MIT2020-08 draft report

Analysis of zooplankton samples collected 2020 - 2021

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Cover. Koheru (*Decapterus koheru*) school, Navire Rock, Mokohinau Islands 15 April 2021. *Screenshot from underwater videography: NNZST*.

Figure 1 (this page). Larval fish in a 'sea' of krill. *Photo: Edin Whitehead*.

SUMMARY

The aim of this and preceding research projects (POP2017-06, POP2019-02) is to better understand the relationship between the diet of sea-surface foraging seabirds, and prey items associated with fish workups [1]. This knowledge can then be used to help identify any mechanisms that could be changing the distribution, occurrence and/or abundance of workups and how that might in turn affect seabird populations. This report presents a summary of the analysis of zooplankton samples collected in the 2020-2021 sampling season (Gaskin et al. 2021) and their relationships with different types of seabird-feeding events. It forms a continuation of the fish school dynamics and zooplankton research conducted between 2017 – 2020 (2017-2018: Gaskin et al. 2019a; 2018-2019: Gaskin et al. 2019b; 2019-2020: Kozmian-Ledward et al. 2020). Six fieldwork days were undertaken in the wider northern Hauraki Gulf between 6 October 2020 and 26 March 2021. The vessel followed a similar route each day, and locations where seabirds were seen feeding were targeted for zooplankton sampling, fish captures, observations on seabirds and fish species, underwater videography, and environmental measurements. Four types of pelagic fish schooling events with associated feeding seabirds were sampled: Mixed Fish School, Kahawai School, Koheru School, and Fish School – unknown type. Two events where no schooling fish were seen but seabirds were feeding were sampled: Current Line and Unknown. Zooplankton samples were subsampled as required and counted into seven groups: Copepoda, Malacostraca, Krill, Thaliacea, Fish, Fish eggs and Other. Each event type was generally able to be defined by specific zooplankton, fish and seabird types/species and certain seabird feeding behaviours. Krill was found to be an important component of many of the fish school events that were sampled, with the krill preyed upon by both fish and seabirds.

This season's research was curtailed by Covid-19 restrictions resulting in a reduction in data collected and subsequent analysis. This needs to be considered when looking at data trends given in this report. There is a need to continue to develop the multi-disciplinary approach used here to fully investigate the associations between oceanographic factors, zooplankton, pelagic schooling fish and prey availability for seabirds in the wider Hauraki Gulf.

INTRODUCTION

Background

A notable feature of north-eastern North Island waters of Aotearoa - New Zealand are aggregations of large numbers of seabirds feeding in what are commonly known as "fish workup" events or "workups". These are typically multi-species feeding aggregations containing zooplankton and fish, and may at times also include cetaceans, e.g., Bryde's whale (*Balaenoptera edeni brydei*), common dolphin (*Delphinus delphis*), or manta rays (*Mobula birostris*). There is a need to better understand the processes that drive workup formation and dynamics as many seabird species, predominantly to drive smaller prey species to the sea surface, making them more accessible to the seabirds as a food

[1] Fish workup or workup are colloquial names for fish school or shoal activity at or close to the sea surface. Also known as bust ups (Australia). Technically, the term 'shoal' refers to a loose aggregation of fish, sometimes comprising different species, whereas a 'school' is typically a group of fish of the same species swimming together in synchrony (Delcourt & Poncin 2012).

RBGU[2], WFTE, AUGA, FAPR, BUSH and FLSH, are potentially dependent on schools of predatory fish source (Gaskin 2017). The relationship between the diet of surface-foraging seabirds, and what prey items are taken by seabirds aggregating at workups is poorly understood. Consequently, this has limited our understanding of the mechanisms through which any changes in the distribution and/or abundance of workups may be driving seabird population changes, such as population status and annual breeding success. For seabird species that interact with workups, population abundance data remains incomplete or unknown which limits our assessment of population trends over time (Gaskin et al. 2019c).

North-eastern North Island waters also support extensive purse-seine fisheries due to the presence of schooling pelagic fish, some of which are important in the diet of seabirds. Fish species targeted by these pelagic fisheries are predominantly kahawai (*Arripis trutta*), trevally (*Pseudocaranx georgianus*), skipjack tuna (*Katsuwonus pelamis*), jack mackerel (*Trachurus declivis*), blue mackerel (*Scomber australasicus*), saury (*Scomberesox saurus*), pilchard (*Sardinops sagax*) and anchovy (*Engraulis australis*). By harvesting fish species which also form part of workups utilised by various seabird species it is possible that seabird populations are negatively impacted by these fisheries. However, the degree to which this may occur is unknown, therefore it is important that we better understand the dependence of seabirds on feeding in association with these fish schools, and the relationship between seabird population trends and changes in abundance and distribution of fish schools.

Summary of previous work

The first report by the Northern New Zealand Seabird Trust (NNZST) for the DOC-CSP on seabird feeding associations with fish workups was as part of INT2016-04: Indirect effects of commercial fishing on Buller's shearwater and red-billed gulls (Gaskin 2017). This report summarised at-sea observations of seabird-fish school activity for the wider Hauraki Gulf region (Cape Brett to Cape Colville and the inner Hauraki Gulf) between October and March from 2006 – 2016. Distinct patterns of feeding behaviour by various Procellariiformes species were observed in relation to differing fish school compositions and activity; as well as at surface krill swarms where there was no fish workup present. A significant number of seabird/fish school observations were found to coincide with major bathymetric features interacting with current flows (e.g., Mokohinau Islands, North-West Reef, Horn Rock, Leigh Reef) and these areas were focussed on in successive research. Zooplankton sampling within fish workups was started in 2017-2018 with the aim of identifying the range of potential seabird prey types available (POP2017-06: Gaskin et al. 2019a). Zooplankton were sampled using a conical plankton net; conducting vertical hauls and horizontal surface tows; inside and outside fish workups, and at current lines. Zooplankton were enumerated into seven taxonomic groups: Copepoda, Malacostraca, Thaliacea, Chaetognatha, Appendicularia, Fish eggs and "Other".

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[2] Seabird codes developed by NNZST: **AUGA:** Australasian gannet (*Morus serrator*), **BLPE:** black petrel, **BUSH:** Buller's shearwater (*Ardenna* (*Puffinus*) *bulleri*), **CODP**: common diving petrel (*Pelecanoides urinatrix*), **COPE:** Cook's petrel (*Pterodroma cookie*), **FAPR:** fairy prion (*Pachyptila turtur*), **FFSH:** flesh-footed shearwater (*Ardenna carneipes*), **FLSH:** fluttering shearwater (*Puffinus gavia*), **GRNO**: grey noddy (*Anous albivittus*), **NZSP**: New Zealand storm petrel (*Fregetta maoriana*), **RBGU:** red-billed gull (*Larus novaehollandiae scopulinus*), **SOSH:** sooty shearwater (*Ardenna grisea*), **STSH:** short-tailed shearwater (*Ardenna tenuirostris*), **WFTE:** white-fronted tern (*Sterna striata*), **WFSP:** white-faced storm petrel (*Pelagodroma marina*).

Zooplankton abundance tended to be highly variable between samples and even between replicates, however, a general seasonal trend was seen with Copepoda being most abundant in spring, Malacostraca and Thaliacea most abundant in summer and Appendicularia most abundant in autumn. No significant differences were found in the total or relative abundance of zooplankton groups from samples taken inside and outside of workups, but given the opportunistic nature of sampling, only a relatively small number of samples were taken.

Complimenting the zooplankton sampling were analyses of seabird regurgitations collected from colonies (Gaskin et al. 2019d). Regurgitation samples from FLSH, FAPR and BUSH were comprised predominantly of zooplankton. Zooplankton were enumerated into the same taxonomic groups as above with the most commonly found prey being Malacostraca (predominantly krill of varying life stages) and Other (juvenile fish)

Zooplankton sampling and analysis for POP2017-06 was continued in 2018-2019, again collecting zooplankton net samples (vertical hauls and horizontal surface tows) opportunistically during various NNZST trips, in the northern wider Hauraki Gulf region (Gaskin et al. 2019b). Zooplankton samples collected by the Auckland Whale and Dolphin Safari (AWADS), from the central Hauraki Gulf, were also analysed. Zooplankton were enumerated into the same taxonomic groups as before, with the addition of a Nauplii group and Chaetognatha being included in the Other group. In the NNZST samples, Thaliacea dominated most samples during spring; in the summer samples Malacostraca and Fish eggs became more dominant, while in autumn Copepoda were often the most abundant. The stomach contents of trevally and kahawai captured at the same time as zooplankton sampling indicated selective feeding of Malacostraca and Nauplii. The AWADS samples taken in the inner Hauraki Gulf often had a different zooplankton composition compared to those taken by NNZST in the outer Gulf, which was thought to be due to the differences in location and types of workups. Overall, no significant differences were found between the zooplankton composition of samples collected inside and outside of workups.

During 2019-2020, nine fieldwork days in the wider northern Hauraki Gulf were undertaken solely to collect data and zooplankton samples on associations between zooplankton, schooling fish, and feeding seabirds for POP2019-02 (Kozmian-Ledward et al. 2020). Three types of fish school event were defined (based on those observed by Gaskin 2017) and sampled: Mixed Fish School, Kahawai School and Tuna School. Three types of non-fish school events where seabirds were feeding were defined and sampled: Current Line, Krill Patches, and Unknown. Zooplankton samples were counted into seven groups: Copepoda, Malacostraca, Nauplii (krill), Thaliacea, Appendicularia, Fish eggs and Other. Each event type was able to be defined by specific zooplankton, fish and seabird types/species and certain seabird feeding behaviours. Krill was found to be an important component of fish school events and preyed upon by both fish and seabirds. Krill was also found at high abundances at Krill Patch events where fish schooling did not occur, but seabirds were seen feeding on the krill. The 2019-2020 season's research was curtailed by Covid-19 restrictions, reducing the planned number of fieldwork days and hence the amount of data available for a detailed analysis.

Seabird feeding associations

Zooplankton occupy a key position in the pelagic food web, transferring the organic energy produced by phytoplankton to higher trophic levels such as fish, seabirds, and baleen whales (Harris et al. 2000; Frederiksen et al. 2006). Zooplankton abundance and diversity are determined predominantly by oceanographic (e.g., temperature, upwelling zones) and biological factors (e.g., predation, phytoplankton productivity) resulting in a high degree of spatial and temporal variability (Zeldis & Willis 2015).

Observations made during zooplankton sampling trips in previous years and during other seabird research trips have identified various types of seabird-feeding events associated with schooling pelagic fish (Table 1). Other types of seabird-feeding events can also be characterised where pelagic fish are not apparent but there are prey available to seabirds (e.g., Current Lines, Krill Swarms). Seabirds utilise a variety of feeding techniques depending on the prey species being targeted and the physical capabilities (e.g., diving, swimming) of the seabird species. Numbers of seabirds attending these feeding events will vary from a handful to tens of thousands.

The research and observations made during previous years for this project in the waters of north-east North Island, have determined prey types of various seabird species feeding in association with schools of pelagic fish. Of the zooplankton, krill (likely to be mainly *Nyctiphanes australis*) appear to be an important prey for BUSH, FLSH, FAPR, RBGU and WFTE (Gaskin et al. 2019b, d). AUGA feed on a variety of planktivorous fish species that include krill in their diet (Gaskin et al. 2019d). Krill is also targeted by larger predatory pelagic fishes such as kahawai, trevally, and albacore tuna (*Thunnus alalunga*) (Gaskin et al. 2019b; Kozmian-Ledward et al. 2020). Dense krill swarms have been observed via underwater videography (floating GoPro rig); particularly at Mixed Fish Schools but also sometimes at the Kahawai School events (Table 1). Patches of krill near the sea surface are seen to mass frenetically as the fish appear to prey on them. Despite these observations, there is still poor knowledge of the diet of sea surface-foraging seabirds and the prey items they are taking during fish workups.

Table 1. Types of seabird-feeding events encountered in the 2020-2021 sampling season (modified from Gaskin 2017). Definition of seabird species codes given below.

