies was significantly lower during 1999 than in other years ($X^2_1 = 9.5$, $p > 0.005$, Table 7.3).

Table 7.3 The hatching, fledging and breeding success (%) of lesser noddies, brown noddies, sooty terns and wedge-tailed shearwaters on Pelsaert Island between 1998 and 2000.

Species		1998	1999	2000
	Hatching	61.4	49.5	71.4
Lesser noddy	Fledging	58.8	43.5	66.2
	Breeding	36.1	21.5	47.2
	Hatching	54.0	65.9	65.6
Brown noddy	Fledging	56.7	48.4	46.0
	Breeding	30.6	31.9	30.2
	Hatching	no data	40.0	44.6
Sooty tern	Fledging	High	High	moderate
	Hatching	72.5	58.1	68.6
Wedge-tailed shearwater	Fledging	89.6	80.0	79.2
	Breeding	64.9	46.5	54.3

7.3.2 Roseate tern

Between 1998 and 2000, summer-breeding roseate terns reared young successfully only during the 1998 breeding season. During 1999 and 2000, all breeding attempts on Pelsaert Island, and other islands visited throughout the Pelsaert Group, were unsuccessful. A summary of breeding attempts for roseate terns is given in Table 7.4.

7.3.3 Crested tern

Although it was not possible to determine a quantitative value of reproductive performance for crested terns, qualitative estimates of breeding performance have been included for comparison to other seabirds breeding on Pelsaert Island. During each year of this study, crested terns bred successfully, with high to very high hatching success and high fledging success. The relative breeding performance of crested terns was checked by searches through colonies for dead nestlings as well as the size of crèches observed adjacent to nesting areas.

Table 7.4 The number, location and estimated reproductive performance of roseate tern colonies in the Pelsaert Group, Houtman Abrolhos between 1998 and 2000.

Breeding season	Number of colonies monitored	Location of colonies	Colony size (pairs)	Observed rate of eggs that hatched	Estimated proportion of chicks fledged
1998	3	Pelsaert-south	900+	high	moderate (> 25%)
		Pelsaert-north	1000	high	high
		Rotundella Islet	500-600	high	high
1999	2	Pelsaert North	500	high	very poor (<1%)
		Jon Jim Island	1000	high	very poor (<1%)
2000	3	Pelsaert-mid	200	high	poor (<10%)
		Square Island	180	low	none
		Burnett Island	20	none	none

7.4 Meal sizes and feeding frequency

The mean mass increments and decrements for wedge-tailed shearwaters, lesser noddies and brown noddies are presented in Table 7.5 and Table 7.6. There was no significant difference in mean daily mass increments between years for either the lesser noddy (ANOVA; $F_{2,78} = 0.22$, $p = 0.80$) or brown noddy (ANOVA; $F_{2,93} = 0.19$, $p = 0.83$). Nor was there any significant annual difference in the mean daily mass loss for each of these species (Lesser noddy, ANOVA; $F_{2,77} = 1.35$, $p = 0.27$; Brown noddy, ANOVA; $F_{2,92} = 2.31$, $p = 0.10$, Table 7.6). Interestingly, there was a significant difference in the mean mass increment for wedge-tailed shearwaters from one year to the next, with nestlings being fed less food during the 2000/2001 breeding season (ANOVA, $F_{2,280} = 9.42$, $p < 0.0005$, Table 7.6). However, there was no significant difference in mass loss between years for wedge-tailed shearwaters ($F_{2,108} = 3.02$, $p = 0.05$).

There was no significant difference in the mean number of feeds that were received by lesser noddy and brown noddy chicks between years (Table 7.7; ANOVA; Lesser noddy

$F_{2,80} = 2.4$, $p = 0.1$; Brown noddy $F_{2,94} = 1.45$, $p = 0.24$). Similarly, there was no significant difference between years in the proportion of wedge-tailed shearwater nestlings that received at least one meal ($Chi^2 = 0.83$, Table 7.8).

Lesser noddies received, on average 2.4 meals during each day, compared to the 1.8 meals received by brown noddy young (Table 7.7). In contrast, crested tern chicks received an average 4.4 meals each day, with between 2 and 7 meals being delivered by both parents (Table 7.7).

Table 7.5 The mean 3-hourly (± S.E.) mass increment (in grams) and mass loss for lesser and brown noddies on Pelsaert Island between 1998 and 2000.

		Year			
Species	**Parameter**	**1998**	**1999**	**2000**	**Total**
Lesser noddy	Mass increment	5.0 (0.5)	5.5 (0.4)	4.8 (1.4)	5.3 (0.3)
	n	37	105	12	154
	Mass loss	3.5 (0.4)	3.1 (0.2)	1.9 (0.4)	3.1 (0.2)
	n	28	118	8	154
Brown noddy	Mass increment	6.0 (0.8)	8.6 (0.6)	6.8 (0.9)	8.2 (0.5)
	n	33	136	39	175
	Mass loss	4.3 (0.7)	5.3 (0.3)	4.9 (0.7)	5.2 (0.3)
	n	27	154	37	191

Table 7.6 The mean (± S.E.) mass increment and mass decrement (loss) for the wedge-tailed shearwater, lesser noddy and brown noddy on Pelsaert Island between 1998 and 2000.

Species	Parameter	Year 1998	1999	2000	Total
Wedge-tailed shearwater	Mass increment	58.3	50.9	36.9	47.1
		(5.0)	(2.8)	(3.0)	(1.9)
	n	54	122	107	283
	Mass loss	30.6	27.9	26.2	27.7
		(2.3)	(1.1)	(3.5)	(1.4)
	n	60	195	142	397
Lesser noddy	Mass increment	14.7	13.8	14.7	14.3
		(1.7)	(0.9)	(1.2)	(0.7)
	n	12	41	28	81
	Mass loss	7.9	5.6	5.9	6.1
		(1.1)	(0.7)	(0.9)	(0.5)
	n	13	41	26	80
Brown noddy	Mass increment	16.6	18.3	17.3	17.7
		(2.8)	(1.6)	(1.4)	(1.0)
	n	13	52	31	96
	Mass loss	7.4	12.3	11.1	11.2
		(1.6)	(1.1)	(1.2)	(0.8)
	n	13	51	31	95

Table 7.7 The mean number ($\pm$ S.E.) number of meals received daily by young of seabirds nesting on Pelsaert Island between 1998 and 2000.

		Year			
Species	**Parameter**	**1998**	**1999**	**2000**	**Total**
Lesser noddy	Mean	2.23	2.31	2.71	2.43
	(S.E.)	(0.2)	(0.13)	(0.17)	(0.09)
	Number of chick days	13	42	28	83
Brown noddy	Mean	1.69	1.92	1.72	1.82
	(S.E.)	(0.13)	(0.09)	(0.09)	(0.06)
	Number of chick days	13	52	32	97
Crested tern	Mean			4.45	4.45
	(S.E.)			(0.14)	(0.14)
	Number of chick days			11	11

Table 7.8 The mean proportion of wedge-tailed shearwater chicks that were fed a minimum of one meal overnight on Pelsaert Island between 1998 and 2000.

			Year	
		1998	**1999**	**2000**
Wedge-tailed shearwater	Mean	74.7	74.1	64.6
	S.E.	5.3	2.9	3.6
	Number of chick nights	54	122	107

7.5 Dietary composition

Between September 1998 and April 2001, a total of 2,341 regurgitates were collected from lesser noddies, brown noddies, sooty terns, crested terns, roseate terns and wedge-tailed shearwaters on Pelsaert Island, Houtman Abrolhos (Table 7.9). Since dietary studies commenced at the Houtman Abrolhos in 1991, a total of 3,351 dietary samples have been collected. A summary of the main prey taxa consumed by seabirds on Pelsaert Island during this period is given in Table 7.10. Terns invariably consumed mainly fish prey and the wedge-tailed shearwater consumed mainly cephalopods.

Table 7.9 The number of regurgitates collected from each seabird species on Pelsaert Island, Houtman Abrolhos between 1998 and 2001.

	Year			
	1998	**1999**	**2000**	**Total**
Lesser noddy	285	216	192	693
Brown noddy	221	136	139	496
Sooty tern	124	103	115	342
Crested tern	90	140	352	582
Roseate tern	59	56	6	121
Wedge-tailed shearwater	34	50	23	107

The dietary composition of each species studied is considered separately below. In general, seabirds at the Houtman Abrolhos took a wide range of prey (Table 7.11). Complete tables showing the percentage number of items, mean volume and frequency of occurrence, as well as the index of relative importance of each prey species for each seabird species in each year of this study are provided in Appendices 3 - 6. To clarify the comparative analysis of this complex data set, we will consider here that the volume of prey provides the most accurate estimate of the importance of each prey species to the diet.

Generally, the amount marine food consumed by seabirds at the Houtman Abrolhos was proportional to the size of the seabird. Wedge-tailed shearwaters and crested terns delivered considerably larger meals than the other terns and noddies as determined by the wet mass of regurgitates collected on Pelsaert Island (Table 7.11). Wet mass for the smaller species ranged from 3-5% of body mass, compared to 7% for brown noddies, sooty terns and crested terns and 8% for wedge-tailed shearwaters .

Table 7.10 The percentage volume (V), percentage numbers (N), frequency of occurrence (F) and rank of the main prey taxa identified from regurgitates of seabirds from Pelsaert Island since 1991.

Bird species		Prey taxon				
		Fish	Squids	Crustaceans	Hydrozoans	Insects
Lesser noddy	**V**	95.9	2.6	1.2		
		(0.4)	(0.4)	(0.2)		
	N	95.1	0.7	4.4		
	F	99.3	9.1	7.8		
	Rank	1	3	2		
Brown noddy	**V**	89.7	9.8	0.4		
		(0.9)	(0.9)	(0.2)		
	N	93.9	2.3	3.7		
	F	98.1	28.5	2.7		
	Rank	1	2	3		
Sooty tern	**V**	33.2	60.9	0.3	0.9	4.2
		(2.2)	(2.4)	(0.1)	(0.2)	(0.9)
	N	65.0	23.4	0.8	2.1	9.9
	F	69.7	74.7	4.3	6.2	12.5
	Rank	1	2	5	4	3
Crested tern	**V**	97.3	1.3	1.7		
		(0.8)	(0.6)	(0.7)		
	N	96.6	1.5	1.9		
	F	97.6	1.5	1.8		
	Rank	1	3	2		
Roseate tern	**V**	99.0	1.0			
		(0.9)	(0.9)			
	N	99.2	0.8			
	F	99.1	1.8			
	Rank	1	2			
Wedge-tailed shearwater	**V**	30.9	68.9	<0.1	0.1	
		(3.8)	(3.8)	(<0.1)	(<0.1)	
	N	56.6	42.8	0.2	0.2	
	F	60.9	80.0	1.7	1.7	
	Rank	2	1	3	3	

Table 7.11 The sizes of the seabirds studied and the numbers and wet masses of dietary samples obtained from each during studies on Pelsaert Island between 1991 and 2000.

	Roseate tern	Lesser noddy	Brown noddy	Sooty tern	Crested tern	Wedge-tailed shearwater
Body mass (g)	108	112	183	157	324	350
Number of samples	123	1303	768	449	708	112
Mean wet mass of sample (g)	3.3 ± 0.5	5.8 ± 0.1	12.5 ± 0.4	11.1 ± 0.5	23.0 ± 1.6	29.4 ± 1.5
Total food items identified	268	28381	17297	2606	411	844
Mean food items per sample	2.4 ± 0.4	26.2 ± 0.9	27.8 ± 0.9	8.6 ± 0.6	1.1 ± 0.1	7.34 ± 0.8

7.5.1 Lesser noddy

Lesser noddy regurgitates were characterised by five main fish prey that contributed 89.3% of volume overall (Appendix 3). These were (in order of importance) beaked salmon (*Gonorynchus greyii*), black-spotted goatfish (*Parupeneus signatus*), Hawaiian bellowfish (*Macrorhamphosis scolopax*), Australian anchovy (*Engraulis australis*) and unidentified clupeids. All prey were larval fishes less than 85 mm standard length. Beaked salmon, black-spotted goatfish and Hawaiian bellowfish occurred in 81.9, 66.0 and 37.5% of regurgitates respectively collected from lesser noddies between 1991 and 2001 (Appendix 3).

Beaked salmon were the most important prey for lesser noddies in all years of this study. However, there were significant differences in the volumetric proportion of all the main prey each year between 1998 and 2000 (Kruskall-Wallis X^2= 9.1, 11.3, 19.1, 65.3, 8.4 for beaked salmon, black-spotted goatfish, Hawaiian bellowfish, Australian anchovy and clupeids respectively, all $p < 0.01$, Appendices 4-6). Over the term of this project, there was no significant difference in the frequency of occurrence of beaked salmon, black-spotted goatfish and Hawaiian bellowfish, but significant differences in the frequency of Australian anchovy (X^2 = 22.4, $p < 0.001$) and clupeids (X^2 =7.8, $p < 0.03$).

7.5.2 Brown noddy

Brown noddies consumed mainly beaked salmon, although they also consumed many of the same prey types found in lesser noddy regurgitates. Beaked salmon accounted for 68.8% by volume and occurred in 94.8% of all brown noddy regurgitates (Appendix 3). Beaked salmon, black-spotted goatfish, Hawaiian bellowfish and Australian anchovy made up 80.2% of the diet of brown noddies by volume. A significant difference between the two noddy species is the larger volume of cephalopods consumed by brown noddies (Appendix 3).

Beaked salmon were also the most important prey in each year of this study in terms of the percentage volume, numerical abundance and frequency of occurrence (Appendices 4-6). There were significant annual differences in the volumes of beaked salmon (Kruskall-Wallis X^2 = 102.7, $p < 0.0005$), black-spotted goatfish (Kruskall-Wallis X^2 = 17.4, $p < 0.0005$), Hawaiian bellowfish (Kruskall-Wallis X^2 = 90.8, $p < 0.0005$), Australian anchovies (Kruskall-Wallis X^2 = 19.8, $p < 0.0005$) and cephalopods (Kruskall-Wallis X^2 = 24.8, $p < 0.0005$) in the diet of brown noddies. There was no annual difference in the volume of unidentified clupeids in regurgitates from brown noddies.

There was no significant difference in the frequency of occurrence of beaked salmon or clupeids, however there were significant annual differences in the frequency of black-spotted goatfish (X^2 = 10.9, $p < 0.005$), Hawaiian bellowfish (X^2 = 21.9, $p < 0.001$), Australian anchovy (X^2 = 13.3, $p < 0.005$) and cephalopods (X^2 = 9.3, $p < 0.01$).

7.5.3 Sooty tern

Sooty terns took a wide variety of prey, including 34 species from 31 families, including terrestrial insects, hydrozoans, gastropods and larval crustaceans. Sooty terns consumed mainly enoploteuthid or unidentified cephalopods (Appendices 3-6). Unidentified cephalopods comprised 65.4 % of the diet of Sooty terns by volume, and occurred in 77.1% of all regurgitates (Appendix 3). Of the non-squid prey consumed by sooty terns, there were higher proportions of lanternfishes (Myctophidae). Also of interest is the significant proportion of hydrozoans, insects and crustaceans compared to the two noddy species. In spite of these differences, beaked salmon, black-spotted goatfish and Hawaiian bellowfish still contributed to the top five prey types found in all sooty tern regurgitates.

There were significant annual differences in the volumes of beaked salmon (Kruskall-Wallis X^2 = 25.7, $p < 0.0005$), black-spotted goatfish (Kruskall-Wallis X^2 = 39.2, $p < 0.0005$), Hawaiian bellowfish (Kruskall-Wallis X^2 = 15.9, $p < 0.0005$) and squids (Kruskall-Wallis X^2 = 47.2, $p < 0.0005$) in the diet of sooty terns. Similarly, there was also considerable variability in the frequency of occurrence of main prey from year to year. Beaked salmon (X^2 = 15.6, $p < 0.001$), black-spotted goatfish (X^2 = 24.3, $p < 0.001$) and Hawaiian bellowfish (X^2 = 11.6, $p < 0.005$) occurred more frequently in regurgitates during 1999. There was no difference in the frequency that squids or lanternfishes occurred in sooty tern regurgitates.

7.5.4 Crested tern

Unlike the offshore-foraging terns above, crested terns fed almost exclusively on reef fishes and nektonic shelf fishes. A total of 51 fish species from 36 families were identified from crested tern dietary samples. Of these, scaly mackerels comprised 22.5 % of the diet by volume and occurred in 23.4 % of all samples (Appendix 3). By volume, the most significant fish prey consumed by crested terns after scaly mackerel were parrotfishes (15.0%), blennies (12.0 %), wrasses (13.9%), apogonids (5.3%) and Australian anchovy (3.1%).

There was no significant difference in the volumes of blennies or wrasses caught by crested terns from one year to the nest. However, there were significant differences in the volumes of anchovies (Kruskall-Wallis X^2 = 19.3, $p < 0.0005$), scaly mackerel (Kruskall-Wallis X^2 = 47.2, $p < 0.0005$) and parrotfishes (Kruskall-Wallis X^2 = 19.8, $p < 0.0005$).

There was also no difference in the frequency of occurrence of blennies, wrasses and scaly mackerel from one year to the next. However, parrot fishes occurred more often in 1999 than in other years (X^2 = 9.8, $p < 0.05$), whilst apogonids were more prevalent in 2000 (X^2 = 9.3, $p < 0.05$).

7.5.5 Roseate tern

Roseate terns also tend to forage nearer to the Houtman Abrolhos than the noddies and sooty tern, but prefer nektonic prey, particularly adult sprats. Although it was difficult to obtain samples from roseate terns during this study, and during the 2000/01 season none were practicably available, some results were obtained. Roseate terns preferred fish prey, consuming mainly beaked salmon (36.9 % by volume), black-spotted goatfish (11.2% by volume) and slender sprat (11.8 % by volume). It was not practicable to assess annual differences in prey occurrence or volumes due to the few samples obtained and the poor breeding years observed. Results from dietary analysis are presented in Appendices 3-6.

7.5.6 Wedge-tailed shearwater

Wedge-tailed shearwaters are the only seabird species studied that is able to actively pursue prey beneath the surface waters. The diet of wedge-tailed shearwaters was the least diverse amongst the seabird community studied, and they took only 11 species of fishes, two species of squid, two crustaceans and a hydrozoan (Appendix 3). They preferred cephalopods (59.8 % by volume), adult scaly mackerel (11.1 % by volume) and dart squids (7.2 % by volume). There was a significant proportion of unidentifiable fish material in wedge-tailed shearwater regurgitates, and this may under-represent some prey types identified from this species.

There were no significant differences in the volume of dart squid, scaly mackerel or beaked salmon. However, there was a significant difference in the volume of unidentified squids from one year to the next (Kruskall-Wallis $X^2 = 8.6$, $p < 0.014$).

Similarly, there were no significant annual differences in the frequency of occurrence of any of the five major prey items recovered from wedge-tailed shearwater regurgitates (Appendices 3-6).

7.6 Seasonal variability in food supply

To assess if any variability in the diet could be explained by seasonal variation in the supply of various prey by seabirds we pooled across years and bird species.

Table 7.12 shows that the proportion of some prey varies considerably from one month to another. This variation was consistent in all years for pooled samples of all seabird dietary samples. There was no significant difference in the presence of clupeids and Australian anchovies from one season to the next. There was, however, significant seasonal change in the volumes of beaked salmon ($X^2 = 15.7$, $p < 0.001$), black-spotted goatfish ($X^2 = 8.5$, $p < 0.025$), Hawaiian bellowfish ($X^2 = 25.7$, $p < 0.001$) and squids ($X^2 = 14.3$, $p < 0.001$).

Table 7.12 The mean (± S.E.) seasonal percentages by volume of key prey identified from regurgitates of seabirds at the Houtman Abrolhos. The pooled data has been grouped into early (Sep/Oct), mid (Nov/Dec) and late (Jan/Feb) parts of the breeding season.

