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Expansion of *Ardenna* shearwater breeding colonies on Broughton Island after eradication of the European Rabbit and Black Rat

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Broughton Island, offshore from Port Stephens, New South Wales is one of the few sites off the Australian east coast where population estimates of shearwaters, using repeatable survey techniques, have been undertaken over an extended period. The most recent survey was undertaken in 2018, almost a decade after the total removal of invasive vertebrates. It was expected that, in line with previous comparable surveys, both the area of occurrence and the estimated breeding numbers of shearwaters would have increased after this removal. From the GPS-delineated area of 31 sub-colonies where transect counts of burrows were made, combined with direct counts at additional small sub-colonies, it was estimated that the breeding area of shearwaters on the island had increased by 31% since 2009. However, the estimated number of breeding pairs had only increased over this period by 11%, as burrow densities had declined. The small increase in breeding area was lower than that recorded in the last comparison made between 1977 and 2009. The burrow density declines were surprising, as the occurrence of the dominant species, the Wedge-tailed Shearwater *Ardenna pacifica*, has been increasing in southern New South Wales since the late 1960s and it has recently expanded its breeding range into Victorian coastal areas. When the relatively low rate of population growth and decreases in burrow density on Broughton Island are viewed in relation to changes in population estimates of shearwater numbers on other east coast islands, it seems likely that off-island factors, such as changes in access to and quality of suitable prey species, may have contributed to these trends.

Keywords: Broughton Island; shearwater; breeding area; burrow density; population expansion; rabbits and rats.

INTRODUCTION

Broughton Island (32°37'S, 152°19'E) is located off the New South Wales (NSW) central coast, 16 km northeast of the entrance to Port Stephens. At 132 ha, it is the largest coastal island in NSW and is dominated by open grass/sedgeland and woodland that extend 91 m above sea level at its eastern end (Carlile *et al.* 2012). The island forms part of the Myall Lakes National Park (NSW NPWS 2002) and contains several huts and a camping area. The only pest vertebrates on the island, the European Rabbit *Oryctolagus cuniculus* and Black Rat *Rattus rattus* were successfully eradicated in 2009 (Priddel *et al.* 2011). Two weeds of significance on the island have been subject to control measures. Bitou Bush *Chrysanthemoides monilifera*, which develops into a large, woody shrub, has been controlled to avoid wholesale loss of native vegetation where it becomes established. Prickly Pear *Opuntia stricta*, a spiny succulent, blocks the use of walking tracks with its splayed growth-form. Whilst Bitou Bush can block seabirds' access to burrows, Prickly Pear impedes the study of the birds but does not affect their burrow density (Carlile, pers. obs.).

The results of several surveys of the island's seabirds have been published (Hindwood and D'Ombrain 1960; Lane 1976; Carlile *et al.* 2012), as well as those of a specific study in 1977 designed to estimate shearwater colonies and burrow density (van Gessel 1978). By 1959 it was established that three species of shearwater, Wedge-tailed *Ardenna pacifica*, Sooty *A. grisea* and Short-tailed *A. tenuirostris*, bred in mixed colonies on the island (Hindwood and D'Ombrain 1960), although Lane (1976) found it difficult to confirm that Sooty Shearwaters were breeding there despite being found occasionally on the surface. The presence of Short-tailed Shearwaters appeared to be constant between the late 1950s and 1970s; a sub-colony below the island's summit contained about 18% Short-tailed Shearwaters in both 1959 and 1972 (Hindwood and D'Ombrain 1960; Lane 1976). This defined area (a 'rookery', Hindwood and D'Ombrain 1960) was resurveyed in 2009 (Carlile *et al.* 2012) and only Wedge-tailed Shearwaters were present. At this time only two other sub-colonies were identified as mixed-species breeding sites (Carlile *et al.* 2012): Wedge-tailed Shearwaters comprised 98% of a major dune colony and 82% of a smaller colony at the western extremity of the island, the other birds in these two areas being Short-tailed Shearwaters, and Sooty Shearwaters could no longer be found on the island.

In van Gessel's 1977 study (van Gessel 1978), colony area was determined by 'walking through a colony' and, we assume, approximating its location on a topographic map, and from that calculating its approximate total area. The relative densities of burrows were calculated in three large colonies in 12 circular plots of 10 m radius. These density estimates and the estimated approximate total area of colonies generated a total of 34,000 shearwater burrows (both Wedge-tailed and Short-tailed Shearwaters) for the island. However, the estimate of breeding pairs of shearwaters was only 13,600, because Van Gessel

(1978) assumed only a 40% burrow occupancy rate as he felt that many burrows were not used by shearwaters because of rabbit occupancy.

