DIET ASSESSMENT AND VULNERABILITY OF WHITE-FACED STORM PETREL *PELAGODROMA MARINA* WITHIN A WARMING HOTSPOT

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Received 17 October 2022, accepted 07 July 2023

ABSTRACT

KARMALKAR, M., ROMAN, L., KASTURY, F., ARCE, F. & SWADLING, K.M. 2023. Diet assessment and vulnerability of White-faced Storm Petrel *Pelagodroma marina* within a warming hotspot. *Marine Ornithology* 51: 281–291.

Shifts in zooplankton communities due to changing ocean climate can affect foraging patterns among planktivorous seabirds. To better understand seabird response to environmental change in Bass Strait, southeast Australia, we investigated the prey species and 16 elements in prey and feathers of the planktivorous White-faced Storm Petrel *Pelagodroma marina*. The krill *Nyctiphanes australis* was the most abundant prey species, followed by several species of post-larval fish; otherwise, the species appeared to be a generalist feeder. Element concentrations of feathers were not significantly influenced by dietary composition. Likewise, element concentrations did not significantly differ between major prey species, confirming that the nutritional profile of these species is likely linked to their seawater environment. Given that White-faced Storm Petrels in Bass Strait substantially rely on a narrow range of prey species, this may increase their vulnerability to events that change their availability. As coastal krill is highly sensitive to sea surface temperatures (SST), the increases in SST predicted under climate change scenarios may alter the timing and abundance of krill swarms, which in turn may affect planktivores, including White-faced Storm Petrels.

Key words: White-faced Storm Petrel, *Nyctiphanes australis*, planktivorous seabirds, Bass Strait, sea surface temperatures, prey species, plastic ingestion.

INTRODUCTION

Seabirds forage on middle trophic levels of the food web, and many are known to travel long distances in search of patchily distributed prey (Hazen *et al*. 2019, Einoder 2009). Given these attributes, seabirds are useful monitors of the condition of marine ecosystems (Mallory *et al*. 2010, Piatt *et al*. 2007). Unfortunately, these same characteristics also expose seabirds to a wide range of anthropogenic threats, including that of a changing ocean climate (Burger & Gochfeld 2004, Dias *et al*. 2019, Sydeman *et al*. 2012).

Changes in the availability of zooplankton that are key prey for seabirds may have consequences for their reproductive success and population dynamics (Abraham & Sydeman 2004). Additionally, essential micronutrients needed by seabirds are influenced by the diet composition and nutritional status of prey species (Elliott 2005). Therefore, changes in the prey species consumed or their nutritional quality can also affect the reproductive success of seabird populations (Formant *et al*. 2021, Jones *et al*. 2018). For example, sudden changes in zooplankton availability have been documented to lead to mass mortality and breeding failure of Cassin's Auklet *Ptychoramphus aleuticus* (Jones *et al*. 2018) and Common Murre *Uria aalge* in the eastern North Pacific (Piatt *et al*. 2020). Shifts in zooplankton related to altered ocean climate also occur in the Southern Hemisphere, particularly in the waters of southeast Australia, as documented in the Common Diving Petrel *Pelecanoides urinatrix* (Fromant *et al*. 2021) and the Red-billed Gull *Larus novaehollandiae scopulinus* (Mills *et al*. 2008). Areas of key concern are those that are warming the most rapidly, especially the continental seas, such as the Bass Strait in southeast Australia (Fromant *et al*. 2021).

Bass Strait is a shallow continental shelf area located between mainland Australia and Tasmania (Fig.1). It is included within the southeast Australian warming hotspot (Ridgway 2007), where the South Australian Current (SAC) weakens and the strength of the East Australian Current (EAC) increases, resulting in oceanic warming (Poloczanska *et al*. 2007, Cai *et al*. 2005). These changes are likely to have a significant impact on the abundance, distribution, and nutritional content of cold water zooplanktonic communities (Evans *et al*. 2020). In turn, these changes might affect planktivorous Procellariiform species found in Bass Strait, such as the White-faced Storm Petrel *Pelagodroma marina*. An estimated 94 500 breeding pairs of this petrel breed on islands in Bass Strait, representing ~25% of the estimated Australian population (Brothers *et al*. 2001). With the continued increase of sea surface temperatures (SST) and the predicted strengthening of the EAC (as discussed in Fromant *et al*. 2020), Tasmanian populations of this species, like other planktivorous seabirds in Bass Strait, may be exposed to shifts in the distribution, quality, and abundance of prey species (Fromant *et al*. 2020). It would be instructive to learn more about the relationship of this seabird to food web variability in this region, but first more information is needed on its diet. The paucity of baseline data, such as preferred prey species, can make it difficult to forecast potential effects of environmental change and the adaptive capacity of a species (Chambers *et al.* 2011).

Therefore, the aims of this study were (1) to determine diet composition of White-faced Storm Petrels breeding in Bass Strait, and (2) to assess the concentration of trace metals in their feathers and prey species to determine the exposure to nutrients through diet during the breeding and non-breeding season. We then contextualise these results to assess how existing and predicted changes in climatic conditions might affect this species in Bass Strait.

