Notornis, 2026, Vol. 73: 73–81, https://doi.org/10.63172/828105bnvayu
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Fishing for information: a review of fish species observed with tara iti (*Sternula nereis davisae*) and in the adjacent waterways

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Abstract: Tara iti (New Zealand fairy tern, *Sternula nereis davisae*) are one of Aotearoa New Zealand's most endangered birds, with decades of conservation effort focused on population monitoring, predator control, and habitat protection. This study examined fish species available to and consumed by tara iti through seine-net surveys (2021–2024) at Waipū and Mangawhai estuaries, supported by direct feeding observations and photography of feeding events. Forty-three fish species were identified across the two sites. While fish community composition differed significantly between estuaries, most variation occurred within sites. Waipū supported a greater diversity of small-bodied indicator species and juveniles of diadromous or estuarine-dependent taxa, whereas Mangawhai was dominated by juvenile flounder and gurnard. All indicator species represent suitable prey for tara iti and their chicks, highlighting the role of estuaries during the breeding season. However, sampling effort remains biased toward east coast estuaries and summer months, underscoring the need for broader temporal and spatial surveys.

Ogle, S.; Southey, I.C. 2026. Fishing for information: a review of fish species observed with tara iti (*Sternula nereis davisae*) and in the adjacent waterways. *Notornis 73*(1): 73–81, https://doi.org/10.63172/828105bnvayu

Key words: fairy tern, diet analysis, fish community, estuarine fish, prey availability, species assemblages

INTRODUCTION

Aotearoa New Zealand's estuaries are home to many birds that are dependent on these dynamic ecosystems; none is closer to the precipice of extinction than tara iti (New Zealand fairy tern, *Sternula nereis davisae*) (Hansen 2006; Robertson *et al*. 2021). Observations of tara iti have been collected by volunteers and Department of Conservation (DOC, previously the New Zealand Wildlife Service) rangers since 1983 and more recently, there has been increased interest in the fish on which they rely for survival.

Previous studies have noted incidental fish identifications during feeding events and described some fish to species-level (Parrish & Pulham 1995); other workers have described tara iti diet based on carbon stable isotope signatures from feathers (Ball 2023; Ismar *et al*. 2014); while surveys of surrounding estuaries and waterways have identified some of the prey species available to tara iti (Ismar *et al*. 2014).

Received 29 September 2025; accepted 26 December 2025
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There is yet to be a robust analysis of fish community compositions at each of the tara iti breeding sites. It is expected that availability of appropriately-sized food alongside optimal fishing conditions play a significant role in the breeding success and survival of juvenile tara iti (McMurdo Hamilton *et al*. 2021). However, with such a limited population of birds, sample sizes remain small for diet techniques including stable isotope, and other biological sample analyses. Furthermore, with conservation management focused on maximising breeding success, resources have been focused on factors that can be more easily manipulated and produce effective results, such as habitat stabilisation and predator control (McMurdo Hamilton *et al*. 2021). As a result, many diet data, especially anecdotal or observational records, are incidental and secondary to observations of tara iti themselves.

We here present a review of observational data of tara iti feeding events collected and documented by DOC staff and volunteers across all four breeding sites, and surveys of fish from the Mangawhai, Waipū, and Pākiri estuaries, as well as from the Te Ārai stream and smaller tributaries of the Mangawhai estuary. These data, while more robust in their identification accuracy, are a representation of the available fish species rather than the species actually being consumed by tara iti. Observational data are anecdotal and are biased towards morphologically distinct groups such as flounder (*Rhombosolea* spp) and juvenile eels (elvers, *Anguilla* spp). Whilst these observations give certainty for easily identified prey, and the records of these span 30 years (Parrish & Pulham 1995), observational data are limited by a varying level of fish-identification skill amongst observers and an ability to accurately identify prey items in difficult conditions before they are consumed. With the introduction of telephoto lenses to many observers' toolkits, more reliable records can be kept of fish being consumed by tara iti, which has greatly increased the number and range of prey items that can be identified.