Event type	Fish species	Seabird species	Activity
Mixed Fish School	Trevally (often the dominant fish species), kahawai, blue maomao, kingfish. Can be just trevally schools.	BUSH, FLSH, FAPR, RBGU, WFTE (plus sometimes SOSH, FFSH, STSH, WFSP, COPE, GRNO)	Tightly packed, very active dense schools, sometimes with several schools merging to form very large schools. Birds either forage in the wake of the schools, or sometimes feed ahead of and around the schools. Fish will erupt explosively if disturbed either from below (e.g., predatory fish) or from above (e.g., birds flying low over school). Shearwaters and prions have been filmed diving in the wake of school activity.
Kahawai School	Kahawai	FLSH, WFTE RBGU, FAPR	Fast-moving schools, birds moving in 'leap-frogging' formations, shearwaters plunging and diving.

			Also, tightly packed schools separate from trevally schools in the same vicinity.
Koheru School	Koheru	RBGU, FLSH	Fairly tightly packed and visible at the surface.
Baitfish School	Pilchard, anchovy, koheru	AUGA, FLSH, BUSH (FFSH, WFSP, COPE)	Often tightly packed schools, sometimes forming spinning 'bait balls' close to the surface. Birds plunging/diving and pursuing prey underwater. Can occur in association with common dolphins.
Krill Patches or Swarms	*Nyctiphanes australis*	BUSH, WFSP, FAPR, COPE, CODP	Birds, either individually or in small groups pecking at krill close to the surface; sometimes making small, flighted dashes to new areas, possibly triggered by activity at surface made by schools of small fish feeding on the krill.
Current Lines	No fish school	FAPR, FLSH, WFSP	Current lines containing planktonic crustaceans, salps and juvenile fish. Birds actively feeding without prey being visible at the surface.

Study area

The study area is located off the north-east North Island, including the northern Hauraki Gulf (Fig. 2). This includes areas where research work has been conducted in previous projects (INT2016-04, POP2017-06 and POP2019-02). Research on seabird feeding associations and diet has been conducted in this area for several years due to the islands in this area being important breeding areas for 27 species which forage in the surrounding waters (Gaskin & Rayner 2013; Forest & Bird 2014).

The wider Hauraki Gulf is a highly productive marine ecosystem with the degree of productivity influenced by both wind and current driven circulation (Taylor & Gaskin 2020). Offshore winds during spring cause upwelling of cool, nutrient rich waters, which together with increasing daylight, promote high levels of phytoplankton production (Booth & Sondergaard 1989; Sharples & Greig 1998). During the summer, the Hauraki Gulf and the surrounding coast are influenced by the warm, nutrient-poor surface waters of the East Auckland Current (EAUC), which are pushed inshore by easterly winds (Chang et al. 2003; Sharples 1997). The EAUC, combined with downwelling caused by the onshore winds, reduces primary productivity during late summer and autumn (Chang et al. 2003). Physical barriers such as headlands and islands enhance local upwelling, together with tidal currents in the Jellicoe, Cradock and Colville Channels that can attain up to three knots (Black et al. 2000; Royal NZ Navy Hydrographic Office Chart NZ53). Sea Surface Temperature (SST) typically ranges from 12.5 to 22 ° C across the Hauraki Gulf (Paul 1968).

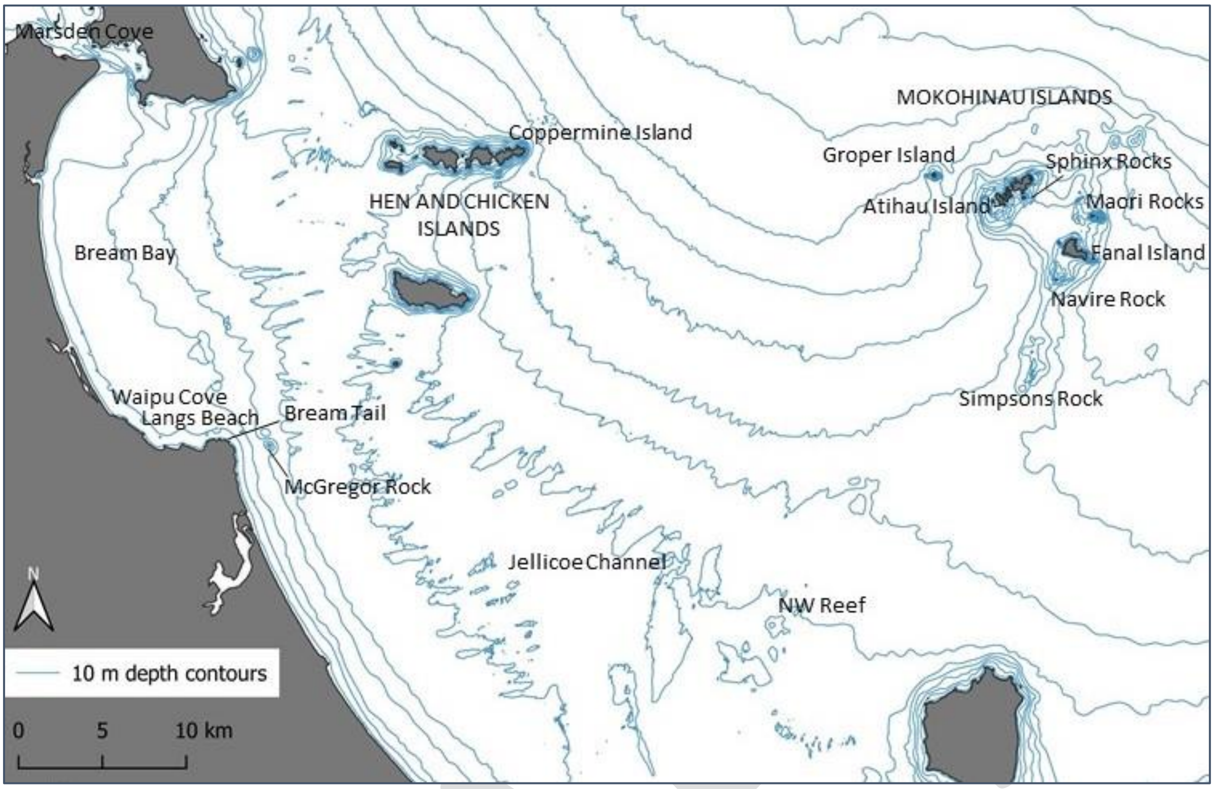

Figure 2. Study area with labelled locations where sampling was undertaken.

METHODS

Field methods

In general, the methodology adopted here was based on that previously described in POP2019-02 (Kozmian-Ledward et al. 2020). However, a major change was to move from a general search for seabird activity over a wide area to following the same basic route with sampling stations determined by activity encountered while vessel cruising. This aimed to provide greater consistency in sampling methods and improve statistical rigour. The same approximate route was undertaken each survey day, starting, and finishing at Marsden Cove Marina, and covering the Marotere/Chicken Islands, Mokohinau Islands including Simpson Rock, North-West Reef, Bream Tail and Bream Bay. This route was undertaken six times over seven fieldwork days between 6 October 2020 and 26 April 2021. The aim was to conduct one trip a month, however, Covid-19 restrictions, vessel unscheduled unavailability and weather conditions meant that no trips were undertaken in January and March.

Fieldwork was undertaken during daylight hours and in calm conditions where possible (Beaufort 3 or less). The general route outlined above was undertaken either in a clockwise or anticlockwise direction with observers continually scanning for seabird and/or surface fish activity (workups). Seabird feeding events where there was no obvious surface fish activity, but birds were feeding, such as along current lines (i.e., flow lines visible at the surface, and sometimes with accumulations of algae and other natural debris such as feathers and vegetation) were also opportunistically sampled while looking for workups.

On arrival at an event, the GPS position and time were recorded together with information on the type of seabird and fish activity occurring. The species of seabirds were recorded, as well as a visual estimate of their numbers and notes on their behaviour. Fish species were recorded where possible with their behaviour. For example, if they were forming dense schools feeding at the surface or the activity was quieter and mostly well below the sea surface. The floating underwater camera rig was deployed at many events to identify schooling fish species and to record activity occurring underwater. A new camera rig was tested that contained multiple cameras that could either be set to various depths down the water column or dropped down through the water column to record fish and other activity beneath work up activity or at sampling locations. The presence of other marine megafauna (e.g., cetaceans, mobulid rays) were also recorded. A YSI meter was used to measure the SST and water clarity was measured using a Secchi disc to the nearest metre.

Zooplankton samples were collected using a conical plankton net, mesh size 1.3 mm, mouth diameter 750 mm, with a flowmeter (General Oceanics 2030R) mounted in the centre of the net mouth (Fig. 3). A tow camera was integrated into the net bridle facing into the net. The net was towed at three knots just below the sea surface, 30 m behind the vessel, for around five minutes, as close to the workup activity as possible where present. One zooplankton sample was collected at each event. Some control zooplankton tows were also undertaken in one of two ways; either in the vicinity of a previously sampled event where activity was no longer occurring, or as an isolated sample at a location where no activity was occurring but where activity had been seen on previous trips. Zooplankton samples were stored in 100% ethanol and were subsampled on the boat if they were too large to preserve in their entirety.

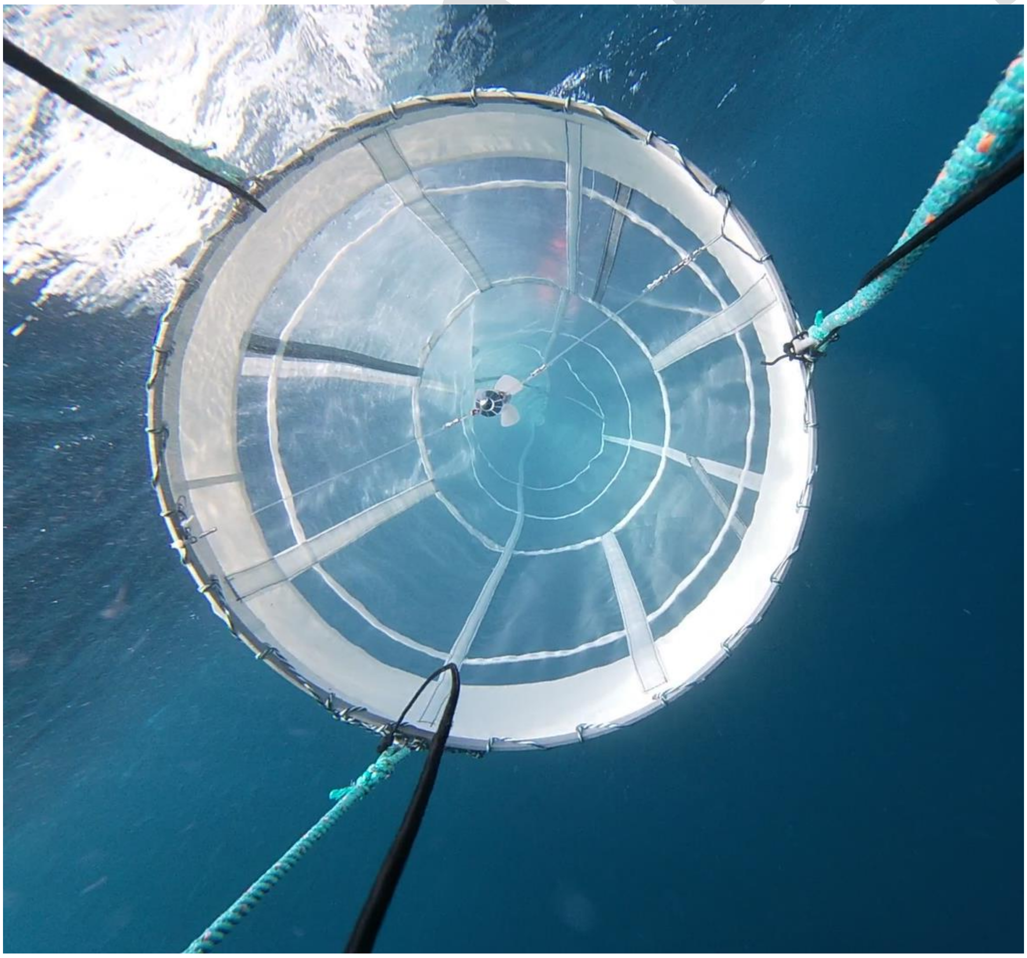

Figure 3. Zooplankton net, viewed from a backward facing tow camera mounted in the tow bridle. The flowmeter is visible in the centre of the mouth of the net. *Screenshot from underwater videography: NNZST*.