STUDY AREA AND METHODS

Study site and field methods

This study was conducted on White-faced Storm Petrels breeding in a colony on Chalky Island (-40°04'60.00"S, 147°52'59.99"E), in eastern Bass Strait (Fig. 1). Despite its relatively low primary productivity, Bass Strait is a key biodiversity region for seabirds, supporting 60% of the seabird species found in Australia (Ross *et al*. 1995). It is located at the confluence of three major oceanic currents, the South Australian Current (SAC), East Australian Current (EAC), and sub-Antarctic Surface Water (SASW); their relative influences vary spatially and temporally at a range of scales (Sandery & Kämpf 2005).

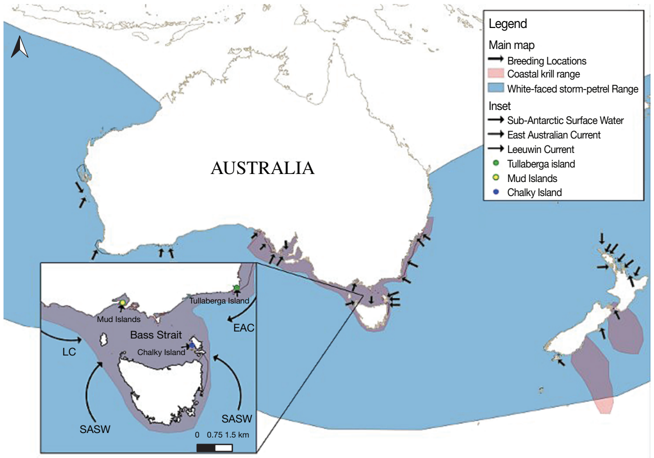

Fig. 1. The distribution and selected breeding locations (arrows) of White-faced Storm Petrels *Pelagodroma marina* in the Australasian region, and the distribution of *Nyctiphanes australis*. The inset map shows the study areas of the present study (Chalky Island) and Underwood's (2012) study (Mud Islands and Tullaberga Island) and is based on a map in Fromant *et al*. 2020. Major sea surface currents influencing the Bass Strait, i.e., Leeuwin Current (LC), East Australian Current (EAC), and Sub-Antarctic Surface Water (SASW), are represented by black curved arrows.

Fieldwork was conducted from 09 January 2021 to 20 January 2021, during the late chick rearing period. Before collection of samples, we acquired an Animal Ethics Permit (Permit number A0023569) from the animal ethics committee at the University of Tasmania and a Scientific Research Permit from the Department of Primary Industry, Parks, Water and Environment (DPIPWE), Government of Tasmania. Birds were captured by mist-netting adults at night, between 11h00 and 03h00 (local, UTC+11), as they returned to the colony to feed their chicks. Two mist-nets were arranged in an L-shape and were deployed on the seaward side of the colony on the northern end of the island. The nets were checked every 10 min and captured birds were immediately removed from the net and placed in cloth bags for sample collection. Each bird was weighed and basic morphometric measurements comprising head-bill, culmen length, tarsus length, tail length, and wing chord were recorded before diet sample collection (Fig. 2).

Diet and feather sample collection

For birds that did not spontaneously regurgitate, diet samples were collected using a modification of the stomach pump outlined by Wilson (1984) (Fig. 2). In brief, a 20-mL syringe fitted with a 4.5-mm transparent latex tube was used to push warm water (40 °C) into the proventriculus of the bird until water began to flow back out and around the sides of the tube. The tube was then removed, and the bird was tipped over a jar while gently massaging against the underside, pushing on the proventriculus, to collect the regurgitate. Each diet sample was drained of excess water and the solid contents were preserved in 10% buffered formalin in individual 50-mL sample jars. Before releasing the bird, 4–5 body feathers were collected from the breast (*n* = 25). All feathers were stored in individual plastic zip-lock bags until analysis. Once the birds were sampled, their feathers were marked with a white marker to avoid being treated again if recaptured and released.

Laboratory methods for diet sample characteristics and composition

In the laboratory, each diet sample (*n* = 74) was removed from storage and rinsed with seawater using a 200 µm mesh sieve.

Fig. 2. Field methodology in brief. White-faced Storm Petrels *Pelagodroma marina* were captured at the edge of the colony via mist-nets placed between the colony and the sea (left). Head-bill, culmen, tarsus, and wing chord length were measured (centre), and diet samples were collected using a modification of the stomach pump method (right).

Solid contents were weighed to record wet mass and then placed in a glass petri dish. Solid contents were examined under a Leica stereomicroscope M205C that was fitted with a Canon 6D Mark II camera and sorted into broad prey categories (fish, krill, crab, copepod, cephalopod, and others). Separated prey categories were weighed to estimate the relative percent contribution to total wet mass of solids. Within each prey category, organisms were counted and identified to the lowest possible taxon. Visual identification of specimens was not always possible, as soft-bodied prey items (e.g., larval fish and some cephalopods) were heavily digested and too degraded to differentiate among taxa. Specific counting rules were applied for quantifying the prey items. Fish were enumerated by counting eyeball pairs and/or flesh and loose bones, as otoliths were too small to use for reliable counting. A single unmatched eyeball was considered one specimen, and where fish was noted from flesh or loose bones, it was assumed that it represented a single individual. In the case of euphausiids, individuals were counted as whole specimens as a priority, or by counting eyeballs that were found loose within digested samples. If an odd number of eyes was found, the krill count for that sample was rounded up. Similarly, for copepods, when the exoskeleton was broken longitudinally, the higher number of halves (back and front) was used. The frequency of occurrence of a prey item was calculated as the percentage of samples in which a particular identifiable prey was recorded. The numerical abundance of each prey category was calculated as the total number of prey items found across all samples and converted to a percentage. Identification of prey species relied on the taxonomic keys of Baker *et al*. (1990), Boltovskoy (1999), and Poore (2004).