The intention of this review is to summarise all relevant prey item availability and observational records for tara iti, indicating the needs for future data collection to start building a more accurate picture of the food resource utilised by Aotearoa's most endangered endemic bird.

METHODS

The two groups of data presented in this review are observation of prey caught by tara iti, and sampling of fish from habitat used by tara iti. Observational and photographic data collected by rangers and volunteers while monitoring tara iti nests or and foraging individuals indicated the range of species consumed. Surveys of nearby streams and estuaries were undertaken at selected sites to ascertain the assemblage of available fish, which will be referred to as collection data for the purpose of this review. Observational data were further divided based on the recording methodology. Data recorded through observation only will henceforth be referred to as anecdotal, and data from photographs will be referred to as photographic. Anecdotal data span from 1995 through to current day, with photographic data being recorded more recently through the use digital photography.

Collection data include records from targeted collection of fish from estuaries and streams surrounding the tara iti breeding sites, from surveys or for supplementary feeding of juvenile tara iti. Methods of collection included seine netting, fyke nets, and Gee Minnow traps. Seine netting is an active collection method of dragging a weighted net through a shallow estuary or stream and depositing any captured fish into a large container for identification. Fyke nets and Marmite-baited Gee Minnow traps are both passive fishing methods and were only used in streams where the tidal flow would not uncover the traps. They were set late in the afternoon, with any captured fish being emptied into a container early the following morning to avoid any mortality due to overheating. Using these methods, fish were identified to species-level resolution in the field using McQueen & Morris (2013) and any fish that could not be identified were photographed for identification by the DOC freshwater team.

In order to combine the data from supplementary feeding collection and estuary surveys with the various studies that have focussed on feeding events (Parrish & Pulham 1995; Preddey 2009; Ismar *et al*. 2014; Jeffries *et al*. 2016; Ball 2023), sampling effort was converted to individual days that observations or survey collections took place (Fig. 1).

Due to the relatively small and inconsistent dataset, photographic and anecdotal data are presented but not analysed. The supplementary feeding data were excluded from analyses due to the majority of collections being from fresh or brackish water, which biased the species composition compared to estuarine habitats predominantly used by adult tara iti when foraging. The survey collection data from the Waipū and Mangawhai estuaries spans from 2021 to 2024 and provided sufficient data for perform statistical analyses. Counts were converted to presence/absence, and analysed using a Sørensen test to identify significant differences in species composition between the two sites. To test for species-level occupancy patterns, a permutational multivariate analysis of variance (PERMANOVA) was used to include an

