BROOD PATCH AND SEX-RATIO OBSERVATIONS INDICATE BREEDING PROVENANCE AND TIMING IN NEW ZEALAND STORM-PETREL *FREGETTA MAORIANA*

MATT J. RAYNER[1], CHRIS P. GASKIN[2], BRENT M. STEPHENSON[3], NEIL B. FITZGERALD[4], TODD J. LANDERS[1,5],
BRUCE C. ROBERTSON[6], R. PAUL SCOFIELD[7], STEPHANIE M.H. ISMAR[8] & MICHAEL J. IMBER†

[1]*School of Biological Sciences, University of Auckland, Private Bag 92019, Auckland, New Zealand (m.rayner@auckland.ac.nz)*
[2]*400 Leigh Road, RD5, Whangateau, Warkworth 0985, New Zealand*
[3]*Eco-Vista: Photography & Research Ltd., P.O. Box 157, Bay View, Napier 4104, New Zealand*
[4]*Landcare Research, Private Bag 3127 Hamilton 3240, New Zealand*
[5]*Auckland Council, Level 4, 1 The Strand, Takapuna, Auckland 0622, New Zealand*
[6]*Department of Zoology, University of Otago, Box 56, Dunedin 9054, New Zealand*
[7]*Canterbury Museum, Rolleston Avenue, Christchurch 8023, New Zealand*
[8]*GEOMAR – Helmholtz Centre for Ocean Research, Experimental Ecology, Düsternbrooker Weg 20, 24105 Kiel, Germany*
†Deceased 28 April 2011

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SUMMARY

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We used measurements of brood patch and moult status to estimate the breeding phenology of New Zealand Storm-Petrel, using birds caught at sea within the Hauraki Gulf Marine Park near Auckland, New Zealand. Birds caught October–January had completely downy brood patches, whereas birds caught February–April had bare brood patches with an observed male bias in the February sex-ratio, consistent with a female pre-laying exodus typical of petrels and with the existence of an unknown colony in the region. No birds captured exhibited primary moult, which is known to occur in storm-petrels during their non-breeding season. Our data support the conclusion that the New Zealand storm-petrel breeds during January–June in northern New Zealand and that field surveys for the species on offshore islands in this region during this period are warranted.

Key words: at-sea captures, breeding phenology, *Fregetta maoriana*, Hauraki Gulf, moult phenology, New Zealand Storm-Petrel

INTRODUCTION

In 2003 the New Zealand Storm-Petrel *Fregetta maoriana* (NZSP; Robertson *et al.* 2011), after 108 years of presumed extinction, was observed at sea within the Hauraki Gulf Marine Park (HGMP) near Auckland, New Zealand (Flood 2003, Stephenson *et al.* 2008a). Ten years following its rediscovery, the biology of this critically endangered seabird remains poorly known.

Procellariiform seabirds, including storm-petrels, are highly mobile and frequently occupy geographically distinct breeding and non-breeding habitats, often at oceanic basin scales (e.g., Imber 1984, Rayner *et al.* 2011). Given such mobility, the presence of NZSP off northern New Zealand is insufficient to confirm local breeding, as birds may use these waters solely for foraging. Moreover, any search for a breeding site of the NZSP in northern New Zealand represents a “needle in a haystack” problem. As storm-petrels are negatively impacted by introduced mammalian predators (Imber 1975), the species would likely be restricted to predator-free island habitats. However, northern New Zealand has an abundance of predator-free offshore islands (Gaskin *et al.* 2011), making chance night-time observations of the species at an island breeding site unlikely. Clearly, indirect means are required to learn more about the species’ natural history.

The examination of brood patch condition is a useful technique for ascertaining breeding status and timing in seabirds such as storm-petrels (Pyle 2008). Analysis of patterns of down loss from captured birds thus provides an indication of the timing of incubation, as down is lost over the brood patch before incubation, and subsequent chick rearing, during which the brood patch is re-feathered (Beck & Brown 1972, McFarlane Tranquilla *et al.* 2003). Unlike passeriformes, procellariiformes such as storm-petrels share incubation of a single egg, meaning brood patch status is an indicator of breeding condition in both male and female birds.

The aim of this study was to use brood patch status of NZSPs caught at sea within the HGMP over a six-year period to estimate breeding phenology and indicate the likelihood of local breeding. We also assessed whether temporal patterns of brood patch formation and sex ratios of captured birds could provide an indication of the likely breeding timetable and sex-specific morphological data for the species.

