INTER-ANNUAL VARIATIONS IN BREEDING PARTICIPATION AT FOUR WESTERN AUSTRALIAN COLONIES OF THE WEDGE-TAILED SHEARWATER *PUFFINUS PACIFICUS*

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SUMMARY

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Wedge-tailed Shearwaters *Puffinus pacificus* breeding at colonies on three islands in the North West Shelf Region of Western Australia showed marked inter-annual variations in the number of burrows excavated at the start of the season, the percentage of these burrows in which eggs were ultimately laid and in breeding success. The number of burrows excavated and the proportion in which eggs were ultimately laid were not correlated indicating that different factors influence these components of breeding participation. Breeding success was affected in some years by local factors, including cyclone tracks and predation, but the greatest factor influencing the number of young reared each season was the number of breeding attempts (participation rate). The percentage of burrows in which eggs were laid varied in similar ways at the three colonies on different islands on the North West Shelf. Because these colonies were separated by up to 140 km, broad-scale, regional oceanographic/trophic factors were implicated. During the 1997 *El Niño* event the percentage of burrows in which eggs were laid dropped dramatically at all the North West Shelf colonies and at a major Wedge-tailed Shearwater colony on Pelsaert Island in the Houtman Abrolhos Group, over 1000 km farther south. The number of burrows excavated each year within the entire Varanus Island colony has been monitored consistently since 1987. There was a significant correlation between the three-year running mean in active burrow numbers and the three-year aggregate, annual Southern Oscillation Index values. This cumulative lag affect in the number of birds excavating burrows at the start of each season suggests that this parameter may be a useful index of the size of the breeding population. Conversely, the percentage of burrows in which eggs are laid, seems to be a measure of prevailing oceanographic/trophic conditions.

Keywords: Wedge-tailed Shearwater, *Puffinus pacificus*, Australia, breeding, *El Niño*

INTRODUCTION

The assessment of breeding performance in seabird colonies is usually based on determining the fate of established breeding attempts from clutch completion to hatching and fledging. However, a range of social, demographic, predator security and prey-availability factors may also determine the proportion of the breeding colony or population participating in a given season. The proportion of the breeding population that may abandon reproductive activity at the pre-laying stage is generally difficult to estimate because of low site attachment during this period. However, it remains highly probable that non-breeding, in both novices and in experienced birds, is a common response to sub-optimal environmental conditions during the pre-laying period (e.g. Wooller *et al*. 1990).

Variations in participation (the number of breeding attempts) may occur more frequently in seabirds that invest in proportionately large eggs with a high energetic content. Shearwaters *Puffinus* spp. produce a single large egg and engage in a pre-laying exodus in order to take on the significant nutritional reserves for its formation (Warham 1990). Low food availability during this period would be expected to reduce the number of pairs commencing a breeding attempt with the laying of an egg.

Wedge-tailed Shearwaters *Puffinus pacificus* are tropical muttonbirds that breed at numerous stations off the Western Australian coastline between Ashmore Reef (12°15'S) and Carnac Island (32°07'S). Large colonies occupy the islands of the Houtman Abrolhos around 28°S and the North West Shelf between 20°30' and 21°40'S (Burbidge *et al*. 1996). In common with other

mutton-birds, Wedge-tailed Shearwaters nest in burrows which are excavated or renovated at the start of each season and have a two to three week pre-laying exodus (Swanson & Merritt 1974, Garkaklis *et al.* 1998).

This paper is based on data from a long-term Wedge-tailed Shearwater monitoring study conducted on three islands on the North West Shelf off Western Australia (Airlie, Serrurier and Varanus Islands). The trends in this study area are compared to a Wedge-tailed Shearwater colony monitored on Pelsaert Island in the Houtman Abrolhos, more than 1000 km to the south. Egg-laying takes place at the end of October and beginning of November on the North West Shelf, about three weeks earlier than at colonies at the Houtman Abrolhos and on Rottnest Island close to the southern limit of the Wedge-tailed Shearwater's breeding distribution. (Garkaklis *et al.* 1998, ISMP 2000).