Fish were caught on rod and line (with bait and/or lures) at events to sample stomach contents for prey identification. When fish were caught, those required for sampling were euthanised immediately by pithing with a spike into the brain cavity. Any other fish caught were returned immediately back to the sea. The length (fork length) and species of all fish landed was recorded. All manipulations were conducted in accordance with the Animal Ethics permit (AEC 14829). The stomach contents of each fish were immediately removed and stored in 100% ethanol. Several fish had empty stomachs, and this was recorded.

Laboratory methods

Zooplankton samples were sub-sampled as required in the laboratory, and counted into seven taxonomic groups: Copepoda, Malacostraca (excluding krill), Krill, Thaliacea, Larval fish, Fish eggs and Other. The categories Appendicularia and Nauplii, used for sorting zooplankton in previous years, were not used this year as they were either not present or only in small numbers respectively. This may have been due to them being excluded by the coarser size of the mesh on the zooplankton net – no zooplankton samples were collected using the finer mesh net this year. Due to the importance of krill in the diets of various seabird and fish species, krill had a separate category this year.

A summary of the taxa details of zooplankton included in each of these groups are given in Gaskin et al. (2019b). Larval fish were collected during the counting process for later identification by Dr T. Trnski (Auckland Museum). The raw counts for each zooplankton group per sample were corrected for the degree of sub-sampling (in the field and the laboratory) and for the volume filtered by the net, by converting the flowmeter readings using the following equations. Abundances were then expressed as number of zooplankton per m^3 of seawater sampled.

Equation 1: Distance, m = Difference in counts x Rotor constant (26,873) / 999999

Equation 2: Volume, m^3 = {3.14159 x (Net mouth radius)^2} x Distance

Samples of fish stomach contents were in varying degrees of digestion which could affect prey identification and enumeration. Samples were subsampled if required and the contents identified and enumerated in the same way as the zooplankton tow samples. Samples often consisted only of the less digestible portions of krill (chitinous parts) and counts were estimated where possible.

From each zooplankton and fish stomach sample containing krill, 50 whole individuals (if present) were randomly selected, photographed and the length (anterior eye to telson) measured from the photos using the open-source program Image J (Schindelin et al. 2012; Fig. 4). This was undertaken to provide a snapshot of potential trends in krill size and therefore life-cycle stage.

Figure 4. Mature female krill with eggs showing body length measurement. *Photo: Charlie Johnson, University of Auckland/NNZST.*

RESULTS

Seabird feeding events

Sampling was conducted at 39 locations over the six trips, 35 of which were where seabirds were seen feeding and four Control locations with no seabird feeding activity (Fig. 5; Table 2). The Control sites comprised two sites at the Mokohinau Islands and one each at North-West Reef and off Langs Beach. At these locations, no birds were present but often fish were present. The sampling trip on 15 April 2020 was particularly quiet in terms of seabird activity with only two seabird feeding events found.

Most of the seabird feeding events could be described as Mixed Fish School events and these were found on five out of six sampling trips, most commonly around the Mokohinau Islands but also at Coppermine Island and North-West Reef. At these events the predominant fish species present was trevally, often together with large numbers of kahawai. Fish feeding could be very active near the surface. Below the trevally and kahawai were often koheru and the occasional kingfish (*Seriola lalandi*), and if close to a rock or island then blue maomao (*Scorpis violacea*) and sweep (*Scorpis lineolatus*) were often present mid-water closer to a reef. Bronze whaler sharks (*Carcharhinus brachyurus*) were observed on several occasions in the fish schools. Seabird species present in high numbers at these events were RBGU, FAPR, FLSH and BUSH.

Four Kahawai Schools were found near the mainland coast in and around Bream Bay over three sampling trips. The most commonly associated seabirds with Kahawai Schools were RBGU, WFTE, FLSH and BUSH. At Navire Rock on 15 April 2020, a school of koheru was seen on the underwater cameras with many RBGU plus some FLSH feeding. At seven seabird feeding events, fish were present, but the species were unable to be determined and the event type defined. From the seabird species and their behaviour, the fish species likely to be present were often able to be presumed. These Unknown Fish School events occurred at the Mokohinau Islands, North-West Reef, Coppermine Island and Jellicoe Channel.

The two Current Line events occurred to the E and SE of Coppermine Island on the October and November trips. FAPR dominated at the former and RBGU at the later. Three events were defined as Unknown as there was no fish activity detected (although there may have been in deeper water) but there was seabird feeding activity. Two Unknown events were found at the Mokohinau Islands in October and one off Langs Beach in April.

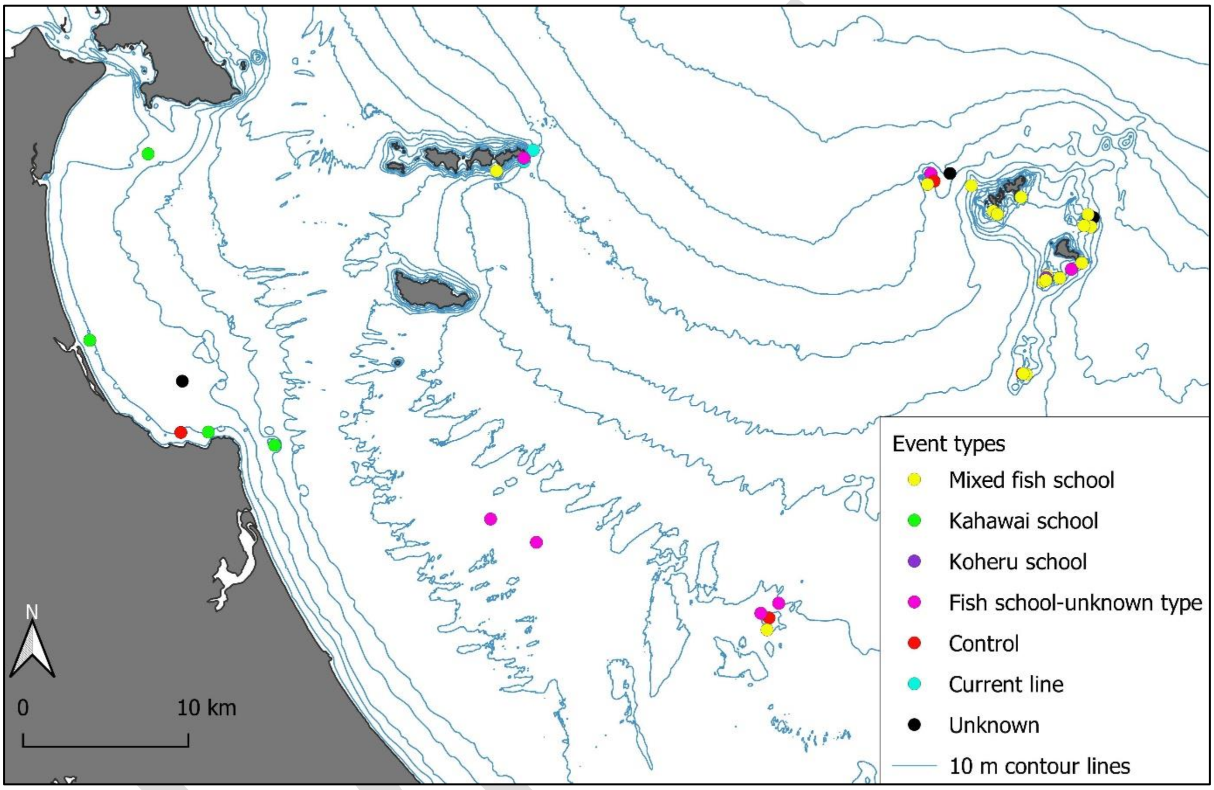

Figure 5: Sampling locations and event types.

Table 2: Event descriptions at sampling locations. Surface and underwater fish observations given where available. Where underwater video recordings were made, more detail has been provided on fish species.

Date	Event #	Event type	Location	Description
6/10/2020	1	Current Line	E. Coppermine Island	Birds scattered and moving in groups detecting activity. FAPR (dom. sp.), FLSH, LISH (1).
6/10/2020	2	Unknown	Groper Island, Mokohinau Islands	Groups of prions and shearwaters moving about, gulls staying put. FAPR (1000s), BUSH (100s), RBGU (50-100),

				WFTE (<10), BBGU (1). Humpback whale in vicinity.
6/10/2020	3	Mixed Fish School	Sphinx Rocks, Mokohinau Islands	Fish active at surface close to the rock: trevally, kahawai. RBGU (200-300), FAPR (c.100), BUSH, FLSH.
6/10/2020	4	Unknown	Maori Rocks, Mokohinau Islands	FAPR, BUSH, RBGU (<10), AUGA also present coming and going to colony. No visible fish schools.
6/10/2020	5	Fish School-Unknown type	S. Fanal Island, Mokohinau Islands	Bird activity without visible fish schools. Presumed trevally school. 2 trevally caught. FAPR (100s), BUSH (10s), BBGU (1).
6/10/2020	6	Control	North-West Reef	No birds or fish during sampling.
6/10/2020	7	Mixed Fish School	North-West Reef	Trevally. RBGU (50-100), WFSP, FAPR, FLSH.
6/10/2020	8	Fish School-Unknown type	Jellicoe Channel	Many gannets either on the water or following common dolphins in split pods, occasionally with dramatic diving. Baitfish likely present. AUGA (100s), FFSH, SOSH, BUSH, FLSH.
20/11/2020	9	Current Line	SE Coppermine Island	RBGU (~500) were foraging on arrival, sporadic foraging during sampling.
20/11/2020	10	Mixed Fish School	Maori Rocks, Mokohinau Islands	Trevally, kahawai, koheru. ~1000 birds, FAPR, RBGU.
21/11/2020	11	Fish School-Unknown type	Groper Island, Mokohinau Islands	Intermittent workup, presumed mackerel school. FAPR (~1000), FLSH.
21/11/2020	12	Mixed Fish School	S. Atihau Island, Mokohinau Islands	Trevally. FAPR (dom. sp.), RBGU.
21/11/2020	13	Control	Simpson Rock, Mokohinau Islands	No birds or fish present
21/11/2020	14	Mixed Fish School	Navire Rock, Mokohinau Islands	Trevally. FAPR (~1000), FFSH (<10).
23/12/2020	15	Control	Langs Beach	Bait fish visible on sounder. 1 kahawai caught. Few WFTE.
23/12/2020	16	Kahawai School	McGregor Rock, Mokohinau Islands	Kahawai. RBGU (~60), FLSH (~60), WFTE, FLSH (2).

23/12/2020	17	Fish School-Unknown type	Jellicoe Channel	Mackerel or trevally school; very mobile. ~1200 birds, FLSH (dom. sp.), BUSH, WFSP, FFSH.
23/12/2020	18	Fish School-Unknown type	North-West Reef	Fish school went down on approach. ~400 birds, BUSH (dom. sp.) FLSH.
23/12/2020	19	Mixed Fish School	Simpson Rock, Mokohinau Islands	Mainly trevally, some kahawai, snapper, bronze whaler shark. FAPR (~500), WFSP, BUSH.
23/12/2020	20	Mixed Fish School	Navire Rock, Mokohinau Islands	Trevally. FAPR (~1500), RBG (~30), BUSH & FFSH (~10 each).
23/12/2020	21	Mixed Fish School	Maori Rocks, Mokohinau Islands	Trevally, kahawai, snapper. FAPR (~80), BUSH (~10).
23/12/2020	22	Mixed Fish School	NW Atihau Island, Mokohinau Islands	Trevally, koheru. FAPR (~1200), SOSH, BUSH.
23/12/2020	23	Fish School-Unknown type	SE Coppermine Island	Unknown fish school. RBGU (~2000).
3/2/2021	24	Kahawai School	Bream Bay	Kahawai with small fish prey, fast moving, some kahawai at surface. FLSH (~100), FFSH (2), BUSH (10), WFTE (5), Terns taking small fish including anchovy.
3/2/2021	25	Kahawai School	Bream Tail	Kahawai. FLSH (~500), BUSH (~100), FFSH (<5), WFTE (<10), RBGU (<5): well-spread.
3/2/2021	26	Fish School-Unknown type	North-West Reef	Near surface: few kingfish, some unidentified juvenile fish. Near bottom: sweep school, few kingfish. Unidentified fish deeper down. FFSH (~30), BUSH (~200), BLPE (1), COPE rafting, WFSP (~5), LBPN (2).
3/2/2021	27	Mixed Fish School	Navire Rock, Mokohinau Islands	Trevally, kahawai, koheru. Bronze whaler shark. RBGU (~1000), BUSH (~100), FLSH (~300), FAPR (~150).