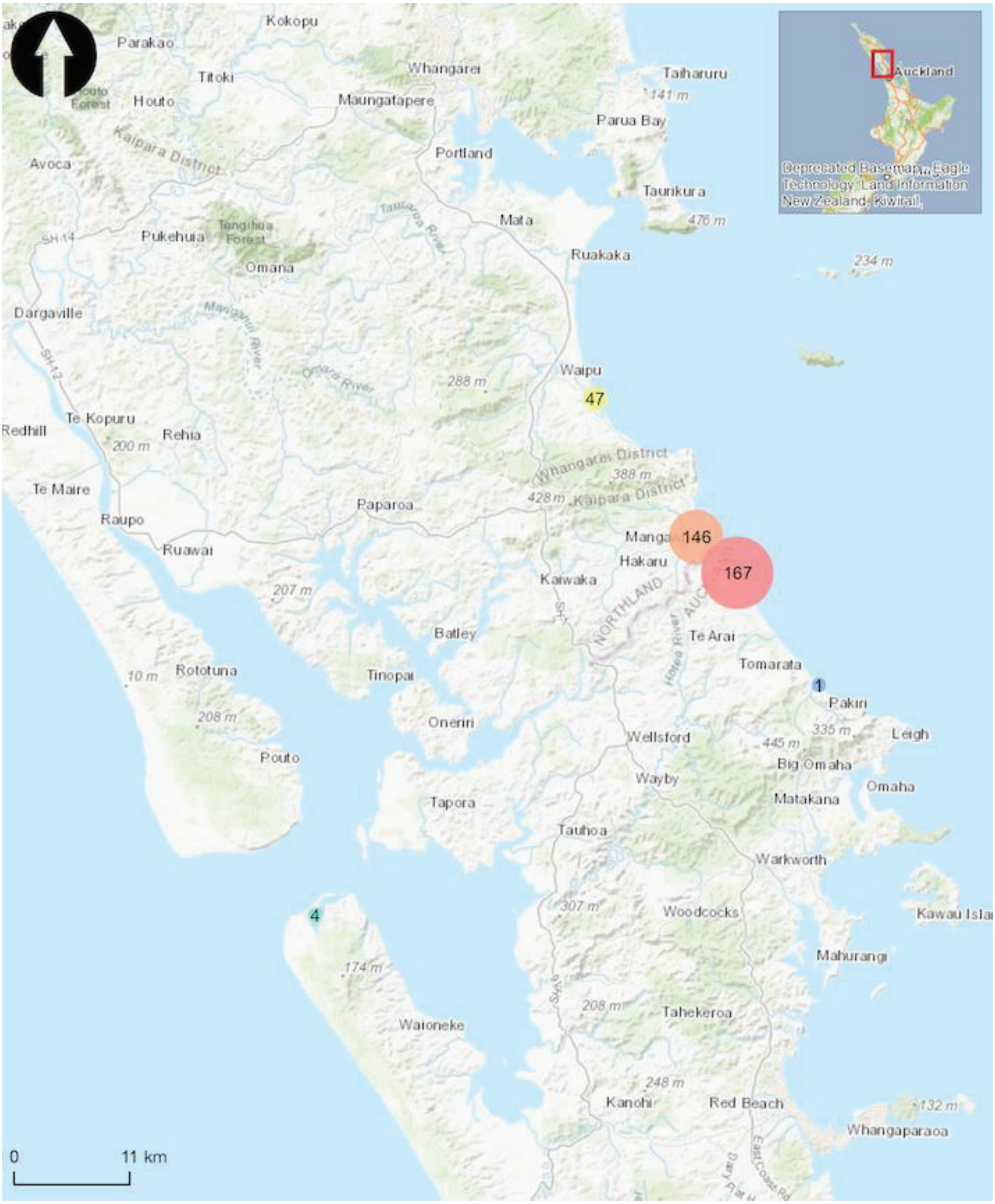

Figure 1. Sampling effort across tara iti foraging sites. Larger, redder circles represent greater numbers of sampling events. Sampling effort was measured in days, and includes both sampling of waterways and anecdotal or photographic recording of prey consumption events.

Indicator Value (IndVal), which confirmed which individual species may be responsible for this variation. These were based on presence-absence data from the PERMANOVA analyses. The IndVal (999 permutations) was applied to these indicators pairwise (Mangawhai cf. Waipū) and the FDR (Benjamini-Hochberg) was applied to the p-values. A non-metric multidimensional scaling (NMDS)