STUDY AREAS

North West Shelf islands

Airlie Island (21°19'S, 115°10'E) is an oval-shaped, vegetated sand cay with a land area of 25.8 ha. The fore dune that fringes the island varies between 6 and 12 m chart-datum. Most of the shearwater colony is located on the low-lying central sand plain. In December 1994 burrow densities ranged from 1.5 to 2.2 burrows/100 m^2 (ISMP 2000). An oil-storage facility occupies 3.1 ha of the island, reducing the original shearwater colony area by about 15%.

Serrurier Island (21°36'S, 114°41'E) is an elongated, vegetated, sand cay with fringing dunes reaching 15 m chart-datum. The island has an area of 187.5 ha. The shearwater colonies occupy much of the undulating, internal sand plain. In December 1994 burrow densities ranged from 3.4 to 6.4 burrows/100 m^2 (ISMP 2000).

Varanus Island (20°39'S, 115°34'E) is the largest island in the Lowendal Archipelago with a land area of approximately 89 ha. It is an irregular, linear outcrop of aeolianite limestone overlain in parts with Holocene sands. The limestone areas and shallow sands are only sparsely vegetated. The shearwater colonies are limited to pockets of shallow soil overlying the limestone. Burrow density in the most significant colony area (Varanus Main Colony) in December 1994 was 3.7 burrows/100 m^2 (ISMP 2000). Oil and gas-storage and production facilities occupy 18 ha of the island abutting the main shearwater colony.

Pelsaert Island, Houtman Abrolhos

Pelsaert Island is located amongst the 47 islands of the southern group of the Houtman Abrolhos archipelago. This group is located approximately 60 km west of Geraldton on the mid-western coast of Western Australia (28°54'S, 113°59'E). Pelsaert Island is a low-lying linear structure (12 km long, 120 ha) of coralline limestone and clinker on the eastern edge of a central lagoon. The surface of the island is primarily vegetated with low saltbush *Atriplex* spp. and samphire *Halosarcia* spp.

METHODS

North West Shelf islands

Active burrows of Wedge-tailed Shearwaters have been counted within marked areas on Airlie, Serrurier and Varanus Islands since the 1985/86 breeding season, as part of the monitoring programmes of three offshore petroleum companies. In 1994/95 these separate monitoring programmes were combined and video-scope observation techniques were introduced to allow the contents of burrows to be recorded.

The video-scope (Dyer & Hill 1991, Garkaklis 1992) was developed as a low disturbance technique of observing the contents of deep or fragile burrows. It consists of a video camera and light source combined within a sealed camera head and connected by a flexible fibre optic cable to a video monitor. The monitor receives images from the camera as it is fed downwards into the burrow. On the North West Shelf islands in 1994/95 the contents of over 95% of shearwater burrows were effectively determined using a video-scope (ISMP 2000).

The areas where burrows were counted on all three islands prior to 1994 were retained for the purpose in the integrated monitoring programme. On Airlie and Serrurier Islands additional, parallel strip-transects were established for video-scope monitoring. Count and video-scope strips were 5 m wide and varied in length depending on the extent of the colony. The strips were divided into 10-m segments in order to locate and record the number of burrows. Two strip transects for both count and video-scope observations were established on Airlie Island with an aggregate sampling area of 5500 m^2. Serrurier Island also had two pairs of strips covering 3000 m^2. Count strips were not investigated with the video-scope to provide a control on the impact of burrow examination.

The entire Main Colony on Varanus Island has been divided into a grid for burrow counts since 1985/86. In 1994 the grid in this colony was divided into alternating count only and video-scope strips. As with the monitoring strips on the other North West islands each grid cell in the Varanus Island colony was a rectangle with an area of 50 m^2. The Main Varanus colony occupied 1.45 ha in 1999/00.

The monitored colonies were visited twice in each season from 1994/95 to 2000/01. The first visit each year was designed to assess breeding participation and occurred in late November/early December after the completion of laying. A second visit was conducted during mid to late March before fledging in order to assess breeding success.