In 2009, colony boundaries were delineated by walking the perimeter with a handheld GPS and then calculating the area of each colony from these readings (Carlile *et al.* 2012). In nine habitat types (based on vegetation communities), burrow counts on 30 transects (50 m x 4 m) spread across the colonies yielded an estimated total of 114,600 burrows. From these data, the number of breeding shearwaters on the island was estimated at 57,300 pairs; this assumed a 50% burrow occupancy rate, which was based on recent surveys elsewhere where burrows were sampled along transects and rates of occupation and the species present were determined (Carlile *et al.* 2012). Lane (1979) revisited Broughton Island in 1979, two years after van Gessel's survey, and considered that the shearwater colonies appeared to be expanding since his initial visit in 1959. Carlile *et al.* (2012) assumed that the much larger estimate that they obtained in 2009, 30 years later, represented a continuation of that expansion, notwithstanding the potential impacts of introduced animals.

The present study describes a further shearwater burrow survey on Broughton Island between October and December 2018 conducted as part of continuing research into soils, vegetation and seabirds to understand the recovery process after removal of feral animals (Tulau and Wilson 2018). It presents a detailed account of shearwater colony expansion and additional sub-colony formation since the 2009 survey.

METHODS

The methods employed to determine burrow density resembled those of Carlile *et al.* (2012), with the addition of direct total burrow counts in sub-colonies considered too small to accommodate the minimum of three (25 m x 2 m) transects used in larger sub-colonies. Open burrow entrances that fell partially or wholly within transect areas were included in the count. Three shearwater colony classifications were employed during the survey, "previously surveyed in 2009", "small and overlooked in 2009" and "new". Some small areas were 'overlooked' in the 2009 survey because we were then attempting to survey all seabird species within three days, whereas the current survey was designed only to survey the extent of *shearwater* nesting. Their status as 'overlooked' was supported by the presence of Prickly Pear in the current survey.

RESULTS AND DISCUSSION

Most colonies surveyed in 2018 had previously been surveyed in 2009 (n = 21), but now occupied a total area of 318,266 m^2 compared with 229,000 m^2 in the earlier survey (Carlile *et al.* 2012). The second most common type of colonies was those considered to have been 'overlooked' in 2009 due to limited survey time availability (n = 5) and they had a combined area in 2018 of 10,336 m^2. Finally, 'new' colony areas (n = 6; total area 5,455 m^2) were located that had not been present in the 2009 survey (Fig. 1, inset). A feature of new colony areas was the absence of Prickly Pear, whereas it was both present and a dominant weed in sub-colonies mapped in 2009. Evidence of the fruits of this weed having been consumed by rabbits on Broughton Island were recorded in the past and germinated seedlings of Prickly Pear were often found in rabbit dung hills (Carlile, unpub. data). The use of shearwater burrows by rabbits on Broughton Island (van Gessel 1978) probably aided the weed's establishment and persistence in areas where the soil was regularly disturbed.

Within 31 sub-colonies, transects covered an area of 4,800 m^2 and contained 1,821 shearwater burrows, with an average burrow density of 0.39 per m^2 (range 0.07 – 0.74 per m^2). Burrow densities in the 'new' areas were lower than the island average (range 0.20 – 0.38 per m^2). From the combined sub-colony areas (332,076 m^2) and their corresponding burrow density estimates (and including the directly-counted 'new' colonies with a total area of 1,981 m^2), the total number of burrows estimated for Broughton Island was 129,000. This represents a total shearwater population of approximately 64,500 pairs (based on approximately 50% burrow occupancy; see Carlile *et al.* 2012).

