ICES Journal of Marine Science

ICES Journal of Marine Science (2015), 72(2), 316–327. doi:10.1093/icesjms/fsu164

Reviews

Population status and threats to Flesh-footed Shearwaters (*Puffinus carneipes*) in South and Western Australia

Jennifer L. Lavers*

Institute for Marine and Antarctic Studies, University of Tasmania, 20 Castray Esplanade, Battery Point, TAS 7004, Australia

**Corresponding author: tel: +61 03 6226 6379; e-mail: jennifer.lavers@utas.edu.au*

Lavers, J. L. Population status and threats to Flesh-footed Shearwaters (*Puffinus carneipes*) in South and Western Australia. – ICES Journal of Marine Science, 72: 316–327.

Received 27 July 2014; revised 20 August 2014; accepted 29 August 2014; advance access publication 3 October 2014.

Seabirds are considered reliable indicators of the marine environment due to their reliance on ocean-based resources and position at the top of the marine foodweb. The status of the world's bird populations have deteriorated over the past 20 years with seabirds declining faster than any other bird group. For some seabird species, a lack of data or synthesis of available data limits our ability to detect changes in population trends and gain insight into the condition of the surrounding marine environment. The Flesh-footed Shearwater (FFSH; *Puffinus carneipes*) exemplifies this with demographic and count data either absent or outdated for most breeding islands. Results of a survey of 20 FFSH breeding islands in South and Western Australia during 2011–2014, and a synthesis of all available data indicate the current global population is substantially smaller than previously thought, comprising no more than 74 000 breeding pairs. While much of the reduction in numbers is due to outdated burrow counts which are shown to be a poor measure of population size in this species, there is evidence of a decline in numbers on at least six islands that account for ~40% of the world's population. A review of novel and existing data on FFSH breeding habits (burrow occupancy and density), concurrent threats, and population size in South and Western Australia are presented here along with priorities for management of this declining marine predator.

Keywords: apex marine predator, cumulative mortality, Flesh-footed Shearwater, indicator species, *Puffinus carneipes*.

Introduction

Seabirds are widely regarded as reliable indicators of the condition of the marine environment due to their sensitivity to, and reliance on, marine resources and position at the top of the marine foodweb (Furness and Camphuysen, 1997). According to the Birdlife International Red List assessment, the status of the world's birds has deteriorated over the past 20 years (BirdLife International, 2013). While these changes were recorded in all major ecosystems, seabirds were substantially more threatened than other groups and declining the fastest (Butchart *et al.*, 2004). Seabird declines often closely track worsening marine conditions (Bond and Lavers, 2014; Becker and Beissinger, 2006), highlighting their ability to identify problems in ocean-based resources.

Australia ranks fourth in the world for seabird diversity, endemism, and threat level (Croxall *et al.*, 2012). Despite this, <6% of seabird breeding islands are monitored as part of the Birds Australia Atlas, with a mere 1.8% of these islands benefitting from repeated surveys (Kirkwood and O'Connor, 2010). Consequently, basic demographic and abundance data are lacking for many of what should be Australia's most valuable marine indicators, the seabirds (Baker *et al.*, 2002; Stephenson *et al.*, 2006).

One such example is the Flesh-footed Shearwater (FFSH; *Puffinus carneipes*). Basic demographic data (e.g. survival) and population trends are almost entirely lacking for this species. Breeding data are also limited, with only a few studies reporting burrow occupancy, productivity, or phenology (McClellan, 1995; Johnstone and Storr, 1998; Powell *et al.*, 2007; Reid *et al.*, 2013a). Data are particularly sparse in South Australia (Robinson and Parker, 1984) and Western Australia, where the majority of the world's population breeds on 42 offshore islands (Table 1; Supplementary Table S1; Johnstone and Storr, 1998).

Previous FFSH population estimates are variable, incomplete, and many are now considered erroneous. Estimates currently range from 220 000 to 400 000 breeding pairs globally (Marchant

Table 1. Estimates of FFSH population size on islands surveyed in South Australia and Western Australia during this study (2011–2014).

Island	Date (D/M/Y)	Breeding pairs	Source
South Australia			
Smith	Nov 1982	150	Robinson and Parker (1984)
	19–20/11/2012	1613 ± 924[a]	This study
Lewis	20–21/11/2011	211 ± 121[a]	This study
Hopkins	20–21/11/2011	0	This study
Western Australia			
Breaksea	1–2/9/1975	1000–5000[b,c]	Abbott (1978a)
	9/12/2011, 12/4/2012	1862 ± 1226[c]	This study
Coffin	5/11/1982	>100	Smith and Kolichis (1981)
	23/1/2012	<200	This study
Cull	4/11/1981	0[d]	Lane (1982a)
	26/1/2012	0[d]	This study
Eclipse	Aug 1973	6000	Fullagar (1978)
		602 ± 272[e]	This study
Frederick	30/10/1981	500–1000 burrows (276 ± 230)[f]	Lane (1982c)
	25/1/2012	148 ± 61	This study
Goose	Jan 1985	250 pairs[c]	Storr (1991)
	27/1/2012	0[e]	This study
Gulch	9/12/1987	2000 burrows (551 ± 460 pairs)[a,f]	Johnstone and Smith (1990b)
	25/1/2014	0[c]	This study
Gunton	10/11/1950	A few burrows	Fairbridge and Serventy (1954)
	26/1/2012	11 ± 6	This study
Long	10/11/1981	N/A	Lane (1982d)
	25/1/2014	500	This study
Migo	1985	A few pairs	Storr (1991)
	3/1/2014	0	This study
Mistaken	23/9/1976	Extirpated[c]	Abbott (1978c)
	5/1/2014	Extirpated[c]	This study
Owen	Unknown	N/A	Serventy *et al.* (1971)
	25/2/2014	≤2000	This study
Richards	3/1/2014	<30	This study
Saddle	1984	2000	R. Johnstone, pers. comm.
	9/1/2014	7695 ± 2054	This study
Sandy	1–4/4/1976	5011[g]	Abbott (1981a)
	3–5/12/2011	3439 ± 1917	This study
Sandy Hook	18–28/5/1977	N/A	Tingay and Tingay (1982)
	25/1/2012	<200	This study
Seal	24/1/2014	0	This study
Shelter	1988	3000 burrows (827 ± 690 pairs)[f]	R. Johnstone, pers. comm.
	6/12/2011, 10/1/2014	184 ± 144	This study
Wickham	Unknown	8000[a]	Johnstone and Storr (1998)
	9/12/1987	0	Johnstone and Smith (1990c)
	28/1/2012	0[c]	This study
Woody	3–16/2/1976	80	Abbott (1981b)
	2000–2003	424 burrows (117 ± 98 pairs)[f]	Powell *et al.* (2007)
	25/1/2012	101 ± 41	This study

For some islands, the species is noted as being present, but population size is not known (reported as N/A). Counts of burrows from historical surveys were multiplied by the occupancy rate for Western Australia to provide an estimate of breeding pairs (mean ± SD; see text).
[a]Likely an overestimate as many, or most, burrows belong to *Puffinus tenuirostris*.
[b]Some burrows may belong to *Pterodroma macroptera*.
[c]European rabbit (*O. cuniculus*) may have contributed to extirpation (see text).
[d]Goats (*C. hircus*) present on island.
[e]Population not directly assessed (see text).
[f]Number of burrows multiplied by mean occupancy rate for Western Australia (see text).
[g]Erroneous estimate of 300 000 pairs revised to 5 011 pairs (see text).

and Higgins, 1990; Johnstone and Storr, 1998; Taylor, 2000; Baker *et al.*, 2002; Brooke, 2004). The discrepancy is primarily due to incomplete field surveys or literature reviews conducted during 1950–1980 that did not account for burrow occupancy rates or distinguish between sympatrically breeding species (see below; Baker *et al.*, 2010; Waugh *et al.*, 2013). Once thought to be abundant and widely distributed, there is now growing concern that many FFSH populations have been declining, unobserved, for many years (Priddel *et al.*, 2006; Cooper and Baker, 2008; Waugh *et al.*, 2013; Reid *et al.*, 2013a). Consequently, the Australian population was recently uplisted from Least Concern to Near Threatened (Garnett *et al.*, 2011). In New Zealand, the species was recently uplisted from "Gradual Decline" to "Nationally Vulnerable" (Robertson *et al.*, 2013). FFSHs have also been recommended for

listing under the Agreement on the Conservation of Albatrosses and Petrels (Cooper and Baker, 2008).

To better understand the status of FFSH populations and highlight what the species can tell us about the health of the marine environment, published and unpublished data on FFSH populations are reviewed with the aim to (i) present new data resulting from recent, wide-scale surveys undertaken on 20 breeding islands in South and Western Australia during 2011–2014, (ii) identify known and potential sources of mortality, and (iii) provide a much-needed estimate of global FFSH breeding populations based on historic and contemporary counts from a subset of islands.