STUDY AREA AND METHODS

We caught NZSP in the outer portion of HGMP between 2005/06 and 2012, and specifically in the area bordered by Little Barrier Island (Hauturu) in the south and the Hen and Chickens and Mokohinau Islands in the northwest and northeast, respectively (Fig. 1). They had previously been observed concentrated in this area during the austral summer (Gaskin & Baird 2005). NZSP were attracted to a chum slick of fish oil and scraps from a bag suspended from the stern of the main vessel. Upon the arrival of one or more NZSP, the chum bag was transferred to a smaller capture vessel. NZSP subsequently following the slick upwind and passing within range (< 5 m), were captured using a hand-held net gun that used compressed air to project a mist net over the target. Birds were returned to the main vessel for processing.

Captured birds were banded with both a numbered bird band and coloured bands (three coloured bands in most cases), and standard morphological measurements were taken including bill length, tarsus full, wing (flattened wing chord), mid-toe claw length and mass. Condition of the brood patch of each captured individual was scored as follows: 0 (completely downy brood patch), 1 (traces of down lost), 2 (approximately half of the brood patch covered in down), 3 (only traces of down remaining), 4 (brood patch entirely bare), 5 (re-feathering present). In 2012, the status of remige and rectrix moult was also noted using the methodology of Ginn & Melville (1983). The sex of each bird was determined using methods detailed by Robertson & Stephenson (2008). Molecular analyses were conducted on either contour feathers (n = 1) or blood samples (n = 26) (<250 μL of blood was collected from the metatarsal vein and preserved in the field in lysis buffer; Seutin *et al.* 1991).

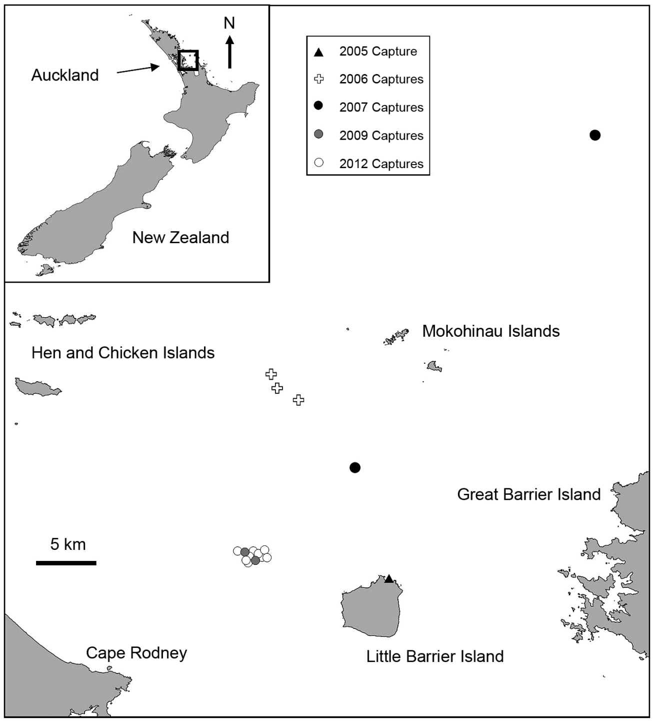

Fig 1. At-sea capture locations of NZSP in the Hauraki Gulf, New Zealand, in 2005 (n = 1), 2006 (n = 3), 2007 (n = 3), 2009 (n = 5) and 2012 (n = 19). Individual locations may denote more than one bird captured; see Appendix 1 (available on the Web site).

We used the binomial distribution against the random expectation of 50% to calculate sex ratio probabilities within capture months, and contingency analysis of categorical sex data (Fisher's exact tests) to assess differences in sex-specific capture bias between months. Student's t-tests were used to assess sex-specific differences in morphometric measurements. Analyses were conducted using JMP 5.1 (SAS Institute) with a threshold of significance set at $\alpha = 0.05$. Data are shown as mean ± SD.

RESULTS

At-sea captures

A total of 31 NZSP were captured between 2005/06 and 2012, with capture locations differing among years (Fig. 1, Appendix 1). The first four captures are detailed by Stephenson *et al.* (2008b). The first live capture of the species was an opportunistic night-time capture off Little Barrier Island in 2005 (Fig. 1, 36.170S, 175.098E). This bird was sexed but its brood patch was not examined, and therefore it is included only in our analysis of capture sex ratios and morphometrics. Also reported by Stephenson *et al.* (2008b) were three NZSP caught in the outer Hauraki Gulf in 2006, west-southwest of the Mokohinau Islands (Fig 1). In 2007 three birds were caught; two approximately half-way between Little Barrier Island and the Mokohinau Islands, and one approximately 30 km northeast of the Mokohinau Islands (Fig 1). In 2009 five NZSP were caught between Hen Island (35.959S, 174.718E) and Little Barrier Island (36.207S, 175.081E). An additional 19 NZSP were caught at the same location in 2012.