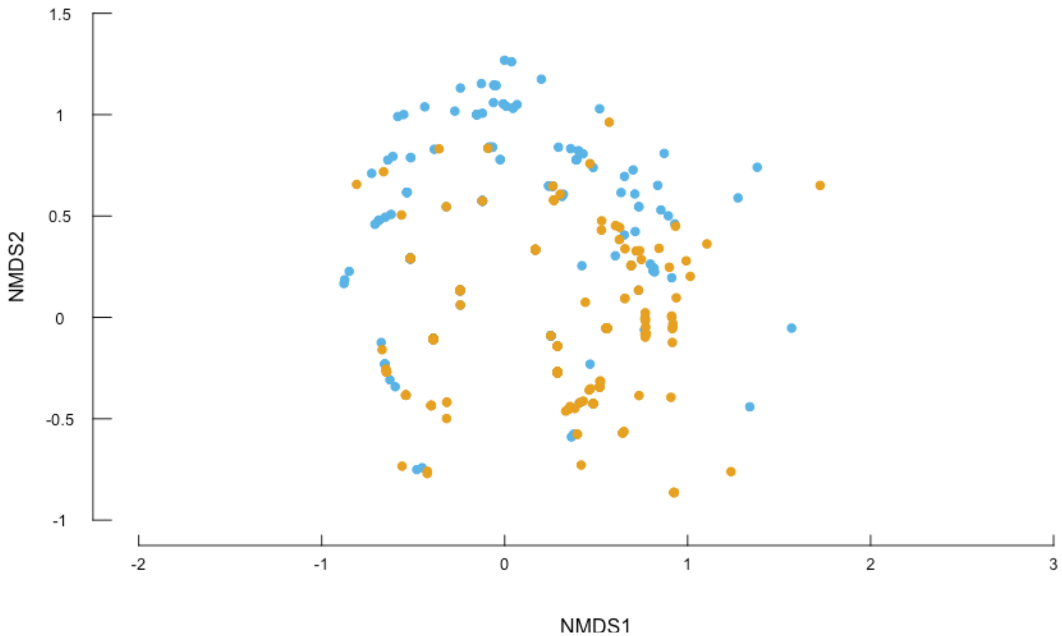

Figure 2. Non-metric multidimensional scaling (NMDS) of estuarine fish communities based on presence-absence data using Bray-Curtis (Sørensen) dissimilarity. Each point represents a sampling event, coloured by estuary (orange = Mangawhai; blue = Waipū).

with Jaccard distance was used to create site clusters of species distribution. Finally, homogeneity of multivariate dispersion (PERMDISP) was checked and Benjamini-Hochberg false discovery rate (FDR) was applied to resulting IndVal p-values. The combination of these analytical techniques allowed for the reporting of both alpha diversity within each site and beta diversity across the sites.

In order to confirm which individual species may be responsible for this variation, an Indicator Species Analysis (IndVal) was undertaken. For site-level differences, an Indicator Species Analysis (IndVal, 999 permutations, Benjamini–Hochberg corrected) was undertaken. Indicator species are taxa whose abundance or occurrence is disproportionately and significantly associated with one site, indicating a difference in community assemblages. These indicator species highlight which taxa are most reliably available as potential prey items for foraging tara iti.

Analyses were performed using R Statistical Software (version 2025.05.1+513, R Core Team 2025) and RStudio (RStudio Team 2023) and the vegan, tidyverse, and dplyr packages (Wickham *et al*. 2019 & 2023; Oksanen *et al*., 2022) were used for community analysis, visualisation, and data wrangling.

Table 1. Mean distance to group centroid (± standard deviation) in multivariate space for fish assemblages at Mangawhai and Waipū estuaries, with sample size (n).

Site	Mean distribution	Standard deviation	n
Mangawhai	0.2365	0.1506	542
Waipū	0.331	0.2065	292

RESULTS

A total of 841 samples was collected across the two estuaries between 2021 and 2024, with 546 from Mangawhai and 295 from Waipū. NMDS ordination of presence–absence data based on Sørensen dissimilarities (Fig. 2) revealed slight clustering of samples by estuary (stress = 0.144), and PERMANOVA confirmed a significant effect of site on fish community composition (df = 1, 833; F = 64.26, R^2 = 0.072; p = 0.001), with estuary of origin explaining approximately 7.2% of the variation. Examination of residual variation (df = 832; R^2 = 0.9283) indicated that most of the compositional variation (~93%) occurred within estuaries rather than between them. PERMDISP further showed that Waipū assemblages were significantly more