Material and methods

Study area

Given the unknown precision of historic population estimates, a survey of 20 of the 41 breeding islands (~35% of the global population) was undertaken in South and Western Australia (Figure 1) between 2011 and 2014 to provide the first data on FFSH populations in this region since the late 1970s (except Woody Island; see below). Additional unpublished data and information on methodology was sought from various authors.

Population census and statistical analysis

Population size was estimated by examination of burrow contents along transects (20 × 2 m) with a Signet wireless inspection camera during November–December 2011, January and April 2012, and December 2013 to February 2014. Where possible, surveys encompassed all vegetated areas of the islands; however, logistical constraints and access (e.g. fragile soil) limited the area covered by some surveys. If the whole island could not be surveyed, effort was focused on sections of the islands where FFSH were previously reported breeding.

Estimates of island size in the literature from the 1970s and 1980s did not account for vegetated and unvegetated (e.g. rocky) area; therefore, island area was re-examined using ArcMAP (version 10). Burrow density (number of burrows m^{-2}) was estimated for all vegetated areas where large, shearwater-sized burrows (entrance >10 cm) were observed. Burrows <40 cm in length that lacked a nesting chamber were excluded from the analysis. The mean and 95% confidence interval for shearwater burrow density was estimated using the boostrap method written in R (version 2.14.2) where 100 000 randomized distributions were generated by resampling with replacement (Manly, 2007). Burrow occupancy (presence of egg, chick, or adult) values were bootstrapped in a similar manner using weighted sampling based on observed probabilities. To account for detection error associated with the burrow inspection techniques (McKechnie *et al.*, 2007), correction factors developed for FFSH in New Zealand (Baker *et al.*, 2010) were applied to burrow occupancy rates estimated during this study (reported as original and corrected value).

The total number of burrows was estimated by multiplying the mean burrow density (calculated from the transect data) by the area of island habitat deemed suitable for shearwater breeding. This number was then multiplied by the mean occupancy rate to give an estimate of breeding population size.

A number of more general and case-specific issues with the historical datasets are identified and detailed below. Where possible, an

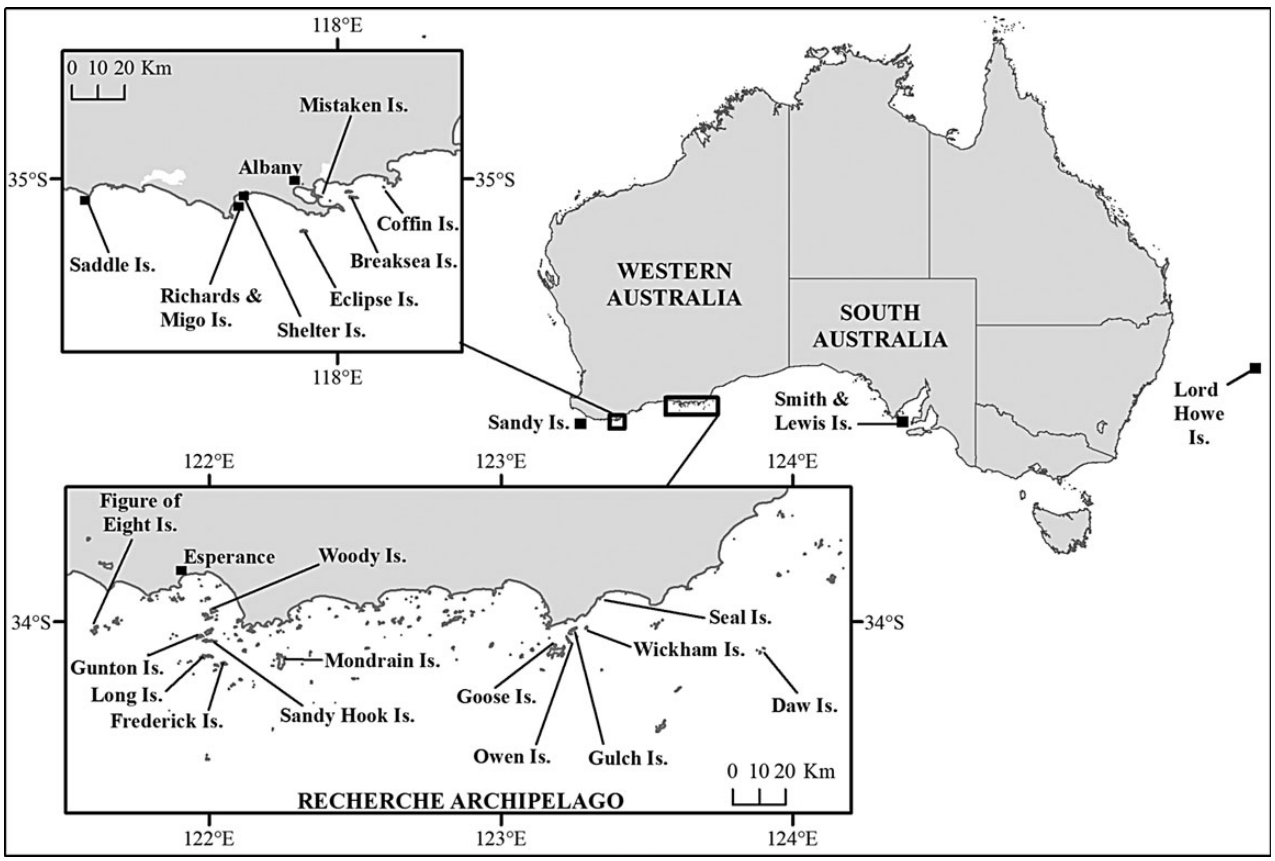

Figure 1. Location of FFSH breeding islands surveyed in 2011–2014 and key islands mentioned in the text.

Table 2. Current global estimate of FFSH breeding pairs.

Locality	Estimate	Year	Source
Western Australia	18 376 – 35 906	2011 – 2014	Table 1 and Supplementary Table S1
South Australia	779 – 2869	2011	This study
Lord Howe Island	14 779 – 18 809	2009	Reid *et al.* (2013a)
New Zealand	10 000 – 15 000	2012	Waugh *et al.* (2013)
Île Saint-Paul	113	1984	Roux (1985)
Global	40 606 – 73 678		

attempt is made to address these issues to allow for historical (Table 1; Supplementary Table S1) and contemporary estimates of population size (Tables 1 and 2) to be compared to provide at least some insight into large-scale changes over time. For example, some authors report burrow counts while others estimate the number of breeding pairs. To standardize the unit of measurement of FFSH population size in Western Australia, the number of burrows reported for a given island was multiplied by the mean occupancy rate for adjacent islands collected within the same period (1976–1986).

Review of known and novel threats

A review of all available published and unpublished data was undertaken to assess the scale and severity of previously identified threats to FFSH populations. Because the surveys of most of the islands visited during this study were the first in over 30 years, data and observations concerning these and other novel threats to breeding populations were also recorded.

Results

Assumptions and limitations

Data on the frequency of breeding are not available for FFSH, so the species was assumed to breed yearly, as has been reported in many (Warham, 1982), but not all shearwater species (Dunlop *et al.*, 2002; Sanz-Aguilar *et al.*, 2010). Estimates of population size, therefore, do not account for birds that may have skipped breeding. Population estimates for South Australian islands (surveyed in November) may be biased low as egg laying may not have been complete (Warham, 1958; Powell *et al.*, 2007).

South Australia

Smith Island (35°00′S, 136°01′E)

Robinson and Parker (1984) first noted ~150 FFSH pairs breeding at Smith Island in November 1982, alongside 1000 Short-tailed Shearwaters (Copley, 1996). A follow-up survey of Smith Island (40 transects covering the entire surface of the island) on 19–20 November 2011 provided a more accurate assessment of population size: 52 burrows were counted. Shearwater burrow density ranged from 0.000 to 0.125 burrows m^{-2} (mean: 0.033 ± 0.034). The original island area estimated by Robinson and Parker (1984; 3.6 ha) appears incorrect. Using satellite images, the area suitable for burrowing is estimated to be 13.4 ha (excluding the rocky perimeter), giving an estimate of 4362 ± 712 shearwater burrows.

Burrow occupancy could not be determined due to equipment malfunction, so the mean occupancy rate recorded on Sandy and Shelter Islands in Western Australia in December 2011 (corrected: 0.370 ± 0.212; see below) was used, as these data were collected in the same year. Using these values, the FFSH breeding population on Smith Island in 2011 is estimated to be 1613 ± 924 pairs (Table 1). While no Short-tailed Shearwaters were seen or heard in November 2011, this does not exclude the possibility some burrows may belong to this species.

Lewis Island (34°57′S, 136°01′E)

Shearwater surveys have not previously been conducted at Lewis Island, but recent observations of FFSHs flying around the island at night suggested that they were likely to be breeding at the island (S. Goldsworthy, pers. comm.). Burrow surveys of the entire island (45 transects) were undertaken at Lewis Island on 20–21 November 2011. Sixteen burrows were counted (mean density 0.009 ± 0.021, range 0.000–0.100 burrows m^{-2}) with 6.4 ha suitable for burrowing (excluding the rocky perimeter). Using the mean burrow occupancy rate as described for Smith Island above gives a population estimate of 211 ± 121 FFSH breeding pairs at Lewis Island in 2011 (Table 1).