3/2/2021	28	Mixed Fish School	Maori Rocks, Mokohinau Islands	Trevally, kahawai, koheru, kingfish. RBGU (1500+), FAPR (50), BUSH & FLSH (~50 combined). Manta ray.
3/2/2021	29	Mixed Fish School	SE Coppermine Island	Trevally, kahawai. RBGU (13), AUGA (2), FLSH, Bronze whaler shark.
15/4/2021	30	Unknown	Langs Beach	BUSH, WFTE, FLSH ~100 total of all species. Sparse foraging.
15/4/2021	31	Control	Groper Island, Mokohinau Islands	Kahawai and trevally near surface, blue maomao school under, kingfish. No birds.
15/4/2021	32	Koheru School	Navire Rock, Mokohinau Islands	Koheru. RBGU (~1200), FLSH (~60).
26/4/2021	33	Kahawai School	Waipu Cove	Kahawai. Scattered workup. RBGU (~50), WFTE (~50), ~100 FLSH showed up later.
26/4/2021	34	Mixed Fish School	Simpsons Rock, Mokohinau Islands	Trevally. RBGU (~10), WFTE (~10).
26/4/2021	35	Mixed Fish School	SE Fanal Island, Mokohinau Islands	Trevally. RBGU <10), shark took fish off the line.
26/4/2021	36	Mixed Fish School	Navire Rock, Mokohinau Islands	Trevally. RBGU (~700).
26/4/2021	37	Mixed Fish School	Maori Rocks, Mokohinau Islands	Small school of trevally. RBGU (~100).
26/4/2021	38	Mixed Fish School	S. Atihau Island, Mokohinau Islands	Trevally. RBGU (~15).
26/4/2021	39	Mixed Fish School	Groper Rock, Mokohinau Islands	Trevally. RBGU (~1200), FLSH (~40), FAPR (~5).

Zooplankton samples

One zooplankton sample was collected at each of the 39 event locations. The number of zooplankton from each taxonomic group per sample was graphed in two ways, as the number of zooplankton per m^3 seawater filtered by the net (Fig. 4A, 4B) and as a relative (percentage) abundance (Fig. 5).

General observations seen across all the zooplankton samples:

- Copepoda were found in 41% of samples; maximum abundance 4.5 per m^3 at Event 23, an Unknown Fish School at Coppermine Island. Copepoda were predominantly calanoid copepods.

- Krill was found in 87% of samples; maximum abundance 129.8 per m^3 at Event 22, Mixed Fish School, Atihau Island. The predominant krill species was presumed to be *N. australis* at a variety of life stages. Another type of krill species appeared to be present in smaller numbers. Some diseased or parasitized krill were also found. Few krill nauplii were found, likely due to them passing through the coarse-sized mesh of the net.
- Malacostraca (excluding krill) were found in 87% of samples; maximum abundance 10.2 per m^3 at Event 17, an Unknown Fish School in Jellicoe Channel. Malacostraca types included stomatopod, crab, squat lobster, caridean shrimp, and porcelain crab larvae; *Jaxea* sp., *Lucifer* sp., amphipods.
- Thaliacea were found in 92% of samples; maximum abundance 349.4 per m^3 at Event 17, an Unknown Fish School in Jellicoe Channel. Thaliacea comprised mainly salps plus some doliolids.
- No Appendicularia were found in any samples.
- Larval fish were found in 49% of samples; maximum abundance 1.3 per m^3 at Event 35, a Mixed Fish School at Fanal Island.
- Fish eggs were found in 38% of samples; maximum abundance 1.25 per m^3 at Event 25, a Kahawai School at Bream Tail.
- Zooplankton from the group 'Other' were found in 59% of samples; maximum abundance 2.6 per m^3 at Event 16, a Kahawai School at McGregor Rock. Zooplankton types in Other included pterotracheidae, chaetognatha, medusae, cladocera, siphonophores, jellies, squid larvae.
- Microplastics were found in the majority of samples.

Fish Schooling events

There were 18 samples from Mixed Fish Schools and the total number of zooplankton in these ranged from 0.5 – 202.1 per m^3. Nearly all samples of zooplankton collected on the 26 April 2020 were very small in volume. The majority of zooplankton samples were dominated by Krill (up to 129.8 per m^3) with the remainder dominated by Thaliacea (up to 197.3 per m^3).

There were four samples from Kahawai Schools and the total number of zooplankton in these ranged from 1.4 – 358.5 per m^3. The largest proportion of zooplankton in these samples was Thaliacea (up to 349.4 per m^3). There was no Krill in any samples and the Malacostraca was comprised of stomatopod, porcelain crab and shrimp larvae plus *Lucifer* sp.

The sample taken from the Koheru School was small at 3.6 total zooplankton per m^3 and was comprised mainly of Krill (2.7 per m^3).

Seven samples were taken from Unknown Fish Schools. The total number of zooplankton in these ranged from 0.9 – 406.4 per m^3. Three samples (E17, 18, 23) were mainly comprised of high numbers of Thaliacea (262.5 – 391.2 per m^3) but also contained the highest numbers of Copepoda (1.7 – 4.5 per m^3) compared to all other samples. E17 from the Jellicoe Channel also had the highest number of Malacostraca (10.2 per m^3), comprised of stomatopod and crab larvae.

Four samples were taken from Control events with total zooplankton numbers ranging from 1.1–16.2 per m^3. The lowest zooplankton abundance was from E13, Simpson Rock and the largest at E31, Groper Island, which comprised mainly of Thaliacea. The sample taken at E6, North-West Reef had the highest number of Krill of all the Control samples at 2.4 per m^3, higher than the three other samples taken at North-West Reef from Mixed Fish School events.

Other events

The two samples taken at Current Line events off the E and SE of Coppermine Island had a total of 22.2 and 5.5 zooplankton per m^3 respectively. The former sample was dominated by Krill (15.4 per m^3).

Three samples were taken from Unknown events with total zooplankton counts ranging from 0.1 – 16.3 per m^3. The two larger samples (E2, Groper Island and E4, Maori Rocks) were dominated by Krill (up to 15.8 per m^3).

Figure 6A: Abundance of zooplankton in each sample. The Event ID gives the date, event number and event type (MF-Mixed Fish School, KA-Kahawai School, KO-Koheru School, FS – Fish School (unknown type), CL – Current Line, UN – Unknown, CO - Control).

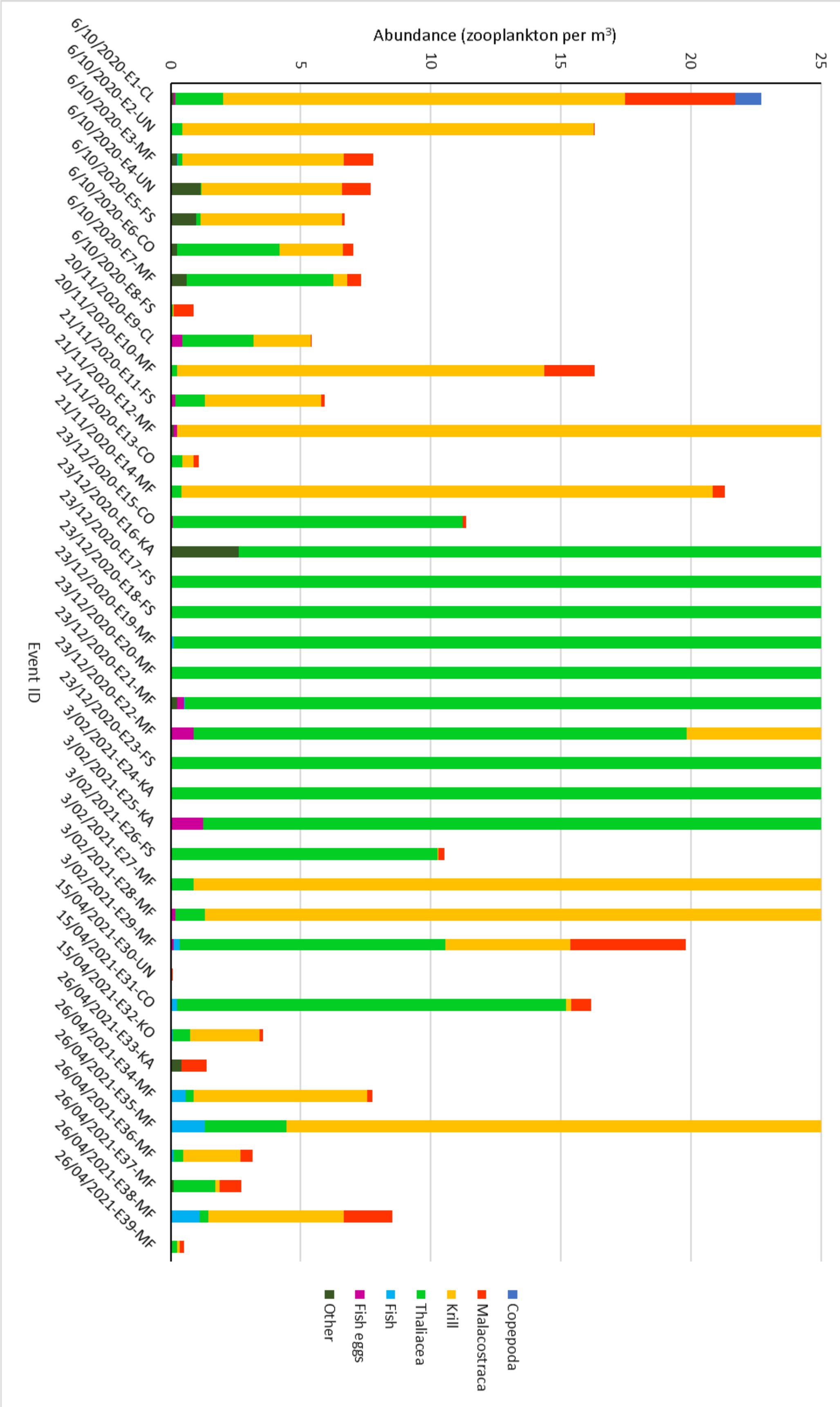

Figure 6B: Abundance of zooplankton in each sample showing abundances < 25 zooplankton per m^3 more clearly. The Event ID gives the date, event number and event type (MF-Mixed Fish School, KA-Kahawai School, KO-Koheru School, FS – Fish School (unknown type), CL – Current Line, UN – Unknown, CO - Control).