In addition to prey, all non-food items, such as plastic pieces and pumice found in the samples, were examined under the microscope to verify that they were not organic material. Plastic pieces and pumice were counted and weighed after drying to estimate the contribution to the total solid wet mass of sample.

Analytical method for trace element analysis

We determined the concentrations of aluminium (Al), arsenic (As), calcium (Ca), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), lead (Pb), selenium (Se), silica (Si), and zinc (Zn). Before trace metal analyses, all feather samples ($n = 25$) were cleaned to remove external contamination, first with Milli-Q water (to remove solid particles, such as sand/dust) and then with acetone (to remove organic compounds) following Borghesi *et al*. (2016). The process was repeated three times, after which the feathers were air dried for 24 hr. Around two to three feathers were weighed and placed in acid-washed Teflon vessels. The use of multiple feathers per sample is recommended due to variation in metal concentrations that occurs among individual feathers (Bond & Diamond 2008). Prey species within each of the individual diet samples, which were separated during stomach content analysis, were rinsed with Milli-Q water and freeze dried in individual glass vials before metal analysis. Prey species that had a high frequency of occurrence and percent mass contribution were included in the metal analysis, while species that appeared to be only a minor component of the diet and had a low frequency of occurrence were excluded.

Prey and feather samples were pre-digested in 5 mL nitric acid (trace element grade, 69%) overnight, followed by digestion using a Mars6 microwave (CEM) according to Kastury *et al*. (2021) (ramping up to 150 °C for 10 mins, holding at 150 °C for 30 mins). Following digestion, the samples were made up to 50 mL using MQ water, syringe-filtered (0.45 μm, cellulose acetate) and stored at 4 °C until analysis using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), following USEPA (1998). Two standard reference materials were used to verify the accuracy of digestion: National Institute of Standards & Technology (NIST) 2976 (Trace Elements and Methylmercury in Mussel Tissue) ($n = 2$) and National Institute for Environmental Studies (NIES) Certified Reference Material No. 13 (Human Hair) ($n = 5$).

Quality assurance and quality control

The quantitative average recovery of As and Pb from NIST 2976 was 105% and 101%, respectively, and the quantitative average recovery of Cd and Zn from NIES No.13 was 97.7% and 80.5%, respectively. During analysis using ICP-MS, one sample in every 20 was run in duplicate and the deviation between these duplicates ($n = 7$) was calculated to be < 5%. Additionally, every 20 samples, three continuous check verifications (CVV) were run at 10, 100, and 1000 parts per billion (ppb), and the deviation from the intended concentration was < 10%. To check for background contamination, nitric acid (69%) blanks ($n = 5$) were analysed. The limit of detection (LOD) of each metal was considered to be three times higher than the blank. For statistical analysis results below the LOD, we assigned half of the LOD value based on Pacyna *et al*. (2019).

Statistical analysis

Statistical analysis was undertaken in R version 4.0.2 (R Core Team 2020). Diet composition was assessed using frequency of occurrence (%FOO), numerical abundance (%n), and percentage contribution of prey classes to solid mass (i.e., fresh wet). The %FOO of each prey category from all samples, including the %FOO of plastic and pumice, was plotted to visualize the overall diet composition. Non-metric multidimensional scaling (nMDS) was then performed using percent mass contribution data to group samples with similar mass contributions of prey classes to total solid wet mass into clusters. Finally, %FOO of each prey category was plotted against prey specific abundance (%P), following Costello (1990) and Amundsen *et al*. (1996), to form a predator feeding strategy plot. Depending on where the prey categories fall along the three axes of the diagram, analysis of the plot can reveal predator feeding strategy (specialist or generalist), prey importance (dominant or rare), and niche width contribution (high within phenotype or high between phenotype). Prey-specific abundance of each prey category was calculated by:

$$(1) \qquad \%P = \frac{\Sigma(\text{prey item frequency})}{\Sigma(\text{prey counts from stomach})} \times 100$$

For analysis of the trace elements, an ANOVA was performed to determine whether there were any differences in trace element concentrations in the feathers of birds with different diet composition during the breeding season. The birds were assigned different dietary groups based on the stomach content analysis of the meal samples. Eight dietary groups were considered: Fish, Krill, Crab, Copepod, Fish+Krill, Fish+Copepod+Crab, Fish+Copepod, and Krill+Copepod. An ANOVA was performed to determine if there were any significant differences among trace element concentrations of individual prey species consumed by the White-faced Storm Petrels.