	Period		
Prey species	**Sep/Oct**	**Nov/Dec**	**Jan/Feb**
Beaked salmon	58.6 (1.2)	43.4 (1.1)	22.6 (1.5)
Black-spotted goatfish	7.9 (0.7)	18.5 (0.8)	24.7 (1.8)
Hawaiian bellowfish	9.9 (0.5)	6.4 (0.4)	1.5 (0.3)
Australian anchovy	3.0 (0.5)	3.4 (0.4)	4.1 (0.7)
Clupeid	4.6 (0.6)	1.6 (0.3)	0.6 (0.3)
Squid	6.0 (0.6)	19.2 (1.0)	28.5 (2.1)
Number of samples	782	1226	394

Overall, seasonal change in the volumetric proportion of the main prey captured by sooty terns, brown noddies and lesser noddies is presented in Figure 7.1. Typically, the mean volume of beaked salmon and Hawaiian bellowfish declined from 60% to 22% and from 10% to 2% respectively as the breeding season progressed. Thus, on average, beaked salmon occur in higher volumes in the diets of these seabirds during the early portion of the breeding period. The mean volume of beaked salmon and Hawaiian bellowfish declined, the mean volume of both black-spotted goatfish and squids increased. Black-spotted goatfish volumes rose from 8 to 25%, whilst the volume of squid rose from 6 to 28% (Figure 7.1). It is assumed that these changes reflect changes in availability of the prey, due to either changes in sizes of prey suitable for capture, or simply a change in abundance of fish species in the reef shallows.

7.7 Variability in diet and the environment

Concurrent with significant annual variation in the volume of prey in the diets of seabirds at the Houtman Abrolhos (see Section above), we considered annual variation in the seasonal pattern of diet described above. The diet of seabirds was significantly different between 'good' and 'poor' breeding years (Figure 7.2). The most dramatic difference can be explained by changes in the volume of beaked salmon. During 'good' years the volume of beaked salmon in regurgitates followed the pattern for all years overall (Figure 7.1). However, beaked salmon volumes during the critical early period (September/October) of the breeding season were significantly lower in 'poor' years (18% compared with 65%, Mann Whitney U=9436.0, p<0.01). Similarly, Hawaiian bellowfish volumes followed the same pattern during 'good' and 'poor' years, but were significantly lower in 'poor' years during Sept/Oct (Mann Whitney U=30449.5, p<0.05) and Nov/Dec (Mann Whitney U=94085.5, p<0.05). Squid volumes were not significantly different during the early (Sept/Oct) to mid (Nov/Dec) portions of the breeding season, but during good years the volume of squid during Jan/Feb, coinciding with the main chick-rearing period in the two squid-eating terns (Brown noddy and sooty tern), rises from 5% (Sept/Oct) to 32% (Jan/Feb). During 'poor' years the volume of squid levels out at only 20%, and although not significantly different, represents a 30% decline in the volume usually expected. The volume of black-spotted goatfish is significantly higher during all periods in regurgitates from 'poorer' years. Furthermore in 'good' years, when mainly beaked salmon are consumed, the volume of black-spotted goatfish represents only 7% of the diet by volume. This volume rises dramatically during the latter parts of the breeding season during which lesser noddies are feeding their young to an average 25-30% by volume of goatfish. However, during poorer years, the volume of black-spotted goatfish during Sep/Oct is nearly doubled to 14%, and is significantly higher for the remaining periods (Mann Whitney U=29447.0, 87012.0, 13982.0 for Sep/Oct, Nov/Dec and Jan/Feb respectively, all p<0.01, Figure 7.2).

7.8 Daily variation in diet

There was no significant variation in the diet of lesser noddies, brown noddies or sooty terns from one day to another during the early October and November sampling tests (Table 7.13). However, there was significant variation in the volume of beaked salmon in lesser noddies (Mann-Whitney U = 105, p = 0.03)), and for beaked salmon in brown noddies (Mann-Whitney U = 49.5, p < 0.01) during the mid-October sampling test. However, it should be noted that sampling occurred only over two consecutive evenings during mid-October, the final evening having been aborted due to bad weather. These results suggest that in the short-term the timing of sampling for regurgitates would not significantly influence the outcomes of the annual and seasonal dietary analysis.

Table 7.13 The percentage volume of main prey types found in regurgitates of lesser noddies, brown noddies and sooty terns during three periods that samples were collected simultaneously over three consecutive evenings during the 1999 breeding season.

Bird species	**Date**	**Prey species**	**Day 1**	**Day 2**	**Day 3**
Lesser noddy	4-6 October	Beaked salmon	60.8	36.7	43.8
		Black-spotted goatfish	8.7	3.1	1.9
		Hawaiian bellowfish	14.5	16.5	14.5
		Squid	0	5.0	8.6
		Clupeids	0	11.7	13.8
	13-14 October	Beaked salmon	53.2	30.6	
		Black-spotted goatfish	5.6	3.3	
		Hawaiian bellowfish	6.8	2.5	
		Squid	1.9	2.5	
		Clupeids	6.5	0	
		Lanternfish	0.0	24.9	
	10-12 November	Beaked salmon	39.0	46.7	50.0
		Black-spotted goatfish	14.7	14.4	7.8
		Hawaiian bellowfish	14.9	13.3	15.3
		Squid	2.9	5.2	4.2
		Anchovy	9.3	5.7	2.8
		Lanternfish	7.8	5.2	15.0
Brown noddy	4-6 October	Beaked salmon	64.0	70.0	95.0
		Black-spotted goatfish	0	0	0
		Hawaiian bellowfish	27.0	30.0	5.0
		Squid	1.0	0	0
	13-14 October	Beaked salmon	49.0	79.9	
		Black-spotted goatfish	0.0	1.6	
		Hawaiian bellowfish	18.8	11.9	
		Squid	15.8	4.7	
	10-12 November	Beaked salmon	43.9	55.5	46.8
		Black-spotted goatfish	0.8	1.1	0.0
		Hawaiian bellowfish	11.4	7.9	12.6
		Squid	37.0	28.0	34.3
Sooty tern	10-12 November	Beaked salmon	4.2	0.7	0.7
		Black-spotted goatfish	0.9	0.9	0.0
		Hawaiian bellowfish	2.9	0.9	0.0
		Squid	55.8	67.7	78.7
		Lanternfish	24.2	5.9	13.0
		Moths	11.9	11.3	4.7

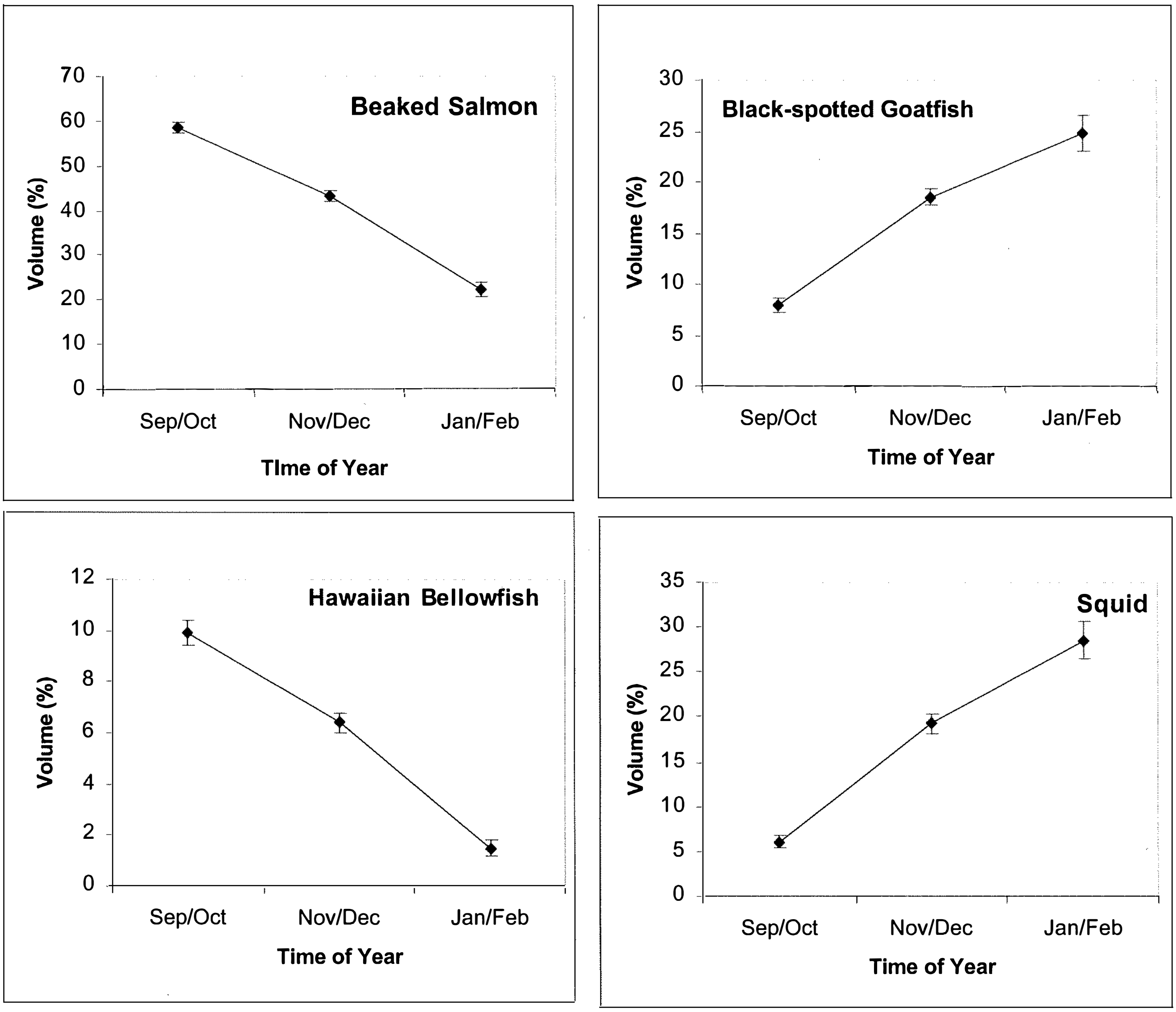


Figure 7.1 Seasonal change in the mean (± s.e.) volume of four main prey types found in the regurgitations of lesser noddies, brown noddies and sooty terns between 1991 and 2000.

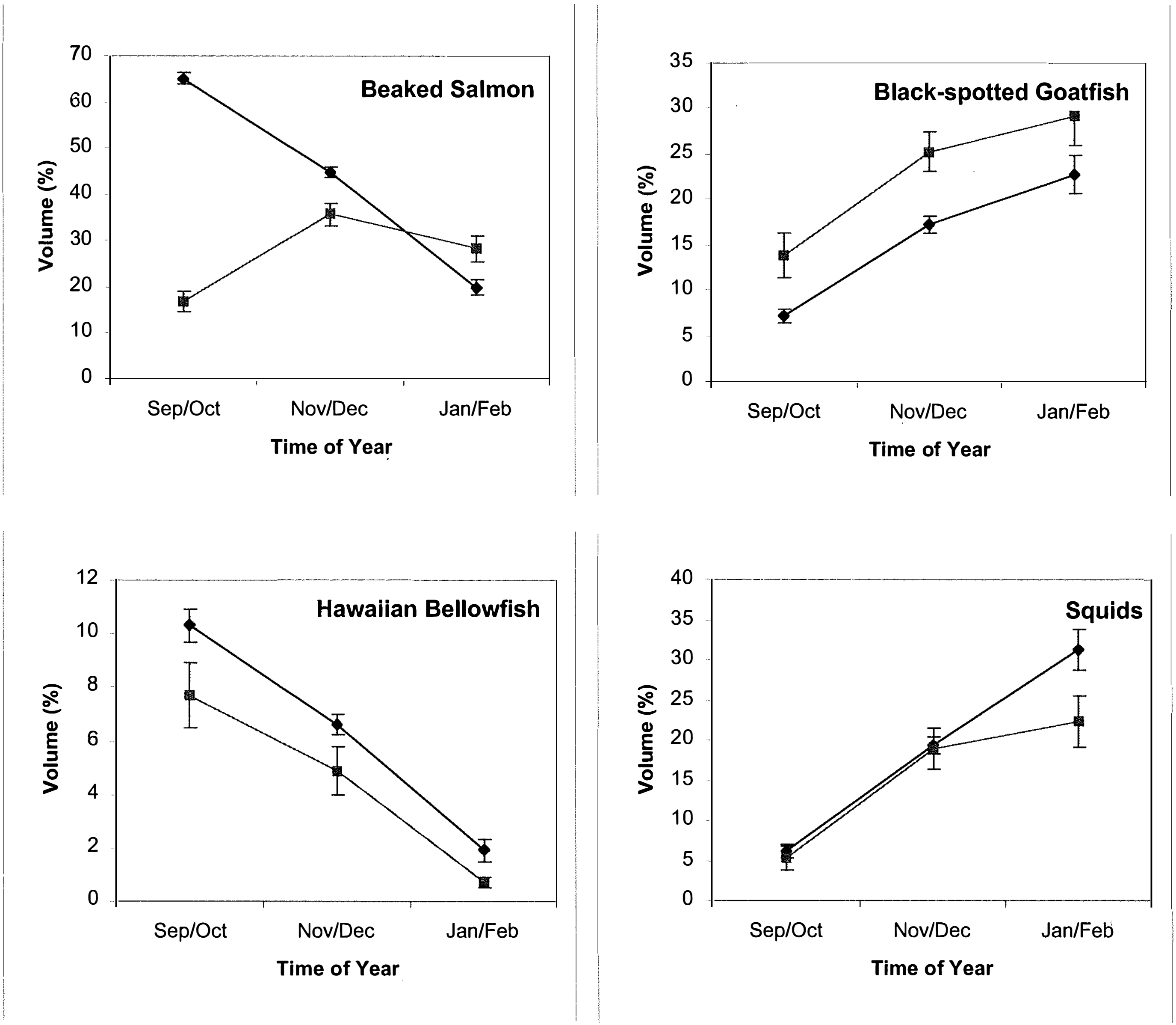


Figure 7.2 Seasonal change in the mean (± s.e.) volume of four main prey types found in the regurgitations of lesser noddies, brown noddies and sooty terns between 1991 and 2000. Regurgitates are pooled into reproductively 'good' (diamonds) and 'poor' (squares) breeding seasons.

7.9 Variability in breeding performance and the environment

7.9.1 Climate

There was no significant difference in the mean annual wind speed, rainfall or maximum and minimum temperatures at the Houtman Abrolhos between 1991 and 2000 (Table 7.14). However, rainfall was highly variable while wind speed at the Houtman Abrolhos was notably stronger during the 2000/01 breeding season (mean wind speed of 33.7 $km.h^{-1}$). Thus, changes in the behaviour of seabirds resulting in delays to breeding or changes in diet could not be attributed to climatic factors.

Table 7.14 Summary of climatic data for the Houtman Abrolhos. Data courtesy of the Bureau of Meteorology.

Year	Wind speed ($km.h^{-1}$)	Min. temperature (°C)	Max. temperature (°C)	Annual rainfall (mm)
1991	27.0	12.4	24.3	495
1992	28.2	12.1	24.7	444
1993	28.5	12.2	25.0	383
1994	27.0	13.2	27.1	319
1995	27.5	12.8	26.0	386
1996	29.2	13.3	26.4	504
1997	27.5	12.8	26.2	364
1998	29.5	13.0	25.9	430
1999	29.5	13.1	27.1	765
2000	33.7	12.9	26.9	368

7.9.2 Variability in oceanographic conditions

Oceanographic conditions vary from one year to the next depending upon the state of the Leeuwin Current which is in turn influenced by ENSO events. Figures 7.5 and 7.6 show the relationship between sea surface temperature (SST), sea level and the southern oscillation index (SOI). During the three years of this study, the SOI returned to positive values after recovering from the severe EL Nino of 1997. Similarly, both sea level and SST increased as a result of a stronger Leeuwin Current. Previously, there was a prolonged El Nino event between 1991 and 1994.

7.9.3 Variability in breeding performance

Figure 7.3 shows the variation in the number of breeding attempts made by wedge-tailed shearwaters, lesser noddies and brown noddies between 1991 and 2000. Although there were no significant differences in participation rate of these species during this study, there were dramatic changes in the number of breeding attempts during the last ten years of research, culminating in a catastrophic and total breeding failure during 1997, the precursor to the 1997/98 El Nino event.

Similarly, there was a corresponding delay to the commencement of breeding (as determined by the laying of eggs) during years that experienced poor participation rates prior to this study (Figure 7.4). The timing of breeding could be delayed by as much as 100 days when compared to earlier-breeding years. During this study the mean lay date varied by as much as 30 days in lesser and brown noddies (Table 7.1). However, some of this variation may be attributable to the recovery of seabird populations at the Houtman Abrolhos from the severe breeding failures observed in 1997 (Table 7.1, Figure 7.4).

7.9.4 The relationship between diet and reproductive performance

Although diet was highly variable, and breeding time was related to the state of the marine environment, there were some significant links between diet and the timing of breeding as well as breeding success. Surprisingly, there was no significant linear relationship between brown noddy breeding success and the volume of beaked salmon in their diet. However, in lesser noddies there was a significant relationship between the volumes of beaked salmon consumed and breeding success ($r^2 = 0.44$, $F_{1,7} = 5.42$, $p = 0.05$). The volume of beaked salmon in the regurgitates of brown noddies was also significantly related to the mean lay date ($r^2 = 0.68$, $F_{1,6} = 12.71$, $p = 0.01$) but this was not the case for lesser noddies.

Tables 7.15 and 7.16 show the size ranges of the main prey consumed, as well as the scaly mackerel consumed by seabirds at the Houtman Abrolhos during the three years of this study. Scaly mackerel consumed by seabirds were always adult specimens, whereas Australian anchovies were consumed as larvae by lesser noddies and brown noddies but as adults by wedge-tailed shearwaters and crested terns. Beaked salmon, Hawaiian bellowfish and black-spotted goatfish were all taken as larvae. Figures 7.9-7.11 show the percentage frequency distributions of the main prey consumed by seabirds at the Houtman Abrolhos for each year from 1998.

7.10 Estimating the seabird consumption

Table 7.17 shows the estimates of quantities of food consumed by seabirds at the Houtman Abrolhos. The estimates specifically for scaly mackerel are shown in Table 7.18. To calculate the amount consumed we have combined the various life-history parameters collected during this and other studies at the Houtman Abrolhos (Surman, 1997; Surman and Wooller, 1995 and 2002) as well as applying standard metabolic requirements from the literature (Furness, 1994) and population estimates from Fuller et al. (1994 and 2000).

Despite the variability in the timing of breeding observed for seabirds at the Houtman Abrolhos, their presence at the islands remains unaffected. Sooty terns, brown noddies and wedge-tailed shearwaters return from their mid-Indian Ocean wintering grounds in mid-August and remain in the vicinity of the Houtman Abrolhos until May of the following year. In contrast, lesser noddies, crested terns and roseate terns are resident at the Houtman Abrolhos year round. Thus, adults need to maintain themselves at the daily food requirement for this period as well as building up reserves for breeding, and later for maintaining young. There is also a period often overlooked that adult birds spend feeding their fledglings away from the nest (post fledging care).

Determining the quantity of food delivered to nestlings was carried out using two methods (see Section 6.3.3). Regurgitate wet mass provides a reasonable estimate of a single food load carried by a parent to feed its young. Repeat weighings of nestlings to determine mass increments provides a backup of this information as well as determining the numbers of meals received by nestlings of each species.

The estimate for wedge-tailed shearwaters has been extrapolated from both the lower value obtained from regurgitate mass and the higher value obtained from mass increments since the former doesn't appear to truly reflect meal size because regurgitates from procellariformes seabirds may not fully empty the proventriculus.