Pelsaert Island

On Pelsaert Island, 30 burrows were marked, using 60-cm canes, at each of two sites (i.e. a total of 60 burrows). These burrows were monitored physically, by reaching into them to establish the contents, every four days from early September to February from 1993/94 to 2000/01.

RESULTS

Between the 1994/95 and 2000/01 seasons the percentage of active burrows in which an egg was laid varied widely. On the North West Shelf islands breeding attempts per burrow ranged from 19.3 to 64.5% on Airlie, 32.8 to 83.6% on Serrurier and 23.7 to 68.3% on Varanus. On Pelsaert Island the inter-annual variation in breeding attempts per burrow was even more extreme ranging, from 1.2 to 69.4%. Figure 1 plots the percentage of breeding attempts (i.e. eggs laid) per burrow at each of the four monitored colonies over the study period. Also shown is the mean annual Southern Oscillation Index (SOI) for each season. The video-scope study period was preceded by the protracted 1991 to 1994 *El Niño* and included the intense event of 1997. Generally the monitored colonies track movements in the SOI and all showed a marked reduction in breeding attempts during the extreme conditions of 1997.

There was no correlation on the North West Shelf islands between the number of burrows excavated at the start of the season and the number in which eggs were ultimately laid. Figure 2 shows the time series in the number of burrows excavated at the three North West Shelf colonies between 1987/88 and 2000/01 compared with mean annual SOI values. The numbers are expressed as percentages of the mean to allow a better comparison between colonies with large differences in the number of monitored burrows. The number of burrows excavated each season at these colonies does show some correspondence with the trend in the SOI but in successive seasons there may be a problem in recounting unoccupied, residual burrows.

An investigation of marked burrows on Serrurier Island indicated that only 16.7% survived at their original location after two seasons and none after three (ISMP 2000). Thus, on the North West Shelf islands, auto-correlation with previous burrow counts is effectively erased in the third season (ISMP 2000).

Figure 3 shows the three-year running average active burrow count for the Varanus Island colony between 1989 and 2000 (NB counts date back to 1987). Also plotted on Figure 3 is the three-year aggregate of the annual SOI values.