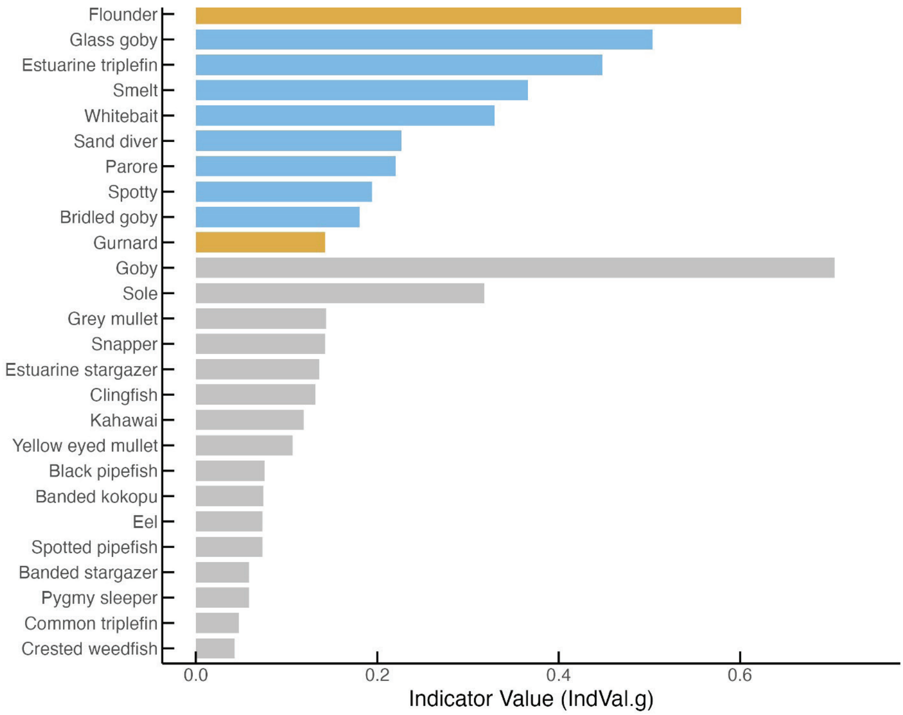

Figure 3. Bar graph comparing the indicator values (IndVal.g) of various fish species observed at Mangawhai (orange) and Waipu (blue). Each species is listed on the y-axis, with the x-axis representing its indicator value. Greyed out species were not statistically significant indicators.

variable than those at Mangawhai (F = 57.17, p = 0.001; Table 1).

Significant indicators for both Mangawhai and Waipū are shown in Fig. 3 and Table 2. Waipū had a greater number of indicator species, including small estuarine taxa (glass goby *Gobiopterus semivestitus*, estuarine triplefin *Forsterygion nigripenne*, sand diver *Tewara cranwellae*), juveniles of diadromous species (whitebait *Galaxias* spp, smelt *Retropinna retropinna*), and fry of marine taxa known to use estuaries as nurseries, e.g. parore (*Girella tricuspidata;* Fig. 4*)*, and spotty (*Notolabrus celidotus*). In contrast, Mangawhai had only two significant indicator species: flounder (*Rhombosolea* spp) and red gurnard (*Chelidonichthys kumu*). Although gobies (Gobiidae spp) accounted for 87% of all catches, their abundance was comparable across estuaries, preventing them from being identified as indicator species. These analyses revealed the estuarine fish communities at Mangawhai and Waipū to differ significantly from each other.