Moult observations

Between 2005/06 and 2009, capture efforts were focussed during October–January. Of the 12 NZSP caught during this period (Fig. 1,

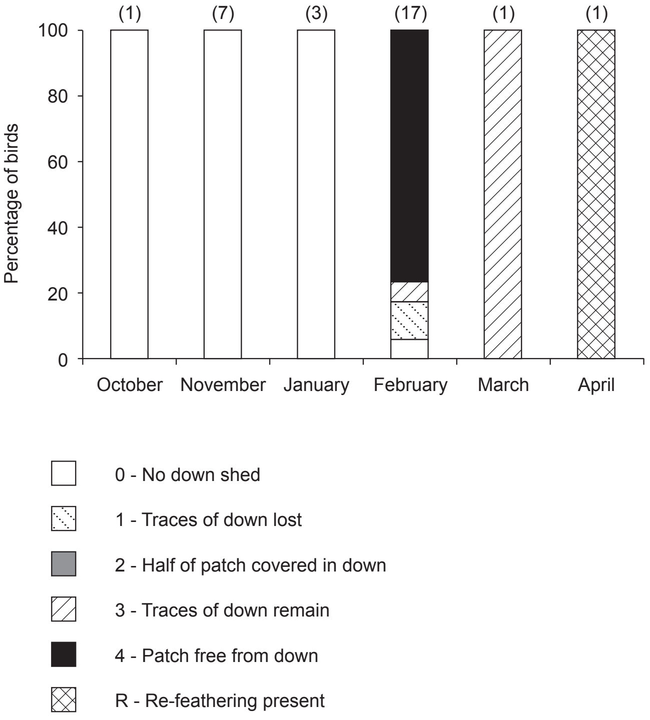

Fig. 2. Brood patch status of 30 NZSP caught between 2006 and 2012 (n in parentheses). See Appendix 1 for capture details.

Fig. 2: 2005, n = 1; 2006, n = 3; 2007, n = 3; 2009, n = 5), all had brood patches with no down shed (score 0; Fig 2). In 2012, captures were targeted during mid- and late summer (February–April) in an attempt to assess brood patch condition across the austral summer. During this period, 19 NZSP (Fig 1: February, n = 17; March, n = 1; April, n = 1) were caught with a mean brood patch score of 3.16 (n = 19, Fig 2). Re-feathering of the brood patch was observed in the one NZSP caught in April.

Nearly completed tail moult was recorded from three male NZSP captured on 8 Feb 2012. One (B60728), with a brood score of 1, had three new rectrices nearing full development in the outer tail (rectrice moult score 445554). The other two birds had brood patch scores of 4, B60729 had a rectrix nearing complete development fourth from outer (score 555455), and B60730 had an outer rectrix nearing complete development (score 455555). Primary moult was not detected in any bird caught in 2012.

Sex-specific capture bias and morphometrics

NZSP captured in spring (November 2009) showed an even sex ratio, i.e. 4:4 male:female (P = 0.27). In contrast, mid- to late summer captures showed a male-biased sex ratio, 3:0 in January 2006 (P = 0.13) and 13:2 ($P < 0.01$) in February 2012. This sex ratio difference between early and mid-to-late summer is significant when contrasting both combined early (October–November) and late (January–April) months (Fisher's exact test, P = 0.028), and when contrasting just November (2009) and February (2012) data in which reasonable sample sizes were available in the same month (Fisher's exact test, P = 0.048). There was no significant sexual-size dimorphism in any morphological parameter tested (Table 1).

DISCUSSION

The NZSP is one of a group of small procellariiformes (including the Beck's Petrel *Pseudobulweria becki* [Shirihai 2008], Black-capped Petrel *Pterodroma hasitata* [Lee 2000], Fiji Petrel *Pseudobulweria macgillivrayi* [Priddel *et al.* 2008] and Chilean Storm-Petrel *Oceanites pincoyae* [Harrison *et al.* 2013]) that represent some of the most poorly known avian taxa in the world. Assessing and conserving these species depends upon the discovery of their unknown breeding sites, yet such work represents massive logistical challenges. The data presented in the current study reflect this challenge, constituting hundreds of hours of field effort and >NZ$100,000 in expenditure. Encouragingly, this effort has not been in vain, as the results of this study provide the first evidence that NZSP present in the Hauraki Gulf during late summer are in breeding condition.

In storm-petrels, brood patch feather loss commences about 30 d prior to egg laying (see reviews in Warham 1990, 1996). Assuming consistency with other storm-petrels, our data indicate laying for NZSP peaks in February, when 16/17 birds exhibited brood-patch scores >0, but likely extends from late January to early March. This laying period is later than for *F. tropica*, recently proposed as NZSP's sister taxon (Robertson *et al.* 2011), which in the South Orkneys lays from late December to late January and exhibits peak brood patch scores during this same period (Beck & Brown 1971). Allowing an incubation period of ~40 d (*F. tropica* 38–44 d; Beck & Brown 1971), this indicates that for NZSP hatching likely occurs in mid-March to mid-April. The capture of one NZSP on 9 April with a re-feathering brood patch is consistent with this phenology, as re-feathering of the brood patch within 2-10 d of hatching has been observed in some species (Ainley *et al.* 1976). A chick-rearing period of 60 d (Warham 1990, 1996) would indicate that NZSP chicks likely fledge between mid-May and mid-June.