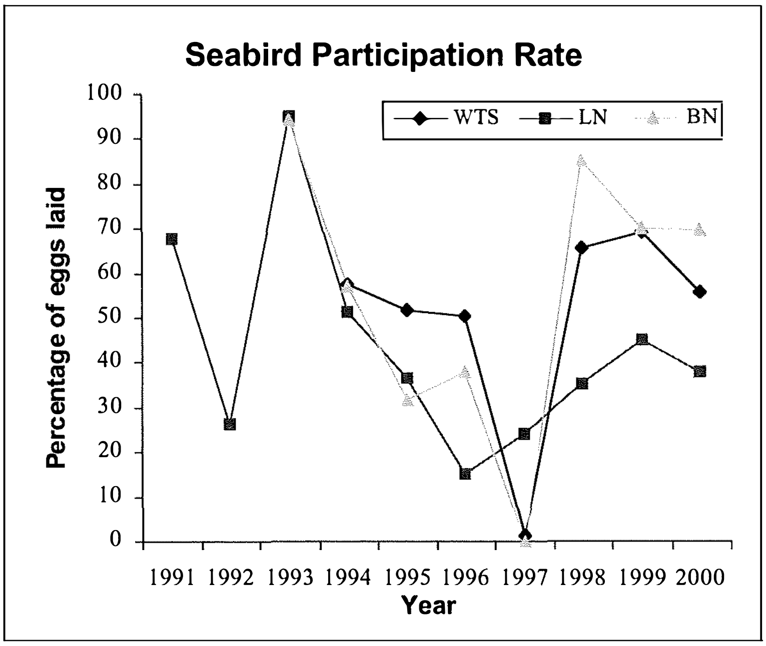


Figure 7.3 The participation rate (number of breeding attempts) of seabirds at the Houtman Abrolhos between 1991 and 2000. Wedge-tailed shearwater (diamonds), lesser noddy (squares) and brown noddy (triangles).

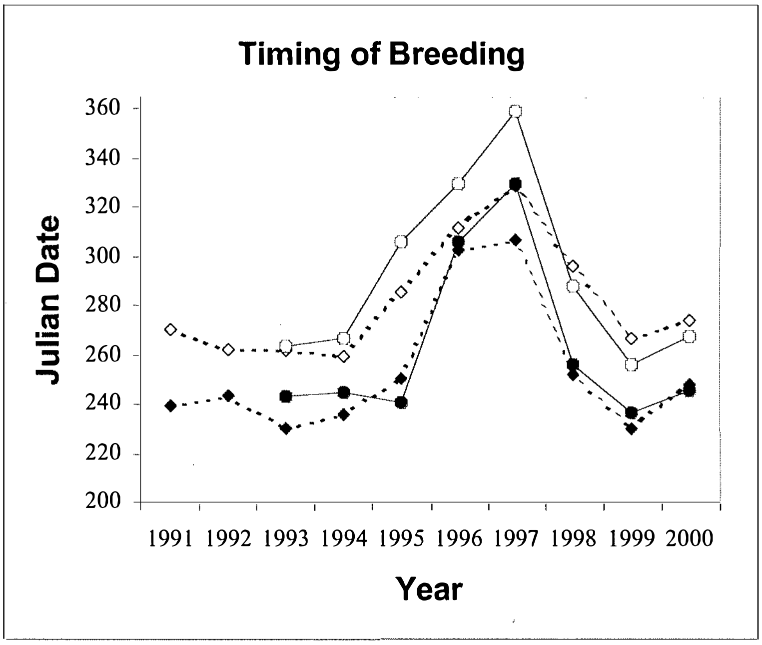
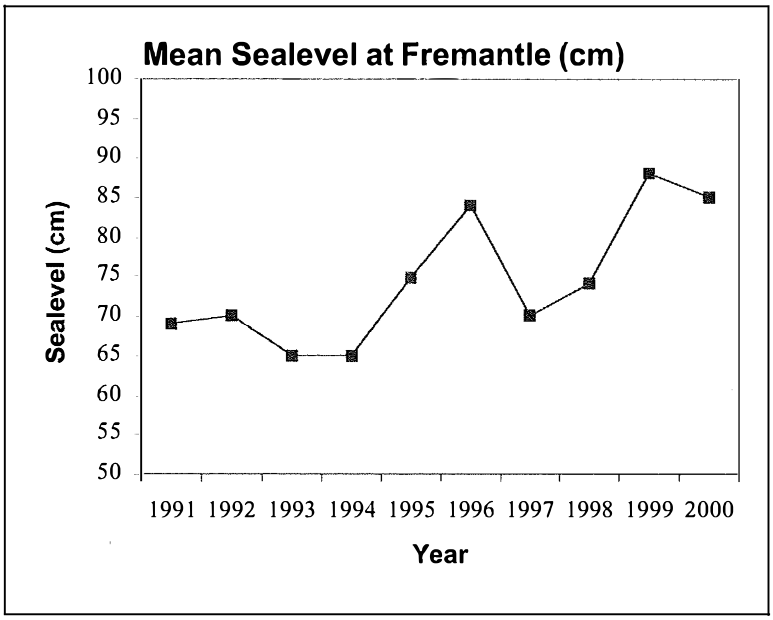


Figure 7.4 The mean lay date (open symbols) and date of first egg (solid symbols) for lesser noddy (diamonds) and brown noddies (circles) between 1991 and 2000.



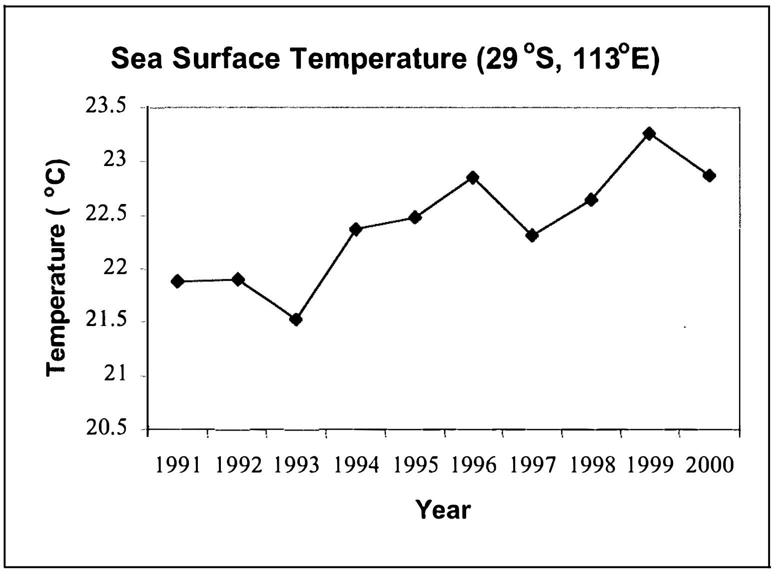


Figure 7.5 The mean sealevel at Fremantle and the mean SST adjacent the Houtman Abrolhos (28°S, 113.5°E).

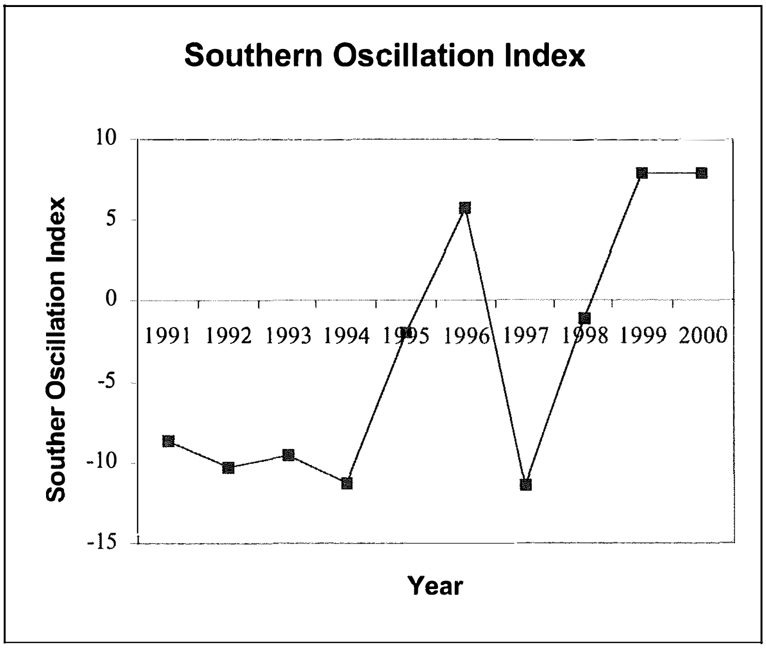


Figure 7.6 The mean annual Southern Oscillation Index (SOI) between 1991 and 2000.

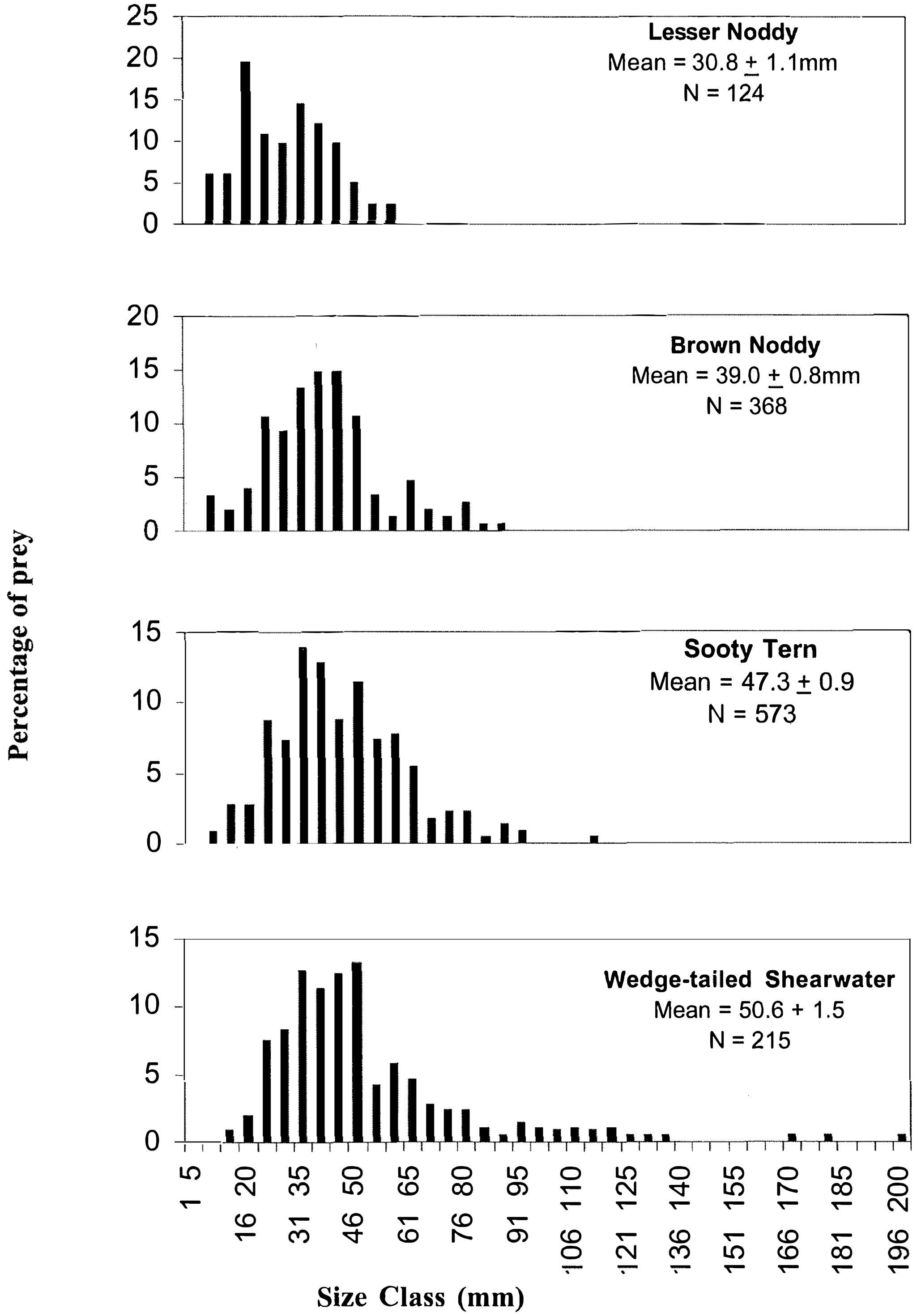


Figure 7.7 Length frequency histograms of squid prey recovered from regurgitates of seabirds from Pelsaert Island between 1991 and 2000.

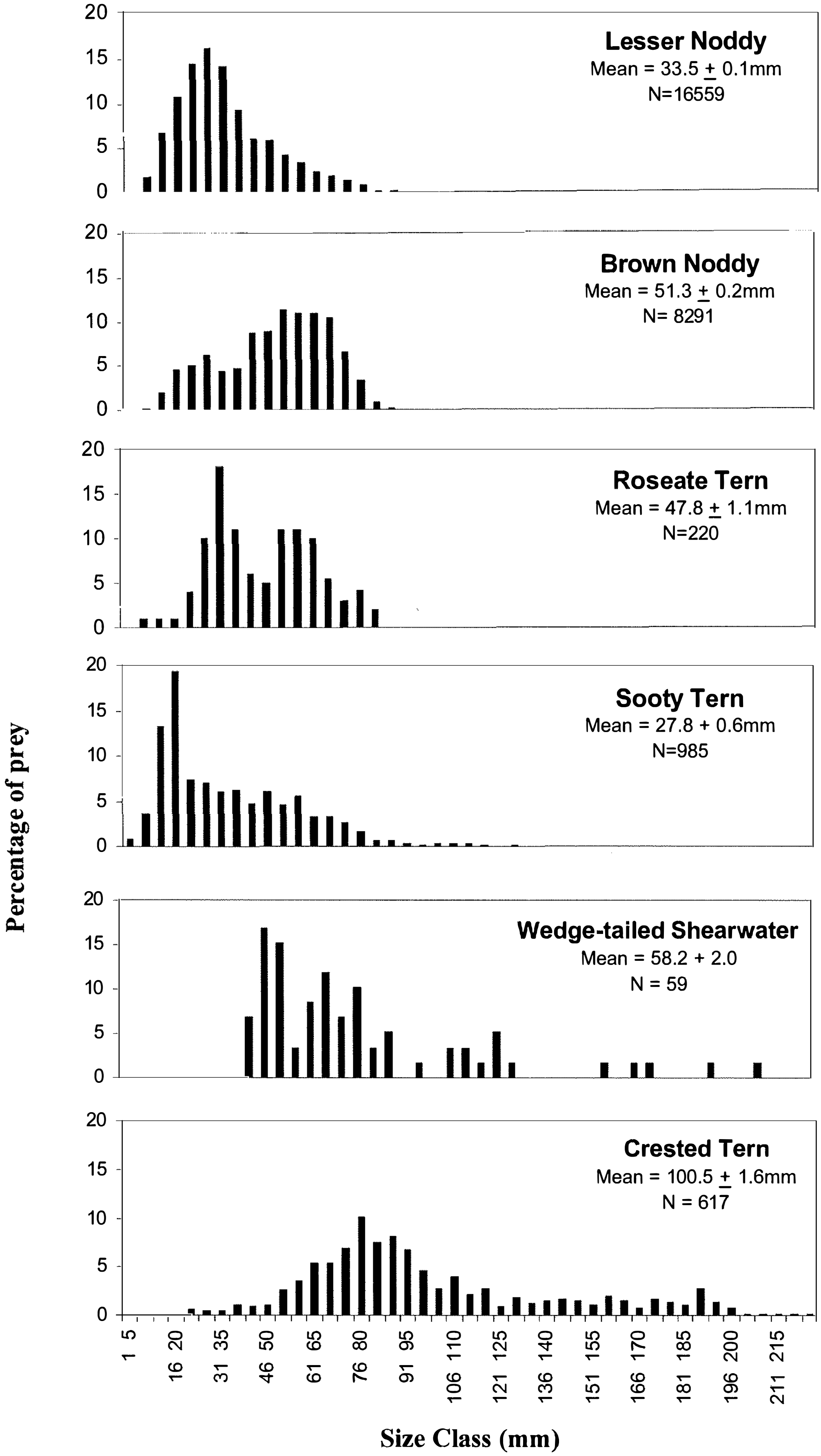


Figure 7.8 Length frequency histograms of fish prey recovered from regurgitates of seabirds from Pelsaert Island between 1991 and 2000.

Table 7.15 The standard length (mm), range and numbers of intact scaly mackerel recovered from regurgitates from seabirds on Pelsaert Island between 1998 and 2000.

	Year		
	1998	**1999**	**2000**
Mean	155.5	154.8	182.7
S.E.	4.1	4.5	3.8
Range	110-175	97-195	100-222
N	15	40	45

Table 7.16 The mean (± S.E.) standard length (mm) of the five main prey consumed by seabirds at the Houtman Abrolhos between 1998 and 2000.

Prey type		Year		
		1998	**1999**	**2000**
Beaked salmon	Mean (± S.E.)	53.9 (0.3)	61.1 (0.5)	59.6 (0.4)
	Range	14-98	23-90	13-99
	N	2,224	621	1,545
Black-spotted goatfish	Mean (± S.E.)	31.1 (0.5)	30.6 (0.5)	31.5 (0.6)
	Range	14-45	18-42	8-51
	N	158	90	152
Hawaiian bellowfish	Mean (± S.E.)	27.9 (0.3)	29.5 (0.9)	25.3 (0.8)
	Range	13-45	12-48	9-45
	N	380	70	129
Australian anchovy	Mean (± S.E.)	29.5 (1.0)		28.7 (0.5)
	Range	17-137		12-123
	N	268		596
Squids	Mean (± S.E.)	41.4 (0.9)	45.8 (1.3)	49.3 (1.1)
	Range	7-129	11-119	3-131
	N	377	240	390

Table 7.17 The time spent at the Houtman Abrolhos, the size of meals (g), the daily energy requirements and the estimated annual food consumed by seabirds breeding at the Houtman Abrolhos.

Parameter		Lesser noddy	Brown noddy	Sooty tern	Crested tern	Wedge-tailed shearwater
Breeding time[1] (d)	Incubation	34	35	28	24	54
	Chick	42	45	70	28	75
Total nestling and post fledging care (d)		60	60	90	60	75
Time in area[2] (d)		365	240	240	365	240
Population size[3]		136,000	324,000	906,600	5,000	2,000,000
Number of feeds/day		2.4 (0.1)	1.8 (0.1)	1	4.4 (0.1)	1
Meal size[4]		5.8 (0.1)	12.5 (0.4)	11.1 (0.5)	23.0 (1.6)	29.4 (1.5)
Mass increments ($g.d^{-1}$)		14.3 (0.7)	17.7 (1.0)			47.1 (1.9)
Field metabolic rate ($kj.d^{-1}$) [5]		110	190	190	250	320
Daily food requirement (g) [6]		21.6	38	38	66	64
Fledging food consumption ($tonnes.year^{-1}$) [7]		56.8	218.7	452.5	15.2	2,205.0-3,532.5
Adult food consumption ($tonnes.year^{-1}$) [8]		1,072.0	2,954.8	8,268.2	120.4	30,720.0
Total food consumption ($tonnes.year^{-1}$)		1,128.8	3,173.5	8,720.7	135.6	32,925-34,252

Sources:

[1] Surman and Wooller (1995), Warham (2000).
[2] Surman (pers. obs.)
[3] Fuller et al. (2000), Fuller et al. (1994).
[4] This study, Surman and Wooller (in press)
[5] Furness (1994)
[6] Calculated from FMR
[7] Fledging food consumption = fledging and post fledging care (days) x meal size x No. nests x No feeds/day
[8] Adult food consumption = population size x No. days at Abrolhos x daily food requirement

Table 7.18 Estimates of the number and mass of adult scaly mackerel consumed by seabirds inhabiting the Houtman Abrolhos each year.