Te Ārai had the most fish-specific sampling days, however, these data are skewed as the stream at this location was one of the main sites used to catch fish for supplementary feeding and captive-rearing of juvenile tara iti; capture of fish for these programmes accounted for 95.2% of the sampling days at Te Ārai stream (Ogle, S.; Wilson, A.; Lagnaz, E.; Wiles, A. 2021; Captive rearing of tara iti / NZ fairy tern (*Sternula nereis davisae*) 2020–2021 breeding season; unpubl. report, Department of Conservation, internal reference DOC-6574587; Ogle, S. 2022; Use and rearing of fish for the tara iti / NZ fairy tern (*Sternula nereis davisae*) captive rearing programme during the 2021-2022 breeding season; unpubl. report, Department of Conservation, internal reference DOC-6955282; Wilson, A.; Ogle, S.; Francescon, C. 2022; Tara iti / NZ fairy tern captive rearing report, 2021–2022 breeding season; unpubl. report, Department of Conservation, internal reference DOC-6951457). The Te Arai survey collections were further biased as they were from the only stream-based (fresh to brackish water) sampling site, resulting in capture of a large number of juvenile īnanga (*Galaxias maculatus*), freshwater pest species such as goldfish (*Carasius auratus*) and mosquitofish (*Gambusia affinis*), and several native bully species (including giant bully *Gobiomorphus gobioides*, redfin bully *G. huttoni*, common bully *G. cotidianus*, and Cran's bully *G. basalis*) that were not recorded at the estuarine sites. When the captive-feeding data were excluded, Mangawhai estuary

Figure 4. Tara iti chick with a juvenile parore (*Girella tricuspidata*), Waipū, 2025-2026 breeding season. Photo by Susan Steedman.

Figure 5. Tara iti chick with an olive rockfish (*Acanthoclinus fuscus*), Waipū, 2024-2025 breeding season. Photo by Darren Markin

was the dominant site for all other data (stable isotope, fish surveys, and monitoring of foraging events; Parrish & Pulham 1995; Ismar *et al*. 2014; Ball 2023). Mangawhai is the stronghold for tara iti, and provides the largest sample size of tara iti at a single locality (Ball 2023).

Data from tara iti breeding season reports data were not included in Fig. 1 as observed fish captures were not consistently reported, and fish identifications without photographic corroboration were considered unreliable.

The final dataset include in this study is a series of 28 photos taken with a telephoto lens at the Waipū and Mangawhai breeding site over the 2024-25 breeding season by volunteer, Darren Markin. Eight different fish species were identified from the photographs including olive rockfish (*Acanthoclinus fuscus*), which had not been recorded using other sampling methods (Fig. 5). A rudd (*Scardinius erythrophthalmus*) carried by a tara iti photographed at Te Ārai river mouth likely came from nearby Tomarata Lake (see Preddey & Pulham 2017) as rudd were illegally introduced to the lake in the 1970s (Wells, R. 2016; The impacts of recreational activities on Lake Tomarata's ecology and water quality; unpubl. report, prepared for Auckland Council by the National Institute of Water and Atmospheric Research; Auckland Council TR2016/033). As these observations are based on high quality photographs, they can be added to the growing dataset of reliably-identified fish consumed by tara iti.

Across the sampled estuaries and breeding sites, identified fish community assemblages showed significant spatial variation. Waipū supported a wide variety of diadromous and estuarine species, whereas Mangawhai was characterised by species which could only be eaten by tara iti in their juvenile forms. Te Ārai, by comparison, was a different ecosystem type, with all samples dominated by īnanga and other freshwater taxa. Photographic observations further expanded the range of prey

Table 2. Significant indicator estuarine fish species at Mangawhai and Waipū estuaries. IndVal.g = Indicator Values.

Species	Common name	Site	IndVal.g	p-value
Forsterygion nigripenne	Estuarine triplefin	Waipū	0.448	0.001
Galaxias spp	Whitebait	Waipū	0.329	0.001
Gobiopterus semivestitus	Glass goby	Waipū	0.504	0.001
Tewara cranwellae	Sand diver	Waipū	0.227	0.001
Retropinna retropinna	Smelt	Waipū	0.366	0.001
Arenigobius bifrenatus	Bridled goby	Waipū	0.180	0.001
Notolabrus celidotus	Spotty	Waipū	0.194	0.006
Girella tricuspidata	Parore	Waipū	0.220	0.006
Chelidonichthys kumu	Gurnard	Mangawhai	0.142	0.031
Rhombosolea spp	Flounder	Mangawhai	0.651	0.001

known to be taken by tara iti, and included fish species from inshore marine environments. The integration of survey, photographic, and anecdotal data revealed that tara iti utilise a great diversity of prey sourced from estuarine, freshwater, and marine habitats. These findings provide a comprehensive baseline for understanding prey availability across the species' core range and allow conservation management discussions to be considered through the lens of tara iti foraging ecology.