Storm-petrels undergo a basic moult strategy. Adults of the most intensively studied northern hemisphere species, Leach's and Ashy Storm-Petrels, begin body moult at chick hatching; tail moult occurs a few weeks later; and inner primary moult begins near the end of or following chick rearing (Ainley *et al.* 1976). Tail moult is virtually finished by chick fledging, and primary moult continues over the winter and is generally completed by the time birds return to breed the following breeding season (Howell 2010). The absence of primary moult in any NZSP captured in the Hauraki Gulf in 2012 supports the conclusion that the breeding season was not advanced in early February, when the bulk of captures took place. To our knowledge, only one NZSP has been observed in flight-feather moult: a bird off Portland, Australia (38°47.69S, 141°27.24E), observed on 6 May 2012, had a primary wing formula of 5411O441 and was beginning secondary moult at S1 (P. Dodd & C. Lester pers. comm.). Based upon current data, this bird was most likely a failed breeder or an immature. The presence of new rectrices in captured NZSPs indicates that tail moult may occur earlier in the annual cycle than in Leach's and Ashy Storm-Petrels (Ainley *et al.* 1976), but requires further investigation.

The lack of sexual dimorphism in NZSP is consistent with studies of other storm-petrels and small petrel taxa (Ismar *et al.* 2010, Medeiros *et al.* 2012). However, inconsistent bias in the sex ratio of captured birds in differing months is intriguing. Given that sex ratio varied from unbiased in November (2009) to strongly male-biased during February (2012), there is little support for a hypothesised imbalance in the population sex ratio. Possibly this pattern indicates sex-specific habitat selection and/or foraging behaviour. For

TABLE 1
Measurements of NZSP caught in the Hauraki Gulf, 2005–2012

		Mean ± SD				
Sex	**n**	**Mass, g**	**Wing, mm**	**Tail, mm**	**Bill length, mm**	**Tarsus, mm**
Combined	27	34.8 ± 3.0	152.3 ± 3.6	64.6 ± 3.8	12.7 ± 3.0	35.1 ± 1.3
Male	20	34.7 ± 3.26	151.8 ± 3.6	64.8 ± 3.6	12.7 ± 0.63	35.0 ± 1.5
Female	7	35.2 ± 2.5	153.6 ± 3.7	64.1 ± 2.8	12.6 ± 0.6	35.3 ± 0.8
P for sex difference[a]		0.68	0.30	0.59	0.48	0.82

[a] t-tests of differences between males and females.

example, studies of European Storm-Petrel (*Hydrobates pelagicus*) have indicated that sex-specific habitat selection occurs during migration, when strong female bias in call-induced capture rates has been observed, but not when birds were captured at breeding sites (Medeiros *et al.* 2012). However, given that the NZSP caught in this study showed inconsistent sex-ratios when captured at or near the same location between years, there is little evidence that sex-specific habitat use mediates capture sex-ratios. A more likely scenario is that the changing sex-ratios between early and late summer correspond to sex-specific differences in attendance at an unknown breeding site. Nearly all procellariiformes exhibit a pre-laying exodus, when females are absent from the breeding site during egg formation (Warham 1990, 1996), with even small (<200 g) birds travelling long distances (Rayner *et al.* 2012). In storm-petrels the pre-laying exodus of female birds is approximately 10 days long, during which males attend the nest site. Male bias observed in the early-February captures of NZSP, when brood patch characteristics indicate the peak laying period, could thus be indicative of female absence from waters near to a local breeding site prior to laying. Conversely, and consistent with current data, an even sex-ratio is predicted during the pre-breeding period (October–December), when both sexes would attend the colony and appear in nearby waters.

The results of this study, combined with seasonal at-sea observations of the species' distribution and abundance (Flood 2003, Gaskin & Baird 2005, Gaskin *et al.* 2011), now strongly support the conclusion that the breeding site of the NZSP lies on one or more islands off the coast of northern New Zealand. Searches for this breeding site should be targeted at a time when colony activity is greatest, affording maximum chances of detecting birds entering and exiting their nesting sites. In small procellariiformes, colony activity is greatest early in the season prior to females' pre-laying exodus, and then during laying, when breeding, non-breeding and pre-breeding birds are all present at colonies (Warham 1990). Our data indicate that multi-island field surveys for NZSP breeding sites would best be targeted from December to February.

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