Hopkins Island (34°57′S, 136°03′E)

Baker (2004) reported 69 760 Short-tailed Shearwaters nesting on Hopkins Island, but no mention of FFSH was made. No shearwaters were seen or heard at Hopkins Island on 20–21 November 2011. A handful of burrows appeared abandoned (i.e. no digging, feathers, and footprints). Given the lack of evidence of FFSH nesting in both the 2004 and 2011 survey, it is unlikely that this species breeds at Hopkins Island.

Sir Joseph Banks (34°35′S, 136°17′E) and Whidby Group (34°34′S, 134°19′E)

There is some evidence that FFSH bred at one or more of the islands in the Sir Joseph Banks Group in the 1930s, but the birds are thought to have disappeared or been greatly reduced in number since that time (Baker, 2004). Large burrows thought to belong to FFSH were reported on Perforated Island (Whidby Group; Coffin Bay National Park) in May 1980; however, a follow-up survey in January 1982 found only Short-tailed Shearwaters (Robinson *et al.*, 1996).

Western Australia

Low counts on at least four islands (Smith and Kolichis, 1981; Lane, 1984b, 1985) were hugely misreported in subsequent reviews due to editorial errors (e.g. >1000 pairs reported as 71 000 pairs; Johnstone and Storr, 1998). The naming of some islands, particularly Stanley Island in the southwest and Wickham (formerly Stanley) Island (Figure 1) in the southeast, has also caused confusion.

FFSHs formerly bred in the Torbay region on mainland Western Australia where nesting was last recorded in 1937 (Warham, 1958). Three populations have gone extinct: Mistaken Island (between 1906 and 1921; see below), Green Island (around the 1830s; Abbott, 1978b; Johnstone and Storr, 1998), and Goose Island (see below). Key findings for a subset of islands surveyed during 2011–2014 are detailed below and summarized in Tables 1 and 2.

Breaksea Island (King George Sound; 35°03′S, 118°03′E)

A survey of Breaksea Island (102 ha) during 22 August to 2 September 1975 (just prior to the birds returning to breed) provided a rough estimate of 1000–5000 FFSH burrows (Abbott, 1978a). Burrow counts along nine transects on the eastern half of the island on 9 December 2011 and 13 April 2012 indicate burrow density was relatively low (mean: 0.033 ± 0.033). Of 77 burrows examined along the top of the island in December, nine were occupied by FFSH (observed: 0.117, corrected: 0.143 ± 0.044) and two by introduced European rabbits (*Oryctolagus cuniculus*; see below). In April 2012, only 6 of 35 burrows inspected at the east end of the island were occupied by FFSH (observed: 0.171, corrected: 0.210). A survey of ~200 burrows on 5–6 April 2014 yielded no FFSH (N. Dunlop pers. comm.). There is increasing concern regarding the suspected decline of this population, likely driven by bycatch in fisheries operating next to the island (N. Dunlop pers. comm. and J.L.L. pers. obs.; see below).

The total area suitable for burrowing is estimated to be 42.42 ha. Using the mean density (0.033 ± 0.033) and occupancy (0.133 ± 0.088) recorded in 2011–2014, the total FFSH population size for Breaksea Island is estimated to be 1862 ± 1226 pairs (Table 1).

In New Zealand, FFSH have abandoned breeding on at least four islands and declined on at least two others (Waugh *et al.*, 2013), with many burrows at existing islands occupied by Grey-faced Petrels (*Pterodroma m. gouldi*), a species that has been reported to outcompete adult FFSH and kill their chicks (Marchant and Higgins, 1990; Taylor, 2000; Rayner *et al.*, 2011; Waugh and Taylor, 2012). This was also observed on Breaksea Island in April 2012 (J.L.L. pers. obs.).

Coffin Island (35°00′S, 118°12′E)

No more than 100 FFSH burrows were present at Coffin Island (14.38 ha) in 1979, located primarily within a 1.35 ha area along the south coast of the island (Smith and Kolichis, 1980).

A survey of Coffin Island on 23 January 2012 noted large burrows along the perimeter of the island, particularly in the south. A small cluster of ~40 burrows at the southeast end of the island appeared active. Upon inspection, three (observed: 0.214, corrected 0.262 ± 0.036) of 14 burrows were occupied by adult FFSH. Transects could not be run in the interior of the island due to thick scrub, so total population size cannot be estimated. However, the island population is thought not to exceed 200 pairs (Table 1).

Cull Island (Recherché Archipelago; 33°55′S, 121°54′E)

Unclear whether FFSH bred at Cull Island before the introduction of goats (*Capra hircus*) in 1935 (Lane, 1982a), but the species was not recorded in November 1981 (Lane, 1982a) or January 2012.

Eclipse Island (35°10′S, 117°53′E)

Eclipse Island (62.7 ha) may be an important FFSH breeding site, but there is uncertainty surrounding the only estimate (6000 pairs in 1978) as the survey was conducted during the non-breeding season and many of the burrows likely belonged to thousands of Great-winged Petrels which breed on the island during the Austral winter (Fullagar, 1978). Three failed attempts to access the island in 2011 and 2012 yielded no new data. Given the potential importance of the colony and uncertainty surrounding the FFSH population estimate, burrow occupancy data for nearby islands in King George Sound (0.252 ± 0.114; see below) are used to provide a rough estimate of current population size. Based on Fullagar's (1978) detailed maps of FFSH colonies, the area suitable for breeding is estimated at 7.24 ha giving an estimate of 602 ± 272 pairs at Eclipse Island in 2011 (Table 1).

Frederick Island (Recherché Archipelago; 34°04′S, 122°00′E)

Around 500–1000 FFSH burrows were reported at Frederick Island on 30 October 1981, of which 5.5% were occupied (Lane, 1982c). Lane's (1982c) estimate may be biased low as some birds may not have returned from their pre-laying exodus. A visual inspection on 25 January 2012 indicated that burrows were scattered across most of the island (39.6 ha), with a dense cluster in the southwest corner (~2.3 ha). Thirty-three burrows were inspected in this area: four contained an adult or chick (observed: 0.121, corrected: 0.148 ± 0.062). Using Lane's (1982c) maximum burrow count and occupancy from 2012 provides an estimate of 148 ± 61 breeding pairs (Table 1).

Goose Island (Recherché Archipelago; 34°04′S, 123°11′E)

Around 250 FFSH pairs have been reported breeding at Goose Island (27.4 ha) (Serventy, 1948; Fairbridge and Serventy, 1954; Storr, 1991). On 27 January 2012, no FFSH or evidence of their activity could be located anywhere on the island, suggesting that the birds have abandoned breeding since the last survey in January 1985 (Storr, 1991). Many burrows were occupied by rabbits that were introduced before 1889 (Serventy, 1953) and whose droppings now blanket the surface of the island.

Gulch Island (Recherché Archipelago; 34°01′S, 123°15′E)

Serventy and Whittell (1967) report an unknown number of FFSH breeding at Gulch Island (30.1 ha), but the original source of these data cannot be traced. Only Short-tailed Shearwaters (2000 pairs) were recorded in March 1984 (Johnstone and Smith, 1990b) and on 25 February 2014.

Gunton Island (Recherché Archipelago; 33°59′S, 121°59′E)

A small number of FFSH burrows were recorded at Gunton Island (75 ha) in the 1960s (Serventy and Whittell, 1967; Serventy *et al.*, 1971). A survey of the entire island on 26 January 2012 yielded ~70 burrows with an occupancy rate of 11.8% (corrected: 0.144), giving a population estimate of 11 ± 6 breeding pairs (Table 1).

Long Island (Recherché Archipelago; 34°02′S, 123°14′E)

Fairbridge and Serventy (1954) reported Long Island (64.0 ha) to be covered with sandy soil and riddled with burrows, suggesting it was "a huge and noisy rookery" and possibly "the largest colony in the Archipelago" (Serventy, 1952a). However, results of a survey of the southern half of the island by Lane (1982d) in November 1981 conflict with this description. A survey of the eastern half of this large, densely vegetated island on 27 February 2014 yielded only a few clusters of 50–100 burrows in soil of sufficient depth, primarily in the south. The reason for the discrepancy in vegetation cover between surveys in the 1950s and more recently is unknown. Five burrows were counted during two transects (0.063 ± 0.018 burrows m^{-2}). A further seven burrows were inspected, two (observed: 0.286, corrected: 0.349 ± 0.103) were found to contain a FFSH chick. Total population size for Long Island is not thought to exceed 500 pairs

Migo Island (Torbay; 35°04′S, 117°39′E)

A few FFSH pairs were recorded breeding on Migo Island (date unknown; 1.93 ha; Storr, 1991). A small colony was confirmed breeding on the southeast corner of the island within the past

decade (P. Collins, pers. comm.). However, a survey of the entire island on 3 January 2014 found no evidence of FFSH breeding.

