Indirect Effects on seabirds in northern North Island

POP2017-06

Summary of activities carried out to collect samples from fish shoals 2018 (Milestone 5) & overall project update

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Prepared by: **Chris Gaskin**, Project Coordinator, Northern New Zealand Seabird Trust, with appended report by **Lily Kozmian-Ledward** (Sea Lily Ltd), **Associate Professor Andrew Jeffs** (University of Auckland) and Chris Gaskin

Cover photo: Fairy prion and trevally school. *Photo: Karen Baird*

Figure 1 (this page): Larval fish and salps. *Photo Edin Whitehead*

Introduction

This project (POP2017-06 Objective 2) sets out to identify the range of potential seabird prey species within fish work-ups, to:

- Characterise fish work-ups by identifying and estimating abundance of the suite of predator species and record observations of their feeding behaviour, and
- Quantify the composition of the mesozooplankton community associated with fish work-ups.

By sampling prey availability within fish work-ups (and in the same water surface zones under normal conditions) there is the potential to provide further information on the range of prey species made available to seabirds by fish work-ups. This report summarises activities from 1 May 2018 - 30 December 2018. It includes cataloguing identification samples collected from September 2017 - April 2018. The report also includes observations made during the course of the study of other marine activity related to seabird feeding, that is, complementary to their feeding in relation fish work ups, most notably feeding over hydrographic features and in association with cetacean feeding.

Methods

Methodology for identifying zooplankton in samples collected 2017-2018 are covered in the report appended here (Appendix 1).

Recommendations made in the POP2017-06 Milestone 2 report (i.e., making regular monthly voyages and adopting a more standardised approach to the plankton sampling regime) have been adopted for the current 2018-2019 season. Logistical limitations remain in that sampling had to be combined with other activities (as agreed in contract negotiations to reduce costs) – for example, surveys for New Zealand storm petrel, island field team transfers (both covered by grants), and in some cases, with bird watching 'pelagics' where participants cover some of the charter costs through donations.

Trips to date have been made from two departure points – Omaha/Whangateau Harbour and Whangarei/Marsden Cove Marina. Sampling locations (fig 2) are approximately within a triangle from Omaha to Mokohinau Islands to Bream Islands with NW Reef, Simpson Rock, Maori Rocks. Marotere (Chickens Islands) and Parry Channel key sampling sites.

At each sampling location fish school size, composition and activity is recorded as best as possible from above the surface. Where possible, an underwater camera rig is deployed to take video of fish and bird activity underwater. At some locations, a Secchi Disk has been deployed to recorded vertical visibility. The videography allows for identifying fish species present in schools, as many schools are composed of mixed species. Seabird activity and abundance is also recorded.

Figure 2. Sampling locations for 2018-2019 season (up to 29 Dec 2018). Black circles denote 30m hauls, white circles surface tows.