RESULTS

Diet sample characteristics and composition

Sampling was conducted over 11 nights and 74 suitable diet samples were selected for analyses (those containing no prey items [*n* = 90], or the items were too digested for accurate visual identification, were excluded from further analyses). The mean solid wet mass of the samples that were included in the analysis was 2.0 ± 1.9 g (Table 1). Overall, the solid wet mass of diet samples was composed of 58% fish, 40% crustacean, and 0.7% cephalopod (Table 1). Pumice was found in 12.2% of all diet samples. Four pieces of plastic were found in three (4%FOO) samples. The overall mean mass of the ingested plastic pieces was 0.0061 g (Table 1).

Prey composition in diet samples

The storm petrels consumed a diverse range of prey items, with their diets composed of fish, cephalopods, and a range of crustaceans including euphausiids, decapods, isopods, and copepods (Fig. 3). Seven identifiable taxa were recorded and 11 411 prey items were separated and identified. Crustaceans and fish comprised most of the prey items by number and percent wet mass (Tables 1, 2). Crustaceans were the main component of the diet and occurred in almost all samples, with a %FOO of 95.9% and %n of 85.5% (Table 2, Fig. 4). The euphausiid *Nyctiphanes australis* was one of the most abundant prey items in terms of number of individuals present (*n* = 6 618, 57.9%) and had a %FOO of 81.1% (Fig. 4).

TABLE 1
Details of the diet samples collected from White-faced Storm Petrels *Pelagodroma marina* at Chalky Island, eastern Bass Strait, southeast Australia in January 2021

Characteristics	Chalky Island (2021)
Sampling dates	09–20 January
Bird weight (g)	55.85 ± 8.97[a]
Diet	
Samples (*n*)	74
Sample weight (g)	2.076 ± 1.96 (0.026–7.83)
Percent wet mass[b]	
Fish (%)	58.70
Crustacean (%)	39.77
Cephalopod (%)	0.74
Pumice	
Occurrence (%)[c]	12.6
Pieces (*n*)	24
Mass (g)	79.60 ± 5.15
Ingested plastic	
Occurrence (%)[d]	4.05
Pieces (*n*)	4
Mass (g)	0.0061

[a] Mean ± standard deviation (minimum–maximum).
[b] Prey class contributions to diet are given as percent wet mass contributions to total solid wet mass of samples.
[c] Pumice occurrence is the percentage of regurgitate samples that contained one or more pieces of pumice.
[d] Plastic occurrence is the percentage of regurgitate samples that contained one or more pieces of plastic.

The copepod *Pontella securifer* and crab megalopa *Ovalipes* sp. were abundant in the diet samples, with %FOO of 62.2% and 68.9%, respectively (Table 2, Fig. 4). Larval fish were also important, although identification to the species level was not possible due to advanced digestion. Larval fish had the highest %FOO (90.5%) among individual prey categories and had the highest contribution to overall solid wet mass (58.7%; Tables 1, 2), despite the numerical abundance of larval fish (14.1%) being relatively low compared to crustaceans. Other crustaceans, including mantis shrimp larvae (Family Tetrasquillidae) and isopod species, were relatively uncommon and occurred in 8.1% and 5.4% of the samples, respectively (Table 2). Cephalopods were a minor dietary component and occurred in only five samples (Appendix 1, available online).

Based on the percent wet mass contributions of prey categories in individual samples, seven clusters of diet preferences were identified (Fig. 5). The largest cluster consisted of samples that had a high percentage contribution of fish to total solid wet mass (25 samples). Samples that had an equal contribution of fish and euphausiid were part of the second largest cluster (24 samples). Ten samples that were mainly euphausiids formed a separate cluster; prey categories such as copepod and crab were the main component by wet mass in six and two samples, respectively.

The predator feeding strategy plot categorises the White-faced Storm Petrel as a generalist feeder, indicated by the cluster of points near the generalist axis (Fig. 6). Euphausiids, predominantly *N. australis*, indicated dominant prey importance and was ingested most

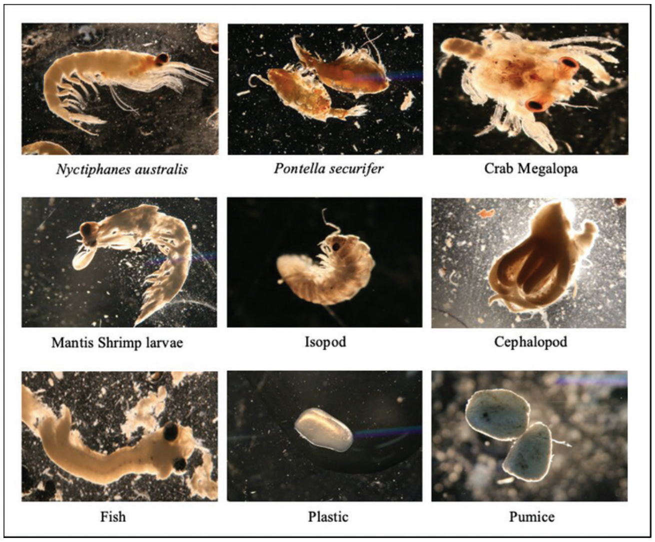

Fig. 3. Picture of prey items, including plastic and pumice pieces, found in the diet of White-Faced Storm Petrel *Pelagodroma marina* in the Bass Strait, southeast Australia.