DISCUSSION

For many years, the tara iti diet was recorded incidentally during studies focused on other topics (Parrish & Pulham 1995; Preddey 2009). This was followed by a limited number of studies with an explicit focus on tara iti foraging behaviour and diet (Ismar *et al*. 2014; Jeffries *et al*. 2016; Preddey & Pulham 2017; Ball, 2023). This current review aimed to add additional data through waterway surveys and photographs of tara iti holding fish.

Despite only being 16 km apart and supporting many of the same bird species, it was found that the Waipū and Mangawhai estuaries had distinct fish community composition. Waipū, is a smaller and shallower estuary than Mangawhai, yet it had a greater heterogeneity of fish assemblages. With the exception of two large-bodied marine species (spotty and parore), all life stages of indicator species were potentially consumable by tara iti. The fish identified as 'whitebait' (*Galaxias* spp, *Retropinna retropinna*) were likely to have been banded kōkopu (*G. fasciatus*) or īnanga (*G. maculatus*) as they were the locally common galaxiids found by surveys of nearby waterways. Both of these species would be consumable by tara iti as both adults and juveniles. This dietary flexibility allows tara iti to adapt to changes in the fish species composition in Waipu estuary (see Maathuis *et al*. 2025). In contrast Mangawhai estuary only had two, but strongly significant, indicators: red gurnard, and flounder. Both species/species groups grow too large in their adult form to be consumed by tara iti, further reinforcing the importance of not only spatial but temporal requirements for effective foraging. Red gurnard and both flounder species likely to be included in these surveys (sand flounder, *Rhombosolea plebeian*, yellow-belly flounder *R. leporina*), spawn in spring to early summer (Colman 1973; Clearwater & Pankhurst 1994). Despite both being identified as indicator species in this study, there are no known records of tara iti catching or consuming gurnard fry. In contrast, *Rhombosolea* spp featured in anecdotal data and were also detected in stable isotope data from feather samples collected from Mangawhai (Ismar *et al*.; 2014; Ball 2023).

Photographic data revealed *Favonigobius* spp. as a significant component of tara iti diet. These gobies were abundance in the seine net surveys; it is likely that tara iti are reliant on areas with high numbers of these fish, which are small enough when adult for all life stages to be readily consumed by tara iti chicks and adults (Ogle, S. 2023; Use and rearing of fish for the tara iti / NZ fairy tern (*Sternula nereis davisae*) captive rearing programme during the 2022-2023 breeding season; unpubl. report, Department of Conservation, internal reference DOC-7388700). While the difference in fish community compositions differed significantly between Mangawhai and Waipū, the difference attributed to site (7.2%) was relatively modest, and was expected given that estuarine environments have high levels of stochasticity (Whitfield & Elliott 2002). From the sampling surveys, all fish identified were small species or the juveniles of larger species, all of which would be theoretically consumable by tara iti if they occurred in water shallow enough for tara iti to catch them (Ismar *et al*. 2014).

Supplementary anecdotal and photographic data revealed an array of species that were not captured during the seine net surveys. These included both marine and freshwater species that were not expected to be captured in estuary surveys (Ismar *et al*. 2014; Ball, 2023; Ogle, S. 2022; Use and rearing of fish for the tara iti / NZ fairy tern (*Sternula nereis davisae*) captive rearing programme during the 2021-2022 breeding season; unpubl. report, Department of Conservation, internal reference DOC-6955282; Ogle, S. 2023; Use and rearing of fish for the tara iti / NZ fairy tern (*Sternula nereis davisae*) captive rearing programme during the 2022-2023 breeding season; unpubl. report, Department of Conservation, internal reference DOC-7388700). This highlights the value of combining multiple data sources and survey techniques to fill the gaps in the entire food supply upon which the tara iti rely.