	Crested tern	Wedge-tailed shearwater
Volume (%)	22.5	11.1
Frequency of occurrence (%)	23.4	12.2
Mean number of scaly mackerel/meal	0.31 (0.02)	0.25 (0.9)
Mean length scaly mackerel (mm)	172.8 (2.3)	140.2 (6.7)
Annual scaly consumption (by volume-tonnes)	30.5	3655-3767.7
Total number scaly consumed[1]	1.34×10^6	1.38×10^8

[1] Number of meals each

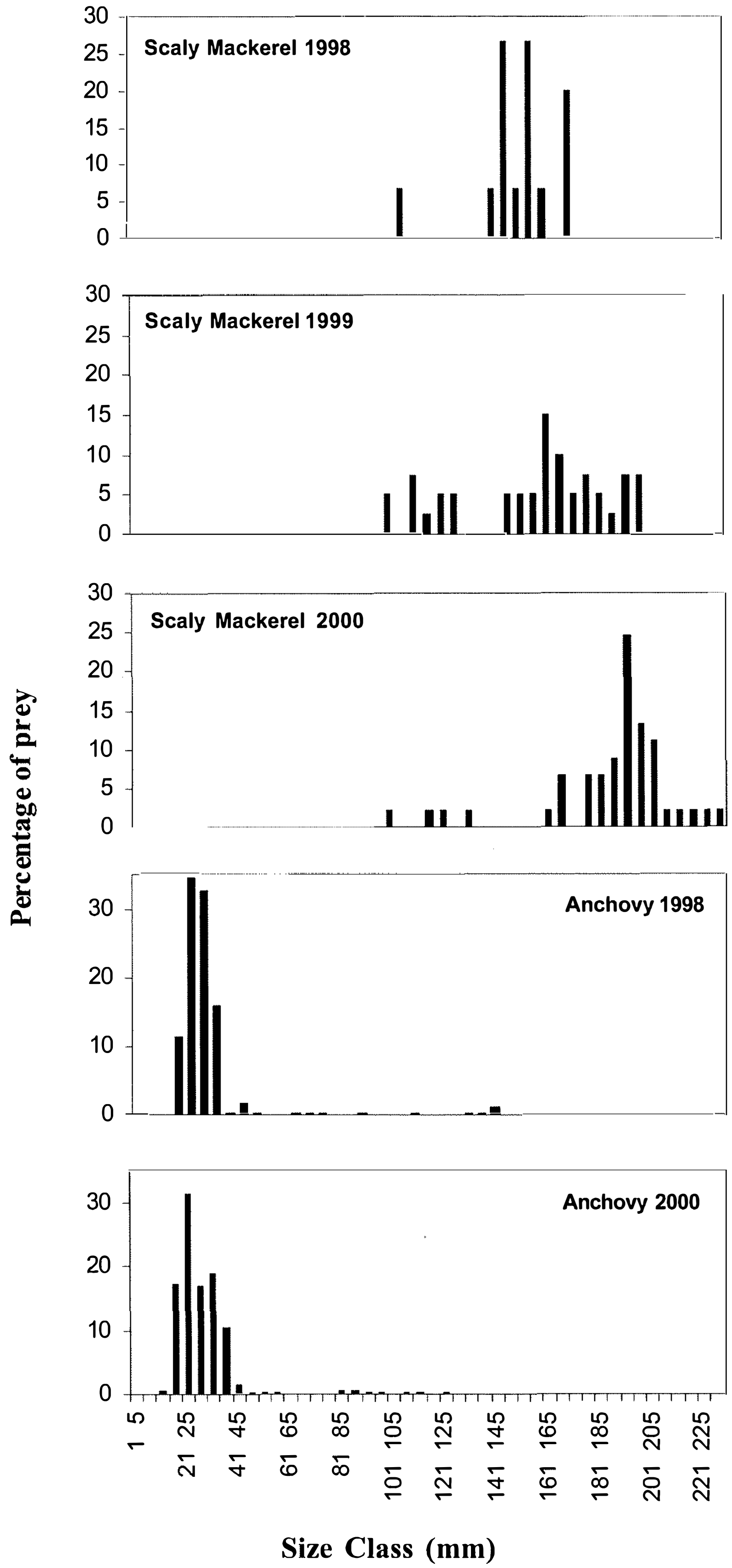


Figure 7.9 The percentage frequency distributions of the lengths of scaly mackerel and Australian anchovy taken by seabirds at the Houtman Abrolhos between 1998 and 2000.

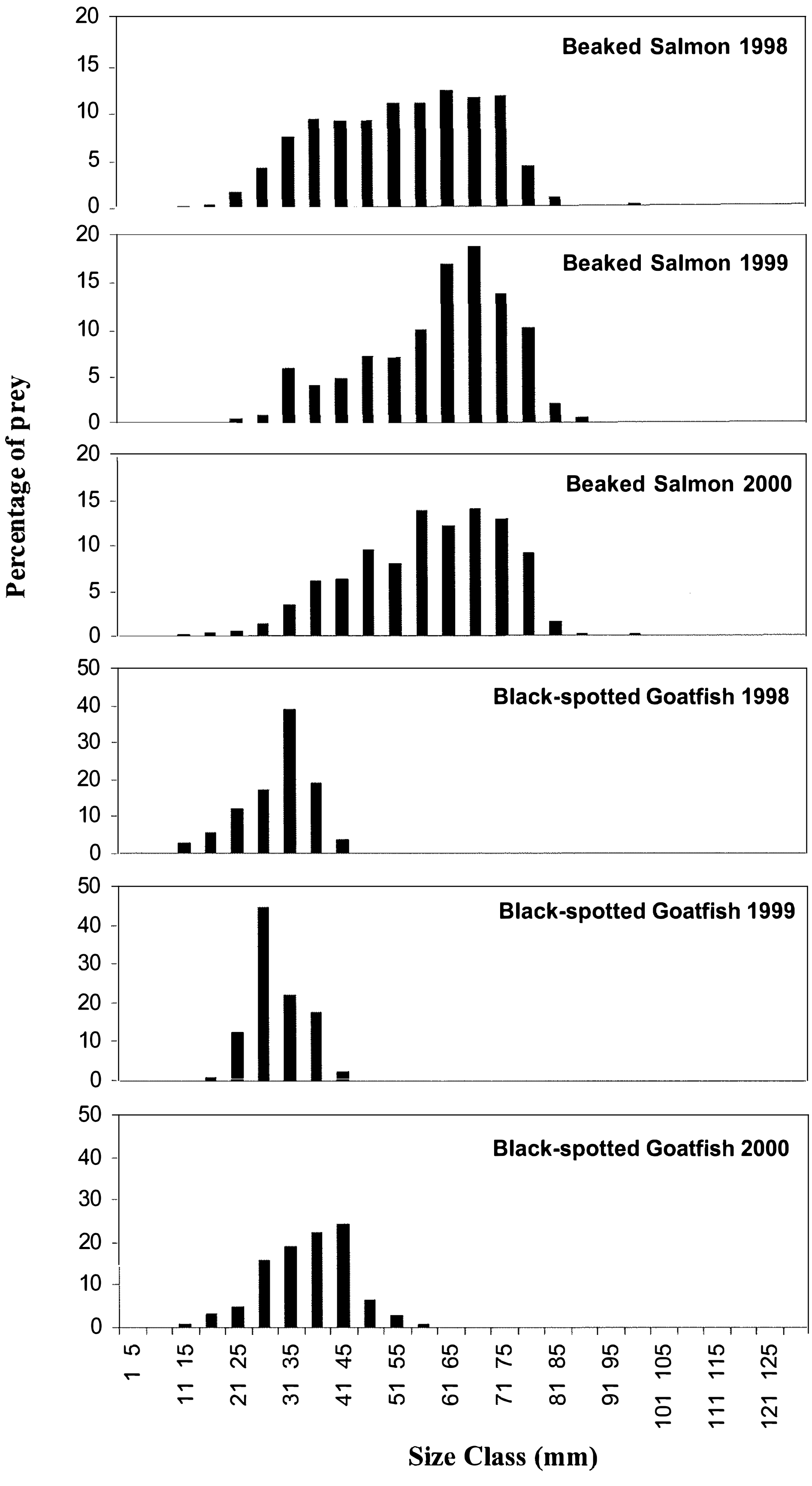


Figure 7.10 The percentage frequency distributions of the lengths of beaked salmon and black-spotted goatfish taken by seabirds at the Houtman Abrolhos between 1998 and 2000.

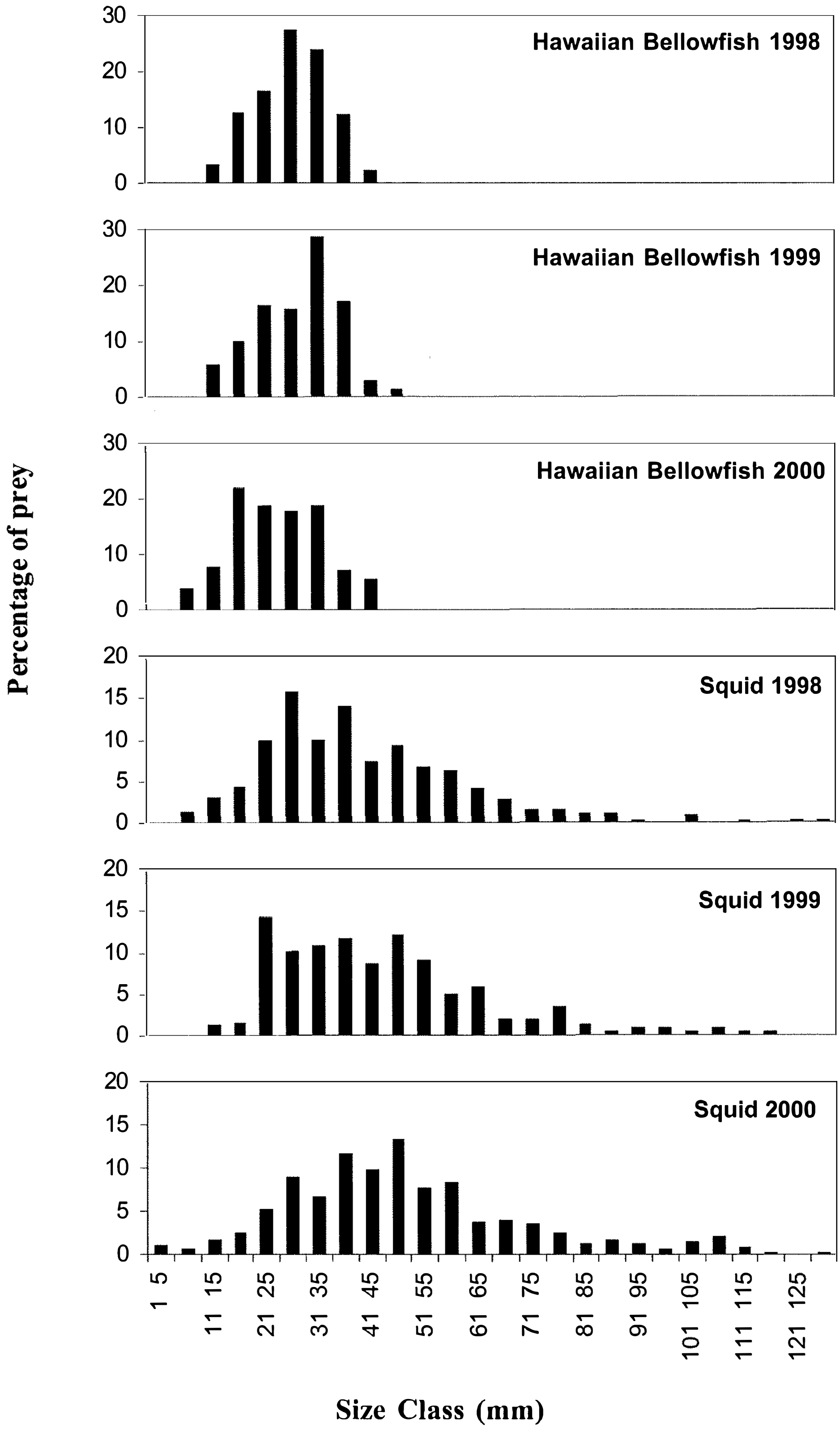


Figure 7.11 The percentage frequency distributions of the lengths of Hawaiian bellowfish and squids taken by seabirds at the Houtman Abrolhos between 1998 and 2000.

7.10 Spatial overlap of seabird foraging and the purse seine fishery

The known spatial extent of foraging areas for six species of seabirds from the Houtman Abrolhos and that of the purse seine fishery are shown in Figure 7.12. Because seabird sightings were logistically limited to transects 600 m wide, those cases where it was reasonable to assume continuity in foraging range between two transects are shown by dotted lines.
The foraging range of crested tern and wedge-tailed shearwater overlapped considerably with the extent of the commercial fishery. This result was not surprising because scaly mackerel was important in the diet of these species. However, whereas the crested tern foraged almost exclusively inside of the islands and close to where the purse seine fishery operates, the wedge-tailed shearwater foraged in all directions around the islands. In particular, the wedge-tailed shearwater ranged widely seaward of the islands.

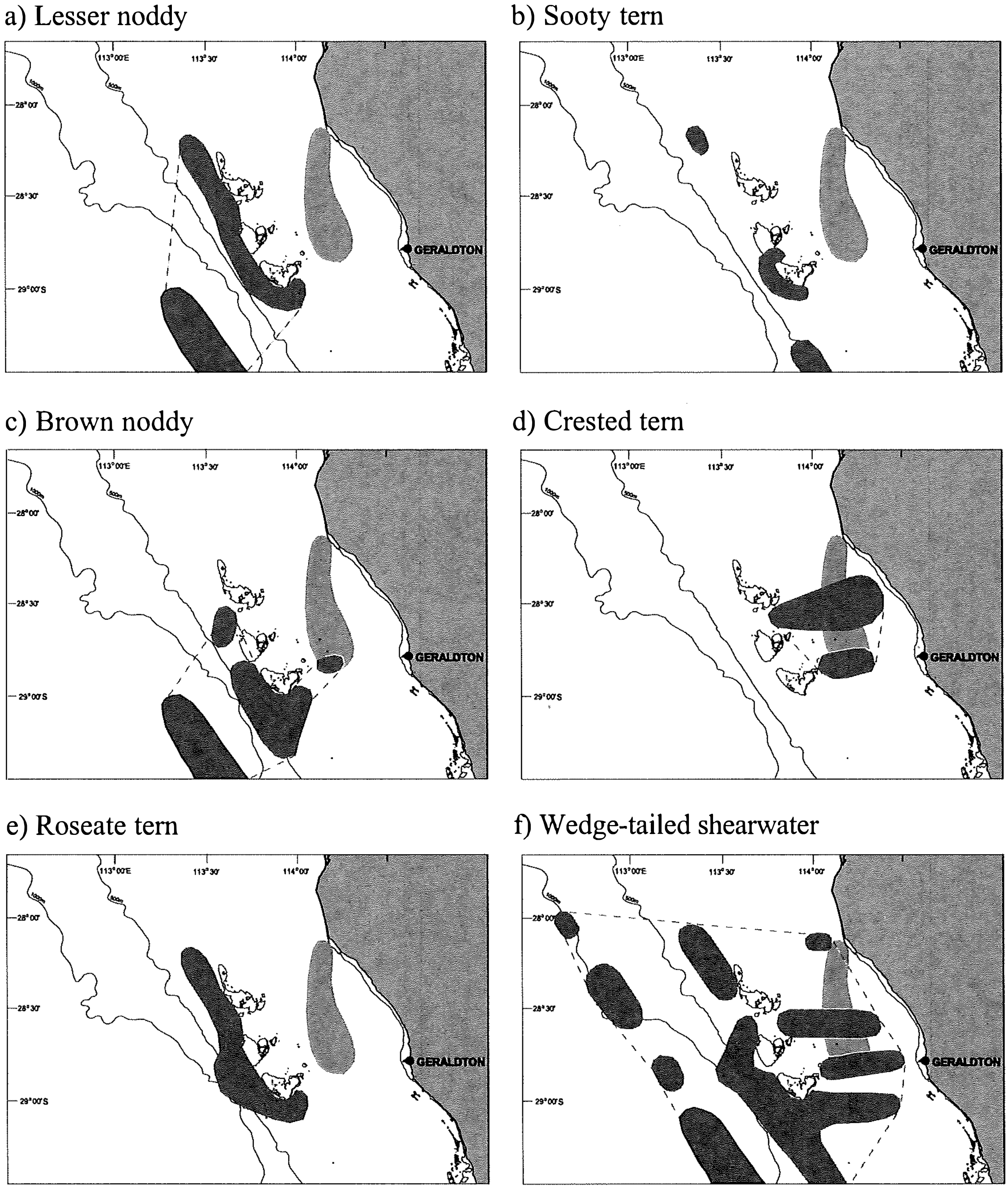


Figure 7.12 Foraging grounds (dark grey areas) of the a) lesser noddy, b) sooty tern, c) brown noddy, d) crested tern e) roseate tern and f) short-tail shearwater in relation to the scaly mackerel fishing area (light grey shaded area).

8 Discussion

8.1 Diet of Houtman Abrolhos seabirds

Overall, 74 species of prey from 56 families were identified in regurgitates of the studied species of seabirds at the Houtman Abrolhos. These comprised 56 species of fish, four insects, two hydrozoans, five molluscs and seven species of crustaceans. Sooty terns consumed the widest variety of prey, taking 34 species from 31 families, including cephalopods, gastropods, hydrozoans, crustaceans and terrestrial insects. The most diverse fish diet was that of the crested tern which consumed 51 species of fish from 36 families. Indeed, the prey taxa in dietary samples from crested terns differed markedly from those taken by the other species studied and were substantially larger. Table 8.1 provides a summary of the dominant prey types. The prey have been grouped into categories which indicate their habitat (i.e. oceanic, reef, pelagic, shelf) and those caught as larvae are also indicated.

At comparable latitudes off the western coasts of other southern hemisphere continents, the Benguela and Humboldt upwelling systems support massive seabird populations, mainly cormorants, sulids (gannets and boobies), pelicans and penguins, that feed on anchovies, pilchards and sardines (Crawford and Jahncke, 1999). Similarly extensive assemblages do not occur off Western Australia, presumably because of the lack of any pronounced upwelling. Nonetheless, over two million seabirds breed annually over the summer months at the Houtman Abrolhos, the only large seabird breeding station in the eastern Indian Ocean and one of the largest in the Australasian region (Fuller et al., 1994; Ross et al., 1995). These large numbers of tropical terns appeared to depend upon a very few species of fish for food in all the years studied (Table 8.1), implying that species such as larval beaked salmon are both regular and highly abundant locally.

Tropical and subtropical seabird assemblages typically contain large numbers of species. The trophic relationships of these tropical species are often more complex than those of cold-water assemblages because of the larger number of prey species available (Croxall, 1987). For instance, Hawaiian seabirds ate 74 species of fish from 56 families (Harrison et al., 1983) and

Table 8.1 Summary of important prey types by percentage volume for each sea bird species in the years 1998 – 2000. For clarity, only the top five prey types are shown, or those that contributed >3%.