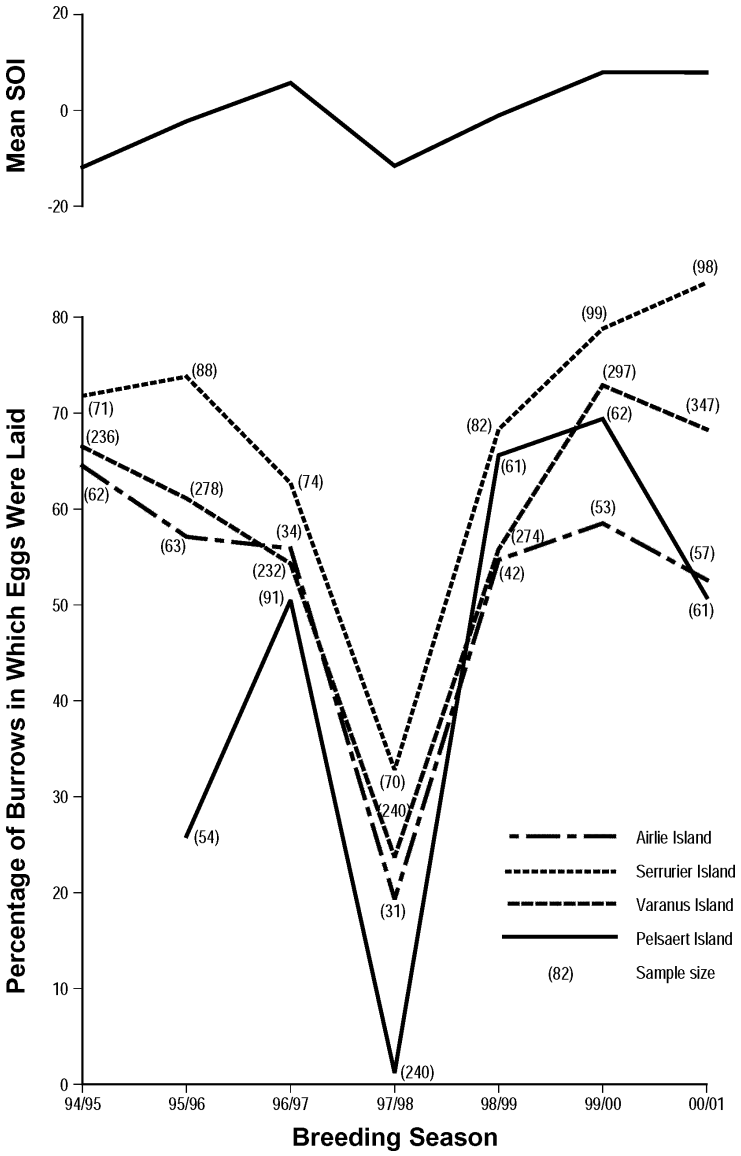


Fig. 1. The percentage of active burrows in which eggs were laid at four Western Australian Wedge-tailed Shearwater breeding colonies over seven seasons between 1994/95 and 2000/01. The number of burrows examined at each colony each season is shown in parentheses. Also plotted is the mean annual Southern Oscillation Index (SOI) for each year of the study.

The three-year rolling average burrow counts for the Varanus colony (the largest continuously monitored colony) correspond closely with the three-year aggregate SOI values and there is a significant positive rank correlation ($r_s = 0.5805$, $P < 0.05$) and demonstrate the cumulative effect of the Southern Oscillation on the number of shearwaters excavating burrows. Burrow numbers in this North West Shelf colony dropped dramatically through the 1991 to 1994 *El Niño* and the 1997 event apparently slowed subsequent recovery. The gradual upward trend from 1998 to 2000 corresponds with positive SOI values in those years. In aggregate terms *El Niño* conditions have dominated the decade and the number of breeding shearwaters excavating burrows on Varanus Island was depressed over most of that period. Figure 4 shows the percentage of monitored burrows on Airlie, Serrurier and Airlie Islands that produced a chick to the pre-fledging stage. There is a strong correspondence between colonies in all years except 1995/96. In that year two tropical cyclone tracks (Frank in December and Jacob in February) passed close to Airlie and Serrurier Islands in the period between monitoring visits. Varanus Island was left relatively unaffected. Breeding success appears to have been reduced on Airlie and Serrurier Islands due to impact of cyclonic winds and heavy rainfall.

A monitor lizard *Varanus acanthurus* preyed upon 22.1% of the eggs in the Varanus Island colony in the 1999/00 season and 4.6% in 2000/2001. However, this predator activity did not obscure the strong breeding success resulting from the prevailing *La Niña* oceanographic conditions.