Mistaken Island (King George Sound; 35°04′S, 117°38′E)

Disturbance from >200 rabbits is thought to have led to the extirpation of FFSH and other Procellariform species from Mistaken Island (9.9 ha; Ogilvie-Grant and Shortridge, 1910; Lane, 1977; Abbott, 1978c; Young, 1981). The rabbits were successfully eradicated in 1980 (Young, 1981), but an island-wide survey on 5 January 2014 provided no evidence of breeding by shearwaters or petrels.

Owen Island (Recherché Archipelago; 34°02′S, 123°14′E)

An unknown number of FFSH were reported to be breeding at Owen Island (4.9 ha; Serventy *et al.*, 1971). A survey of the island on 26 February 2014 yielded many discrete areas of dense burrows in sandy, unstable soil, particularly along the south coast (~2.45 ha). From transect counts (0.194 ± 0.075 burrows m^{-2}), the population is estimated at 1978 ± 216 breeding pairs in 2014; however, this is likely an overestimate as burrows are not evenly distributed across the surface of the island. The total population is not thought to exceed 1500 pairs (Table 1).

Richards Island (Torbay; 35°03′S, 118°03′E)

The first survey of FFSH on Richards Island (0.51 ha) was undertaken on 3 January 2014. Two small colonies on the south side of the island contained ~80 burrows. Twenty-two burrows were inspected, five (observed: 0.227, corrected: 0.277) contained adult FFSH. The total FFSH breeding population for Richards Island is not thought to exceed 30 pairs (Table 1).

Saddle Island (Walpole; 35°03′S, 116°44′E)

The first record for Saddle Island (26 ha) comes from Clark (1841) who reported the island was "covered by sooty petrel burrows" that were captured at night and eaten. A brief survey in 1990 reported 2000 pairs of FFSH (Storr, 1991). A partial survey of the north-central part of the island (encompassing ~1 ha on either side of the saddle; Figure 2) on 9 January 2014 suggests Storr's (1991) estimate is too low as extensive areas of burrows were located in sandy soil. Twenty-six burrows were counted during two transects (0.325 ± 0.106 burrows m^{-2}). A further 49 burrows were inspected along the periphery of the colony where stable soils permitted, 13 (observed: 0.265, corrected: 0.324) contained FFSH. The area suitable for burrowing is estimated to be 7.3 ha, giving an estimate of 7695 ± 2054 FFSH breeding pairs making this the largest breeding colony in Western Australia (Table 1).

Sandy Island (Point D'entrecasteaux; 34°51′S, 116°02′E)

A survey in 1976 reported an estimated 300 000 breeding pairs based on the inspection of 63 burrows thought to be occupied by FFSH due to the presence of footprints (Abbott, 1981a). Recent discussions indicate editorial errors occurred, with an estimated 266,000 individual birds (133 000 burrows) rounded up to 300 000 and misquoted as breeding pairs (I. Abbott, pers. comm.).

The following changes were made to provide a more accurate estimate of FFSH population size at Sandy Island than that obtained in 1976. The original island area used by Abbott (1981a; 25 ha) includes a large sandy peninsula and rocky perimeter (Figure 2). Island size was rescaled to 6.28 ha (the area suitable for burrowing). Using this value, the number of burrows on Sandy Island in 1976 is estimated to be 33 410. Burrow occupancy was not recorded on Sandy Island in 1976, but the contents of 300 burrows were checked during a brief visit on 7 October 1981 with two adult birds recorded in each of 10 burrows (occupancy 0.033; Lane, 1982e). Using this value gives ~1102 pairs; however, this is considered an underestimate as most birds would not yet have returned from the pre-laying exodus. Using burrow occupancy data collected on 9 November 1982 on nearby Flat Island (0.15; Lane, 1985) gives~5011 pairs (Table 1).

Results of an island-wide survey (38 transects) in December 2011 indicate burrow density varied greatly across the island from 0.000 to 0.150 burrows m^{-2} in the south to 0.275 burrows m^{-2} in the sandy valley at the northern end. Burrow occupancy rates (corrected) also varied from south to north: 0.081 and 0.782, respectively. Using the average burrow density (0.105 ± 0.059 burrows m^{-2}) and occupancy (observed: 0.425, corrected: 0.520 ± 0.323) gives 3439 ± 1917 breeding pairs in 2011 (Table 1).

Sandy Hook Island (Recherché Archipelago; 34°01′S, 122°00′E)

A brief survey on 10 November 1950 recorded nesting of FFSH in a valley located behind the beach on the southeast side of Sandy Hook Island (Serventy, 1952b). Tingay and Tingay (1982) visited the island in May 1977 when FFSH were no longer present, but reported an unknown number of burrows along the south coast and in the northwestern part of the island. A survey of the eastern half of the island on 25 January 2012 recorded 49 burrows in the valley behind the beach (~0.49 ha) and 11 burrows at the northeast tip of the island (~0.87 ha). Eleven burrows were too deep to identify their contents and four were discovered to be false entrances. Excluding these, only three burrows (observed: 0.071, corrected: 0.087 ± 0.043) were occupied with a further eight burrows showing some evidence of recent activity. Population is not thought to exceed 200 pairs (Table 1).

Seal Island (Recherché Archipelago; 33°55′S, 122°52′E)

The first survey of Seal Island (0.38 ha) was undertaken on 24 February 2014. The interior of this small island is dominated by thick scrub and no FFSH could be located.

Shelter (Muttonbird) Island (Torbay; 35°03′S, 117°41′E)

The FFSH population at Shelter Island (2.74 ha) was estimated at 3000 burrows in 1988 (R. Johnstone, unpublished data). Except for the steep slope along the northeast side, it was possible to count nearly all the remaining burrows in discrete colonies separated by large boulders in December 2011. A total of 502 burrows were counted with a further 300 burrows estimated for the slope. The contents of 40 burrows were examined with a scope of which 18.0% were occupied. A survey of 164 marked burrows in the south-east corner of the island from 31 December 2013 to 17 January 2014 yield a burrow occupancy of 0.477 (mean corrected both years: 0.230 ± 0.180). Together, these values give an estimate of 184 ± 144 breeding pairs (Table 1).

Wickham Island (Recherché Archipelago; 34°01′S, 123°17′E)

Up to 10 000 FFSH pairs were previously reported to breed at Wickham Island (Serventy and Whittell, 1967). While the original source of these data could not be located, three FFSH were banded at Wickham Island in November 1982 (D. Drynan, pers. comm.). Surveys of the island in December 1987, November 2011 (P. Collins, pers. comm.), and January 2012 (J.L.L., pers. obs.), recorded only Short-tailed Shearwaters (8000 pairs; Johnstone and Smith, 1990c). Similar discoveries were made at nearby Gulch

Figure 2. Introduced goats (*C. hircus*) and African box thorn (*Lycium ferocissimum*) have devastated Cull Island (top panel), FFSH colony on the north side of Saddle Island (middle panel), adult FFSHs taken as bycatch (bottom panel).

Island (see above) and further west at Figure of Eight Island where 150 burrows presumed to belong to FFSH contained only Short-tailed Shearwaters (Lane, 1982b; Johnstone and Smith, 1990a).

Woody Island (Recherché Archipelago; 33°57′S, 122°01′E)

Woody Island (150.7 ha) has been the focus of historical surveys (Abbott, 1981b; Fairbridge and Serventy, 1954) and research into FFSH breeding ecology (Powell *et al.*, 2007, 2008). No burrows were recorded on 30 November 1950, attributed to frequent man-made fires that decimated the native vegetation (Fairbridge and Serventy, 1954). In the 1980s, ~80 pairs were reported breeding in two bays in the southwest (~0.27 ha) and in the southeast at Twiggy Bay (~0.26 ha; Abbott, 1981b; Lane, 1984a). Additional surveys undertaken in 2000–2003 found a total of 424 burrows along the southern coast of the island (Powell *et al.*, 2007). Twenty-three burrows were inspected in Twiggy Bay on 25 January 2012, five were occupied by an adult or chick (observed: 0.238, corrected: 0.291). Using Powell *et al.*'s (2007) estimate of 424 burrows and the 2012 occupancy rate gives a total population of 101 ± 41 breeding pairs (Table 1).

Threats to FFSHs in South and Western Australia

FFSH populations are influenced by a range of natural and anthropogenic threats both on land and at sea. A subset of these threats are reviewed here, with emphasis on those identified in South and Western Australia for which new data were collected during the 2011–2014 survey.

Fisheries

FFSHs routinely attend fishing vessels to feed on baited hooks, discards, and prey attracted to the surface by vessels (Falla, 1930; Wood, 1990; Wahl *et al.*, 2005; Baker *et al.*, 2010). This behaviour exposes individuals to risk of incidental mortality through interactions with fishing gear (Bartle, 1974; Freeman, 1992). The birds can be killed or injured when they ingest or become entangled in hooks during the setting or hauling of longlines. The death of a breeding adult by any of these causes subsequently results in nest failure as both members of the pair are needed for incubating the egg and provisioning of the chick.