Prey species	**Stage & Habitat**	**Lesser noddy**			**Brown noddy**			**Sooty tern**			**Crested tern**			**Roseate tern**			**Wedge-tailed shearwater**		
		1998	1999	2000	1998	1999	2000	1998	1999	2000	1998	1999	2000	1998	1999	2000	1998	1999	2000
Beaked salmon	larvae, inshore	45	53	45	60	86	61	4	15	3				40	47			5	
Goatfish	larvae, inshore	17	28	20				5	11					4	7	17			
Hawaiian bellowfish	larvae, oceanic	11	11	6	13	4	4		6						9				
Lanternfish	oceanic							7	5	6							3		
Veilfin	oceanic													16	9				
Gobbleguts	reef											5	5						
Coral blenny	reef										7	12	12						
Parrotfish	reef										15	15	15						
Other small reef fish	reef										5	5	10						
Squid	reef				15	5	20	70	46	82							67	52	66
Scaly mackerel	small pelagic										22	22	22				11	16	13
Sprats	small pelagic													27	5	59			4
Australian anchovy	small pelagic	10		14	5		6				9								
Sole	shelf														18				
Trevallies	shelf			4			3												
Moths	terrestrial								5										

sooty terns and brown noddies at the Dry Tortugas, Florida, consumed 84 species from 33 families (Hensley and Hensley, 1995). In contrast, crested terns in South Africa (33°S) consumed only 20 fish species (Walter et al., 1987). This compares with the 51 fish species from 35 families taken by the seabirds we studied.

One difference with our study is that other studies of tropical terns have indicated large amounts of squid in their diets (Ashmole and Ashmole, 1967; Harrison et al., 1983; Diamond, 1983), whereas in our study only sooty terns and brown noddies consumed substantial proportions of squid. Terns in assemblages nearest the equator, at Ascension Island, Kiritimati (formerly Christmas Island, Ashmole and Ashmole, 1967) and the Seychelles (Diamond, 1983) consumed higher proportions of squid relative to fish than did terns at Hawaii (Harrison et al., 1983), farther from the equator. The seabirds we studied were even more distant from the equator and consumed even less squid, congruent with this trend. Similarly, Walter et al. (1987) found that crested terns foraging over the temperate Benguela Current consumed even fewer squids (6% numerical abundance). However, the assemblage we studied bred on islands on a continental shelf, whereas the others were on oceanic islands and this, rather than latitude, may account for the differences in the amount of squid in their diets. Similarly, the Galapagos archipelago lies on the equator, yet squid is less evident in the diets of seabirds there than on Kiritimati or Ascension Island (Harris, 1977). This may be because the Galapagos is influenced not only by tropical currents, but also by cooler, temperate currents.

In common with other studies, the seabirds we examined ate mainly the larval and juvenile life-stages of the fishes taken. Around Hawaii, sooty terns, noddies and wedge-tailed shearwaters feed offshore, largely in association with predatory fishes (Harrison et al., 1983), a situation also observed frequently at the Houtman Abrolhos. All the terns we examined carried meals of similar size (3-7%) relative to their body mass, but noddies ate many more items. This is a consequence of the tiny prey they consume, using a delicate pattering action to seize food from the surface, often hovering in the process (Harris, 1977). Crested terns and wedge-tailed shearwaters mainly consumed prey of adult size at the Houtman Abrolhos, although roseate terns consumed large proportions of adult sprats as well as the larval fishes common to other seabirds studied.

Food supply for smaller seabirds such as the noddies, sooty tern and roseate tern is largely comprised of larval fishes obtained from surface waters. Kitaysky et al. (2000) found that kittiwakes (*Rissa tridactyla*), a surface feeding seabird, experiencing low food supply had a lower breeding success, whereas in pursuit diving seabirds such as thick-billed murres (*Uria lomvia*) were more buffered from the effects of changes in food supply. Thus, one would expect that any delay to the commencement of breeding and reproductive success for the smaller, surface feeders may be strongly linked to changes in larval supply to the feeding areas.

The proportion of key prey species in the regurgitates of seabirds on Pelsaert Island changes depending upon several factors. There was a demonstrated seasonal change in diet, most likely the result of a change in the availability of prey. In the two noddy species, beaked salmon were dominant in the diet during the early part of the breeding season (Figure 7.1) but became less so as the season progressed. Then, lesser noddies switched to a diet of mainly black-spotted goatfish and brown noddies to one of squid. However, during reproductively poor years, beaked salmon occurred in lower proportions at the start of the breeding season than they did in reproductively good years. Since beaked salmon are the main prey consumed by brown noddies, this species exhibited greater reproductive failure than did the lesser noddy. Although the lesser noddy consumed significant proportions of beaked salmon, they were able to buffer against negative breeding impacts by foraging successfully for the smaller black-spotted goatfish larvae.

This variability in the supply of food for seabirds was not so evident for crested terns, roseate terns or wedge-tailed shearwaters. Crested terns were found to consume a wide variety of fish prey that could be broken down into reef fishes and pelagic fishes. Although previous studies have recently identified foraging site fidelity in seabirds (Hamer et al., 2001), it remains unclear whether the location of foraging by crested terns may be affected by personal choice, tide or other factors. Thus, the time of sampling, as well as the individuals sampled may influence the type of prey recovered from crested terns.

The level of daily variation in the diet composition in sooty terns, brown noddies and lesser noddies was found not to be significant (Table 7.13). Thus, the samples collected from these species were unlikely to vary enough from one day to the next to influence the overall dietary composition.

Few roseate tern samples were available during this study. Roseate terns are also dependent on the beaked salmon, but also forage over schools of slender and blue sprats. Unfortunately, during this study, few colonies established successfully, and even fewer were able to successfully rear young. Roseate terns were observed to be particularly dependent upon the activity of small tunas that drove their prey to the surface.

Variability in diet of the offshore foraging terns (Lesser noddy, brown noddy and sooty tern) and variability in reproductive timing and performance (see 8.2 below) appear to be influenced by oceanographic parameters. The Leeuwin Current is a seasonal current flowing most strongly during the winter months. It is also influenced by ENSO events, flowing more weakly during years when the SOI is very low. A stronger Leeuwin Current (indicated by higher sea levels at

Fremantle) delivers more tropical water to waters adjacent to the Houtman Abrolhos. During poor breeding-years (Figure 7.2) when the Leeuwin Current flowed more strongly, there were less beaked salmon in the diets of seabirds, presumably because less were available to be caught. It is unclear whether the warmer water associated with the Leeuwin Current affects the spawning of adult beaked salmon, or whether the stronger southwards current flow may displace prey beyond the foraging range of seabirds, or inhibit movement of prey into the foraging range. Studies on Lancelin Island, approximately 300 km to the south of the Houtman Abrolhos reveal that Beaked salmon remain the main prey item in Brown noddy diets during these warmer years (J. N. Dunlop, pers comm.) even though this is not the case at the Houtman Abrolhos. Beaked salmon are a sub-tropical to warm-temperate species (Hutchins and Swainston, 1986); trawl bycatch data indicates their distribution does not appear to extend as far north as the Exmouth Gulf (S. Newman, Dept. of Fisheries, unpublished data from FRDC Project 2000/132 on inshore fish assemblages north of Exmouth) nor even to Shark Bay (WA Museum, unpublished data), which is in accordance with the known distribution of beaked salmon (Hutchins and Swainston, 1986). Trawl by-catch data are not available for the Geelvink Channel but it appears as if this region represents the northern limit of beaked salmon distribution. Therefore, the considerable larval supplies of beaked salmon that becomes available to seabirds at the Houtman Abrolhos are from adults distributed locally and or to the south of the islands. The epipelagic behaviour of larval beaked salmon, which makes this prey type accessible to seabirds, would also make them susceptible to surface currents. The dominant current on the mid-continental shelf of the lower-west and mid-west coast of WA during the seabirds breeding season is the northward flowing Capes Current. The presence of this current supports the contention that the supply of larval beaked salmon may arise from adults distributed south of the islands.

Only wedge-tailed shearwaters and crested terns were found to consume scaly mackerel. All scaly mackerel identified from regurgitates of these species were adult fishes greater than 97 mm standard length. Wedge-tailed shearwaters forage over all shelf and oceanic waters adjacent to the Houtman Abrolhos (Surman, 1997) and crested terns forage mainly in the Geelvink Channel (between the coast and the Houtman Abrolhos) and over reef flats within the Houtman Abrolhos (Surman and Wooller, in press). Scaly mackerel were mainly captured by purse seine fishers in the central regions of the Geelvink Channel (Gaughan and Mitchell, 2000). It is clear that the locality of scaly mackerel, and their size exclude them from the diets of smaller seabirds. The scaly mackerel recovered from regurgitates of crested terns are likely to have been caught in a similar area to that of the purse seine fishery (Fig. 7.12). While this was not so evident for wedge-tailed shearwaters, whose foraging distribution extended well beyond the purse seine fishing grounds, there was nevertheless a strong association between the breeding failure of this species and scaly mackerel fishery failure in 1997. Although scaly mackerel do not form a highly important prey type by volume for the wedge tailed shearwater, the high oil content of small pelagic fish such as sardines may well increase their importance in terms of energy requirements required for breeding, as suggested for Australasian gannets in south-eastern Australia (e.g. Bunce and Norman, 2000).

8.2 Breeding behaviour as an indicator of changes in the marine environment

The timing of breeding of seabirds often reflects the conditions of the marine environment over which they forage. In extreme cases, such as the intense 1982/83 El Nino event in the Pacific Ocean, many species fail to arrive at breeding sites (Schreiber and Schreiber, 1984) and at other breeding stations delayed breeding by up to a month (Ainley et al., 1986). These delays to breeding were found to be linked to warm water intrusions masking more highly productive and cooler waters thereby displacing or reducing the abundance of fishes available to piscivorous seabirds (Montevecchi and Meyers, 1997; Klages et al., 1992).

Similarly, it was found that at the Houtman Abrolhos since 1991 there have been significant changes in the timing of breeding of the main seabird populations. Both brown noddies and lesser noddies delayed breeding by up to three months during 1996 and 1997 in what appeared to be a response to rising sea surface temperatures as indicated by a stronger flow of the Leeuwin Current (Fig 7.5). Although this relationship became less clear during 1997/98, this period also coincided with the onset of another severe El Nino event (Fig 7.6) that may have had further influence on the ability of seabirds at the Houtman Abrolhos to recover from the previous year's poor breeding conditions. At the Farallon Islands off the west coast of California, it took several years for some seabird species to return to usual breeding numbers and success rates after the 1982/83 El Nino (Ainley and Boekelheide, 1990; Ainley et al., 1986). Ainley et al. (1986) also observed that the effects on seabirds of large-scale climatic and oceanographic changes may not manifest themselves until the following breeding year.

Responses to oceanographic change at the Houtman Abrolhos were limited to the three offshore-foraging terns (Sooty tern, lesser noddy and brown noddy) and the wedge-tailed shearwater, but did not influence the breeding performance of crested terns. This can be explained by the foraging behaviour of crested terns. Crested terns consume two main prey types, adult reef fishes that are found over shallow reef flats, and adult pelagic fishes that are found in the Geelvink Channel (Table 8.1). It is unclear at this stage whether individual birds show a preference for particular prey types, however if the supply or availability of one type is lowered, then the crested terns are able to supplement their diet with the other. In Scotland, Uttley et al. (1989) found differential responses of two terns to a reduction in a key prey species. Common terns (*Sterna hirundo*) were able to switch their diet whereas Arctic terns (*Sterna paradisaea*) were unable to do so due to strong site fidelity for foraging locations, and a lack of other prey in these areas to supplement their diet. The fidelity of seabirds to foraging grounds has only recently been studied. Hamer et al. (2001) found that individual gannets were extremely consistent in their foraging locations. Flight paths recorded during previous work at the Houtman Abrolhos (Surman, 1997) indicated that lesser noddies, brown noddies and sooty terns foraged regularly across specific sectors to the SW, W and NW of the Houtman Abrolhos. If food supply over these waters became limited, then it would be reasonable to assume that these species would be less well adapted to forage in other areas, particularly in consideration that their larval sources of prey are usually not found in more coastal areas.

Seabird behaviour at the nest on the Houtman Abrolhos indicates then that the marine environment and prey availability in waters adjacent to the Houtman Abrolhos is highly variable. This agrees with oceanographic observations that indicate that the flow of the dominant current, the Leeuwin Current, is strongly influenced by the activity of El Nino.

When the Leeuwin Current flows more weakly due to ENSO events (Fig 7.5 and 7.6) some species of seabirds at the Houtman Abrolhos respond by breeding earlier and with a higher success rate. Since the 1991 weak ENSO event, both lesser noddies and brown noddies have shown a steady delay in the commencement of breeding as well as a decrease in success associated with late breeding up until 1996 (Fig 7.4). With a return to cooler SST and a weaker Leeuwin Current in response to the 1997/98 ENSO (Figs 7.5, 7.6) we would have anticipated a return by seabirds to early breeding and higher reproductive success. However, contrary to expectations, breeding commenced later in 1997 and success was the lowest for any year of this study. This response was particularly noticeable in the three migratory species, the sooty tern, brown noddy and wedge-tailed shearwater. The poor breeding year of 1997 may have occurred despite apparently favourable oceanographic conditions due to the cumulative effects of the past two later breeding years. Seabirds often take time to recover from more stressful breeding conditions (Harris and Wanless, 1997).

Seabirds on Pelsaert Island are annual breeders, although in common with seabirds breeding at lower latitudes, tend to exhibit a more relaxed breeding schedule due to the longer window of opportunity for raising young. Breeding times in some species during this study varied by as much as a month, similar to the finding of Surman (1997, 1998) where breeding in the lesser noddy and brown noddy varied by as much as 100 days from year to year. This apparent flexibility suggests frequent and catastrophic changes in the supply of food in the seas adjacent the Houtman Abrolhos.

Delay in breeding coupled with lower breeding participation rates and lower breeding success are key indicators of insufficient food for successful breeding (Ainley and Boekelheide, 1990). Although there were no significant differences in the participation rates of breeding seabirds on Pelsaert Island in the three years of this study, during the previous seven years there were significant relationships between the timing of breeding, the participation rate and breeding success (Surman, 1997, unpublished obs.). Specifically, during years when birds commenced breeding later, fewer attempted to breed and reproductive success was significantly lower. In extreme years, such as the 1997 breeding season, few birds attempted to breed and none raised chicks successfully.

8.3 Seabird consumption and risk assessment for the scaly mackerel fishery and other fishing activities.

8.3.1 Fluctuations in seabirds and fish stocks

The dependence of seabirds upon commercially important fish stocks has been well documented. Rindorf et al. (2000) found that lesser sandeel (*Ammodytes marinus*) availability was directly related to breeding success in seabirds in the North Sea. There is a large-scale industrial fishery for sandeels in the North Sea, and it has been demonstrated that fishing pressure exacerbates any environmental changes in sandeel abundance (Rindorf et al., 2000). Not surprisingly, Golet et al. (2000) found that pigeon guillemots (*Cepphus columba*) experienced large fluctuations in their annual diet largely due to fluctuations in the abundance of their key prey, Pacific sand lance (*Ammodytes hexapterus*). In this study, as in others (Boersma, 1978; Sydeman et al., 1991), reproductive success was influenced by the abundance of key prey.

8.3.2 Risk assessment for scaly mackerel

There has not been a dedicated research effort on the scaly mackerel fishery since the completion of FRDC Project 1995/037 in 1998 (Gaughan and Mitchell, 2000); no information on the age-structure of the catch has been obtained since that time. Therefore, the time series of fishery and biological data for the scaly mackerel *(Sardinella lemuru)* fishery in the Houtman Abrolhos region is too short to be of use developing a population model. Given that no estimate of population size was possible for scaly mackerel along the mid-west coast of WA during this previous study and that the presence of only a single vessel in the fishery since 1997 diminishes our ability to infer absolute abundance from catch rates, the rish assessment between the fishery and seabirds at the Abrolhos Islands must be undertaken in a subjective manner rather than through objective modelling. This is not to say that the assessment is not valid; subjective risk assessments are accepted under international law in those cases where suitable quantitative data may not be available (e.g. Office International des Epizooties, 2001). Furthermore, no quantitative data are available for other important prey species, so by default these must be assessed subjectively.

Scaly mackerel decreased in abundance from the waters inshore of the Houtman Abrolhos during 1997, when catches in the purse seine industry dropped to 600 tonnes from >1500 tonnes in the previous two years in 1997 (Fig. 8.1). This was also anecdotally recorded by local aircraft pilots who observed fewer schools of scaly mackerel during the 1997/98 season (Gaughan and Mitchell, 2000). The disappearance of scaly mackerel schools and the simultaneous complete breeding failure of wedge-tailed shearwaters at the Houtman Abrolhos suggest that scaly mackerel are sufficiently important in the diet of wedge-tailed shearwaters to prevent breeding when not accessible to the colonies or at insufficient abundance in the feeding areas. The decline in abundance of scaly mackerel in the Houtman Abrolhos region continued into 1998. Thus, there was also insufficient abundance of scaly mackerel as of May 1998 for the purse seine fishery to begin operating, which meant it did not operate at all for that year, noting that the season typically runs from April to September.

The coincidental strong negative signals for both the seabirds and the fishery provide a good basis for which to infer future scenarios. However, the 'crash' in the fishery in 1998 that coincided with breeding failure of wedge-tailed shearwaters in late 1997, the subsequent breeding 'recovery' of the birds by late 1998 and then of the fishery by mid-1999 indicates that changes in availability in the vicinity of the Abrolhos Islands, rather than the overall stock size was the cause of both events. Thus, whereas the areas searched by seabirds and the fishery may not have contained scaly mackerel in abundance, the stock of scaly mackerel may well have still been healthy but located elsewhere. This further suggests, as previously recommended by Gaughan and Mitchell (2000), that further investment in the scaly mackerel fishery poses a high economical risk if the fishery is in some way constrained to the current fishing grounds in the Geelvink Channel between the Abrolhos Islands and the mainland. Currently, the fishery is constrained to this region because of the necessity to fish in reasonable proximity to the landing facility at Geraldton.

The data sets for the fishery and for the breeding success of seabirds at the Abrolhos are insufficient to detect any influence (i.e. causal effects) of the former on the latter. The current management arrangements in the fishery appear to present minimal risk to the Abrolhos Islands seabirds. However, even without further investment in the fishery, the nominal TAC of 2,700 tonnes should not be increased without further good evidence that this would not impact on the seabirds. When stocks and or availability in the Abrolhos Islands region are high, then increases in catch could be possible without adverse effects on the seabirds. However, information on stock size of scaly mackerel is likely to be difficult to obtain in a timeframe sufficient to permit setting of higher TACs within any given year. Indeed, precise estimates of the scaly mackerel biomass may never be obtained but instead may, at best, be inferred. Therefore to permit higher exploitation of the scaly mackerel in the Abrolhos Island region, particularly at a level close to what is deemed to be full utilization of the stock, would present a risk to the wedgetail shearwaters simply because of the uncertainty around the size of the stock.

Although this study has not demonstrated evidence of competition between seabirds and the scaly mackerel fishery, the seabird community has adapted to feeding conditions around these waters for at least 12,000 years, and have most likely reached an equilibrium, prior to the onset of any purse seine fishery. An important aspect of such an equilibrium for the wedgetail shearwaters is that it operates over timescales relevant to this species' ~30 year lifespan. It has now been established that the population of wedgetail shearwaters does not breed when scaly mackerel are at low abundance in this bird's foraging grounds. Under precautionary management and in consideration of ecosystem functioning, what needs to be determined is whether periodic breeding failure is contrasted by periodically very successful breeding and if so are such successful years crucial to the long term sustainability of the shearwater populations. In other words, is average breeding success the important parameter for population equilibrium, with very successful breeding years a pre-requisite for the seabirds long term sustainability through bolstering the average breeding success rate? Again, lack of precise estimates of scaly mackerel stock size off the mid-west coast of WA, both now and most likely also in the future, indicates that any expansion of the purse seine fishery must be undertaken in a manner sufficient to ensure that the ability of seabird species to periodically achieve very high rates of breeding success will not be impacted.