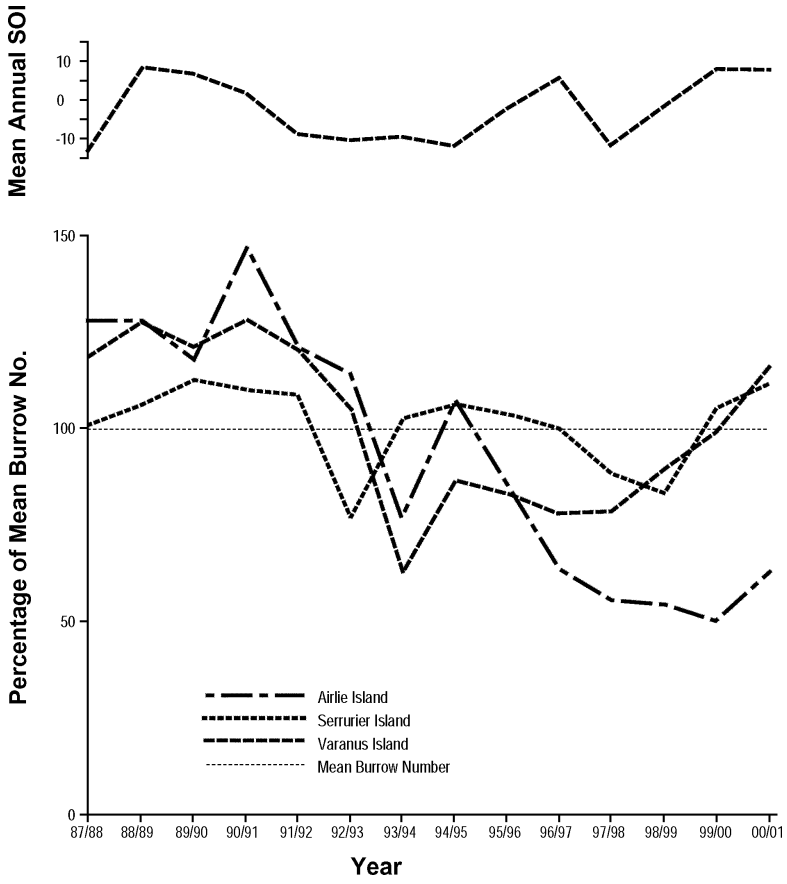


Fig. 2. The three-year running mean active burrow count for the Varanus Island colony compared with the three-year aggregate annual SOI for the period 1989 to 2000.

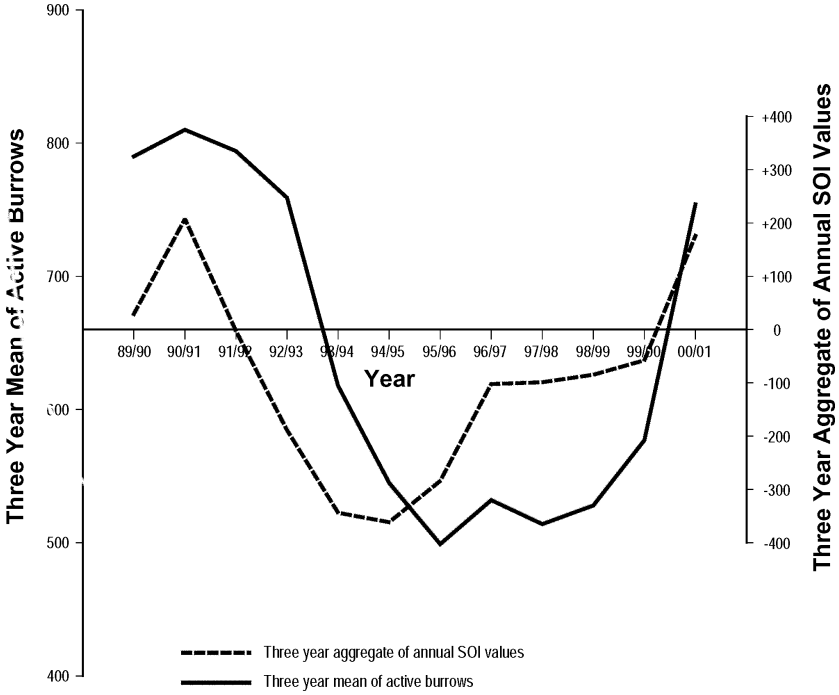


Fig. 3. The time series of aggregate burrow counts for Airlie, Serrurier and Varanus Islands from 1987/88 to 2000/01. Numbers are expressed as percentages of the running mean. Also shown is the time series for the mean annual SOI.