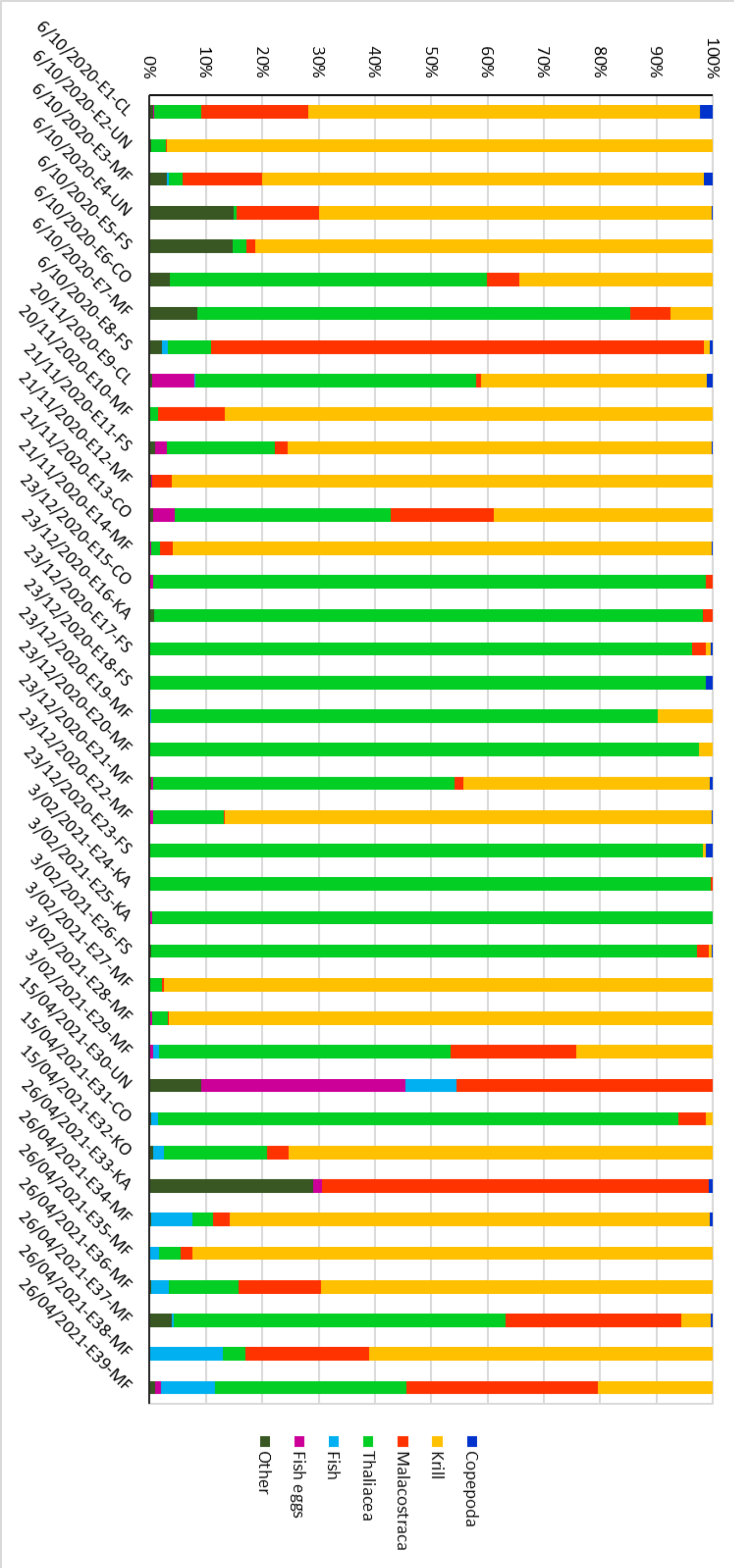

Figure 7. Relative abundance (%) of each zooplankton group within each sample. The Event ID gives the date, event number and event type (MF-Mixed Fish School, KA-Kahawai School, KO-Koheru School, FS – Fish School (unknown type), CL – Current Line, UN – Unknown, CO - Control).

Fish captures

Twenty-six fish were captured from 18 events for gut contents analysis (Table 3). Overview of all fishes landed:

- Trevally, (n=15), 36 – 53 cm FL
- Kahawai, (n=5), 35 – 57 cm,
- Koheru, (n=3), 34 – 41 cm,
- Kingfish, (n=1), 93 cm
- Snapper, *Chrysophrys auratus*, (n=2), 34 and 48 cm

The sampled trevally, kahawai and koheru gut contents were predominantly Krill, with two trevally also containing fish remains (Trev10 and 15). A single kingfish sample had only fish remains in the gut. Other prey found in trevally (Trev5, 13, 14, 15) and kahawai (Kaha5), were crab, shrimp and squat lobster larvae; and pteropods. The two sampled snapper had empty guts (Table 3).

Table 3. Details of sampled fish for stomach contents analysis. Fish codes: Trev – trevally; Kohe – koheru; Kaha – Kahawai; Snap – Snapper; King – kingfish.

Event ID	Event type	Fish #	FL (cm)	Notes
6/10/2020-E5	Fish School-Unknown type	Trev 1	53	Empty stomach.
6/10/2020-E5	Fish School-Unknown type	Trev 2	44	Empty stomach.
20/11/2020-E10	Mixed Fish School	Trev 3	45	Large sample, all krill.
20/11/2020-E10	Mixed Fish School	Trev 4	47	Large sample, all krill.
20/11/2020-E10	Mixed Fish School	Kohe 1	34	Quite digested, appears to be mainly/all krill.
21/11/2020-E14	Mixed Fish School	Trev 5	45	Partially digested, appears to be mainly krill; two crab larvae.
23/12/2020-E15	Control	Kaha 1	38	Empty stomach.
23/12/2020-E19	Mixed Fish School	Snap 1	34	Mostly empty stomach, few unidentifiable items.
23/12/2020-E19	Mixed Fish School	Kaha 2	57	Very digested sample, appears to be mainly/all krill.
23/12/2020-E19	Mixed Fish School	Trev 6	38	Empty stomach.
23/12/2020-E20	Mixed Fish School	Trev 7	44	Large sample, all krill.
23/12/2020-E21	Mixed Fish School	Snap 2	48	Empty stomach except for two unidentifiable items.
23/12/2020-E21	Mixed Fish School	Trev 8	43	Large sample, all krill.
23/12/2020-E22	Mixed Fish School	Kohe 2	38	Sample missing.

3/2/2021-E24	Kahawai School	Kaha 3	35	Empty stomach.
3/2/2021-E26	Fish School-Unknown type	King 1	93	Small, very digested sample. Appear to be remains of small fish - some pieces of spine.
3/2/2021-E27	Mixed Fish School	Trev 9	44	Quite digested, appears to be mainly/all krill.
3/2/2021-E27	Mixed Fish School	Trev 10	44	Quite digested, appears to be mainly/all krill plus potentially some fish flesh/skin.
3/2/2021-E28	Mixed Fish School	Kaha 4	53	Large sample, partially digested, appears to be mainly/all krill.
3/2/2021-E29	Mixed Fish School	Trev 11	46	Very digested, appear to be mainly/all krill pieces.
15/4/2021-E31	Control	Trev 12	40	Very digested, appear to be mainly/all krill pieces.
15/4/2021-E31	Control	Kaha 5	48	Mainly krill; one pteropod.
15/4/2021-E32	Koheru School	Kohe 3	41	Very digested, appear to be mainly/all krill pieces.
26/4/2021-E34	Mixed Fish School	Trev 13	36	Large sample, mainly krill, one pteropod.
26/4/2021-E35	Mixed Fish School	Trev 14	39	Large sample, mainly krill. Shrimp and squat lobster larvae, six in total.
26/4/2021-E36	Mixed Fish School	Trev 15	43	Large sample, partially digested, mainly krill. One of each: crab larva, pteropod, larval fish.

Thirteen out of the total 26 fish landed (10 trevally, 1 koheru, 2 kahawai) had stomach contents in good enough condition for prey enumeration and comparison with the corresponding zooplankton tow sample (Fig. 8). All the fish were caught at Mixed Fish School events except for one kahawai caught at a Control event. The sampled fish all contained greater proportions of Krill than the corresponding zooplankton tow sample from the same event. This is most evident at Events 20 and 31, where the fish guts contained > 99.7% Krill compared to < 2.4% Krill in the zooplankton tow.

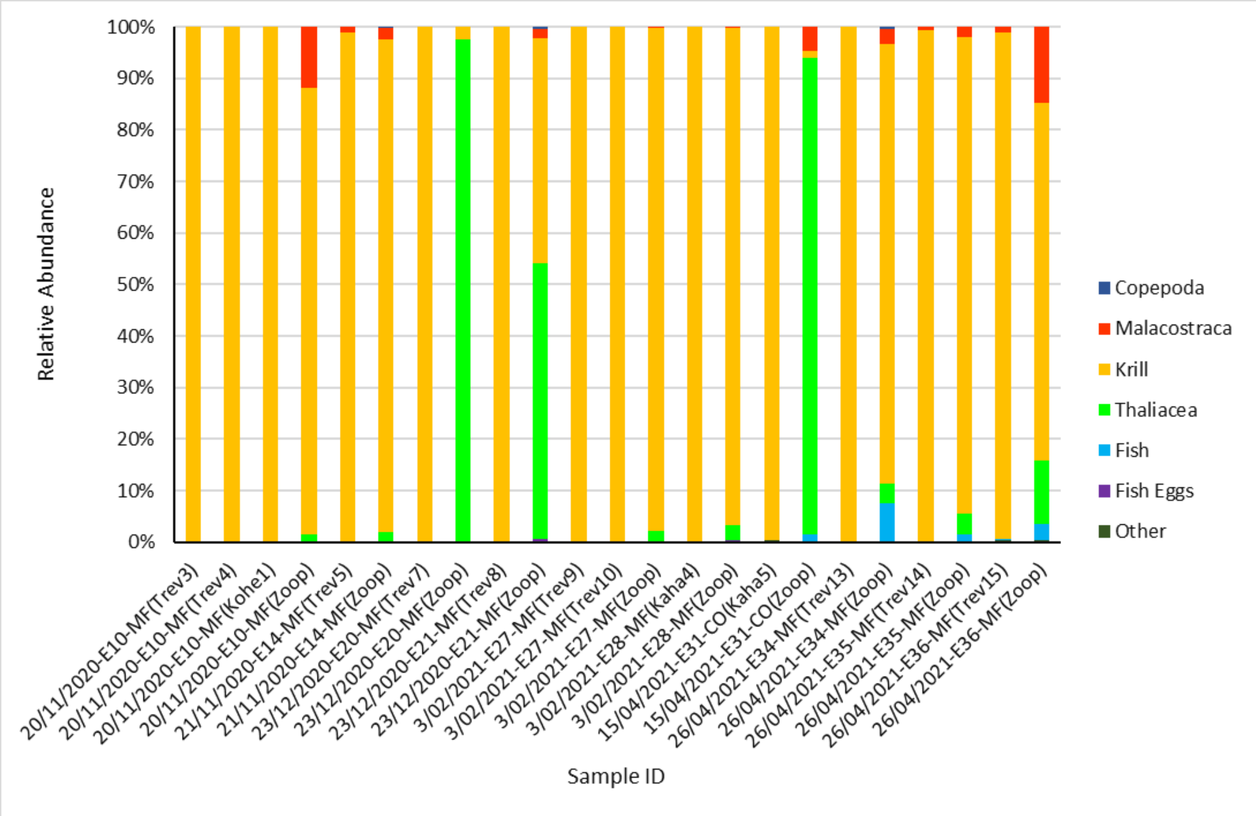

Figure 8. Relative abundance (%) of fish gut contents and comparative zooplankton tows. The Sample ID gives the date, event number, event type (MF-Mixed Fish School, CO - Control), and if the sample is a fish gut contents (e.g., Trev3) or a zooplankton tow (Zoop).

Krill lengths

Twenty-three zooplankton samples contained krill in sufficient quantities and quality for length measurements. Krill length measurements were combined for each month (Fig. 9) and for each event type (Fig. 10). The number of length measurements per month varied from 150 to 300 depending on the number of samples available that contained krill. Overall, krill lengths ranged from 3.9 – 17.5 mm. Mean krill length across the season approximated a bell-shaped curve with a mean length of 9.2 mm in October, increasing to a maximum of 13.7 mm in December and dropping to a low of 9.1 mm in April. Overall, there was a large variation in the length of krill sampled within and between months across the field season.

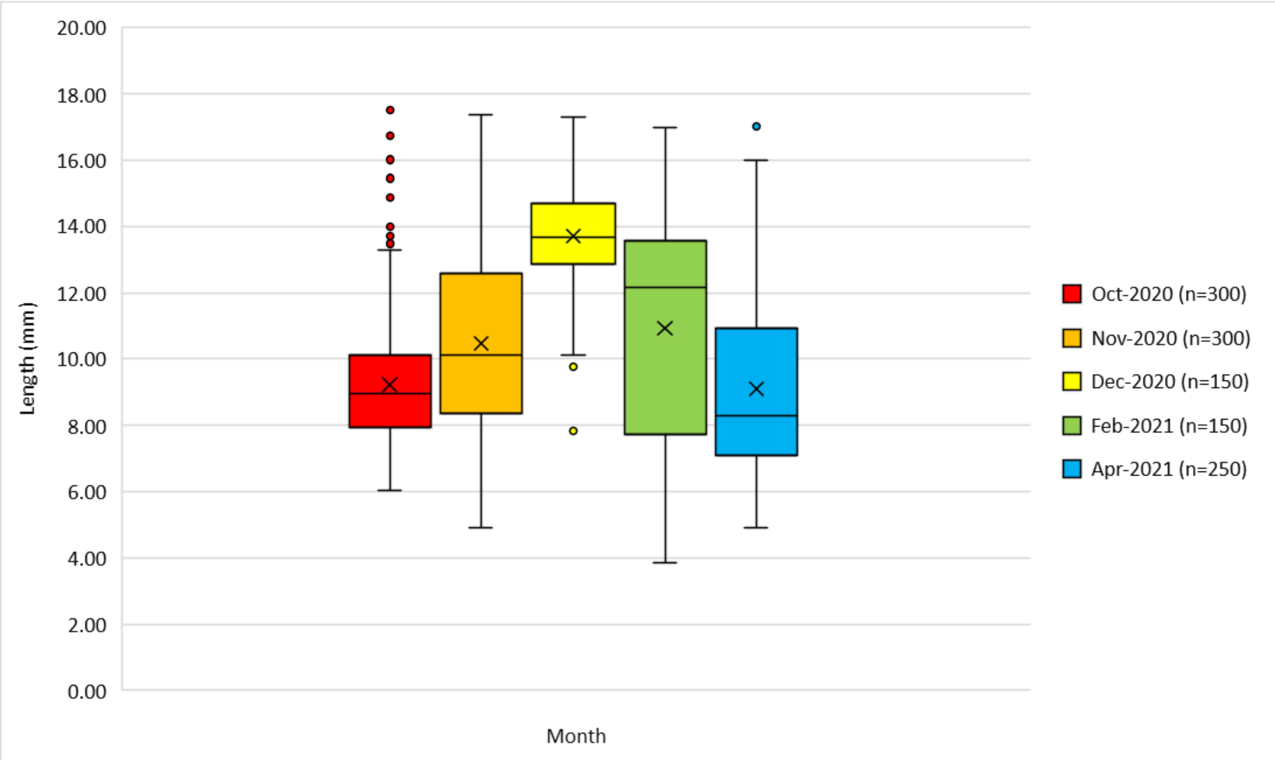

Figure 9. Krill body lengths from zooplankton samples grouped by month. The number of krill measured from each month is given in brackets in the legend.