8.3.3 Risk assessment for non-scaly mackerel species

The important species other than scaly mackerel were beaked salmon, black-spotted goatfish, Hawaiian bellow fish, and a range of fish and squid that occur in the reef-flats around the Abrolhos Islands.

The prominence of larval beaked salmon in the diets of the seabirds studied over several years indicates a considerable abundance of larvae of this species in waters adjacent to the Houtman Abrolhos. Adult beaked salmon inhabit estuarine and coastal sand flats off south-western Australia south of 29° S (Hutchins and Swainston, 1986). Beaked salmon are of debatable eating quality and grow to about 50 cm in length (Gomon et al., 1994). Their relatively small maximum size and slender body form suggests that they would not be strongly accepted as a food fish in the market and are therefore unlikely to be targeted by commercial fishing operations. Furthermore, they have not featured as an abundant species in trawl surveys of shelf waters in south-western WA (Laurenson et al., 1993). This further suggests that beaked salmon would not be targeted as a commercially viable species because Australian fisheries have traditionally targeted the high end of the market when fishing for human-consumption products, with the aim of exporting the majority of the product. In the event there was expansion of the shelf trawl industry along the mid-west and lower-west coast of WA, by-catch of beaked salmon would need to be independently monitored to ensure it was insignificant.

Black-spotted goatfish are almost exclusively taken during their extended pelagic phase, prior to settling into their benthic lifestyle. While the small (<50 mm length) black-spotted goatfish are of important to seabirds at the Abrolhos Islands this group is not at risk from targeted fishing. Perhaps any risk to the supply of larval black-spotted goatfish could be if the adults were suffering fishing mortality. However, there is no targeted fishing on the adult stages. While adults are suitable for eating, like the beaked salmon they also have a relatively small maximum size (47 cm in length) species that are therefore unlikely to attract commercial interest in the future. Although Hutchins and Swainston (1986) claim that black-spotted goatfish occupy shallow reef and sand habitat, this should more correctly be described as sand habitats adjacent to reefs. The survey work by Laurenson et al. (1993) has shown some goatfish species to be susceptible to trawling, but the black-spotted goatfish has yet to be recorded as an abundant bycatch species from trawl survey along the midwest coast of WA. It is therefore probable that this species is not being threatened by current trawling activities.

The bellowfish was the third species to be taken exclusively during the pelagic phase. As with the above two important species, these early life history stages are too small to be targeted by fishing. In contrast to the above species, the adults occupy a broad range of depths (60 – 500 m), are widely distributed throughout temperate waters of southern Australia and reach a maximum length of only 18 cm (Gomon et al., 1994). These features make bellowfish less susceptible to impact than the other species and the risk to them from human activities is thus considered to be negligible.

The importance of fish and squid from the reef flats indicate that the reef-flats habitat must continue to be protected. There are currently no identified negative impacts on the reef flats around the Abrolhos Islands. However, any potential changes in usage of the Abrolhos Islands land and surrounding waters must specifically address factors which may physically (e.g. cover), chemically (e.g. nutrient load) or biologically (e.g. biodiversity changes) impinge on the reef-flat habitat. Given that the Abrolhos Islands are already heavily regulated, the current and future risk to the reef-flat habitat can be considered low.

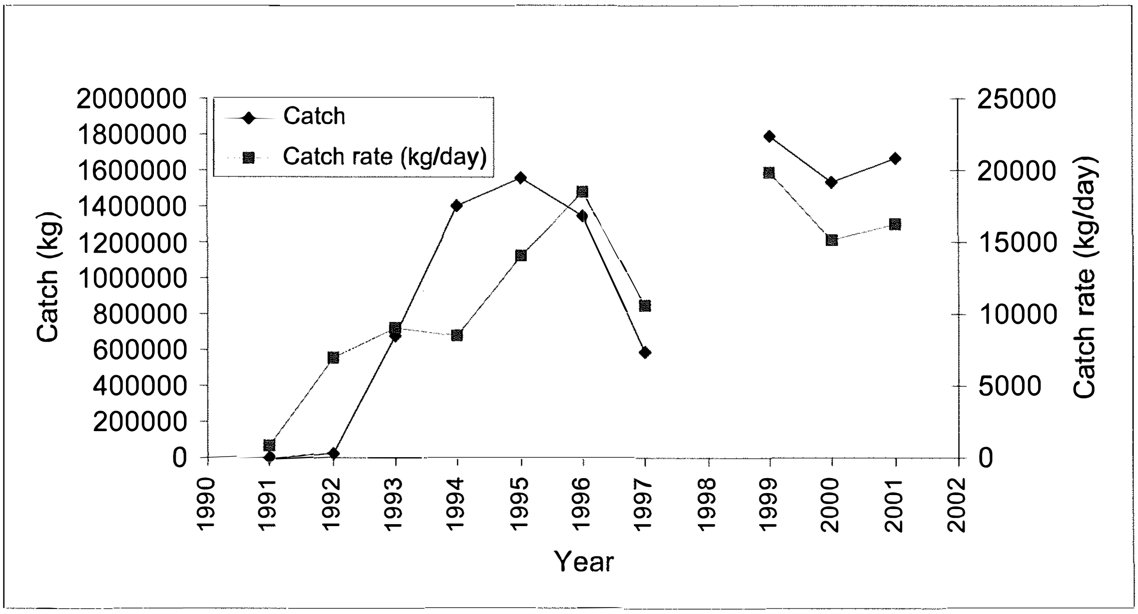


Figure 8.1. Annual catch and catch rate of scaly mackerel by the dominant vessel in the mid-west coast purse seine fishery. Maximum catch for the whole fleet was 2,200 tonnes in 1996.

9 Benefits

The purse seine industry and relevant managers will now have a clear indication that they share fish resources with seabirds and that scaly mackerel are an important dietary item for two of the bird species that nest on the Houtman Abrolhos, including the most abundant species. Whereas previously such claims from, for example, the Conservation Sector, were seemingly dismissed, this study has taken a step towards overcoming the perception that seabirds can be ignored in fisheries management. This was achieved through collaboration of fishery scientists with seabird researchers. Fisheries staff were thus able to bring in a strong background and understanding of both fisheries and fish biology issues that were beyond the scope of seabird specialists. In contrast, the seabird data provided an understanding of the broader ecosystem links around the Abrolhos Islands that would not have been possible through traditional fisheries research that focuses on small numbers of targeted species. This collaborative approach has therefore ultimately provided balance in the communication of the research results and provides a foundation for improved acceptance by the commercial industry of the need to consider ecosystem functioning within the fisheries management framework. This project was the first to co-consider fisheries and seabirds in WA and will therefore be used as a case example for a variety of fisheries.

The other key benefit of this study is that potential users of the reef-flat habitat of the Houtman Abrolhos will now have an understanding of the importance of this habitat to the islands' seabirds. Finally, the importance of larvae, epipelagic stages of certain demersal fish now show the importance of both an ecosystem approach to managing fishing activities, and, highlight the need to consider the possible influences of distant activities.

Current or future areas of interactions with food resources of Houtman Abrolhos seabirds (purse seining, reef-flats, demersal trawling) can now refer directly to those species proven to be important for breeding success of seabirds. This will benefit ongoing management and assessments of current activities. Furthermore, planning for any future activities will have a base-level of knowledge from which to guide preliminary risk analyses.

10 Further development

Not applicable – no commercial applications.

11 Planned outcomes

This project was needed to determine whether or not purse seining for scaly mackerel in the Geraldton region was detrimental to seabirds breeding at the Houtman Abrolhos Islands. Specifically, the question to be addressed was whether or not the industry could be expanded. While this study found no evidence for negative impacts of purse seining on Abrolhos seabirds, it has determined that the periodic absence of scaly mackerel from the region in which the fishery operates not only negatively impacted seabird breeding but also negates the ability for the fleet to expand if it remains tied to the current fishing grounds, which lie between the Abrolhos Islands and the mainland. If purse seine fishing was to be undertaken in regions away from the current fishing grounds, and if operators could find economically viable concentrations of scaly mackerel, then some level of fleet expansion would be possible.

The detailed description of seabird diets obtained in this study, along with the depicted relationships between breeding success and oceanography, provide a baseline of information that will be relevant to a range of fishing and conservation issues along the mid-west coast of Australia.

12 Conclusion

Objectives and conclusions

1. **To determine the quantity and species composition of the diets of Abrolhos seabird species for which there is inadequate information.**

This was successfully undertaken, as shown by the extensive species lists in the Appendices 3 – 6, and represents a strength of this study. This study has shown that around the Houtman Abrolhos Islands fish (e.g. wrasse, parrot fish) and squid of the reef shallows, small pelagic fish in the broader region inshore and offshore of the islands and larval stages of several species, of which beaked salmon and goatfish are particularly important, each form an integral part of the diets of the islands' seabirds. The dominant small pelagic fish in the region is the scaly mackerel, which is fished commercially. The importance to the seabirds of this and other small pelagic fish such as sprats has now been shown unequivocally.

2. To determine the relationships between diet and nesting success.

This was successfully undertaken. As expected from studies elsewhere, the breeding success of seabirds at the Houtman Abrolhos is closely linked to their diet. The diets of seabirds varied from one year to the next, and influenced both the timing of breeding and reproductive performance; breeding success was strongly influenced by the abundance of the key prey types in the diet. Significantly, during 1997 when scaly mackerel abundance in the fishery declined, the wedge-tailed shearwater did not attempt to breed.

3. To extend the time-series of dietary and oceanographic information for seabird species whose diets have already been studied to gain an understanding of oceanographic effects on prey availability and the ability of the birds to respond.

This was successfully undertaken (Figs. 7.3 and 7.4). This time-series now extends over ten years and clearly shows longer-term trends are evident. The length of the time series is also important because sub-decadal patterns are often difficult to interpret. Seabird breeding behaviour on the Houtman Abrolhos indicates that the marine environment and prey availability in waters adjacent to the Houtman Abrolhos are highly variable. This agrees with oceanographic observations that indicate that the flow of the dominant current, the Leeuwin Current, is strongly influenced by the activity of El Nino.

4. To model the fishery/fish stock/seabird interactions to estimate the sustainable yield from the fishery that does not significantly affect the Abrolhos seabird populations.

Mathematical modelling was not undertaken because the data sets were of insufficient size to allow appropriate consideration of uncertainty during parameter estimation. A qualitative risk assessment was therefore undertaken. Although the planned modelling exercise was not possible, the negligible breeding activity by wedge-tailed shearwaters in 1997 and the reduced catch rates in the fishery in 1997 (and no fishing in 1998) provide a conclusive link between ecological responses and fishery performance. Thus, even without an estimate of scaly mackerel stock size, this study confirms that interannual changes in availability in the Geraldton/Houtman Abrolhos region is a key factor in managing the fishery.

The critical importance of the reef shallows to seabirds at the Houtman Abrolhos has not previously been reported – risk assessments for any current or future activities involving the reef shallows at the Houtman Abrolhos must now consider this information. The importance of beaked salmon and goatfish is potentially relevant to trawling activities since these types of fish live on soft-substrate bottoms which are amenable to towed fishing gear. Because the locations of the populations that give rise to the larval stages of beaked salmon and goatfish are unknown there is a risk that bycatch of these species in other regions could adversely affect larval supply in the vicinity of the Houtman Abrolhos.

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Appendix 1: Intellectual property

No saleable items were developed during this project.

Appendix 2: Staff

Department of Fisheries:	D. Gaughan, R. Mitchell, M. Moran, R. O'Halloran, R. Owens, D. Wilkins.
Murdoch University:	C. Surman, R. Wooller
Department of Conservation and Land Management:	J. Blyth, A. Burbidge, P. Fuller

Appendix 3: The dietary composition of seabirds on Pelsaert Island between 1991 and 2000.

	Lesser noddy				Brown noddy				Sooty tern			
Prey Species	N	V	F	**R**	N	V	F	**R**	N	V	F	**R**
<u>Osteichthyes</u> Bony Fishes												
Gonorynchidae												
Beaked salmon *Gonorychus greyii*	35.6	45.5 (0.9)	81.9	**1**	62.9	68.8 (1.1)	94.8	**1**	11.8	6.4 (0.8)	23.2	**3**
Mullidae												
Black-spotted goatfish *Parupeneus signatus*	18.4	27.4 (0.9)	66.0	**2**	1.9	1.2 (0.2)	18.0	**5**	10.8	7.3 (0.9)	27.6	**2**
Macrorhamphosidae												
Hawaiian bellowfish *Macrorhamphosus scolopax*	5.8	7.7 (0.4)	37.5	**3**	7.8	7.6 (0.5)	46.0	**2**	6.5	2.8 (0.5)	15.8	**4**
Engraulidae												
Australian Anchovy *Engraulis australis*	14.9	4.8 (0.5)	12.8	**4**	8.9	2.6 (0.4)	8.2	**4**	<0.1	<0.1 (<0.1)	0.2	**23**
Blenniidae Blennies	1.2	0.4 (0.1)	4.8	**13**	3.9	0.5 (0.2)	2.5	**8**	0.6	0.1 (<0.1)	0.4	**16**
Veliferidae Veilfin *Velifer multiradiatus*	<0.1	0.2 (0.1)	4.0	**23**	0.2	0.6 (0.1)	4.0	**11**	0.3	0.6 (0.2)	2.2	**14**
Monocanthidae												
Leatherjackets *Eubalichthys sp.*	0.3	0.2 (<0.1)	4.1	**14**	0.1	0.4 (0.2)	1.6	**13**	1.0	0.4 (0.2)	2.2	**13**
Clupeidae Blue Sprat *Spratelloides robustus*	<0.1	0.2 (0.1)	0.5	**23**								
Clupeids: unid.	10.9	3.9 (0.5)	7.6	**5**	2.3	0.9 (0.3)	2.2	**9**	<0.1	0.1 (0.1)	0.2	**23**
Sprats: unid.	0.5	0.1 (<0.1)	0.5	**20**	<0.1		0.1	**21**	<0.1		0.2	**23**
Myctophidae Lanternfish	0.6	1.4 (0.3)	2.5	**10**	2.2	2.5 (0.5)	4.9	**7**	7.5	5.4 (0.9)	10.0	**5**
Carangidae Trevallies: unid.	0.1	0.8 (0.2)	2.8	**12**	0.4	0.8 (0.2)	3.4	**10**	3.7	1.3 (0.4)	3.6	**9**
Pilotfish *Naucrates ductor*	<0.1	0.1 (<0.1)	0.7	**22**	<0.1	<0.1 (<0.1)	0.3	**20**	0.1	0.1 (<0.1)	0.9	**18**
Jacks *Decapturus sp.*	0.1	0.4 (0.1)	1.8	**16**	<0.1	0.4 (0.1)	2.0	**12**	<0.1	0.2 (0.1)	0.4	**21**
Scombridae Blue mackerel *Scomber australasicus*	<0.1	<0.1 (<0.1)	0.2	**22**	<0.1	<0.1 (<0.1)	0.7	**19**	0.1	0.1 (<0.1)	0.7	**20**
Soleidae Sole	<0.1	0.1 (<0.1)	0.8	**21**	<0.1	<0.1 (<0.1)	0.1	**21**				
Sphyraenidae Barracudas	0.1	0.3 (<0.1)	2.4	**15**	0.1	0.2 (<0.1)	2.1	**14**	<0.1	<0.1 (<0.1)	0.4	**22**
Hemiramphidae												
Long-finned Garfish *Euleptorhamphus longirostris*	<0.1	<0.1 (<0.1)	0.4	**23**	<0.1	<0.1 (<0.1)	0.1	**21**				
Exocoetidae Flying Fish	0.2	0.1 (<0.1)	1.8	**18**	0.2	0.2 (<0.1)	2.5	**12**	0.2	0.3 (0.2)	1.1	**15**
Labridae Wrasses: unid	2.0	0.5 (0.1)	4.9	**9**	0.4	<0.1 (<0.1)	1.6	**13**				
Congridae Conger eels	0.1	0.3 (0.1)	1.1	**19**	<0.1	0.1 (0.1)	0.9	**17**				
Synodontidae Lizardfish	0.1	0.1 (<0.1)	1.0	**21**	<0.1	<0.1 (<0.1)	0.1	**21**				
Pomacentridae Damselfishes	<0.1	<0.1 (<0.1)	0.2	**25**	<0.1	<0.1 (<0.1)	0.1	**21**				
Caesioscorpididae Sweeps	0.2	0.2 (<0.1)	2.0	**17**	<0.1	<0.1 (<0.1)	0.3		<0.1	<0.1 (<0.1)	0.2	**23**
Tetraodontidae Puffer Fish *Lagocephalus sceleratus*	<0.1	<0.1 (<0.1)	0.1	**26**	<0.1	<0.1 (<0.1)	0.3	**20**	<0.1	0.1 (<0.1)		**20**
Ephipidae Batfish	<0.1	<0.1 (<0.1)	0.1	**26**	<0.1	<0.1 (<0.1)	0.1	**20**				

Prey Species	Lesser noddy N	V	F	R	Brown noddy N	V	F	R	Sooty tern N	V	F	R
Kyphosidae Drummers	<0.1	<0.1 (<0.1)	0.1	**26**	<0.1	<0.1 (<0.1)	0.1	**21**				
Unidentified Fishes	1.4	1.4 (0.2)	13.2	**6**	1.6	1.2 (0.2)	11.1	**6**	2.9	2.0 (0.5)	9.6	**7**
Mollusca												
Cephalopoda Squids: unid.	0.5	2.4 (0.3)	8.3	**7**	2.5	11.5 (0.9)	30.3	**3**	20.2	65.4 (2.0)	77.1	**1**
Dart Squids *Enoploteuthidae sp.*	<0.1	0.1 (<0.1)	0.4	**23**	<0.1	0.2 (0.1)	0.7	**16**	3.3	2.7 (0.7)	2.9	**10**
Spirula spirula									<0.1	0.1 (<0.1)	0.4	**22**
Gastropoda									<0.1	<0.1 (<0.1)	0.4	**22**
Crustacea												
Stomatopoda Mantis Shrimps	0.7	0.4 (0.1)	3.3	**11**	0.1	0.2 (0.1)	1.3	**15**	0.1	0.1 (<0.1)	0.9	**18**
Isopoda Isopods	<0.1	<0.1 (<0.1)	0.4	**23**					<0.1	<0.1 (<0.1)	0.2	**23**
Euphausiacea Krills	5.1	0.7 (0.2)	4.0	**8**	3.0	0.2 (<0.1)	2.2	**9**	17.8	0.6 (0.3)	1.8	**8**
Decapoda												
crab	0.2	<0.1 (<0.1)	0.3	**25**					0.1	<0.1 (<0.1)	0.9	**18**
cray	<0.1	<0.1 (<0.1)	0.3	**24**								
unid crust	<0.1	0.1 (<0.1)	0.3	**24**					<0.1	<0.1 (<0.1)	0.1	**24**
Prawns Panaeidae	<0.1	<0.1 (<0.1)	0.9	**22**	<0.1	<0.1 (<0.1)	0.4	**18**	0.3	0.1 (0.1)	0.4	**19**
Hydrozoa *Porpita porpita*									0.2	<0.1 (<0.1)	0.9	**17**
Velella velella									1.4	0.7 (0.2)	4.7	**11**
Insecta **Lepidoptera** Moths									5.0	1.7 (0.4)	7.1	**6**
Orthoptera Grasshoppers									0.3	0.3 (0.1)	1.6	**13**
Coleoptera Beetles									0.2	<0.1 (<0.1)	0.4	**21**
unid insects									1.2	1.0 (0.4)	2.9	**12**