Based on the GIS-generated data of identified colonies from the 2009 survey (Carlile *et al.* 2012), the total area of shearwater colonies on Broughton Island in 2018 had expanded by 31% in nine years (Table 1). When compared to the colony extent established by van Gessel (1978), the tabulated data indicate that the net annual rate of increase was a little less between the 1977 and 2009 estimates (2.5% annually) than between the 2009 to 2018 estimates (4.3% annually). It is likely that the 1977 estimate, without the accuracy of GPS digital technology, may have underestimated the true extent of the island's shearwater colonies. However, the measurements of colony area in 2009 and 2018 both used the same technology and the growth in this period was more rapid than in the earlier comparison. Whilst the size of the shearwater population increased between 2009 and 2018, the density of the birds in 2018 had decreased compared to that in 2009, and resembled that measured in 1977 (Table 1). Given that rats and rabbits had been absent since 2009, it could reasonably be assumed that this decrease in density would have been due to the removal of this on-island, negative impact on shearwater breeding and the population consequently 'spreading out'. However, in reviewing shearwater breeding here and elsewhere on the NSW coast, including sites with and without feral animals, a different explanation of the changes in population size and densities on Broughton Island may be reached.

Table 1

A comparison of changes in area of occupation, burrow density and estimated number of breeding shearwater pairs on Broughton Island from surveys conducted between 1977 and 2018.

Survey period	Area of occupation (m^2)	Mean (± SE) burrow density per m^2	Number of burrows	Number of shearwaters (assumed % burrow occupancy)	Source
October 1977	102,719	0.331 (0.06)	34,000	9,662 (40)	van Gessel 1978
December 2009	229,104	0.485 (0.05)	110,875	55,670 (50)	Carlile *et al.* 2012
Oct-Dec 2018	334,057	0.386 (0.06)	129,000	64,500 (50)	Present study