TABLE 2
Diet of White-faced Storm Petrel *Pelagodroma marina* at Chalky Island, eastern Bass Strait, southeast Australia in 2021

Prey species	Occurrence[a]		Individuals[b]	
	Frequency occurrence	%FOO[c]	Numerical abundance	%n[d]
Crustaceans (all)	71	95.94	9 787	85.55
Euphausiidae				
Nyctiphanes australis	60	81.08	6 618	57.85
Copepoda				
Pontella securifer	46	62.16	1 964	17.16
Decapoda				
Mantis shrimp larvae (Family Terasquillidae)	6	8.10	14	0.12
Crab megalopa (*Ovalipes* sp.)	51	68.91	1 177	10.29
Unidentified isopod	4	5.40	14	0.12
Fish				
Post larval fish	67	90.54	1 618	14.14
Unidentified cephalopod	5	6.75	6	0.050

[a] Occurrence is the number of regurgitate samples containing each prey type.
[b] Individuals is the numerical abundance calculated as the total number of prey items found across all samples.
[c] %FOO is the frequency occurrence converted to a percentage.
[d] %n is the numerical abundance converted to a percentage.

frequently, whereas prey categories such as cephalopod, isopod, and decapod indicated rare prey importance and were eaten by just a few individuals. A high within-phenotype component (WPC) was found for fish, copepod, and crab prey categories (Fig. 6).

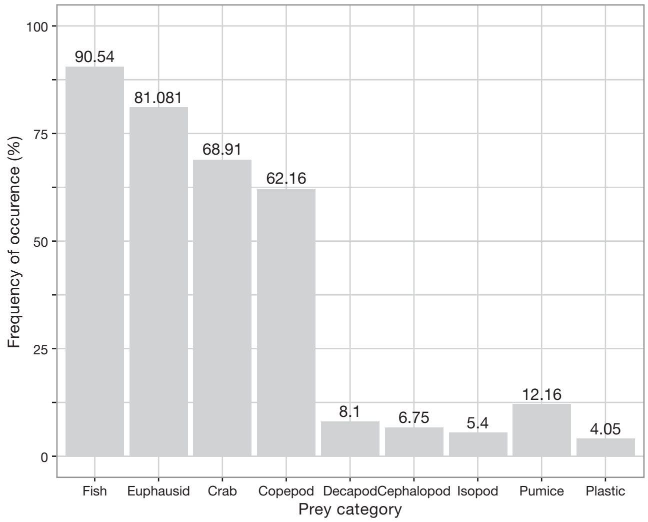

Fig. 4. Frequency of occurrence (%FOO) of prey categories, pumice, and plastic found in the stomachs of White-faced Storm Petrels *Pelagodroma marina* (n = 74). The numbers on top of the bars refer to the %FOO.

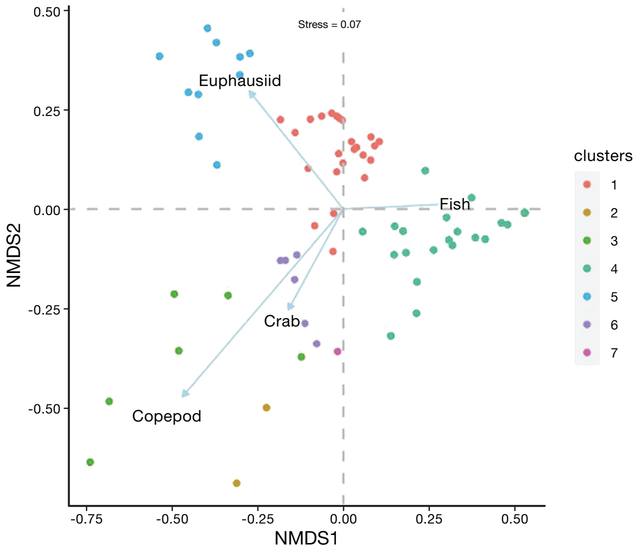

Fig. 5. Non-metric multidimensional scaling on prey percentage contribution data with colour clusters based on hierarchical clustering of percentage contribution data. Cluster 1 represents samples mainly composed of fish and krill; cluster 2 is crab; cluster 3 is copepod; cluster 4 is fish; cluster 5 is euphausiid; cluster 6 is fish, copepod, and crab; and cluster 7 is fish and cephalopod.