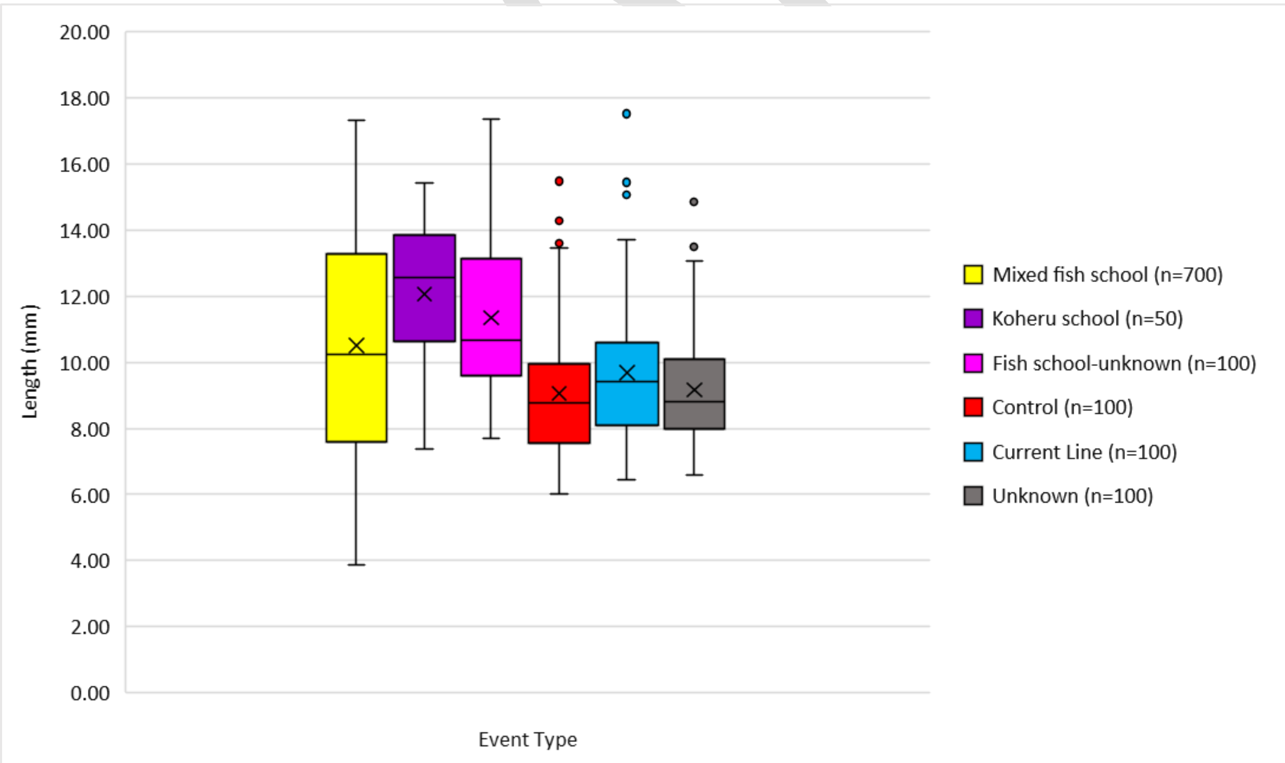

Figure 10. Krill body lengths from zooplankton samples grouped by event type. The number of krill measured from each month is given in brackets in the legend.

The number of krill measured at each type of event varied from 50 to 700 (Fig. 10). No krill were found at Kahawai School events. In general, krill were larger at fish school events in comparison to events where fish were not visibly schooling. Krill lengths from the three fish schooling events ranged from 3.9 – 17.4 mm with mean lengths 10.5, 12.1 and 11.4 mm for the Mixed Fish, Koheru and Fish School-Unknown events respectively. Krill lengths from the other events ranged from 6.0 – 17.5 mm with mean lengths 9.1, 9.7 and 9.2 mm for the Control, Current Line and Unknown events respectively. There was large variation in krill lengths both among and within categories of event type.

Nine of the fish gut samples contained krill in sufficient quantities and quality for length measurements. These were compared with krill lengths in zooplankton samples taken at the same event – six of which contained enough krill for measurements (Fig. 11). For the trevally caught from Mixed Fish School events, four contained krill with larger mean lengths than the corresponding zooplankton sample and two contained krill with smaller mean lengths. The kahawai caught from a Mixed Fish School event contained krill with a larger mean length than the zooplankton sample. Krill from samples collected on 26 March (both fish gut and zooplankton), all had smaller mean lengths than samples collected earlier.

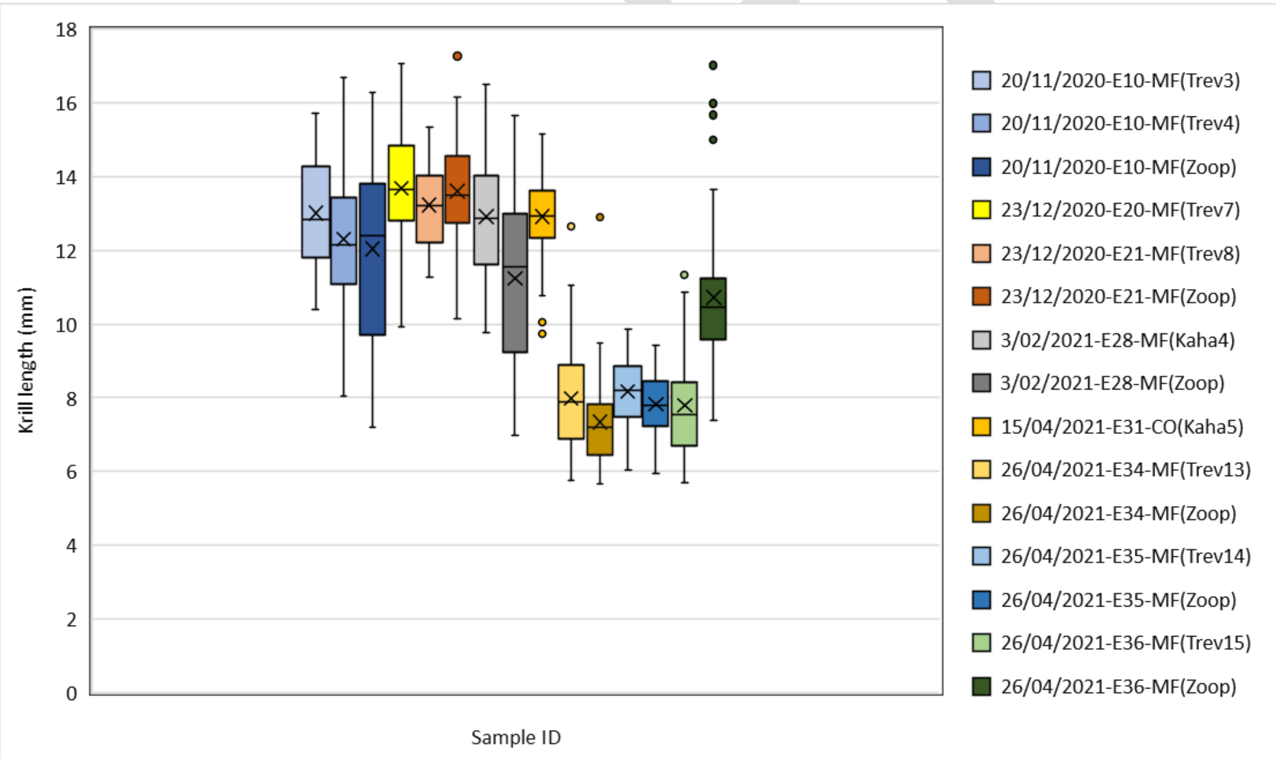

Figure 11. Krill body lengths in fish gut samples and corresponding zooplankton sample (if available) from the same event number. Fifty krill measured from each sample. The Sample ID gives the date, event number, event type (MF-Mixed Fish School, CO - Control), if the sample is fish gut contents (e.g., Trev3) or a zooplankton tow (Zoop).

Oceanographic data

Water clarity measurements were taken at all events except for E8. SST measurements were taken at all events except those on the October trip. Water clarity varied from 2.5 – 15.5 m with the inshore sites e.g., Bream Bay generally having the lowest water clarity and sites at the Mokohinau Islands having the highest water clarity. Maori Rocks had a slightly lower clarity than other Mokohinau Island sites sampled on the same day from December onwards. SST ranged from 18.2 – 21.8 °C and generally increased from October to February then became cooler in April. E14 at Langs Beach was much higher than other sites on the same day, 21°C versus 19.1 °C at McGregor Rock.

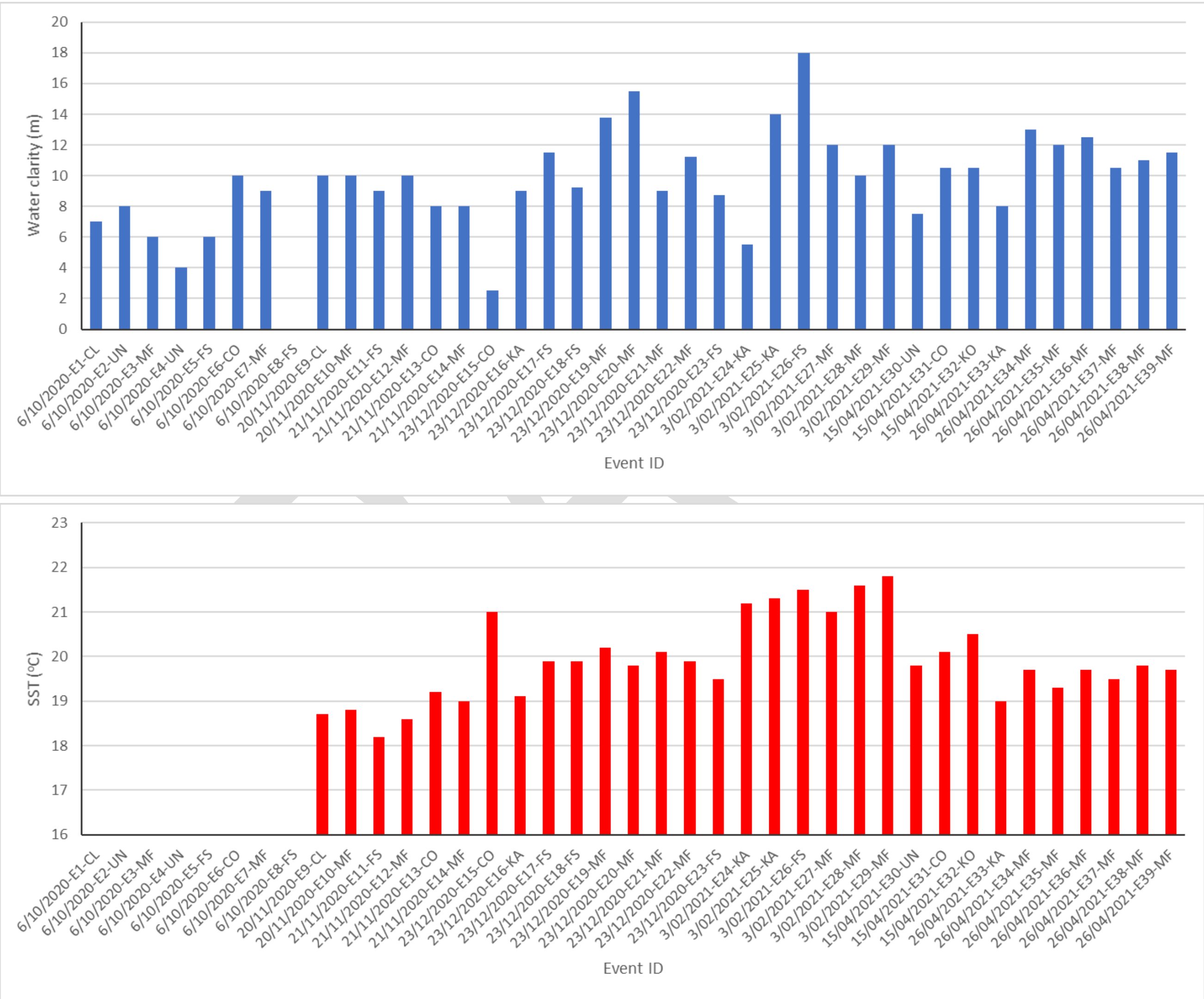

Figure 12. Water clarity (top) and SST measurements (bottom). Where no data is shown, no measurement was taken.