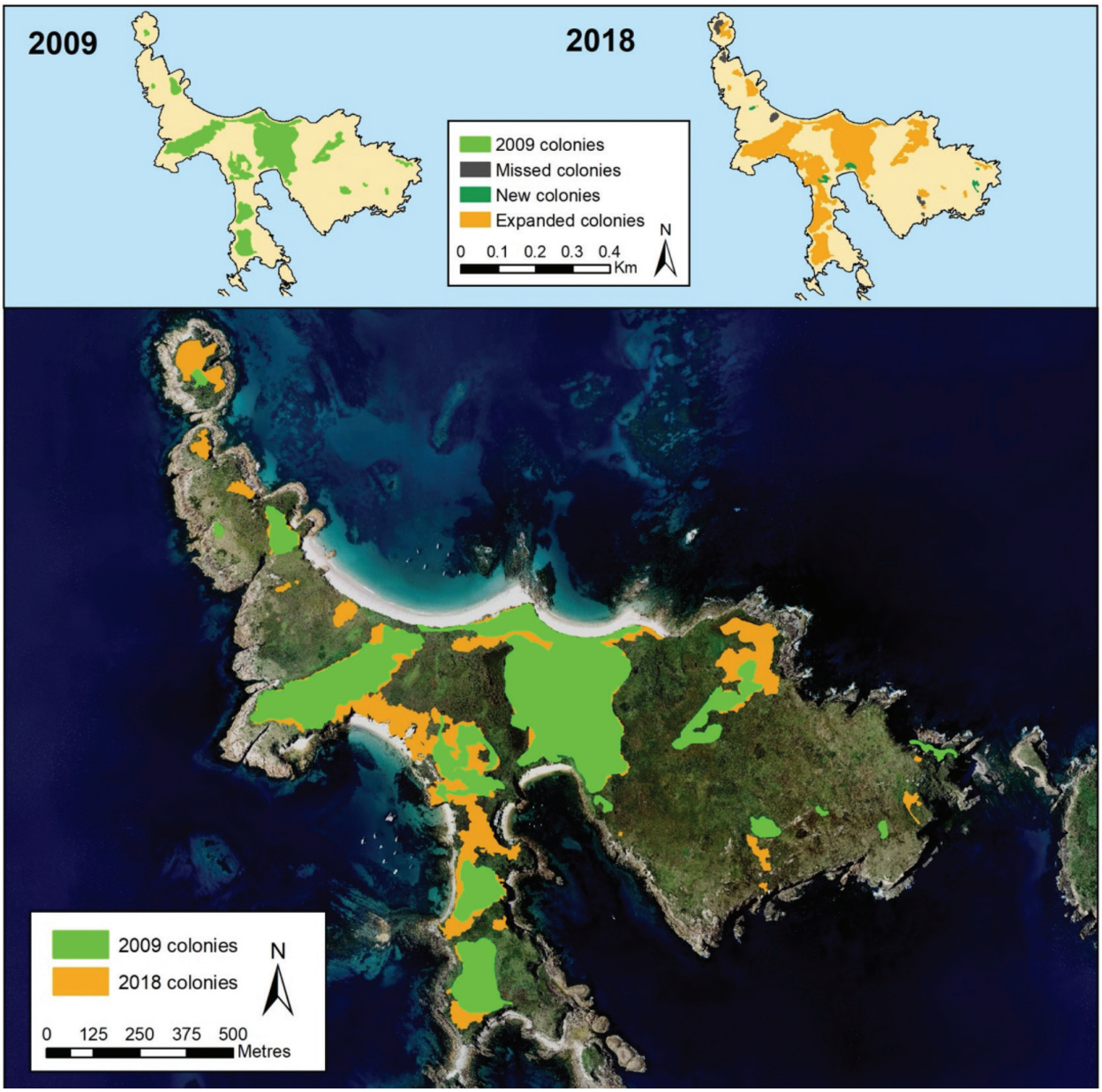

Figure 1. *A comparison of shearwater burrowing habitat between surveys in 2009 and 2018 overlayed on an aerial image of Broughton Island, Port Stephens NSW. Inset: mapped extent of colonies in 2009 (green), with the 2018 survey additionally showing the location of new colonies (dark green) and missed colonies (black) from the previous survey.*

Lane (1979) felt certain that the shearwater colonies on Broughton Island had expanded between his first and last visits to the island (1959–1979) and Carlile *et al.* (2012) reported a further increase in 2009. Shearwater numbers, particularly those of Wedge-tailed Shearwaters, recently appear generally to be increasing in NSW. This has been documented on Barunguba (Montague Island: 36°15′S, 150°13′E) since the 1960s, where Wedge-tailed Shearwaters have become increasingly dominant over the more temperate breeding Short-tailed Shearwater (Fullagar 1973; Priddel *et al.* 2016). More recently, Wedge-tailed Shearwaters have established a breeding colony in Victorian coastal waters for the first time (Hunter 2020), perhaps indicating that an expansion in numbers has been ongoing for some time.

More immediately pertinent to the current study is that on other islands in the Port Stephens area that have adequate soils for burrowing and where a full population estimate has been undertaken, increases in shearwater numbers resemble those on Broughton Island over comparable periods up to the early 2000s (Table 2). All estimates for this area from the 1970s to the 2000s have yielded similar rates of increase in populations irrespective of the presence/absence of rats and/or rabbits. This indicates that the observed population increases in this area were not driven by declines in feral animals, but more likely by offshore or out-of-region factors that allowed immigration or higher fecundity among breeding birds in this region.

It was unexpected that the shearwater burrow density on Broughton Island would have decreased, given the clear increase in colony area over the last decade. The decline in burrow density in this period cannot be plausibly explained by the removal of feral animals, as they appear not to have

Table 2

A comparison of the annual rate of change in shearwater burrow numbers on islands in the Port Stephens area from 1970s to 2018.

Island	Island size (ha)	Estimated no. of burrows	Annual Rate of change	Feral animals present	Source
Broughton 1977	132	34,000	–	rat, rabbit	van Gessel 1978
Broughton 2009	132	110,875	+0.037	rat, rabbit	Carlile *et al.* 2012
Broughton 2018	132	129,000	+0.017	Nil (eradicated 2009)	This study
Little Broughton 1973	27	14,000	–	rat	Lane 1976
Little Broughton 2010	27	70,526	+0.043	rat (eradicated 2009)	Carlile *et al.* 2013
Boondelbah 1970	9	8,000	–	nil	Morris 1976
Boondelbah 2003	9	29,400	+0.041	nil	Priddel & Carlile 2004

N.B. Cabbage Tree Island was excluded as the original estimate was only given as a range (Fullagar 1976).

impeded the population expansions seen between 1977 and 2009. This decline in burrow numbers would appear to indicate more recent pressures operating at sea. For example, a localised decline in foraging for chick provisioning over this time may have limited breeding success (e.g. Kowalczyk *et al.* 2014; Franci *et al.* 2015) and therefore subsequent recruitment, or decreased fitness for breeding of returning adults (e.g. O'Dwyer *et al.* 2006; Fayet *et al.* 2017) may have reduced their ability to participate fully in reproduction, reducing the number of active burrows and consequently our detection of shearwaters. There are no long-term population studies of Wedge-tailed Shearwaters in NSW or elsewhere to corroborate this decline and highlight where environmental stressors may be operating. Further research is required to increase our understanding of the changing population dynamics of this common species.

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