Significant levels of FFSH bycatch have been reported in Australian (up to 6800 per year; Gales *et al.*, 1998; Baker and Wise, 2005; Trebilco *et al.*, 2010; Reid *et al.*, 2012) and international fisheries (Robards, 1993; Tuck *et al.*, 2003; Ogi, 2008; Tuck and Wilcox, 2008; Artukhin *et al.*, 2010; Reid *et al.*, 2013b) for many years. While large reductions in FFSH bycatch in the Australian Eastern Tuna and Billfish Fishery have recently been welcomed, the change is largely due to vessels shifting north, not due to altered fishing practices; therefore, bycatch is likely to return to

high levels if the fishery moves back south (Reid *et al.*, 2012). An assessment of population viability for Lord Howe Island's FFSH in 2007 indicated the current (improved) domestic bycatch rates were sustainable and the population should stabilize or increase (Tuck and Wilcox, 2008). This prediction has not eventuated; suggesting bycatch in other fisheries or non-fisheries related mortality (e.g. plastic ingestion) is now driving population trends.

Recent data for pelagic longline fisheries managed by the Western and Central Pacific Fisheries Commission ranked FFSH bycatch risk at 29 of 70 seabird species assessed (Waugh *et al.*, 2012). However, this ranking is biased low as the authors used an inflated global population of 18 million individuals, likely confused with Short-tailed Shearwaters. In New Zealand, FFSH bycatch in bottom longline and trawl fisheries within the Hauraki Gulf is considered to be far more than what the populations can sustain (Richard *et al.*, 2011) with up to 15 birds taken in a single trip (Gaskin and Rayner, 2013). Overall, FFSH are classified as being at "very high risk" from bycatch in New Zealand commercial fisheries (Sharp *et al.*, 2013).

New data on FFSH bycatch in the West and South Coast Purse Seine Managed Fisheries in King George Sound off Albany, Western Australia (six vessels operated in 2012) suggest up to six adult birds are killed per boat per day with >880 birds entangled in one season (Figure 2; DEF, 2005; Dunlop, 2011). Eight adult birds banded in Western Australia (primarily on Breaksea Island) were taken as bycatch in King George Sound during 1991–2013 (ABBBS, 2013). Three of these birds were banded on Wickham Island (500 km east) in November 1982 suggesting birds from across Western Australia are taken in this, and likely other, fisheries (Lavers *et al.*, 2013). Despite efforts to reduce bycatch (e.g. diurnal closures), at least 82 adult birds were taken in 2009, 10 males and 1 female in April 2010, 18 males and 2 females in April 2011, 41 adult males during January–November 2012, and at least 30 adults (67% male) in 2013 (overall 87% male killed in 2009–2013; J.L.L., pers. obs.). In contrast, 54–56% of adult birds taken in the Eastern Tuna and Billfish Fishery during 1998–2006 were male (Baker and Wise, 2005; Trebilco *et al.*, 2010). Small numbers of shearwaters have also been reported as bycatch by South Australian purse-seine vessels (Knight and Vainickis, 2011).

Entanglement of shearwaters in the lines of recreational and commercial fishers also occurs in coastal towns across Western Australia and New Zealand, and likely elsewhere. Many are unhooked and released alive, but others are intentionally killed (M. Stadler, pers. comm. and J.L.L., pers. obs.; Abraham *et al.*, 2010; Tennyson *et al.*, 2012). Of 27 adult birds tagged on Lord Howe Island in late-October 2013, at least one had been hooked by recreational fishers as of March 2014.

Fishing activities can also influence seabird populations indirectly through altering the availability, quantity, or quality of their food supplies (Furness, 2003). Competition with commercial fisheries has been implicated in the collapse of many seabird populations around the globe (Fefer *et al.*, 1984; Green *et al.*, 1998), including the FFSH (Bond and Lavers, 2014).

Introduced species

The habit of nesting in burrows on the ground exposes the FFSH to contact with introduced species. Predation by European red foxes (*Vulpes vulpes*) is implicated in the disappearance of a FFSH breeding population on mainland Western Australia in the late 1930s (Warham, 1958; Serventy *et al.*, 1971). On Île Saint-Paul, black rats and rabbits were eradicated after they decimated FFSH and other seabird populations (Micol and Jouventin, 2002; Thiebot *et al.*, 2010). European rabbits likely limit FFSH populations on Breaksea, Mistaken, Goose, and Charley Islands (see above). Black rats have invaded Lord Howe Island and Mistaken Island, but the degree to which they predate or disturb FFSH is unknown (Young, 1981; Priddel *et al.*, 2006). In New Zealand, the largest FFSH colonies occur on islands free of rats (Taylor, 2000; Gaskin and Rayner, 2013).

Plastic ingestion

The "entanglement in or ingestion of anthropogenic debris in marine and estuarine environments" is listed as a key threatening process under the New South Wales *Threatened Species Conservation Act 1995* (DEWHA, 2009). While FFSH are not identified in this legislation, the species is undoubtedly the most affected Australian seabird with 90% of chicks sampled at Lord Howe Island in 2011 containing considerable quantities of plastic (Lavers *et al.*, 2014). The ingestion of plastic has been shown to significantly reduce FFSH fledgling body mass and wing length, which is thought to lower juvenile survival by at least 11% (Lavers *et al.*, 2014). The ingestion of plastic has been implicated in the decline of the Lord Howe Island population (Priddel *et al.*, 2006; Hutton *et al.*, 2008; Lavers *et al.*, 2014). Significant quantities of plastic found on the surface of FFSH colonies on Ohinau Island suggesting this is also an issue in New Zealand (Buxton *et al.*, 2013).

Contamination

Mean concentration of mercury in adult FFSH feathers (6.04 $\pm$ 4.00 ppm) from across their breeding range (Bond and Lavers, 2011) exceed the hypothesized toxic effect level for mercury (5 ppm; Burger, 1993) and are among the highest values recorded for any seabird.

Climate change and extreme weather events

During 1936–2011, FFSH from South and Western Australia more than doubled their trophic niche and dropped an entire trophic level, the largest change in $\delta^{15}N$ reported in any marine bird (Bond and Lavers, 2014). These changes were attributed to the altered pattern and frequency of the *El Niño*-Southern Oscillation and likely reflect significant shifts in the size, abundance, or location of the shearwaters preferred prey. FFSH breed in a narrow latitudinal band in Australia (34–35°N, except Lord Howe Island at 31°N) and exhibit strong site fidelity; therefore, a shift in the distribution of their prey could also negatively affect breeding success (DECC, 2008; Chambers *et al.*, 2011).

Current climate forecasts predict the warming trend to continue, leading to increased "tropicalization" of southwest Western Australia, a region already identified as one of three hotspots where rising temperature trends exceed the Indian Ocean basin average (Feng *et al.*, 2009). This "tropicalization" may lead to increased competition between FFSH and more tropical sympatric species like the Wedge-tailed Shearwater *P. pacificus* which is expanding its range in Western Australia (Bond and Lavers, 2014; Bancroft *et al.*, 2004).

Flooding of burrows during storms, and the consequent loss of eggs and chicks, has also been identified as an increasing source of climate-related mortality for Australian seabirds (Serventy and Curry, 1984; Chambers *et al.*, 2011; Tiller *et al.*, 2013), including FFSH (Serventy *et al.*, 1971; Smith and Kolichis, 1981). Thousands of FFSH eggs were lost when burrows were flooded following three major storms in southwestern Western Australia

on 29 November and again on 1 and 6 December 2012. More than 54 mm of rain fell during that week, with November 2012 being the third wettest month recorded since 1900 (BOM, 2012). FFSHs breeding on many low-lying islands in Western Australia (e.g. Sandy and Coffin Island; <3 m elevation) are likely at risk from storm surge, coastal erosion, and other serious impacts such as *El Niño* events that are predicted to double in frequency and severity owing to climate change (Cai *et al.*, 2014).

Discussion

The Western Australian population of FFSH is currently estimated at 18 300–35 900 pairs (Tables 1 and 2; Supplementary Table S1), substantially lower than the 350 000 pairs previously reported (Johnstone and Storr, 1998). While confidence limits surrounding estimates of population size are wide due to the time-lag between surveys and inaccurate methods used in previous years, the results mirror observed and suspected declines across the remainder of the species' breeding range (Waugh *et al.*, 2013; Reid *et al.*, 2013a), the implications of which are worrying given what seabirds can tell us about the health of the marine environment (Furness and Camphuysen, 1997).

The data presented here suggest the number and severity of many threats has increased in the past 30 years and the long-held perception that the species is abundant and can buffer these threats is incorrect. Like most seabirds, FFSH face pressures from a wide range of natural and anthropogenic threats. The rapid increase in the proportion of shearwaters ingesting plastic, high levels of trace metal contamination, and evidence of trophic declines linked to ocean warming and prey depletion suggest the marine environment surrounding many breeding colonies has deteriorated in recent decades (Bond and Lavers, 2011, 2014; Lavers *et al.*, 2014).