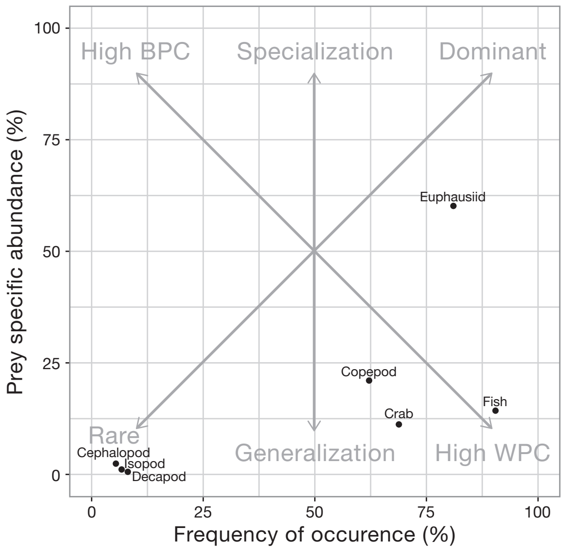

Fig. 6. Prey-specific abundance plotted against %FOO of prey categories for White-faced Storm Petrel *Pelagodroma marina* from Chalky Island, eastern Bass Strait, southeast Australia. Axes of foraging patterns are from Costello (1990) and Amundsen *et al*. (1996). The vertical axis represents predator feeding strategy (specialist vs. generalist). The two diagonal axes represent prey importance (rare vs. dominant) and niche width contribution (high within-phenotype [WPC] contribution vs. high between-phenotype contribution [BPC]). Prey-specific abundance (y-axis) used numerical counts of prey in stomach.

Trace element concentrations in feathers and prey species

Among the metals examined, the concentrations of Na, Cd, and Cr were below the limit of detection in the feather samples and, thus, were excluded from further analyses (Table 3). The concentrations of As, K, Ni, and Mn were present in detectable concentrations only in one feather sample and were also excluded from further analyses. There was no statistically significant difference among trace element concentration in feathers of birds with different diet groups ($P > 0.05$). However, the concentration of Mg in feathers of White-faced Storm Petrels that had a fish-dominant diet during the breeding season was slightly higher (0.06) than Mg concentration in feathers of storm petrels of other diet groups.

During trace element analysis of prey species, only the euphausiid *N. australis*, copepod *Pontella securifer*, crab megalopa *Ovalipes* sp., and fish that were separated during stomach content analysis were analysed for trace metals (Table 3). Other prey species were excluded, as they were only a minor component of the diet. Concentrations of Cd, Cr, K, Na, and Ni were less than the limit of detection in more than 30% of the prey species samples (Table 3) and were excluded from statistical analysis. There was no statistically significant difference among any of examined trace elements of the different prey species ($P > 0.05$).

DISCUSSION

This study documented the diet composition of a planktivorous seabird, the White-faced Storm Petrel, based on stomach content analysis of birds at a colony in Bass Strait. The two salient results

TABLE 3
Trace element concentrations (mean ± standard deviation, mg/kg) in feathers and prey species of the White-faced Storm Petrel *Pelagodroma marina* sampled at Chalky Island, eastern Bass Strait, southeast Australia

Trace element	White-faced Storm Petrel feathers ($n = 25$)	*Nyctiphanes australis* ($n = 9$)	Fish ($n = 17$)	*Pontella securifer* ($n = 6$)	Crab megalopa ($n = 5$)
Al	43.24 ± 102.15	54.01 ± 62.73	269.79 ± 470.3	40.72 ± 49.72	44.91 ± 70.77
As	< LOD[a]	0.59 ± 0.17	0.97 ± 1.13	0.47 ± 0.08	0.79 ± 0.62
Ca	1 026.28 ± 1 322.41	3 349.86 ± 1 555.92	20 160.03 ± 41 242.27	2 701.15 ± 4 273.55	8 108.546 ± 8 273.43
Cd	< LOD[a]	> 30% < LOD	> 30% < LOD[a]	> 30% < LOD[a]	> 30% < LOD[a]
Cr	< LOD[a]	> 30% < LOD	> 30% < LOD[a]	> 30% < LOD[a]	> 30% < LOD[a]
Cu	5.37 ± 10.66	29.03 ± 11.82	37.33 ± 62.91	27.72 ± 27.57	13.324 ± 7.28
Fe	133.7 ± 513.36	35.05 ± 25.25	391.81 ± 777.45	37.63 ± 55.33	47.106 ± 50.44
K	< LOD[a]	> 30% < LOD	> 30% < LOD[a]	> 30% < LOD[a]	> 30% < LOD[a]
Mg	724.13 ± 416.37	3 449.53 ± 1 088.19	7 076.73 ± 11 298.22	2 380.08 ± 1 211.75	2 090.156 ± 1 444.24
Mn	< LOD[a]	4.88 ± 0.38	9.72 ± 18.53	0.87 ± 1.19	3.07 ± 2.91
Na	< LOD[a]	> 30% < LOD	> 30% < LOD[a]	> 30% < LOD[a]	> 30% < LOD[a]
Ni	< LOD[a]	> 30% < LOD	> 30% < LOD[a]	> 30% < LOD[a]	> 30% < LOD[a]
Pb	11.24 ± 18.11	4.88 ± 10.98	2.48 ± 4.57	1.44 ± 3.1	7.442 ± 11.4
Se	1.52 ± 2.13	2.39 ± 1.44	2.81 ± 3.23	3.98 ± 4.23	1.074 ± 0.97
Si	419.52 ± 341.31	219.57 ± 353.89	651.48 ± 1139.9	154.19 ± 219.45	372.84 ± 541.6
Zn	170.09 ± 122.18	94.21 ± 53.34	181.77 ± 337.33	60.65 ± 61.21	107.63 ± 48.91