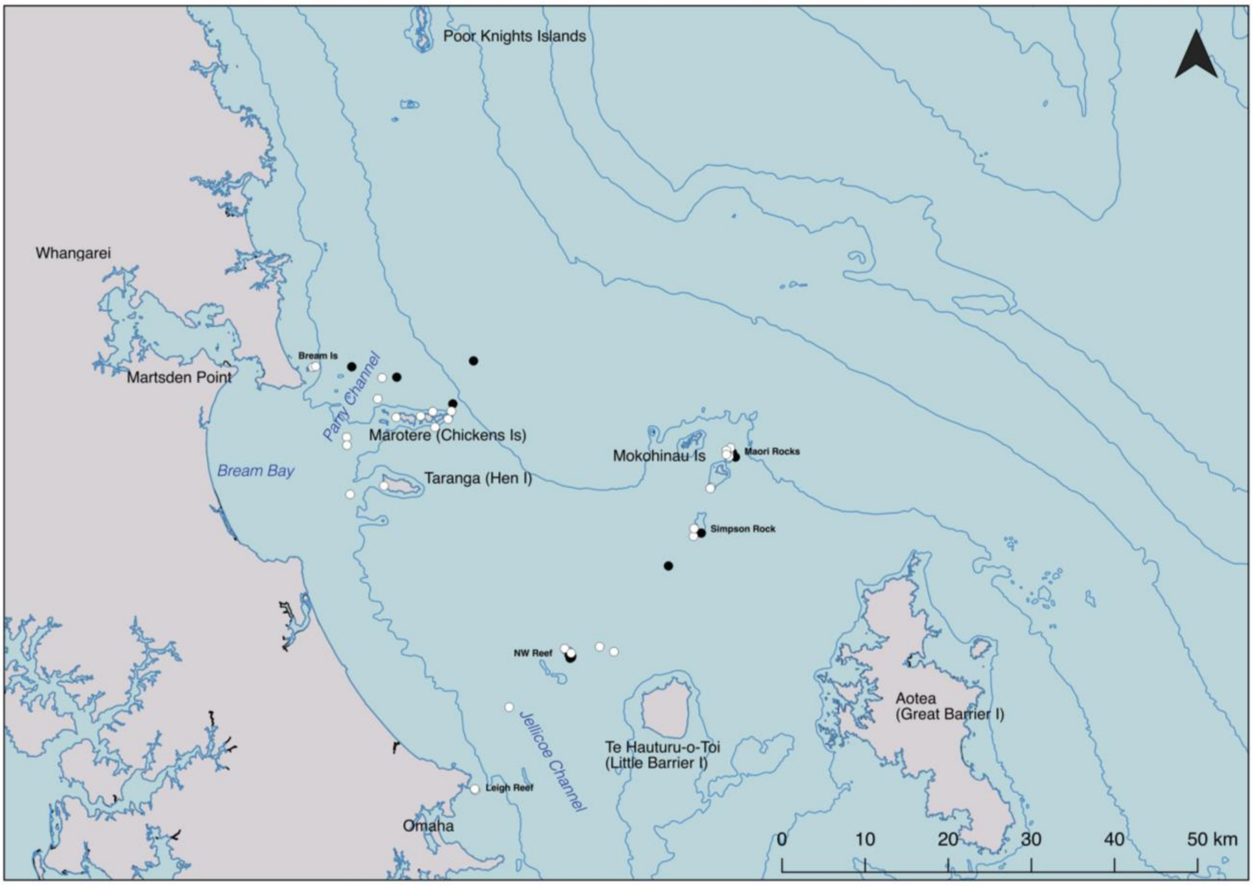


Figure 3. Surface trawl across the face of a fish school at NW Reef, feeding birds include prions, shearwaters and red-billed gulls. The orange buoy is attached to the rim of the open end of the net. *Photo: Tony Whitehead*

Results

Identification of samples collected 2017-2018

A full report on the identification of samples from 2017-2018 season has been completed (Kozmian-Ledward et al 2019) and is appended here (Appendix 1).

Plankton sampling 2018-2019 season

See Table 1 for sampling effort for season to date.

Figure 3. Euphausiids and salps in one of the 'sock' cod-ends. *Photo: Edin Whitehead.* Figure 4 (insert). Dense euphausiids from horizontal tow across the front of a fish school. *Photo: Edin Whitehead.*

Table 1. Sampling effort 30 September to 29 December 2018 [1]