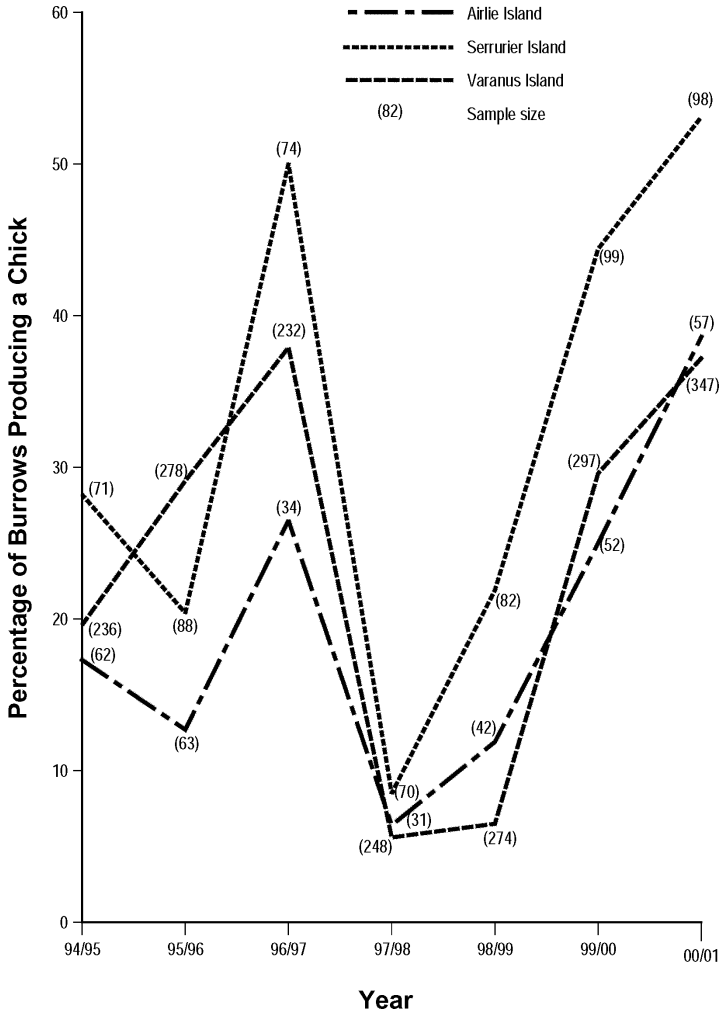
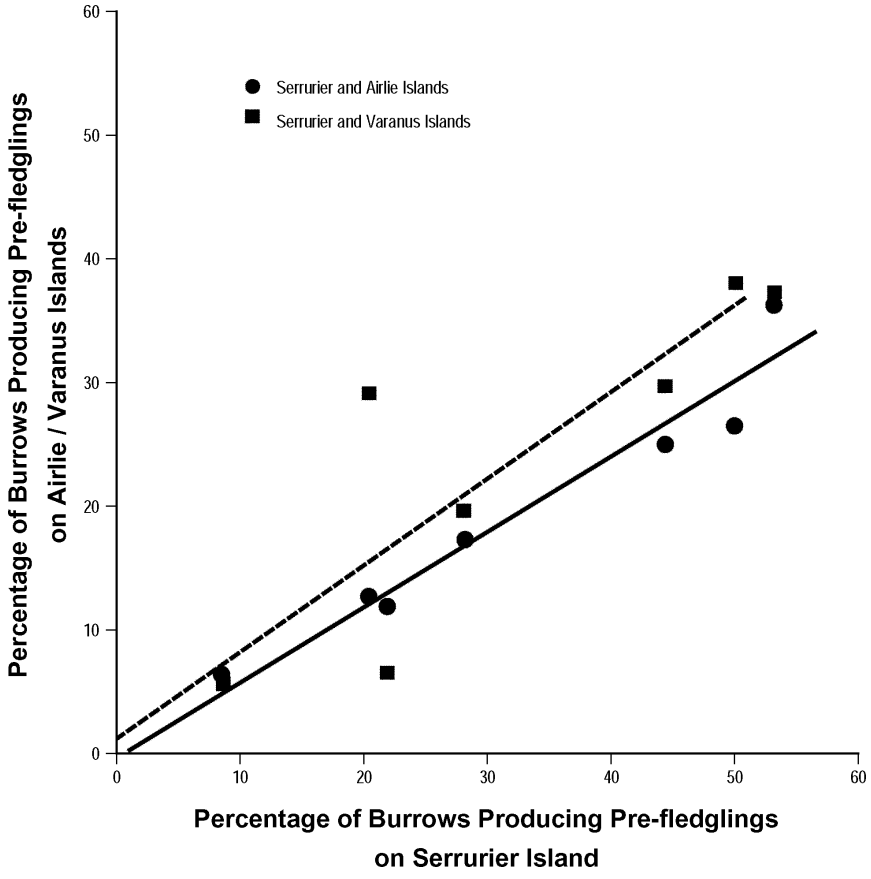