DISCUSSION

The sampling this year (2020-2021) continued from research on prey availability to seabirds at pelagic fish schooling events that was started in 2017. Sampling trips this year were conducted during spring (Oct-Nov), early summer (Dec), late summer (Jan-Feb) and autumn (Mar-Apr), with sampling at the various locations repeated on most trips. Sampling at each location only provided a snapshot in time of the activity in terms of zooplankton, fish and seabirds and some associated environmental factors but adds to the overall body of data obtained during the previous years of research. Direct comparisons between research years are difficult due to difference in equipment (nets, flowmeter) and methods (vertical and horizontal surface tows; event classifications) used, but broad comparisons can be made.

Fish schooling events

Four types of pelagic fish schooling events were recorded this research year (2020-2021), with the highest abundances of potential seabird zooplankton prey (Krill and other Malacostraca) being sampled from Mixed Fish School events. These events all occurred at locations adjacent to isolated islands or above underwater pinnacles that rise from deeper water, with a key location being the waters surrounding the Mokohinau Islands. Mixed Fish School events also tended to be the most dramatic in activity, sometimes with the schools of fish covering up to c. 1500 m^2, especially with several schools merging, fish breaking the surface and large numbers of seabirds feeding. While trevally tended to be the dominant fish species seen in Mixed Fish School events, kahawai, kingfish, koheru and snapper were viewed by the underwater videography and caught from these schools. Stomach contents from trevally, kahawai and koheru caught at these events were entirely comprised of krill. From underwater video observations, krill could often be seen in dense patches near the sea surface. Underwater videos from the floating camera rig show krill moving into view and becoming progressively agitated as fish approach. FAPR and BUSH tended to be the most common bird species at these events. A previous study of the regurgitations from these two seabird species found that, particularly for FAPR, krill (including nauplii) was an important prey type (Kozmian-Ledward et al. 2020). Mixed Fish School events were also the most found event in the previous season (2019-2020), also around the Mokohinau Islands, plus North-West Reef and Coppermine Island. Abundances of zooplankton in the Malacostraca group appeared to be greater in the 2019-2020 season that in the 2020-2021 season.

Figure 13. Mixed school of trevally and kahawai, off Burgess Island, Mokohinau Islands. *Photo: Edin Whitehead.*

Figure 14. Mixed School of trevally and kahawai school, off Coppermine Island, Marotere / Chickens Islands. *Screenshot from underwater videography: NNZST*.

Figure 15. Predominantly kahawai school at Groper Rock, Mokohinau Islands. *Screenshot from underwater videography: NNZST*.

As, in previous research years, Kahawai Schools were commonly found near the mainland coast, although in 2019-2020 they were also found at the Mokohinau Islands. Classification of events using the predominant fish species present can be difficult due to only being able to observe those fish at or near the surface. The underwater videos obtained from the GoPro rig give some insights into what fishes and activity is occurring deeper down but only in a small area at a time. The previously classified Kahawai Schools may have had other fish species involved. No krill was found at the Kahawai Schools this year with samples generally dominated by Thaliacea. However, at McGregor Rock off Beam Tail, other Malacostraca types were present in the form of porcelain crab and stomatopod larvae. Only one kahawai was caught at these events and its stomach was empty. In the last season, a single kahawai caught at a Kahawai School event, only contained juvenile fish. However, at a Kahawai School event at Leigh Reef in the last season, the kahawai appeared to be feeding on krill which could be seen near the sea surface; also, the zooplankton tow sample contained many krill. The Kahawai School event sampled at Bream Bay this year had WFTE and BUSH feeding on small fish such as anchovy (*Engraulis australis*). Given the highly patchy spatial distribution of zooplankton, especially krill, it is possible that krill were present at some Kahawai School events but not captured by the zooplankton net. Small pelagic fishes are planktivorous with their prey including Malacostraca, copepods and larval fishes, some of which were present but possibly the low numbers sampled were due to the coarse mesh size of the net.

Figure 16 (left). BUSH lunging to catch an unidentified leaping fish (circled). Figure 16 (right). WFTE with anchovy. *Photos: Edin Whitehead.*

The four Control events were in locations where Mixed Fish Schools (Mokohinau Islands, North-West Reef) or Kahawai Schools (Langs Beach) often occur, but at the time of sampling there were no seabirds or fish feeding at the surface, although there were sometimes fish deeper down, viewed on the vessel's depth sounder. The Control zooplankton sample taken at North-West Reef in October contained a higher abundance of Krill than the Mixed Fish School sample taken in the same area 30 minutes later, when RBGU came to feed when there were fish feeding at the surface. The Control zooplankton samples taken at Simpson Rock and Groper Island were small compared to zooplankton samples taken at Mixed Fish School events at the Mokohinau Islands. At the Groper Island Control site there were many fish subsurface but no birds present. Gut contents of a trevally and kahawai caught here contained krill, the former quite digested. The kahawai may have been feeding fairly recently but perhaps at depth. The Control zooplankton sample taken off Langs Beach in December was small, but mainly comprised of Thaliacea, as were most of the contents of the zooplankton samples taken in the Kahawai School.

One Koheru School was sampled this year, the first for this research work. No other fish species were seen on the corresponding underwater video. The zooplankton sample obtained was relatively small but dominated by krill, as was the stomach contents of a koheru caught at the same event. This event was at Navire Rock where several Mixed Fish Schools were also sampled this year. The predominant birds feeding at this event were RBGU.

There were several fish schooling events that could not be defined due to either sporadic views of the fishes involved, not allowing for identification, or that did not fit the existing event types. Those at the Mokohinau Islands were likely to have been Mixed Fish Schools, given their prevalence in this area. Two events were in the Jellicoe Channel, one in conjunction with common dolphins (E8). Common dolphins are known to feed on jack mackerel (*Trachurus* spp.) and anchovy (Meynier et al. 2008), and these fish species are also prey for AUGA (Gaskin & Adams 2018), so these may have been the prey species here for both the dolphins and the seabirds. The zooplankton sample obtained here was small and was comprised mainly of Malacostraca (no krill). The other Jellicoe Channel zooplankton sample may have been at a blue mackerel (*Scomber australasicus*) school (E17) given the location and activity seen. The zooplankton sample here was comprised predominantly of Thaliacea but also contained Malacostraca as well as Krill which would provide potential prey for the mackerel. The dominant bird species here, FLSH may have been preying on small mackerel species. An undefined fish school event was sampled at North-West Reef (E26) with kingfish and unidentified juvenile fish seen near the surface on the underwater video, with a school of sweep near the reef. The predominant bird species was BUSH. The zooplankton sample here was relatively small and mainly Thaliacea.

Other events

The Current Line events sampled this season contained higher abundances of Krill and Malacostraca than those sampled in the previous season. Both events in this season were located close to Coppermine Island, and the current and potential upwelling may have been concentrating the krill – the current lines in the previous season were further from land. In this season's events, FAPR and RBGU were the dominant bird species, both of which prey on krill (Gaskin & Adams 2018).

The two Unknown events sampled at the Mokohinau Islands were both dominated by krill, but no fish were seen at these events even though birds were observed feeding at these locations. Birds were feeding at the Unknown event off Langs Beach but the corresponding zooplankton sample was very small.

No Krill Patch events were found this season despite several being sampled in the previous season in the Jellicoe Channel and North-West Reef area. These events were found on very calm days in late January and early February 2020. No trip was undertaken in January 2021, and the wind speed and sea state were not recorded for the early February 2021 trip so it is unknown if the sea conditions prevented potential krill swarms being seen.

Zooplankton prey availability for seabirds

Krill have been found to be an important prey for FLSH, BUSH, FAPR and RBGU feeding in association with fish schools. Other zooplankton are prey for fishes that are in turn preyed upon by AUGA and FFSH. Zooplankton is also an important prey for CODP, WFSP and NZSP but seldom observed to be in association with the presence of fish schools (Gaskin 2017).

The general hypothesis of this study is that schooling pelagic fish drive krill and other prey species to the surface making them more readily available to surface feeding seabirds. The alternative hypothesis is that krill aggregate at or near the surface in areas of upwelling or current flows which then attract schools of pelagic fish, whose feeding activity, provides visual and potentially olfactory cues to attract feeding seabirds. In both cases, when fish schools come across the krill patches (in high enough concentrations) they go into 'feeding mode', massing even more tightly together and potentially further concentrating the krill; in turn their feeding activity potentially advertises krill presence to aerial predators. The presence of the commotion, and smell and sound of the fish feeding at the surface, potentially act as cues for seabirds that there is abundant prey available. However, in the 2019-2020 season, krill were found to aggregate in areas away from fish schools (defined as Krill Patch events) and were targeted by seabirds cued by other visual signs besides surface schooling activity and potentially also olfactory signs. For example, in very calm conditions, even the riffles caused by small fish attacking krill swarms from below may have advertised the krill presence to birds (predominately BUSH) foraging in the area. At these events, birds were scattered over a wide area, in comparison to the denser aggregations at fish school events.

The predominant krill species in the Hauraki Gulf and northern North Island waters, *N. australis*, only occurs in coastal waters of southeast Australia and New Zealand and is known to be an important prey for many species of fish, seabirds, and cetaceans (Bary 1954; O'Brien 1988; McClatchie et al. 1989, Torres et al. 2014). *Nyctiphanes australis* is known for daytime surface swarming activity, which makes them highly vulnerable to predation by seabirds and fish, however, the reasons for this krill behaviour, is not fully understood (O'Brien 1988). It has been suggested that krill may; 1) congregate at the sea surface to feed, 2) be driven to the surface by predators, 3) be passively brought to surface by currents or upwelling, 4) actively come to the surface to satisfy internal demands related to maturation or reproduction (Komaki 1967). Swarming in *N. australis* (and other krill species), has been found to often be highly coordinated with individuals showing parallel orientation and reacting to external stimuli (e.g., predators, stationary obstructions) as a unit, in a similar way to fish schools (O'Brien 1988). Dense patches of krill are formed as a result and are surrounded by areas of water with no krill. This schooling behaviour creates spatial patchiness, and together with their potential reactive movements to avoid vessels and sampling gear, can make representative sampling of krill difficult.

Figure 17. FLSH feeding with leaping krill. *Photo: Edin Whitehead.*

In this study, krill was seen swarming at the surface at fish schooling events. It is thought that mature krill may aggregate at the surface for reproductive reasons (Mauchline & Fisher 1969). Mature females of *N. australis* range in length from 9.8 – 17.0 mm and males from 12.0 – 16.0 mm (Barry 1954; Brinton et al. 2000). Krill of these sizes, including females carrying eggs as well as metanauplii (i.e., the first free-swimming stage) were found at many fish schooling events throughout the field season. However, smaller krill occurred at these events also, indicating other reasons for surface swarming behaviour. Analysis of krill lengths from zooplankton samples showed a wide range of sizes at all events, however, there was generally a greater proportion of krill larger than 10 mm at fish schooling events compared to the Control and non-fish school events which may indicate prey selectivity by pelagic fish.