Information provided by the 2011–2014 surveys and review of known threats is both troubling, and complicated by a number of factors such as erroneous historical estimates. Estimating FFSH burrow occupancy is also made difficult by the length of their burrows (up to 3 m) and habit of blocking the entrance with herbage, making quick assessments of occupancy (e.g. based on the presence of footprints) nearly impossible (J.L.L., pers. obs.; Serventy *et al.*, 1971). Despite these challenges, intensive burrow surveys on a subset of islands have yielded valuable data. In Western Australia, burrow occupancy is low compared with Lord Howe Island (58–67%; Dyer, 2001; Reid *et al.*, 2013a) and New Zealand (44%; Baker *et al.*, 2010), but has changed little over 30 years: 0.263 ± 0.182 during 1978–1986 (nine islands; see above) compared with 0.288 ± 0.146 during 2011–2014 (nine islands; $p > 0.05$). This result highlights the need to (i) scale back historical estimates of breeding numbers based solely on burrow counts by ~75% and (ii) gain a detailed understanding of natural variation in the species ecology (e.g. low burrow occupancy is normal for FFSH in Western Australia), a crucial feature for an effective indicator species.

Future recommendations

Future efforts should focus on many of the research priorities identified for seabirds, globally, including improving our understanding of population dynamics and ability to manage anthropogenic impacts (Baker *et al.*, 2002; Cooper and Baker, 2008; Lewison *et al.*, 2012). Accurate estimates of population size and demographic parameters are critical to diagnosing environmental causes of population decline and provide a framework for predicting responses to management (Croxall and Rothery, 1991; Green, 1995). These data are lacking for most FFSH breeding islands, including many thought to support large populations (e.g. Eclipse and Mondrain Islands have not been surveyed in >30 years; Figure 1).

While factors driving the ongoing decline of FFSH at Lord Howe Island (e.g. plastic ingestion, bycatch, and to a lesser extent, development; −1.3% per annum since 1978; Reid *et al.*, 2013a; Lavers *et al.*, 2014) are fairly well understood, this is not the case for the remaining breeding islands (Waugh *et al.*, 2013). Seabirds, and other long-lived species with low fecundity, have a limited capacity to recover from perturbations (Musick, 1999); therefore, early detection and mitigation of threats is key to effective management. For FFSH, protection of important breeding colonies (e.g. World Heritage listed Lord Howe Island is the world's single largest colony with ~16 000 breeding pairs; Reid *et al.*, 2013a), significant reductions in bycatch in the Australian domestic fishery (Reid *et al.*, 2012), and concurrent removal of rats and cessation of harvesting from Titi Island in New Zealand (Gaze, 2000) have all proven insufficient to reverse population declines (Waugh *et al.*, 2013; Reid *et al.*, 2013a). Clearly, a more precautionary and proactive, rather than reactive, approach is required for this species along with improved recognition of emerging threats.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Acknowledgements

BirdLife Tasmania, Gabbie Kylie Foundation, South Australia Nature Foundation, Save our Shearwaters Foundation, Trading Consultants Ltd, Two Hands Project, and the W.V. Scott Charitable Trust provided funding for this research. Special thanks go to R. Anderson, B. Barton, C. & G. Biddulph, S. Butler, M. Carey, N. Cheshire, T. Cole, P. Collins, S. Comer, A. Forrest, S. Goldsworthy, D. Guilfoyle, A. McGilvray, R. Mills, C. Powell, J. Pridham, P. Sharp, H. Simpson, M. Stadler, S. Stuckenbrock, V. Wellington, the Australian Bird and Bat Banding Scheme, South Australian Department of Environment, Water, and Natural Resources, and Western Australian Department of Parks and Wildlife for generously providing data, logistical support, and assistance in the field. This research was undertaken with approval from the South Australia and University of Tasmania animal ethics committees (A0010874, A0012279, and M25957–1). This manuscript benefited greatly from discussions with I. Abbott, A. Bond, A. Burbidge, V. Byrd, K. Camphuysen, N. Dunlop, S. Garnett, R. Johnstone, D. Oro, and two anonymous reviewers improved previous drafts.

References

ABBBS. 2013. Flesh-footed Shearwater Banding and Recoveries. Australian Bird and Bat Banding Scheme Canberra.

Abbott, I. 1978a. Breaksea Island, King George Sound. Seabird Islands No. 55. Corella, 2: 24–26.

Abbott, I. 1978b. Green Island, Oyster Harbour, Western Australia. Seabird Islands No. 60. Corella, 2: 34–35.

Abbott, I. 1978c. Mistaken Island, King George Sound, Western Australia. Seabird Islands No. 59. Corella, 2: 32–33.

Abbott, I. 1981a. Sandy Island, Western Australia. Seabird Islands No. 110. Corella, 6: 69–70.

Abbott, I. 1981b. Woody Island, Archipelago of the Recherche, Western Australia. Seabird Lslands No. 107. Corella, 5: 62–61.

Abraham, E. R., Berkenbusch, K. N., and Richard, Y. 2010. New Zealand Aquatic Environment and Biodiversity. Report No. 64. 52 pp.

Artukhin, Y. B., Burkanov, V. N., and Nikulin, V. S. 2010. Прилов морских птиц и млекопитающих на дрифтерном промысде лососей в северо-эападной части тихого океана [Accidental Bycatch of Marine Birds and Mammals in the Salmon Gilnet Fishery in the Northwestern Pacific Ocean]. Moscow: Skorost' Tsveta, 264 pp.

Baker, B., Hedley, G., and Cunningham, R. 2010. Data collection of demographic, distributional, and trophic information on the Flesh-footed Shearwater to allow estimation of effects of fishing on population viability: 2009–10 field season. Report prepared for The Ministry of Fisheries No PRO2006-01.

Baker, G. B., Gales, R., Hamilton, S., and Wilkinson, V. 2002. Albatrosses and petrels in Australia: a review of their conservation and management. Emu, 102: 71–97.

Baker, G. B., and Wise, B. S. 2005. The impact of pelagic longline fishing on the Flesh-footed Shearwater *Puffinus carneipes* in eastern Australia. Biological Conservation, 126: 306–316.

Baker, J. L. 2004. Towards a system of ecologically representative Marine Protected Areas in South Australian marine bioregions. Technical report.

Bancroft, W. J., Garkaklis, M. J., and Roberts, J. D. 2004. Continued expansion of the Wedge-tailed Shearwater, *Puffinus pacificus*, nesting colonies on Rottnest Island, Western Australia. Emu, 104: 79–82.

Bartle, J. A. 1974. Seabirds of eastern Cook Strait, New Zealand, in autumn. Notornis, 21: 135–166.

Becker, B. H., and Beissinger, S. R. 2006. Centennial decline in the trophic level of an endangered seabird after fisheries decline. Conservation Biology, 20: 470–479.

BirdLife International. 2013. State of the World's Birds: Indicators for Our Changing World. BirdLife International, Cambridge, UK.

BOM. 2012. Monthly climate summary for Western Australia: November 2012. Bureau of Meteorology, Canberra.

Bond, A. L., and Lavers, J. L. 2011. Trace element concentrations in feathers of Flesh-footed Shearwaters (*Puffinus carneipes*) from across their breeding range. Archives of Environmental Contamination and Toxicology, 61: 318–326.

Bond, A. L., and Lavers, J. L. 2014. Climate change alters the trophic niche of a declining apex marine predator. Global Change Biology, 20: 2100–2107.

Brooke, M. d. L. 2004. Albatrosses and Petrels across the World. Oxford University Press, Oxford, UK.

Burger, J. 1993. Metals in avian feathers: bioindicators of environmental pollution. Reviews in Environmental Toxicology, 5: 203–311.

Butchart, S. H. M., Stattersfield, A. J., Bennun, L. A., Shutes, S. M., Akçakaya, H. R., Baillie, J. E. M., Stuart, S. N., *et al.* 2004. Measuring global trends in the status of biodiversity: Red List indices for birds. PLoS Biology, 2: e383.

Buxton, R. T., Currey, C. A., Lyver, P. O. B., and Jones, C. J. 2013. Incidence of plastic fragments among burrow-nesting seabird colonies on offshore islands in northern New Zealand. Marine Pollution Bulletin, 74: 420–424.

Cai, W., Borlace, S., Lengaigne, M., van Rensch, P., Collins, M., Vecchi, G., Timmermann, A., *et al.* 2014. Increasing frequency of extreme El Niño events due to greenhouse warming. Nature Climate Change, 4: 111–116.

Chambers, L. E., Devney, C. A., Congdon, B. C., Dunlop, N., Woehler, E. J., and Dann, P. 2011. Observed and predicted effects of climate on Australian seabirds. Emu, 111: 235–251.