Information on tara iti diet is constrained by several biases. All studies were undertaken in the summer months, during the tara iti breeding season (Parrish & Pulham 1995; Jeffries *et al*. 2016). Like birds, fish species undergo seasonal dynamics, including changes in abundance, size, and spatio-temporal distribution (Colman 1973; Clearwater & Pankhurst 1994; Yungnickel *et al*. 2020). The current information is also skewed towards the east coast and fish community composition there, due to extremely low numbers of tara iti that breed on the west coast (Ismar *et al*. 2014; Preddey & Pulham 2017; Ball 2023). Finally, each of the sampling methods has associated limitations and biases. These include morphologically distinctive fish species being recognised and reported more commonly anecdotally, and photographs of birds with fish being obtained more readily at breeding sites.

As a result, current data present only a partial picture of tara iti diet, and may not be fully representative of their diet throughout their range and outside of the breeding season. Without a specific objective to identify fish community health, population size, distribution and overall assemblages, combined with the aforementioned biases and lack of standardisation, the ability to evaluate and manage the estuarine ecosystems critical to tara iti survival (Ferreira *et al*. 2005) is severely constrained.

The comparative analysis of the estuarine fish species at Mangawhai and Waipū highlights the utility and limitations in sampling methods and available prey-based assessments to inform tara iti conservation. As the fish captured excluded exclusively marine or freshwater species, there are still significant gaps in this knowledege. As tara iti are known to forage in marine, estuarine, and freshwater environments (Ismar *et al*. 2014; Preddey & Pulham 2017), it is critical that future sampling spans all available foraging habitats. Methodologically, the integration of observational, anecdotal, and photographic data has further broadened the prey spectrum including novel records (e.g. rudd and olive rockfish). The increasing use of photographs to identify prey items will also start to inform prey size availability. Combining these data with those collected through biological samples and DNA metabarcoding expands the knowledge base further still.

This review emphasises the constraints and challenges associated with synthesising datasets collected with unequal efforts across sites and seasons, and varied methodologies to inform conservation decisions. However, it also highlights the value of a broad suite of sampling techniques and has created a robust baseline for site-level comparison; future research should expand on this framework. In order to do this, it is recommended that sampling techniques are standardised and undertaken with the intent of collecting fish-related data, rather than incidental records. Furthermore, data collection across all seasons and sites using complimentary survey techniques such as observational data and biological sample analysis alongside fish community assemblage sampling, will inform site-specific conservation decisions driven by prey-specific insights and further strengthen the evidence base for targeted management and long-term recovery planning for tara iti.

This review highlights variation in prey type availability between two of the four tara iti breeding sites, indicating the importance of incorporating local food source diversity and availability into tara iti management strategies. Our study also highlights the need for wider ecosystem restoration and research to ensure estuarine protection efforts prioritise the maintenance of diverse, abundant fish communities in order to support a growing tara iti population.

ACKNOWLEDGEMENTS

This work was undertaken by a wide group of DOC staff and volunteers. Surveys of the Waipū and Mangawhai estuaries, led by Ian Southey and Susan Steedman, were funded by the New Zealand Fairy Tern Charitable Trust. The increase in photography at breeding sites and the addition of photographic records of the different fish species was championed by Darren Markin. Tony Beauchamp provided invaluable advice and experience to support interests in diet and the wider ecosystems. All mahi to support tara iti conservation is undertaken in collaboration with Patuharakeke, Ngāti Wai, Ngāti Whātua o Kaipara, Ngāti Manuhiri, Te Uri O Hau, and the Pākiri G Trust and their kaitiaki.

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