Fig. 4. The percentage of burrows producing a pre-fledged chick in video-scope monitored burrows on Airlie, Serrurier and Varanus Islands between the 1994/95 and 2000/01 breeding seasons. Sample sizes shown in parentheses.

The percentage of burrows producing pre-fledglings on Serrurier Island was correlated with the percentage on Airlie Island ($r_5 = 0.955$, $P < 0.005$) and on Varanus Island ($r_5 = 0.850$, $P < 0.05$). These relationships between colonies (Fig. 5), that are a considerable distance apart, indicate the oceanographic factors operating on a regional scale accounted for much of the variation in breeding success.

DISCUSSION

Breeding participation in Wedge-tailed Shearwaters has two measurable components, the number of nest burrows excavated/renovated to a functional state and the number of those burrows in which eggs were eventually laid (i.e. breeding attempts). The two parameters were not correlated on the North West Shelf islands between the 1994/95 and 2000/01 breeding seasons. A major contributory factor to this is probably significant non-breeding, in the poorer years, by shearwaters that excavated or renovated burrows earlier in the season. Inter-annual variations in breeding participation may be greater in tropical Wedge-tailed Shearwaters, with more variable food resources, than in cool-water species such as the Short-tailed Shearwater *P. tenuirostris* (Wooller *et al.* 1990).



The availability of prey resources to seabird populations is difficult to measure but is clearly related, amongst other factors, to oceanographic conditions within the foraging range of colonies (e.g. Wooller *et al.* 1991, Kitayski & Golubova 2000). The *El Niño* Southern Oscillation (ENSO, measured by the Southern Oscillation Index or SOI) is established as a driver of ocean scale shifts in sea temperatures and salinities, currents and areas of biological productivity (Allan *et al.* 1996). Whereas not in itself a measure of oceanographic conditions, the Southern Oscillation Index (SOI) is a robust predictor of a number of marine variables. In Western Australia the SOI has been correlated, at various localities, with sea temperature and salinity, sea level as a surrogate for Leeuwin Current strength, and with recruitment rates to various fisheries (Pearce & Walker 1991).

Fig. 5. The linear relationships between the percentage of burrows producing pre-fledged chicks on Serrurier and Airlie Islands and between Serrurier and Varanus Islands.

The 1997 ENSO event had a dramatic effect on the number of Wedge-tailed Shearwaters attempting to breed in that season. It also appears that the oceanographic factors reducing food availability during the pre-laying period operated not only on a regional scale, affecting all the North West Shelf study colonies, but at least as far south as the Houtman Abrolhos. The impact on the Pelsaert Island colony was greater than on the North West Shelf with a negligible number of breeding attempts initiated. Locations farther south in the narrow Leeuwin Current stream may be more susceptible to ENSO effects.

The proportion of nest burrows in which eggs were laid was probably a robust indicator of feeding conditions during the pre-laying period in each season. However, the number of active burrows excavated each season appears to be more indicative of the cumulative impact of environmental/oceanographic conditions from previous breeding seasons. As such it is a potential index of longer-term trends in the size of breeding populations. Used together these parameters both have potential as indicators of the oceanographic/trophic factors influencing breeding in Wedge-tailed Shearwaters during the pre-laying period.

Despite factors, such as cyclones and predators, that impacted differentially at the three North West Shelf colonies, the major component of breeding success remained the participation rate. This may be the case in many tropical seabirds exposed to large, unpredictable variations in marine productivity or prey availability.

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