Clark, W. N. 1841. Journal of an expedition to Nornalup, on the Deep River of the sealers, in the months of March and April, 1841. *In* The Inquirer. Perth, Trove, WA, Australia.

Cooper, J., and Baker, G. B. 2008. Identifying candidate species for inclusion within the Agreement on the Conservation of Albatrosses and Petrels. Marine Ornithology, 36: 1–8.

Copley, P. B. 1996. The status of seabirds in South Australia. *In* National Seabird Workshop, pp. 139–180. Ed. by G. J. B. Ross, K. Weaver, and J. C. Grieg. Environment Australia, Canberra.

Croxall, J. P., Butchart, S. H. M., Lascelles, B., Stattersfield, A. J., Sullivan, B. J., Symes, A., and Taylor, P. 2012. Seabird conservation status, threats and priority actions: a global assessment. Bird Conservation International, 22: 1–34.

Croxall, J. P., and Rothery, P. 1991. Population regulation of seabirds: implications of their demography for conservation. *In* Bird population studies: relevance to conservation and management, pp. 272–296. Ed. by C. M. Perrins, J. D. LeBreton, and G. M. Hirons. Oxford University Press, Oxford.

DECC. 2008. Lord Howe Island biodiversity management plan. Department of Environment and Climate Change (NSW), Sydney.

DEF. 2005. Application to Department of Environment and Heritage on the West Coast Purse Seine managed fishery and South Coast Purse Seine managed fishery. Western Australia Department of Fisheries, Perth.

DEWHA. 2009. Threat Abatement Plan for the impacts of marine debris on vertebrate marine life. Department of the Environment, Water, Heritage and the Arts, Canberra.

DSEWPaC. 2012. Assessment Period Commencing 1 October 2012: Nomination of *Puffinus carneipes*. Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Dunlop, J. N., Long, P., Stejskal, I., and Surman, C. 2002. Inter-annual variations in breeding participation at four Western Australian colonies of the Wedge-tailed Shearwater *Puffinus pacificus*. Marine Ornithology, 30: 13–18.

Dunlop, N. 2011. Protected species bycatch in Zone 1 of the South Coast Purse Seine Fishery 2010/11.

Dyer, P. K. 2001. Burrow occupancy by Wedge-tailed Shearwaters and Flesh-footed Shearwaters on Lord Howe Island. Corella, 26: 38–40.

Fairbridge, R. W., and Serventy, V. N. 1954. The Archipelago of the Recherche: Part 1b Physiography.

Falla, R. A. 1930. The distribution and breeding habits of petrels in Northern New Zealand. Records of the Auckland Institute and Museum, 1: 245–263.

Fefer, S. I., Harrison, C. S., Naughton, M. B., and Shallenberger, R. J. 1984. Synopsis of Recent Seabird Research Conducted in the Northwestern Hawaiian Islands. ICES Document UNIHI-SEAGRANT-MR-84–01.

Feng, M., Weller, E., and Hill, K. 2009. The Leeuwin Current. NCCARF Publication 05/09.

Freeman, A. 1992. Petrels on the Mernoo Bank and Chatham Rise. Notornis, 39: 57–58.

Fullagar, P. 1978. Eclipse Island, Western Australia. Seabird Island No. 54. Corella, 2: 21–23.

Furness, R. W. 2003. Competition between fisheries and seabird communities. Scientia Marina, 67: 33–45.

Furness, R. W., and Camphuysen, K. 1997. Seabirds as monitors of the marine environment. ICES Journal of Marine Science, 54: 726–737.

Gales, R., Brothers, N., and Reid, T. 1998. Seabird mortality in the Japanese tuna longline fishery around Australia, 1988–1995. Biological Conservation, 86: 37–56.

Garnett, S., Szabo, J., and Dutson, G. 2011. Action Plan for Australian Birds 2010. Commonwealth Scientific and Industrial Research Organization Publishing, Canberra, ACT. 456 pp.

Gaskin, C. P., and Rayner, M. J. 2013. Seabirds of the Hauraki Gulf: natural history, research and conservation.

Gaze, P. 2000. The response of a colony of Sooty Shearwater (*Puffinus griseus*) and Flesh-footed Shearwater (*P. carneipes*) to the cessation of harvesting and the eradication of Norway rats (*Rattus norvegicus*). New Zealand Journal of Zoology, 27: 375–379.

Green, K., Slip, D. J., and Moore, G. J. 1998. The take of fish species by seabirds and marine mammals in the Australian Fisheries Zone around Heard Island: the potential for competition with a commercial fishery. Polar Biology, 20: 273–280.

Green, R. E. 1995. Diagosing causes of bird population declines. Ibis, 137: S47–S55.

Hutton, I., Carlile, N., and Priddel, D. 2008. Plastic ingestion by Flesh-footed Shearwaters, *Puffinus carneipes*, and Wedge-tailed Shearwaters, *Puffinus pacificus*. Papers and Proceedings of the Royal Society of Tasmania, 142: 67–72.

Johnstone, R. E., and Smith, L. A. 1990a. Gulch Island, Archipelago of the Recherche, Western Australia. Seabird Island No. 204. Corella, 6: 133–134.

Johnstone, R. E., and Smith, L. A. 1990b. Gulch Island, Archipelago of the Recherche, Western Australia. Seabird Islands No. 204. Corella, 14: 133–134.

Johnstone, R. E., and Smith, L. A. 1990c. Wickham Island, Archipelago of the Recherche, Western Australia. Seabird Islands No. 203. Corella, 14: 131–132.

Johnstone, R. E., and Storr, G. M. 1998. Handbook of Western Australian Birds. Western Australian Museum, Perth.

Kirkwood, J., and O'Connor, J. (Eds) 2010. The state of Australia's birds 2010: islands and birds. *In* Supplement to Wingspan, 20. Birds Australia, Melbourne.

Knight, M., and Vainickis, A. 2011. Interactions with Threatened, Endangered or Protected. Species in South Australian Managed Fisheries – 2008/09, 2009/10, and 2010/11.

Lane, S. G. 1977. A survey of breeding seabirds on Mistaken Island, Western Australia. Western Australian Naturalist, 14: 27–28.

Lane, S. G. 1982a. Cull Island, Archipelago of the Recherche, Western Australia. Seabird Islands No. 123. Corella, 6: 69–70.

Lane, S. G. 1982b. Figure of Eight Island, Archipelago of the Recherche, Western Australia. Seabird Islands No. 126. Corella, 6: 75–76.

Lane, S. G. 1982c. Frederick Island, Archipelago of the Recherche, Western Australia. Seabird Islands No. 119. Corella, 6: 61–62.

Lane, S. G. 1982d. Long Island, Archipelago of the Recherche, Western Australia. Seabird Islands No. 122. Corella, 6: 67–68.

Lane, S. G. 1982e. A visit to Sandy Island, Western Australia. Western Australian Naturalist, 15: 76.

Lane, S. G. 1984a. Further notes on visits to islands of the south coast of Western Australia. Corella, 8: 64–66.

Lane, S. G. 1984b. Stanley Island, Western Australia. Seabird Islands No. 148. Corella, 8: 121–122.

Lane, S. G. 1985. Flat Island, Western Australia. Seabird Islands No. 149. Corella, 8: 123–124.

Lavers, J. L., Bond, A. L., and Hutton, I. 2014. Plastic ingestion by Flesh-footed Shearwaters (*Puffinus carneipes*): implications for chick body condition and the accumulation of plastic-derived chemicals. Environmental Pollution, 187: 124–129.

Lavers, J. L., Bond, A. L., Van Wilgenburg, S. L., and Hobson, K. A. 2013. Linking at-sea mortality of a pelagic shearwater to breeding colonies of origin using biogeochemical markers. Marine Ecology Progress Series, 491: 265–275.

Lewison, R., Oro, D., Godley, B. J., Underhill, L., Bearhop, S., Wilson, R. P., Ainley, D. G., *et al.* 2012. Research priorities for seabirds: improving conservation and management in the 21st century. Endangered Species Research, 17: 93–121.

Manly, B. F. J. 2007. Randomization, Bootstrap and Monte Carlo Methods in Biology. Boca Raton, FL.

Marchant, S., and Higgins, P. J. 1990. Handbook of Australian, New Zealand, and Antarctic Birds. Volume 1: Ratites to Ducks. Oxford University Press, Melbourne.

McClellan, R. 1995. Breeding Biology of the Flesh-Footed Shearwater on Karewa Island. Victoria University, Wellington.

McKechnie, S., Fletcher, D., Moller, H., Scott, D., Newman, J., and Bragg, C. 2007. Estimating and correcting for bias in population assessments of Sooty Shearwaters. Journal of Wildlife Management, 71: 1325–1335.

Micol, T., and Jouventin, P. 2002. Eradication of rats and rabbits from Saint-Paul Island, French Southern Territories. *In* Turning the Tide: the Eradication of Invasive Species, pp. 199–205. Ed. by C. R. Veitch, and M. N. Clout. International Union for the Conservation of Nature.