Conclusions

This study and previous studies highlight the importance of seabirds feeding in association with pelagic fish schools. At the same time, observations made during previous research (INT2016-04, POP2017-06 and POP2019-02) reinforce observations that seabirds adopt a range of feeding associations with respect to prey, and importantly the way prey is made available. While a good number of seabird species regularly associate with fish work ups, of these only FAPR, FLSH and RBGU could be regarded as zooplankton specialists in these situations. Diving petrels and storm petrels also feed on zooplankton, but generally do so away from fish work ups, a sign that zooplankton prey is present in more open waters not necessarily linked to the major bathymetric features and upwelling zones that feature in these studies.

There is a need to better understand the foraging distribution, behaviours, and diet of several species during breeding, as well as for those species that are largely resident in northern waters during non-breeding periods and assess how any variability in foraging distribution and effort affects breeding success. Fisheries can reduce the abundance of forage fish and may also change the community structure of schools of pelagic fish potentially resulting in smaller and less frequent workups reducing food availability. Foraging plasticity by seabirds may buffer any potential impacts from changing prey distributions, not only through fisheries impacts but also climate change. As seabirds are long-lived and many are slow to mature, they may struggle to adapt to rapidly changing environmental conditions compared to species with shorter generation times. Also, burrow nesters (e.g., petrels, shearwaters, prions, little penguins) are extremely faithful to their colonies (natal site fidelity), which with prey-shifting could make the distances travelled to find food longer and unstainable. Whereas surface nesters (e.g., gannets, gulls, terns) are better able to move nesting closer to their feeding grounds (Gaskin 2021). Thus, seabird science can emphasise the role of seabirds as indicator species for marine ecosystem health (Furness & Camphuysen 1997; Tasker et al. 2000, Wagner & Boerma 2011).

Our research has focused on a suite of species that we have identified as key for the study of pelagic fish schools in north-east North Island waters and potential indirect adverse effects (Gaskin 2017; Gaskin et al. 2019b). There had been no previous studies in the wider Hauraki Gulf (or indeed New Zealand) that sample zooplankton in relation to seabird foraging prior to this project. Our use of zooplankton nets to conduct surface horizontal tows through fish workups combined with underwater videography appears to be novel in this regard. Previous studies on zooplankton in the wider Hauraki Gulf pelagic environment are few (e.g., Jillett 1971; Zeldis & Willis 2015). For example, Jillett (1971) used a Clarke-Bumpus sampler to conduct three replicate oblique hauls at a single station in the Jellicoe Channel at monthly intervals for 14 months. Zeldis & Willis (2015) conducted single vertical hauls using a zooplankton net at multiple stations from the inner Hauraki Gulf to the outer continental shelf and repeated this over several multi-day research voyages. Carroll et al. (2019) conducted systematic zooplankton sampling in a study examining the diet of Bryde's whales in the Hauraki Gulf, using DNA extraction techniques to examine community composition in relation to the species composition of whale faecal matter. Zooplankton abundance and diversity are determined predominantly by oceanographic (e.g., temperature, upwelling zones, bathymetric features) and biological factors (e.g., primary productivity and predation) which result in a large amount of spatial and temporal variability (Zeldis & Willis 2015). However, the detailed mechanisms of the drivers of this spatial and temporal heterogeneity in relation to availability of seabird prey in the wider Hauraki Gulf are yet to be identified. While there is likely to be large inter-annual variation due to climate variability, the mechanisms driving this occurrence will not necessarily change.

Due to the importance of krill and potentially other zooplankton types in the diet of various seabird, fish, baleen whale and mobulid ray species in the wider Hauraki Gulf region, more research is recommended on the distribution, lifecycle, behaviour, effects of environmental factors, and whether commercial fishing of planktivorous fish species has a positive or negative effect on krill/zooplankton abundances. There is also the need to continue to develop our multi-disciplinary approach to fully investigate indirect effects of fisheries on seabirds through the study of these species, complemented by ongoing investigation into fish school dynamics and seabird diet, foraging distribution and behaviour utilising high resolution tracking, and breeding success.

REFERENCES

Bary, B. M. (1954). Notes on ecology, systematics, and development of some Mysidacea and Euphausiacea (Crustacea) from New Zealand. *Pacific Science*, 10, 431-436.

Black, K. P., Bell, R. G., Oldman, J. W., Carter, G. S. & Hume, T. M. (2000). Features of three-dimensional barotropic and baroclinic circulation in the Hauraki Gulf, New Zealand. *New Zealand Journal of Marine & Freshwater Research*, 34(1), 1-28.

Booth, W. E. & Sondergaard, M. (1989). Picophytoplankton in the Hauraki Gulf, New Zealand. *New Zealand Journal of Marine & Freshwater Research*, 86(1), 139-146.

Brinton, E., Ohman, M. D., Townsend, A., W., Knight, M. D. & Bridgeman, A. L. (2000). *Euphausiids of the World Ocean*. World Biodiversity Database CD-ROM Series. Springer Berlin Heidelberg.

Carroll, C., Gallego, R., Sewell, M. A., Zeldis, J., Ranjard, L., Ross, H. A., Tooman, L. K., O'Rorke, R., Newcomb, R. D. & Constantine, R. (2019). Multi-locus DNA metabarcoding of zooplankton communities and scat reveal trophic interactions of a generalist predator. *Scientific Reports* 9(1), 1-14.

Chang, F. H., Zeldis, J., Gall, M. & Hall, J. (2003). Seasonal and spatial variation of phytoplankton assemblages, biomass and cell size from spring to summer across the north-eastern New Zealand continental shelf. *Journal of Plankton Research*, 25(7), 737-750.

Delcourt J. & Poncin P. (2012). Shoals and schools: back to the heuristic definitions and quantitative references. *Reviews in Fish Biology and Fisheries*, 22, 595-619.

Forest & Bird (2014). New Zealand seabirds: sites at sea, seaward extensions, pelagic areas. The Royal Forest & Bird Protection Society of New Zealand, Wellington, New Zealand. 91 p.

Frederiksen, M., Edwards, M., Richardson, A. J., Halliday, N. C. & Wanless, S. (2006). From plankton to top predators: bottom-up control of a marine food web across four trophic levels. *Journal of Animal Ecology*, 75, 1259-1268.

Furness, R. W. & Camphuysen, C, J. (1997). Seabirds as monitors of the marine environment. *ICES Journal of Marine Science*, 54(4), 726-737.

Gaskin, C. & Rayner, M. (2013). Seabirds of the Hauraki Gulf: natural history, research and conservation. Hauraki Gulf Forum, Auckland, New Zealand. 143 p.

Gaskin, C. (2017). Procellariiformes associating with shoaling fish schools – northern New Zealand. Report prepared by Northern NZ Seabird Trust for the Conservation Services Programme, Department of Conservation. 52 p.

Gaskin, C.P., Adams, N. (2018). Summary of activities carried out to collect samples from seabirds 2017-2018 (Milestone 3). Report prepared by Northern NZ Seabird Trust for the Conservation Services Programme, Department of Conservation. POP2017-06. 15 p.

Gaskin, C., Kozmian-Ledward, L., Jeffs, A. (2019a). Indirect effects on seabirds in the northern North Island region. Final report of at-sea fish shoal sampling prepared by Northern NZ Seabird Trust for the Conservation Services Programme, Department of Conservation. POP2017-06. 40 p.

Gaskin, C., Adams, N., Kozmian-Ledward, L., Jeffs, A. (2019b). Indirect effects on seabirds in the northern North Island region. Final report on comparison of fish shoals and seabird diet prepared by Northern NZ Seabird Trust for the Conservation Services Programme, Department of Conservation. POP2017-06. 48 p.

Gaskin, C., Frost, P., Friesen, M. (2019c). Indirect effects on seabirds in the northern North Island region. Final report on seabird colony and population assessments prepared by Northern NZ Seabird Trust for the Conservation Services Programme, Department of Conservation. POP2017-06. 23 p.

Gaskin, C., Kozmian-Ledward, L., Jeffs, A., Adams, N, Doyle, E. (2019d). Indirect effects on seabirds in the northern North Island region. Final report of seabird diet sampling prepared by Northern NZ Seabird Trust for the Conservation Services Programme, Department of Conservation. POP2017-06. 50 p.

Gaskin, C., Lukies, K., Jeffs, Spreitzenbarth, S. and Kozmian-Ledward, L. (2021). Final report on fish shoal sampling conducted October 2020 – April 2021. Prepared by Northern NZ Seabird Trust for the Conservation Services Programme, Department of Conservation. MIT2020-08. 41 p.

Gaskin, C.P. (ed) (2021). The State of Our Seabirds 2021. Seabird ecology, research and conservation for the wider Hauraki Gulf region. Northern New Zealand Seabird Charitable Trust, Auckland, New Zealand. 154 p.

Harris, R. P., Wiebe, P. H., Lenz, J., Skjoldal, H. R. & Huntley, M. (2000). *Zooplankton Methodology Manual*. Academic Press.

Jillett, J. B. (1971). Zooplankton and hydrology of the Hauraki Gulf, New Zealand. *Oceanographic Institute Memoir no. 53*.

Komaki, Y. (1967). On the surface swarming of euphausiid crustaceans. *Pacific Science*, 21, 433-448.

Kozmian-Ledward, L., Jeffs, A. and Gaskin, C. 2020. Fish shoal dynamics in north-eastern New Zealand. Final report summarising analysis of zooplankton samples 2019-20. Prepared by

Northern NZ Seabird Trust for the Conservation Services Programme, Department of Conservation. POP2019-02. 52 p.

Mauchline, J. & Fisher, L. R. (1969). The biology of euphausiids. *Advances in Marine Biology*, 7, 1-454.

Meynier, L., Stockin, K. A., Bando, M. K. H., & Duignan, P. J. (2008). Stomach contents of common dolphin (*Delphinus* sp.) from New Zealand waters. *New Zealand Journal of Marine and Freshwater Research*, 42: 257-268.

McClatchie, S., Hutchinson, D. & Nordin, K. (1989). Aggregation of avian predators and zooplankton prey in Otago shelf waters, New Zealand. *Journal of Plankton Research*, 11(2), 361-374.

O'Brien, D. P. (1988). Surface schooling behaviour of the coastal krill *Nyctiphanes australis* (Crustacea: Euphausiacea) off Tasmania, Australia. *Marine Ecology Progress Series*, 42, 219-233.

Paul, L. J. (1968). Some seasonal water temperature patterns in the Hauraki Gulf, New Zealand. *New Zealand Journal of Marine & Freshwater Research*, 2(3), 535-558.

Schindelin, J., Arganda-Carreras, I., Frise, E. et al. (2012). Fiji: an open-source platform for biological-image analysis. *Nature Methods*, 9(7), 676-682.

Sharples, J. (1997). Cross-shelf intrusion of subtropical water into the coastal zone of northeast New Zealand. *Continental Shelf Research*, 17(7), 835-857.

Sharples, J. & Greig, M. J. N. (1998). Tidal currents, mean flows, and upwelling on the north-east shelf of New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 32, 215-231.

Tasker, M. L., Camphuysen, C. J., Cooper, J., Garthe, S., Montevecchi, W. A. & Blaber, S. J. M. (2000). The impact of fishing on marine birds. *ICES Journal of Marine Science*, 57, 531-547.

Taylor, P. & Gaskin, C. (2020). Fish shoal dynamics in north-eastern North Island. POP2019-02. Milestone 2: Interim report on oceanographic features in the study area. Report prepared by Northern NZ Seabird Trust for the Conservation Services Programme, Department of Conservation. 17 p.

Torres, L., Gill, P., Hamner, R. & Glasgow, D. (2014). Documentation of a blue whale foraging ground in the South Taranaki Bight, New Zealand. Paper SC/65b/SH02 submitted to the IWC Scientific Committee (unpublished).

Wagner, E. L. & Boersma, P. D. (2011). Effects of fisheries on seabird community ecology. *Reviews in fisheries science*, 19(3), 157-167.

Zeldis, J. R. & Willis, K. J. (2015). Biogeography and tropic drivers of mesoplankton distribution on the northeast continental shelf and in Hauraki Gulf, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 49(1), 60-86.