[a] LOD is the limit of detection

and their interpretations are as follows: (1) Diet composition of these birds is reflective of a generalist forager and is similar to the diet composition of other generalist storm petrel species (Quillfeldt 2002, Frith *et al*. 2020, Spear *et al*. 2007). Despite being a generalist species, White-faced Storm Petrels are heavily reliant on two prey groups, coastal krill and post-larval fish. (2) Element concentrations of feathers were not significantly influenced by prey preference, nor did element concentrations differ significantly among major prey species, indicating that regardless of diet composition, White-faced Storm Petrels from Chalky Island are all exposed to a similar suite of nutrients. We argue, below, that reliance on few prey types can be disadvantageous for marine predators if the dominant prey species is vulnerable to climate perturbations. This is an important consideration for coastal krill as a key prey species, as the predicted increase in effects of climate change might result in the reduced availability of coastal krill for White-faced Storm Petrels and other predators in the Bass Strait.

Diet

White-faced Storm Petrels breeding on Chalky Island, foraging in Bass Strait, have a generalist diet, with a majority of the individuals feeding on coastal krill and post-larval fish, and relatively few individuals feeding on other prey items. Most of the diet samples had a higher percentage of crustaceans and fish by wet mass and numerical abundance, and only one sample had a higher percentage of cephalopod by wet mass (Appendix 1). This characterisation of the diet is consistent with studies of diet in other generalist storm petrel species such as Wilson's Storm Petrel *Oceanites oceanicus* (Quillfeldt 2002) and Leach's Storm Petrel *Hydrobates leucorhous* (Frith *et al*. 2020). Several krill species have been found to be an important food item in the diet of many Procellariiformes (Fromant *et al*. 2020, Schumann *et al*. 2008, Quillfeldt 2002, Prince 1980), and the White-faced Storm Petrels in this study followed this general pattern.

Coastal krill was the most abundant prey item consumed by storm petrels in this study. The occurrence of coastal krill is restricted to the neritic waters (continental shelf waters) of southeastern Australia and neighbouring New Zealand, where other species of krill are rare or absent (Blackburn 1980). Coastal krill play an important role in the coastal ecosystem, indicated by its dominance in the diets of several vertebrates in southeast Australia, including cetaceans, seabirds, and commercially important fish species (Gill *et al*. 2011, Mills *et al*. 2008, Young *et al*. 1993, O'Brien 1988). They are known to exhibit surface swarming behaviour throughout the year off the Tasmanian coast (O'Brien 1988). White-faced Storm Petrels tracked during chick-rearing in the eastern North Atlantic show a dispersed foraging distribution, travelling up to 214 ± 208 km from the colony (Alho *et al*. 2022). Despite limited data on the foraging behaviour of the species in Bass Strait, the abundance of coastal krill in this study indicates that birds were most likely provisioning their chicks from short foraging trips within Bass Strait. Bass Strait spans approximately 200 km North to South by 300 km wide (or approximately 400 km including continental shelf), a foraging radius that would reflect what was reported by Alho *et al*. (2022), though tracking studies would be needed to confirm this.

The overall diet composition of the White-faced Storm Petrel in this study was broadly similar to a study conducted by Underwood (2012) on the diet of White-faced Storm Petrels breeding on Mud Island and Tullaberga Island, in northern Bass Strait. Underwood's (2012) study is the only other information on White-faced Storm Petrel diet in Bass Strait. Crustaceans were the main component, with *N. australis* also being the dominant prey type. However, there were considerable differences in the diversity of prey species/taxa consumed, with the White-faced Storm Petrels from Chalky Island consuming only seven identifiable prey taxa, compared to 25 recorded taxa in the diet of the birds from northern Bass Strait (Underwood 2012). This variation in diet composition could result from these populations foraging in different locations and/or due to changes in the abundance of different prey species through time. The absence of multi-year dietary data of different populations in Bass Strait prevents our understanding of how small, abundant seabird species have adapted to changing environments (Fromant *et al*. 2021). Hence, there is minimal comparative capacity to assess whether this observed variation in diet between White-faced Storm Petrel colonies is due to changes in prey species availability over time or is the result of the two populations foraging in different locations. Obviously, a more detailed study is needed.

Effects of climate variation in the Bass Strait

White-faced Storm Petrels breed in many locations around Australia (Underwood 2012, Bothers *et al*. 2001), and though their generalist foraging behaviour enables them to adapt to available prey, many of their breeding locations in Australia overlap with the distribution of *N. australis* (Fig.1). The abundance of *N. australis* in the stomach contents of White-faced Storm Petrels in the present study, and those sampled in northern Bass Strait 15 years earlier (Underwood 2012), reinforce the importance of the krill species in the diet of these birds in the southeast Australian region. The distribution and availability of coastal krill varies substantially among years in relation to SST (Mills *et al*. 2008, Young *et al*. 1993) and is influenced by the spatially and temporally variable oceanographic processes that influence the productivity in Bass Strait. The optimal SST range for *N. australis* is 12–18 °C (Sheard 1953). As coastal krill are a key zooplankton prey for marine predators (Mills *et al*. 2008, Sheard 1953), variability in abundance of coastal krill has been observed to influence the foraging behaviour of sea birds (Fromant *et al*. 2021, Manno *et al*. 2014, Mills *et al*. 2008). For example, the absence of coastal krill in years of positive SST anomaly was connected to a delayed breeding time, longer foraging trips, and reduced breeding success of the Red-billed Gull in New Zealand (Mills *et al*. 2008). The average SST in Bass Strait during the 2020–2021 summer was 16.5 °C (± 1.3 °C) (Formant *et al*. 2021). Because the 2020–2021 summer SST were well within the thermal tolerance range of coastal krill, White-faced Storm Petrels are unlikely to have experienced altered availability of their preferred prey during this breeding season.