Prey Species	Crested tern N	Crested tern V	Crested tern F	Crested tern R	Roseate tern N	Roseate tern V	Roseate tern F	Roseate tern R
Osteichthyes Bony Fishes								
Gonorynchidae								
Beaked salmon *Gonorychus greyii*	0.2	0.4 (0.2)	0.4	**20**	17.9	36.9 (4.2)	38.3	**1**
Mullidae								
Black-spotted goatfish *Parupeneus signatus*	6.8	0.1 (0.1)	0.1	**17**	22.9	11.2 (2.6)	15.0	**2**
Yellow-stripped Goatfish *Parupeneus chrysopleuron*	<0.1	<0.1 (<0.1)	0.1	**24**				
Macrorhamphosidae								
Hawaiian bellowfish *Macrorhamphosus scolopax*	0.6	0.6 (0.3)	0.4	**18**	3.2	6.2 (2.0)	7.5	**7**
Engraulidae								
Australian Anchovy *Engraulis australis*	2.4	3.1 (0.6)	3.5	**6**	7.0	0.7 (0.6)	1.5	**9**
Myctophidae Lanternfishes	<0.1	0.1 (0.1)	0.1	**24**				
Blenniidae Blennies: unid.	0.2	0.4 (0.2)	0.4	**18**	0.3	<0.1 (<0.1)	0.8	**14**
Brown Coral Blenny *Atrosalarius fuscus*	6.0	11.6 (1.2)	11.4	**3**				
Monocanthidae Leatherjackets	0.5	0.9 (0.3)	1.0	**15**				
Gobiidae gobies	1.5	2.7 (0.6)	2.8	**8**				
Veliferidae Veilfin *Velifer multiradiatus*	0.1	0.3 (0.2)	0.3	**22**	5.2	11.7 (2.8)	12.8	**4**
Clupeidae scaly mackerel *Sardinella lemura*	14.9	22.5 (1.6)	23.4	**1**				
Blue Sprat *Spratelloides robustus*	1.2	2.6 (0.6)	2.5	**9**	7.9	7.2 (2.1)	9.0	**5**
Slender Sprat *S. gracilis*	0.5	0.8 (0.3)	1.0	**16**	17.4	11.8 (2.7)	14.3	**3**
Carangidae								
unidentified trevally	0.6	1.3 (0.4)	1.3	**14**				
Jacks *Decapturus sp.*	0.3	0.5 (0.5)	0.6	**19**	0.3	0.1 (0.1)	0.8	**14**
Scombridae Blue mackerel *Scomber australasicus*	0.4	<0.1 (<0.1)	0.1	**23**				
Hemiramphidae								
Long-finned Garfish *Euleptorhamphus longirostris*	<0.1	0.1 (0.1)	0.1	**24**	1.5	0.8 (0.5)	2.3	**10**
Labridae Wrasses: unid	2.6	5.4 (0.8)	5.5	**4**				
Moon Wrasse	1.1	2.3 (0.6)	2.4	**10**				
Scribble-tailed Wrasse	<0.1	0.1 (0.1)	0.1	**24**				
Silver-streaked Wrasse *Stethojulis strigiventer*	1.6	3.2 (0.7)	3.2	**7**				
Western King Wrasse *Coris auricularis*	0.1	2.9 (0.6)	3.0	**9**				
Scaridae Parrotfishes	8.6	15.0 (1.3)	15.8	**2**				
Soleidae Sole	<0.1	0.1 (0.1)	0.1	**24**	3.0	7.5 (2.3)	7.5	**6**
Sphyraenidae Barracudas	<0.1	0.1 (0.1)	0.1	**24**				
Pomacentridae Damselfishes	2.6	4.6 (0.7)	5.2	**5**				
Millers Damselfish	0.3	0.6 (0.3)	0.6	**18**				

Prey Species		Crested tern N	V	F	R	Roseate tern N	V	F	R
Congidae	Conger Eels	0.2	0.4 (0.2)	0.4	**20**				
Ophichthidae	Snake Eels	<0.1	0.1 (0.1)	0.1	**24**				
Syngnathidae	Seahorses	<0.1	0.1 (0.1)	0.1	**24**				
Plotosidae	Catfish	0.1	0.4 (0.2)	0.3	**21**				
Ephipidae	Batfish					0.3	0.8 (0.8)	0.8	**13**
Atherinidae	Hardyheads	0.2	0.4 (0.2)	0.4	**20**	0.6	1.5 (1.0)	1.5	**8**
Kyphosidae									
	Low-finned Drummer *Kyphosis vaigiensis*	0.2	0.4 (0.2)	0.4	**20**				
	Western Buffalo Bream *K. cornelii*	<0.1	0.1 (0.1)	0.1	**24**				
	Stripey *Microcanthus strigatus*	0.2	0.4 (0.2)	0.4	**20**				
Apogonidae	Gobbleguts	2.7	5.3 (0.8)	1.5	**4**				
Synodontidae	Lizard fish	<0.1	<0.1 (<0.1)	0.1	**24**				
Lethrinidae									
	Spangled Emperor *Lethrinus nebulosus*	<0.1	0.1 (0.1)	0.1	**24**				
Priacanthidae	Big Eyes	0.3	0.6 (0.3)	0.6	**18**				
Nemipteridae									
	Western Butterfish Pentapodus vitta	0.6	1.3 (0.4)	2.3	**12**				
Acanthuridae	Surgeonfishes	<0.1	0.1 (0.1)	0.1	**24**				
Chaetodontidae	Butterflyfishes	<0.1	0.1 (0.1)	0.1	**24**				
Sillaginidae	Whiting *Sillago sp.*	<0.1	0.1 (0.1)	0.1	**24**				
Holocentridae	squirrelfishes	<0.1	0.1 (0.1)	0.1	**24**				
Tetraodontidae	Puffer fish *Lagocephalus sceleratus*	0.3	0.7 (0.3)	0.7	**17**	0.3	0.8 (0.8)	0.8	**13**
Unidentified Fishes		1.2	1.9 (0.5)	2.3	**11**	0.9	1.1 (0.8)	1.5	**11**
Crustacea **Decapoda**		1.4	2.8 (0.6)	2.8	**8**	0.3	0.8 (0.8)	0.8	**13**
Mollusca									
Cephalopoda	Squids: unid.	0.1	0.4 (0.2)	0.3	**21**	0.6	0.8 (0.8)	1.5	**12**
	Cuttlefish	0.7	1.3 (0.4)	1.6	**13**				
Insecta **Orthoptera**	Grasshoppers	0.1	0.3 (0.2)	0.3	**22**				

Prey Species	Wedge-tailed Shearwater N	V	F	IRI
Osteichthyes Bony Fishes				
Gonorynchidae				
Beaked salmon *Gonorychus greyii*	10.2	3.1 (1.1)	16.3	**3**
Mullidae				
Black-spotted goatfish *Parupeneus signatus*	1.4	0.5 (0.3)	4.8	**8**
Macrorhamphosidae				
Hawaiian bellowfish *Macrorhamphosus scolopax*	0.7	0.1 (0.1)	2.0	**11**
Engraulidae				
Australian Anchovy *Engraulis australis*	3.5	0.6 (0.3)	2.0	**9**
Clupeidae				
scaly mackerel *Sardinella lemura*	3.1	11.1 (2.5)	12.2	**4**
Slender Sprat *Spratelloides gracilis*	8.8	0.7 (0.7)	0.7	**10**
Myctophidae				
Lanternfish	11.4	2.9 (1.3)	6.1	**6**
Carangidae Unidentified Trevallies	0.2	0.1 (0.1)	0.7	**14**
Jacks *Decapturus sp.*	1.2	2.1 (1.1)	3.4	**7**
Scombridae				
Blue mackerel *Scomber australasicus*	0.3	0.7 (0.5)	1.4	**12**
Hemirhamphosidae Flying garfish	0.2	0.1 (0.1)	0.7	**14**
Exocoetidae Flying Fish	0.2	0.2 (0.2)	0.7	**13**
Unidentified Fishes	12.9	10.7 (2.1)	29.1	**2**
Mollusca				
Cephalopoda Unidentified squids	35.1	59.8 (3.7)	69.6	**1**
Dart Squids *Enoploteuthidae sp.*	5.2	7.2 (2.1)	7.4	**5**
Crustacea				
Isopoda Isopods	0.3	<0.1 (<0.1)	1.4	**12**
unid crust	0.2	<0.1 (<0.1)	0.7	**14**
Hydrozoa				
Velella velella	0.2	<0.1 (<0.1)	1.4	**14**

Appendix 4: The dietary composition of seabirds on Pelsaert Island during 1998

	Lesser noddy				Brown noddy				Sooty tern			
Prey Species	N	V	F	**R**	N	V	F	**R**	N	V	F	**R**
<u>Osteichthyes</u> Bony Fishes												
Gonorynchidae												
Beaked salmon *Gonorychus greyii*	34.5	45.1 (1.8)	85.2	**1**	58.6	58.9 (1.8)	96.4	**1**	11.9	3.9 (0.9)	22.0	**2**
Mullidae												
Black-spotted goatfish *Parupeneus signatus*	9.5	17.1 (1.4)	59.7	**2**	0.7	1.3 (0.3)	15.4	**6**	7.9	4.7 (1.5)	18.7	**4**
Macrorhamphosidae												
Hawaiian bellowfish *Macrorhamphosus scolopax*	7.3	11.0 (0.9)	51.9	**4**	12.3	13.4 (0.9)	71.9	**2**	3.8	1.5 (0.4)	12.2	**6**
Engraulidae												
Australian Anchovy *Engraulis australis*	28.7	10.1 (1.3)	29.7	**3**	13.0	4.9 (1.2)	14.9	**4**				
Blenniidae blennies:unid	1.0	0.5 (0.2)	7.4	**11**	<0.1	<0.1 (<0.1)	0.9	**17**				
Veliferidae Veilfin *Velifer multiradiatus*	<0.1	0.4 (0.2)	2.1	**19**	<0.1	0.3 (0.1)	2.3	**13**	0.4	0.7 (0.5)	2.4	**11**
Monocanthidae												
Leatherjackets *Eubalichthys sp.*	0.2	0.2 (<0.1)	5.3	**15**	<0.1	<0.1 (<0.1)	0.5	**18**	0.3	0.3 (0.2)	2.4	**12**
Clupeidae Blue Sprat *Spratelloides robustus*	<0.1	0.1 (<0.1)	0.7	**22**								
Unidentified Clupeids	6.1	2.8 (0.9)	3.9	**6**	2.6	0.5 (0.4)	1.8	**9**				
unidentified sprats	1.6	0.5 (0.3)	0.7	**17**								
Myctophidae Lanternfish	1.0	3.5 (1.0)	5.3	**8**	1.4	1.4 (0.5)	4.5	**8**	12.3	7.2 (1.9)	13.8	**3**
Carangidae Trevallies: unid.	0.1	0.4 (0.2)	3.2	**16**	0.7	0.4 (0.2)	2.3	**10**	14.4	1.1 (0.6)	2.4	**7**
Jacks *Decapturus sp.*	<0.1	0.1 (<0.1)	1.1	**21**	<0.1	0.4 (0.2)	1.8	**14**	0.1	0.4 (0.4)	0.8	**15**
Soleidae Sole	<0.1	<0.1 (<0.1)	0.7	**22**								
Sphyraenidae Barracudas	<0.1	0.5 (0.2)	4.2	**14**	0.1	0.4 (0.2)	4.1	**11**				
Exocoetidae Flying Fish	<0.1	0.4 (0.1)	5.3	**13**	0.1	0.2 (<0.1)	5.2	**12**	0.1	0.3 (0.3)	0.8	**16**
Labridae Wrasses: unid	3.2	1.0 (0.4)	7.4	**7**	<0.1	<0.1 (<0.1)	0.5	**18**				
Congridae Conger eels	0.3	0.7 (0.4)	2.5	**14**	0.1	0.3 (0.3)	1.4	**15**				
Synodontidae Lizardfish	<0.1	<0.1 (<0.1)	1.4	**20**	<0.1	<0.1 (<0.1)	0.5	**18**				
Pomacentridae Damselfishes	<0.1	<0.1 (<0.1)	1.1	**21**	<0.1	<0.1 (<0.1)	0.5	**18**				
Caesioscorpididae Sweeps	0.2	0.2 (<0.1)	3.5	**18**					0.1	<0.1 (<0.1)	0.8	**17**
Tetraodontidae Puffer Fish *Lagocephalus sceleratus*	<0.1	0.1 (0.1)	0.4	**24**								
Ephipidae Batfish					<0.1	<0.1 (<0.1)	0.5	**18**				
Unidentified Fishes	1.7	1.6 (0.4)	14.5	**5**	0.9	1.8 (0.5)	12.2	**5**	1.4	1.2 (0.6)	7.3	**10**
<u>Mollusca</u>												
Cephalopoda Squids:unid.	0.5	1.8 (0.5)	9.2	**9**	2.7	14.9 (1.7)	38.0	**3**	27.8	68.9 (3.5)	82.9	**1**
Dart Squids *Enoploteuthidae sp.*	<0.1	0.2 (0.2)	0.4	**23**	<0.1	0.3 (0.2)	0.9	**16**	2.2	3.8 (1.7)	4.1	**9**
Gastropoda									0.5	<0.1 (<0.1)	1.6	**13**

Prey Species		Lesser noddy N	V	F	R	Brown noddy N	V	F	R	Sooty tern N	V	F	R
<u>Crustacea</u>													
Stomatopoda	Mantis Shrimps	0.8	0.5 (0.2)	3.9	**12**								
Isopoda	Isopods	<0.1	<0.1 (<0.1)	1.1	**21**					0.3	<0.1 (<0.1)	0.8	**16**
Euphausiacea	Krills	1.4	0.9 (0.4)	5.7	**10**	5.8	0.4 (0.2)	2.7	**7**	0.2	<0.1 (<0.1)	1.6	**14**
Decapoda	crab	0.3	<0.1 (<0.1)	0.7	**20**								
	cray	0.1	<0.1 (<0.1)	1.1	**21**								
	Prawns Panaeidae	<0.1	<0.1 (<0.1)	0.4	**24**								
	Velella velella									2.9	1.2 (0.6)	7.3	**8**
<u>Insecta</u>													
Lepidoptera	Moths									9.9	4.6 (1.3)	15.4	**5**
Orthoptera	Grasshoppers									0.3	<0.1 (<0.1)	0.8	**16**

Prey Species	Crested tern N	V	F	R	Roseate tern N	V	F	R
Osteichthyes Bony Fishes								
Gonorynchidae								
Beaked salmon *Gonorychus greyii*					15.5	39.7 (6.5)	39.0	**1**
Mullidae								
Black-spotted goatfish *Parupeneus signatus*					10.9	4.0 (2.4)	6.8	**4**
Macrorhamphosidae								
Hawaiian bellowfish *Macrorhamphosus scolopax*					1.9	5.2 (2.9)	5.1	**7**
Engraulidae								
Australian Anchovy *Engraulis australis*	9.3	3.1 (0.6)	12.2	**3**	15.5	1.6 (1.3)	3.4	**6**
Blennidae								
Brown Coral Blenny *Atrosalarius fuscus*	6.5	11.6 (1.2)	7.8	**4**				
Monocanthidae Leatherjackets	0.7	0.9 (0.3)	1.1	**14**				
Veliferidae Veilfin *Velifer multiradiatus*					7.7	16.4 (4.8)	18.6	**3**
Clupeidae scaly mackerel *Sardinella lemura*	32.3	22.5 (1.6)	35.6	**1**				
Blue Sprat *Spratelloides robustus*	2.1	2.6 (0.6)	2.2	**11**	4.5	6.2 (2.9)	8.5	**5**
Slender Sprat *S. gracilis*	1.4	0.8 (0.3)	2.2	**12**	20.6	21.1 (5.2)	23.7	**2**
Carangidae								
Jacks *Decapturus sp.*					0.6	0.3 (0.3)	1.7	**10**
Scombrida Blue mackerel *Scomber australasicus*	0.7	<0.1 (<0.1)	1.1	**16**				
Hemiramphidae								
Long-finned Garfish *Euleptorhamphus longirostris*					0.6	0.2 (0.2)	1.7	**11**
Labridae Wrasses: unid	4.3	5.4 (0.8)	6.7	**5**				
Moon Wrasse	3.6	2.3 (0.6)	5.6	**8**				
Western King Wrasse *Coris auricularis*	4.3	2.9 (0.6)	6.7	**7**				
Scaridae Parrotfishes	9.4	15.0 (1.3)	14.4	**2**				
Pomacentridae Damselfishes	4.3	4.6 (0.7)	6.7	**6**				
Kyphosidae								
Western Buffalo Bream *K. cornelii*	0.7	0.1 (0.1)	1.1	**16**				
Apogonidae Gobbleguts	9.4	5.3 (0.8)	1.1	**15**				
Holocentridae squirrelfishes	0.7	0.1 (0.1)	1.1	**16**				
Tetraodontidae Puffer fish *Lagocephalus sceleratus*					0.6	1.7 (1.7)	1.7	**9**
Unidentified Fishes	5.0	1.9 (0.5)	4.4	**9**				
Crustacea								
Decapoda	2.1	2.8 (0.6)	3.3	**10**	0.6	1.7 (1.7)	1.7	**9**

Prey Species		Crested tern N	V	F	R	Roseate tern N	V	F	R
Mollusca									
Cephalopoda	Squids:unid					1.2	1.9 (1.7)	3.4	**8**
	Cuttlefish	0.7	1.3 (0.4)	1.5	**13**				
Insecta									
Orthoptera	Grasshoppers	0.1	0.3 (0.2)	1.1	**17**				

Prey Species	Wedge-tailed Shearwater			
	N	V	F	IRI
<u>Osteichthyes</u> Bony Fishes				
Gonorynchidae				
Beaked salmon *Gonorychus greyii*	3.0	0.6 (0.4)	13.5	**6**
Mullidae				
Black-spotted goatfish *Parupeneus signatus*	1.1	0.8 (0.8)	5.4	**8**
Macrorhamphosidae				
Hawaiian bellowfish *Macrorhamphosus scolopax*	1.1	0.3 (0.3)	2.7	**9**
Engraulidae				
Australian Anchovy *Engraulis australis*	12.9	1.6 (1.1)	5.4	**4**
Clupeidae scaly mackerel *Sardinella lemura*	2.7	11.1 (2.5)	10.8	**3**
Myctophidae				
Lanternfish	9.2	2.9 (1.3)	2.7	**7**
Unidentified Fishes	13.7	10.7 (2.1)	43.2	**2**
<u>Mollusca</u>				
Cephalopoda Unidentified squids	46.6	59.8 (3.7)	78.4	**1**
Dart Squids *Enoploteuthidae sp.*	4.9	7.2 (2.1)	5.4	**5**
<u>Hydrozoa</u>				
Velella velella	0.4	<0.1 (<0.1)	2.7	**10**

Appendix 5: The dietary composition of seabirds on Pelsaert Island during 1999.