Musick, J. A. 1999. Ecology and conservation of long-lived marine animals. American Fisheries Society Symposium, 23: 1–10.

Ogi, H. 2008. International and national problems in fisheries seabird by-catch. Journal of Disaster Research, 3: 187–195.

Ogilvie-Grant, W. R., and Shortridge, M. G. C. 1910. On a collection of birds from Western Australia. Ibis, 52: 156–191.

Powell, C., Bradley, S., and Wooler, R. 2008. Is colony attendance by shearwaters influenced by bright moonlight or inclement weather? Papers and Proceedings of the Royal Society of Tasmania, 142: 35–44.

Powell, C. D. L., Wooller, R. D., and Bradley, J. S. 2007. Breeding biology of the Flesh-footed Shearwater (*Puffinus carneipes*) on Woody Island, Western Australia. Emu, 107: 275–283.

Priddel, D., Carlile, N., Fullagar, P., Hutton, I., and O'Neill, L. 2006. Decline in the distribution and abundance of Flesh-footed Shearwaters (*Puffinus carneipes*) on Lord Howe Island, Australia. Biological Conservation, 128: 412–424.

Rayner, M. J., Taylor, G. A., Thompson, D. R., Torres, L. G., Sagar, P. M., and Shaffer, S. A. 2011. Migration and diving activity in three non-breeding Flesh-footed Shearwaters *Puffinus carneipes*. Journal of Avian Biology, 42: 266–270.

Reid, T., Hindell, M., Lavers, J. L., and Wilcox, C. 2013a. Re-examining mortality sources and population trends in a declining seabird: using Bayesian methods to incorporate existing information and new data. PLoS ONE, 8: e58230.

Reid, T., Hindell, M., and Wilcox, C. 2012. Environmental determinants of the at-sea distribution of encounters between Flesh-footed Shearwaters *Puffinus carniepes* and fishing vessels. Marine Ecology Progress Series, 447: 231–242.

Reid, T., Tuck, G. N., Hindell, M. A., Thalmann, S., Phillips, R. A., and Wilcox, C. 2013b. Nonbreeding distribution of Flesh-footed Shearwaters and the potential for overlap with north Pacific fisheries. Biological Conservation, 166: 3–10.

Richard, Y., Abraham, E. R., Thompson, F. N., and Berkenbusch, K. 2011. Counts of seabirds around commercial fishing vessels within New Zealand waters. Unpublished report for Department of Conservation.

Robards, M. D. 1993. Plastic ingestion by North Pacific seabirds. U.S. Department of Commerce. NOAA-43ABNF203014. Washington, DC.

Robertson, H. A., Dowding, J. E., Elliott, G. P., Hitchmough, R. A., Miskelly, C. M., O'Donnell, C. F. J., Powlesland, R. G., *et al.* 2013. Conservation Status of New Zealand Birds, 2012. New Zealand Threat Classification Series 4. 22 pp.

Robinson, A. C., and Parker, S. A. 1984. First breeding record of the Fleshy-footed Shearwater in South Australia. South Australian Ornithologist, 30: 13–14.

Robinson, T., Canty, P., Mooney, T., and Rudduck, P. 1996. South Australia's offshore islands. Department of Environment and Natural Resources, Adelaide.

Roux, J. P. 1985. Status of *Puffinus carneipes* in Saint Paul Island (38°43′ S, 77°30′ E). Oiseau et la Revue Francaise D'Ornithologie, 55: 155–157.

Sanz-Aguilar, A., Tavecchia, G., Genovart, M., Igual, J. M., Oro, D., Rouan, L., and Pradel, R. 2010. Studying the reproductive skipping behavior in long-lived birds by adding nest inspection to individual-based data. Ecological Applications, 21: 555–564.

Serventy, D. L. 1948. The Great-winged Petrel *Pterodroma macroptera* in Western Australia. Emu, 47: 211–213.

Serventy, D. L. 1952a. The Archipelago of the Recherche: Part 2 Birds. Australian Geographical Society Reports No. 1, Melbourne.

Serventy, D. L., and Curry, P. J. 1984. Observations on colony size, breeding success, recruitment and inter-colony dispersal in a Tasmanian

colony of Short-tailed Shearwaters *Puffinus tenuirostris* over a 30-year period. Emu, 84: 71–79.

Serventy, D. L., Serventy, V., and Warham, J. 1971. The Handbook of Australian Sea-Birds. Reed, Sydney.

Serventy, D. L., and Whittell, H. M. 1967. Birds of Western Australia. Lamb Publications Ltd, Perth.

Serventy, V. N. 1952b. The Archipelago of the Recherche. Part 2: Birds. Australian Geographic Society Report, 1: 1–24.

Serventy, V. N. 1953. The Archipelago of the Recherche, Part 4. Mammals. Australian Geographical Society Reports No. 1, Melbourne.

Sharp, B. R., Cryer, M., Richard, Y., and Abraham, E. R. 2013. New Zealand's approach to assessment of risk to seabirds associated with fishing-related mortality. *In* Fifth meeting of the Seabird Bycatch Working Group. La Rochelle, France.

Smith, G. T., and Kolichis, N. 1980. The flora and fauna of Coffin Island. Western Australian Naturalist, 14: 225–228.

Smith, G. T., and Kolichis, N. 1981. Coffin Island, Western Australia. Corella, 5: 66–68.

Stephenson, B. M., Robertson, C. J. R., Minot, E. O., and Springett, B. P. 2006. Understanding global trends in seabirds – are there winners and losers? Acta Zoologica Sinica, 52: 653–656.

Storr, G. M. 1991. Birds of the South-west Division of Western Australia. Records of the Western Australian Museum Supplement No. 35, Perth.

Taylor, G. A. 2000. Action plan for seabird conservation in New Zealand. Part B: Non-Threatened Seabirds. Ed. by Conservation. Wellington.

Tennyson, A., Hunter, S., Miskelly, C. M., Baylis, S., Waugh, S. M., Bartle, S., Gartrell, B., *et al.* 2012. Causes of seabird mortality in the Bay of Plenty, Oct-Nov 2011. *In* Ornithological Society of New Zealand conference. Tauranga.

Thiebot, J.-B., Barbraud, C., Scofield, R. P., Cherel, Y., and Bretagnolle, V. 2010. New petrel records on Île Saint-Paul, southern Indian Ocean. Notornis, 57: 50–53.

Tiller, C. J., Klomp, N. I., Fullagar, P. J., and Heyligers, P. C. 2013. Catastrophic breeding failure in shearwaters caused by heavy rainfall. Marine Ornithology, 41: 97–99.

Tingay, A., and Tingay, S. R. 1982. Sandy Hook Island, Archipelago of the Recherche, Western Australia. Seabird Islands No. 120. Corella, 6: 63–64.

Trebilco, R., Gales, R., Lawrence, E., Alderman, R., Robertson, G., and Baker, G. B. 2010. Characterizing seabird bycatch in the eastern Australian tuna and billfish pelagic longline fishery in relation to temporal, spatial and biological influences. Aquatic Conservation: Marine and Freshwater Ecosystems, 20: 531–542.

Tuck, G. N., Polacheck, T., and Bulman, C. M. 2003. Spatio-temporal trends of longline fishing effort in the Southern Ocean and implications for seabird bycatch. Biological Conservation, 114: 1–27.

Tuck, G. N., and Wilcox, C. 2008. Assessing the Potential Impacts of Fishing on the Lord Howe Island Population of Flesh-footed Shearwaters. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 89 pp.

Wahl, T. R., Tweit, B., and Mlodinow, S. G. 2005. Birds of Washington State: Status and Distribution. Oregon State University Press, Corvalis.

Warham, J. 1958. The nesting of the shearwater *Puffinus carneipes*. The Auk, 75: 1–14.

Warham, J. 1982. The annual cycle of the Sooty Shearwater *Puffinus griseus* at the Snares Islands, New Zealand. Notornis, 29: 269–292.

Waugh, S. M., Filippi, D. P., Kirby, D. S., Abraham, E., and Walker, N. 2012. Ecological Risk Assessment for seabird interactions in Western and Central Pacific longline fisheries. Marine Policy, 36: 933–946.

Waugh, S. M., and Taylor, G. 2012. Annual Report on Project POP2011-02 Flesh-footed Shearwaters – population study trial and at-sea distribution. Te Papa Museum of New Zealand, Auckland.

Waugh, S. M., Tennyson, A., Taylor, G., and Wilson, K.-J. 2013. Population sizes of shearwaters (*Puffinus* spp.) breeding in New Zealand, with recommendations for monitoring. Tuhinga, 24: 159–204.

Wood, K. A. 1990. Temporal and zonal patterns of abundance of shearwaters (*Puffinus*) off central New South Wales. Australian Wildlife Research, 17: 453–466.

Young, C. 1981. Rabbit eradication on islands of the Western Australian coast. Swans, 11: 13–16.

Handling editor: Kees Camphuysen