Trace metal concentrations in feathers and prey species

Analysis of the trace metal concentrations revealed that there was no statistically significant difference in the concentration of trace metals in the feathers of birds having different diet compositions and in the prey species consumed by White-faced Storm Petrels in eastern Bass Strait. Thus, irrespective of their diet composition during the breeding season, White-faced Storm Petrels may be exposed to similar nutrients, and a change in the abundance of certain prey species might not affect the nutritional intake of the birds. However, as the sample size considered in this study was relatively low and the standard deviation of each metal was high, it is challenging to disentangle whether the lack of significant results is because there was no difference or the sample size was too low for the difference to be detected.

Ingestion of plastic

In addition to the prey species identified in the diet samples, plastic debris were also discovered in the diet of White-faced Storm Petrels sampled at Chalky Island. Due to their surface feeding, high incidences of debris ingestion in White-faced Storm Petrels have been recorded in the literature in multiple ocean basins (e.g., Roman *et al*. 2019, Ryan 1987, Furness 1985, Spear *et al.* 1995). Ingestion of plastic by White-faced Storm Petrels in this study was significantly lower than in previous studies of this species. The %FOO of plastic in this study was 4.1%, compared to 84% %FOO in White-faced Storm Petrels from Gough Island (*n* = 19; Furness 1985) and 88% FOO in those of South African waters (*n* = 24; Ryan 1987).

White-faced Storm Petrels in this study ingested lower amounts of plastic compared to the birds sampled during Underwood's (2012) study on Mud Island and Tullaberga Island in northern Bass Strait (Fig. 1). Although the reasons for this variation in plastic ingestion among breeding colonies are largely unknown, there are several factors that can influence the variation in the incidence of marine debris ingestion in seabird species. Because the White-faced Storm Petrels at Mud Islands are located in closer proximity to the city of Melbourne, Australia, it is possible that these individuals are exposed to more plastic compared to the individuals from Chalky Island in the sparsely human-populated eastern Bass Strait.

Nevertheless, the occurrence of plastic in the regurgitate samples in this study indicates that plastics are being ingested by these birds and possibly being delivered to chicks. As storm petrels are currently predicted to be at high risk of debris ingestion (Roman *et al*. 2019), an increase in plastic pollution in waters off southeastern Australia could result in an increase in plastic ingestion by storm petrels. At current rates, however, the rate of plastic ingestion in this region is lower than storm petrels in other parts of the world.

Potential future of White-faced Storm Petrels in Bass Strait

The dependence of White-faced Storm Petrels that breed on Bass Strait islands on relatively few prey types (such as coastal krill and post-larval fish) may increase the impacts of reduction in abundance of preferred prey species. As climate change models have predicted an intensification in the EAC due to large scale ocean circulation changes (Cai *et al*. 2005), modification of zooplankton communities and abundances in the marine system of southeastern Australia in response to the warming temperatures (Evans *et al*. 2020) are likely to exacerbate the long-term effects on higher trophic marine species (Fromant *et al*. 2021, Osborne *et al*. 2020, Sanford *et al*. 2019).

During years of intensified EAC, zooplankton species abundance, particularly coastal krill biomass, has been shown to decrease strongly (Young et al. 1993). This may intensify as temperature events such as marine heatwaves are predicted to increase in magnitude and frequency (Oliver *et al*. 2019). We posit that increased extreme temperatures are likely to adversely affect seabirds in Bass Strait, including White-faced Storm Petrels, through the potential decreased abundance of coastal krill or phenological mismatches between the timing of krill swarming and seabird chick rearing.

CONCLUSIONS

This study has provided an improved understanding of the diet composition and nutrient exposure of White-faced Storm Petrels during their chick-rearing phase at a colony in Bass Strait. The diet composition and nutrient exposure data that have been collected can be used as a benchmark against which any future change to the diet and nutritional status of the prey of the White-faced Storm Petrel can be measured and help elucidate potential changes to the population due to ongoing climate change in a global warming hotspot.

ACKNOWLEDGEMENTS

The authors thank the IMAS (Institute of Marine and Antarctic Studies), CSIRO (Commonwealth Scientific and Industrial Research Organisation), and the Pacific Seabird Group for providing funding towards the fieldwork. We would also like to acknowledge the contributions of Peter Puskic, Samantha Seah, and Peter Vaughan for their help and input during data collection and fieldwork. This paper benefitted greatly from the comments offered by reviewers. The authors would also like to thank the Editor in Chief of Marine Ornithology, David Ainley, for his valuable feedback. Thank you.

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