	Lesser noddy				Brown noddy				Sooty tern			
Prey Species	N	V	F	**R**	N	V	F	**R**	N	V	F	**R**
<u>Osteichthyes</u> Bony Fishes												
Gonorynchidae												
Beaked salmon *Gonorychus greyii*	52.2	52.9 (2.4)	85.6	**1**	82.9	86.2 (1.9)	97.8	**1**	23.8	14.6 (2.6)	39.2	**2**
Mullidae												
Black-spotted goatfish *Parupeneus signatus*	26.6	27.8 (2.2)	69.4	**2**	0.3	0.3 (0.2)	3.0	**15**	16.2	11.3 (2.2)	43.1	**3**
Macrorhamphosidae												
Hawaiian bellowfish *Macrorhamphosus scolopax*	9.3	10.6 (1.2)	46.8	**3**	5.1	4.2 (0.6)	39.0	**2**	14.9	5.7 (1.5)	27.5	**4**
Engraulidae												
Australian Anchovy *Engraulis australis*	3.2	0.4 (0.2)	4.2	**5**	<0.1	<0.1 (<0.1)	1.5	**14**	<0.1	<0.1 (<0.1)	1.0	**18**
Blenniidae Blennies	0.9	0.2 (0.1)	1.9	**10**	<0.1	<0.1 (<0.1)	0.7	**16**				
Veliferidae Veilfin *Velifer multiradiatus*	<0.1	<0.1 (<0.1)	0.5	**18**	<0.1	0.3 (0.2)	1.5	**12**	0.5	1.2 (0.6)	3.9	**12**
Monocanthidae												
Leatherjackets *Eubalichthys sp.*	0.1	<0.1 (<0.1)	0.9	**17**	<0.1	<0.1 (<0.1)	0.7	**16**	<0.1	<0.1 (<0.1)	1.0	**18**
Clupeidae Herrings						<0.1 (<0.1)	0.7	**16**				
Myctophidae Lanternfish	0.7	1.1 (0.6)	2.8	**8**	1.9	1.4 (0.9)	2.2	**5**	7.6	4.6 (1.7)	8.8	**5**
Carangidae Trevallies	0.2	0.6 (0.3)	2.8	**10**	0.2	0.5 (0.2)	4.4	**7**	0.6	1.6 (0.7)	5.9	**9**
Pilotfish *Naucrates ductor*	<0.1	<0.1 (<0.1)	0.5	**18**					<0.1	0.1 (0.1)	1.0	**18**
Jacks *Decapturus sp.*	<0.1	0.1 (0.1)	0.5	**18**								
Scombridae Blue mackerel *Scomber australasicus*									<0.1	0.1 (0.1)	1.0	**18**
Soleidae Sole	<0.1	<0.1 (<0.1)	0.5	**18**								
Sphyraenidae Barracudas	0.1	0.2 (<0.1)	2.3	**11**	<0.1	<0.1 (<0.1)	0.7	**16**	<0.1	0.1 (0.1)	1.0	**18**
Hemiramphidae												
Long-finned Garfish *Euleptorhamphus longirostris*	<0.1	0.2 (0.2)	1.4	**13**								
Exocoetidae Flying Fish	0.1	0.1 (<0.1)	1.4	**15**	<0.1	<0.1 (<0.1)	0.7	**16**	0.6	1.1 (0.8)	2.9	**13**
Labridae Wrasses	2.5	0.6 (0.3)	5.6	**4**	1.2	0.2 (0.1)	1.5	**8**				
Congridae Conger eels	<0.1	0.2 (0.1)	1.9	**12**	<0.1	0.1 (<0.1)	2.2	**13**				
Synodontidae Lizardfish	0.7	0.5 (0.2)	3.2	**9**								
Caesioscorpididae Sweeps	<0.1	<0.1 (<0.1)	0.9	**17**								
Tetraodontidae Puffer Fish *Lagocephalus sceleratus*									0.2	0.4 (0.3)	2.0	**15**
Ephipidae Batfish	<0.1	<0.1 (<0.1)	0.5	**18**								
Kyphosidae Drummers	<0.1	0.1 (0.1)	0.5	**18**	0.1	0.1 (0.1)	0.7	**16**				
Unidentified Fishes	0.4	0.8 (0.4)	6.5	**7**	1.1	0.7 (0.4)	6.6	**4**	2.2	1.5 (0.5)	13.7	**8**
<u>Mollusca</u>												
Cephalopoda Squids: unid.	0.3	1.9 (0.8)	5.1	**5**	1.9	4.6 (1.3)	17.6	**3**	16.7	46.4 (4.2)	60.8	**1**

Prey Species		Lesser noddy N	V	F	R	Brown noddy N	V	F	R	Sooty tern N	V	F	R
	Dart Squids *Enoploteuthidae sp.*	<0.1	0.3 (0.2)	1.4	**12**	<0.1	0.7 (0.7)	0.7	**11**	2.5	6.2 (2.3)	6.9	**7**
	Spirula spirula									0.2	0.3 (0.3)	1.0	**16**
Crustacea													
Stomatopoda	Mantis Shrimps	1.4	0.4 (0.2)	4.6	**6**	0.7	0.4 (0.4)	1.5	**9**	0.3	0.3 (0.2)	2.0	**15**
Euphausiacea	Krills	0.2	<0.1 (<0.1)	0.9	**16**	3.7	<0.1 (<0.1)	1.5	**6**				
Decapoda	Prawns Panaeidae	0.4	0.4 (0.1)	4.2	**14**	0.3	0.1 (<0.1)	2.2	**10**				
Hydrozoa	*Porpita porpita*									0.6	0.2 (0.2)	2.9	**14**
	Velella velella									1.3	0.6 (0.4)	4.9	**10**
Insecta													
Lepidoptera	Moths									10.4	1.6 (0.7)	7.8	**6**
Orthoptera	Grasshoppers									0.6	1.0 (0.6)	4.9	**11**
Coleoptera	Beetles									<0.1	0.1 (0.1)	1.0	**17**

Prey Species	Crested tern N	V	F	R	Roseate tern N	V	F	R
<u>Osteichthyes</u> Bony Fishes								
Gonorynchidae								
Beaked salmon *Gonorychus greyii*					36.6	46.8 (6.6)	50.0	**1**
Mullidae								
Black-spotted goatfish *Parupeneus signatus*					15.8	6.7 (3.1)	8.9	**4**
Yellow-stripped Goatfish *Parupeneus chrysopleuron*	0.6	<0.1 (<0.1)	0.8	**16**				
Macrorhamphosidae								
Hawaiian bellowfish *Macrorhamphosus scolopax*	1.2	0.6 (0.3)	1.5	**12**	7.9	9.4 (3.8)	12.5	**3**
Engraulidae								
Australian Anchovy *Engraulis australis*	0.6	3.1 (0.6)	0.8	**11**				
Blenniidae blennies:unid.	0.6	0.4 (0.2)	0.8	**15**				
Brown Coral Blenny *Atrosalarius fuscus*	10.8	11.6 (1.2)	12.1	**3**				
Veliferidae Veilfin *Velifer multiradiatus*					4.9	8.9 (3.8)	8.9	**6**
Clupeidae scaly mackerel *Sardinella lemura*	34.9	22.5 (1.6)	34.8	**1**				
Blue Sprat *Spratelloides robustus*					1.9	1.8 (1.8)	1.8	**7**
Slender Sprat *S. gracilis*					20.8	5.0 (2.8)	5.4	**5**
Carangidae Jacks *Decapturus sp.*	0.6	0.5 (0.5)	0.8	**14**				
Labridae Moon Wrasse	2.4	2.3 (0.6)	3.0	**6**				
Scribble-tailed Wrasse	0.6	0.1 (0.1)	0.8	**16**				
Western King Wrasse *Coris auricularis*	3.6	2.9 (0.6)	3.8	**4**				
Scaridae Parrotfishes	26.5	15.0 (1.3)	28.8	**2**				
Soleidae Sole	0.6	0.1 (0.1)	0.8	**16**	9.9	17.9 (5.2)	17.9	**2**
Pomacentridae Damselfishes	1.8	4.6 (0.7)	2.3	**6**				
Millers Damselfish	2.4	0.6 (0.3)	3.0	**8**				
Congidae Conger Eels	0.6	0.4 (0.2)	0.8	**15**				
Ophichthidae Snake Eels	0.6	0.1 (0.1)	0.8	**16**				
Syngnathidae Seahorses	0.6	0.1 (0.1)	0.8	**16**				
Ephipidae Batfish					1.0	1.8 (1.8)	1.8	**8**
Atherinidae Hardyheads					1.0	1.5 (1.0)	1.8	**9**
Apogonidae Gobbleguts	1.8	5.3 (0.8)	1.5	**7**				
Tetraodontidae Puffer fish *Lagocephalus sceleratus*	1.2	0.7 (0.3)	0.9	**13**				
Unidentified Fishes	3.0	1.9 (0.5)	3.8	**5**				
<u>Crustacea</u> **Decapoda** Prawns	1.2	2.8 (0.6)	1.5	**10**				
<u>Mollusca</u>								
Cephalopoda Squids: unid.	0.6	0.4 (0.2)	0.8	**15**				
Cuttlefish	1.8	1.3 (0.4)	2.3	**9**				

Prey Species	Wedge-tailed Shearwater N	V	F	IRI
<u>**Osteichthyes**</u> Bony Fishes				
Gonorynchidae				
Beaked salmon *Gonorychus greyii*	13.0	4.9 (2.5)	17.6	**4**
Mullidae				
Black-spotted goatfish *Parupeneus signatus*	2.9	0.7 (0.5)	5.9	**8**
Macrorhamphosidae				
Hawaiian bellowfish *Macrorhamphosus scolopax*	1.2	0.2 (0.2)	3.9	**10**
Clupeidae scaly mackerel *Sardinella lemura*	4.2	16.4 (4.9)	19.6	**3**
Myctophidae Lanternfish	17.9	5.8 (3.1)	9.8	**6**
Carangidae Unidentified Trevallies	0.5	0.4 (0.4)	2.0	**12**
Jacks *Decapturus sp.*	3.4	6.0 (3.0)	9.8	**7**
Scombridae Blue mackerel *Scomber australasicus*	0.7	1.9 (1.4)	3.9	**9**
Hemirhamphosidae Flying garfish	0.5	0.4 (0.4)	2.0	**12**
Exocoetidae Flying Fish	0.5	0.5 (0.5)	2.0	**11**
Unidentified Fishes	10.3	10.4 (3.9)	25.5	**2**
<u>**Mollusca**</u>				
Cephalopoda Unidentified squids	35.1	38.7 (6.2)	52.9	**1**
Dart Squids *Enoploteuthidae sp.*	9.0	13.3 (4.7)	13.7	**5**
<u>**Hydrozoa**</u>				
Velella velella	0.2	0.1 (0.1)	2.0	**13**

Appendix 6: The dietary composition of seabirds on Pelsaert Island during 2000.

Prey Species	Lesser noddy				Brown noddy				Sooty tern			
	N	V	F	R	N	V	F	R	N	V	F	R
Osteichthyes Bony Fishes												
Gonorynchidae												
Beaked salmon *Gonorychus greyii*	23.9	45.0 (2.5)	78.6	**1**	53.0	60.7 (2.9)	90.7	**1**	4.4	3.0 (1.2)	11.9	**4**
Mullidae												
Black-spotted goatfish *Parupeneus signatus*	12.9	19.9 (5.7)	61.2	**2**	1.8	1.3 (0.4)	18.6	**5**	2.1	1.4 (0.8)	10.2	**5**
Macrorhamphosidae												
Hawaiian bellowfish *Macrorhamphosus scolopax*	4.2	5.7 (0.8)	35.2	**4**	4.3	3.9 (0.8)	28.6	**4**	2.3	1.4 (0.6)	9.3	**6**
Engraulidae												
Australian Anchovy *Engraulis australis*	30.2	13.6 (0.1.9)	33.2	**3**	25.9	5.8 (1.4)	17.9	**3**				
Blenniidae Blennies	0.7	0.5 (0.2)	7.1	**10**	<0.1	<0.1 (<0.1)	0.7	**18**				
Veliferidae Veilfin *Velifer multiradiatus*	<0.1	<0.1 (<0.1)	0.5	**20**	0.3	1.2 (0.5)	5.0	**8**	<0.1	0.4 (0.4)	0.8	**12**
Monocanthidae												
Leatherjackets *Eubalichthys sp.*	0.3	0.3 (<0.1)	7.1	**12**	0.1	<0.1 (<0.1)	2.1	**14**	<0.1	0.3 (0.3)	0.8	**13**
Clupeidae Blue Sprat *Spratelloides robustus*	<0.1	0.9 (0.6)	1.0	**15**								
Myctophidae Lanternfish	0.3	0.6 (0.5)	1.0	**16**	0.9	1.5 (1.0)	2.9	**9**	5.2	5.6 (2.0)	11.0	**3**
Carangidae Trevallies: unid.	0.4	3.7 (0.9)	10.2	**6**	0.8	2.9 (0.9)	10.7	**7**	0.7	2.2 (1.2)	5.9	**7**
Pilotfish *Naucrates ductor*	<0.1	<0.1 (<0.1)	0.5	**20**								
Jacks *Decapturus sp.*					<0.1	0.1 (0.1)	0.7	**17**				
Soleidae Sole	<0.1	<0.1 (<0.1)	1.5	**17**								
Sphyraenidae Barracudas	0.2	0.4 (0.2)	3.6	**13**	0.1	0.3 (0.2)	2.9	**16**	<0.1	0.1 (0.1)	0.8	**15**
Exocoetidae Flying Fish	<0.1	<0.1 (<0.1)	1.0	**19**	<0.1	0.2 (0.2)	2.9	**13**				
Labridae Wrasses	1.6	0.9 (0.3)	10.2	**7**	0.5	0.2 (0.1)	5.7	**10**				
Congridae Conger eels	0.2	0.8 (0.6)	1.5	**14**	<0.1	<0.1 (<0.1)	0.7	**17**				
Synodontidae Lizardfish	<0.1	<0.1 (<0.1)	1.0	**18**								
Caesioscorpididae Sweeps	0.4	0.6 (0.2)	6.1	**11**	<0.1	<0.1 (<0.1)	1.4	**15**				
Unidentified Fishes	0.6	1.0 (0.4)	10.7	**8**	2.4	1.4 (0.6)	10.7	**6**	1.8	0.4 (0.2)	6.8	**8**
Mollusca												
Cephalopoda Squids: unid	0.2	1.9 (0.7)	5.6	**9**	3.4	19.8 (2.7)	39.3	**2**	15.8	82.1 (3.0)	89.0	**1**
Squids: Dart *Enoploteuthidae sp.*	<0.1	0.3 (0.3)	0.5	**18**	<0.1	0.1 (0.1)	1.4	**13**	6.1	0.8 (0.8)	0.8	**9**
Spirula spirula									<0.1	0.2 (0.2)	0.8	**11**
Crustacea												
Stomatopoda Mantis Shrimps	0.3	0.3 (0.2)	2.6	**14**	0.2	0.2 (<0.1)	4.3	**12**				
Euphausiacea Krills	13.8	1.6 (0.7)	6.1	**5**	0.5	0.2 (0.2)	3.6	**11**	51.0	2.2 (1.3)	3.4	**2**
Decapoda Crabs	<0.1	<0.1 (<0.1)	1.0	**30**								

Prey Species		Lesser noddy N	V	F	R	Brown noddy N	V	F	R	Sooty tern N	V	F	R
	Prawns Panaeidae	<0.1	<0.1 (<0.1)	0.5	**23**								
Hydrozoa	*Porpita porpita*									<0.1	<0.1 (<0.1)	0.8	**15**
	Velella velella									0.2	<0.1 (<0.1)	2.5	**11**
Insecta													
Lepidoptera	Moths									0.3	0.1 (<0.1)	3.4	**10**
Coleoptera	Beetles									0.4	<0.1 (<0.1)	0.4	**14**

Prey Species		Crested tern N	V	F	R	Roseate tern N	V	F	R
<u>Osteichthyes</u>	Bony Fishes								
Gonorynchidae									
	Beaked salmon *Gonorychus greyii*	0.2	0.4 (0.2)	0.6	**21**				
Mullidae									
	Black-spotted goatfish *Parupeneus signatus*					25.0	16.7 (16.7)	16.7	**3**
Macrorhamphosidae									
	Hawaiian bellowfish *Macrorhamphosus scolopax*	0.1	0.6 (0.3)	0.3	**23**				
Engraulidae									
	Australian Anchovy *Engraulis australis*	2.1	3.1 (0.6)	3.4	**8**				
Myctophidae	Lanternfishes	0.1	0.1 (0.1)	0.3	**25**				
Blenniidae unid	blennies:	0.1	0.4 (0.2)	0.3	**24**				
	Brown Coral Blenny *Atrosalarius fuscus*	4.5	11.6 (1.2)	11.6	**3**				
Monocanthidae	Leatherjackets	0.4	0.9 (0.3)	1.1	**15**				
Gobiidae	Gobies: unid.	2.2	2.7 (0.6)	5.7	**6**				
Veliferidae Veilfin	*Velifer multiradiatus*	0.2	0.3 (0.2)	0.6	**22**				
Clupeidae	scaly mackerel *Sardinella lemura*	8.5	22.5 (1.6)	19.0	**1**				
	Blue Sprat *Spratelloides robustus*	1.5	2.6 (0.6)	3.7	**10**	50.0	59.2 (20.0)	66.7	**1**
	Slender Sprat *S. gracilis*	0.3	0.8 (0.3)	0.9	**17**				
Carangidae	Trevally: unid.	0.8	1.3 (0.4)	2.3	**13**				
	Jacks *Decapturus sp.*	0.3	0.5 (0.5)	0.9	**19**				
Labridae	Wrasses-unid	1.0	5.4 (0.8)	2.8	**7**				
	Moon Wrasse	0.6	2.3 (0.6)	1.7	**12**				
	Silver-streaked Wrasse *Stethojulis strigiventer*	2.0	3.2 (0.7)	5.4	**5**				
	Western King Wrasse *Coris auricularis*	0.8	2.9 (0.6)	2.3	**11**				
Scaridae	Parrotfishes	4.9	15.0 (1.3)	11.1	**2**				
Soleidae	Sole	0.1	0.1 (0.1)	0.3	**25**				
Pomacentridae	Damselfishes	2.6	4.6 (0.7)	0.3	**14**				
Congidae	Conger Eels	0.1	0.4 (0.2)	0.3	**24**				
Atherinidae	Hardyheads	0.3	0.4 (0.2)	0.9	**20**				
	Stripey *Microcanthus strigatus*	0.2	0.4 (0.2)	0.6	**21**				
Apogonidae Gobbleguts		2.4	5.3 (0.8)	6.8	**4**				
Lethrinidae	Spangled Emperor *Lethrinus nebulosus*	0.1	0.1 (0.1)	0.3	**25**				
Priacanthidae	Big Eyes	0.2	0.6 (0.3)	0.6	**20**				
Nemipteridae	Western Butterfish *Pentapodus vitta*	0.8	1.3 (0.4)	2.3	**13**				

Prey Species		Crested tern N	V	F	R	Roseate tern N	V	F	R
Acanthuridae	Surgeonfishes	0.1	0.1 (0.1)	0.3	**25**				
Chaetodontidae	Butterflyfishes	0.1	0.1 (0.1)	0.3	**25**				
Sillaginidae	Whiting *Sillago sp.*	0.1	0.1 (0.1)	0.3	**25**				
Holocentridae	Squirrelfishes	0.1	0.1 (0.1)	0.3	**25**				
Tetraodontidae	Puffer fish *Lagocephalus sceleratus*	0.3	0.7 (0.3)	0.9	**18**				
Unidentified Fishes		0.2	1.9 (0.5)	0.6	**16**	25.0	24.2 (16.8)	33.3	**2**
Crustacea	Prawns	1.4	2.8 (0.6)	4.0	**9**				
Mollusca Cephalopoda	Cuttlefish	0.8	1.3 (0.4)	2.3	**13**				
Insecta Orthoptera	Grasshoppers	0.2	0.3 (0.2)	0.6	**22**				

Prey Species	Wedge-tailed Shearwater N	V	F	IRI
Osteichthyes Bony Fishes				
Gonorynchidae				
Beaked salmon *Gonorychus greyii*	4.2	2.2 (14)	13.6	**6**
Clupeidae				
scaly mackerel *Sardinella lemura*	4.2	13.0 (7.2)	13.6	**3**
Slender Sprat *Spratelloides gracilis*	37.0	4.4 (4.4)	4.5	**4**
Myctophidae				
Lanternfish	1.1	0.1 (0.1)	4.5	**7**
Unidentified Fishes	14.9	14.4 (6.9)	27.3	**2**
Mollusca				
Cephalopoda Unidentified squids	26.3	57.2 (10.0)	59.1	**1**
Dart Squids *Enoploteuthidae sp.*	4.3	8.7 (6.0)	9.1	**5**