Sample label #	Date	Time (hrs)	Lat	Long	Depth (<30m)	Surface tow (<1m) - 6 mins @	Preserved sample /total sample (ml)	Vis (m)	Comments/notes
1A-1B	30/08/18	1200	-35.92157	175.16091					Drop on angle with drifting boat in wind; just north of Maori Rocks. No work up. FAPR, CODP, FLSH, AUGA - also GFPE. Numbers of birds 'milling around' espcially further out to sea.
2A-2B	30/08/18	1348	-35.92051	175.16182					Simpson's Rock. No birds, no work up.
3A-3C	30/08/18	1457	-36.00862	175.12280					NW Reef - no birds. Split sample in two and saved half
4A-4C	30/08/18	1602	-36.29239	174.82757					Big flock, fish schiool at surface. FLSH and RBGU. Net burst during tow.
1	10/10/18	0815	-36.14395	174.94965				21	NW Reef - no birds. Split sample in two and saved half
2	10/10/18	0828	-36.14276	174.94995					Ditto
3	10/10/18	0840	-36.14330	174.95225					NZ fur seal feeding on John Dory; birds attracted. 3-4 NZSP, WFSP, FAPR, BUSH and FLSH, one WCAL
4A-4B	10/10/18	1027	-35.92026	175.16105			200/400		3 miinute trawl at 1.6kns. Maori Rocks. RBGU feeding over current line off NW stack. Half sample discarded - 200ml
5	10/10/18	1044	-35.92213	175.15752			800/2000		3 minute trawl. RBGU, WFTE over fish school, 2 AUGA. 2L sample, less than half retained.
6	10/10/18	1108	-35.92501	175.15760					3 minute trawl. RBGU, FAPR over fish school. 600ml from sample discarded.
			-35.92501	175.15760					two camera drops
7	10/10/18	1158	-35.91547	175.15931					4 minute trawl. Lots of BUSH, FAPR and RBGU following school.
8	10/10/18		-36.01223	175.11243					Simpson's Rock. WFTE of rock. No birds at sampling site.
9A-9E	10/10/18	1415	-36.04502	175.07988			1000/2000		WFSP galore, BUSH, FLSH and RBGU feeding at surface; no fish school activity. 2L sample, 1L retained
10	10/10/18		-36.14722	174.95107				20	Trevally and kahawai school, WFSP, FLSH and RBGU
	10/10/18		-36.14722	174.95107					Two camera drops
1.1-1.3	26/10/18	1024	-35.86994	174.68789			350 / 650		6 min tow at 1.5kns. c. 50 common dolphins, 10-15 FFSH and up to 3 AUGA. Following dolphins feeding. Photo of AUGA with squid in bill
2.1-2.3	26/10/18	1052	-35.88969	174.71287					Trevally school. 100-200 RBGU. C. 20 WFTE. Close to Tara Rocks
	26/10/18	1128	-35.89056	174.78216					Camera drop - BUSH and WFTE, trevally school
3.1-33	26/10/18	1131	-35.91843	175.15378			550 / 1100		As above - 10-30m from the school.
4.1-4.3	26/10/18	1302	-35.92292	175.15398			350/750		Maori Rocks. 5 min tow at 1.5kns. Huge numbers of FAPR, FLSH and BUSH, also RBGU and WFTE. Fish school activity - trevally and kahawai - very eruptive at times suggesting kingfish present
5.1-5.3	26/10/18	1320	-35.92543	175.16602			600/1200		As above - 10-30m from the school.
	26/10/18								Camera drop - videro shows birds diving.
6.1-6.3	26/10/18	1342	-35.92543	175.16602			400/400		As above - dense krill as tow made very close to school.
7	26/10/18	1545	-35.87851	174.78414					North of Coppermine Island - in lee of SW wind. No fish school activity.
1.1-1.3	14/11/18	911	-36.20160	174.87086			450/2400		No fish activty at surface, however, big numbers of birds feeding over a wide area including common dolphins. FLSH, BUSH, FAPR, CODP, WFTE, COPE, 1 FFSH and 1 WCAL. No fish activity.
2.1-2.3	14/11/18	954	-36.14480	174.95316			350/750	12	No fish activity. NW Reef. FAPR, COPE scattered.
3.1, 3.2	14/11/18	1115	-36.13407	174.99022			whole sample		Eruptive fish activity, though not readily visible at surface. Large numbers of prions (mainly) with RBGU and three or four BUSH. One LISH was seen amongst them as well.
4	14/11/18	1142	-36.13928	175.00944			whole sample		Same. Small sample - whole collected. Camera drop with video of fish - trevally, kahawai and kingfish
5	14/11/18	1542	-36.29102	174.82690			whole sample		Near Leigh Reef. Kahawai school. C.200 WFTE, FLSH and RBGU. Activity spread over 500m
1.1, 1.2	21/11/18	1254	-35.91208	174.64741					No fish school. CODP, WFSP and a few FFSH foraging over a large area. A lot of birds on the water. Algae picked up in trawl.
2.1-2.3	21/11/18	1314	-35.92078	174.64793			350/1100		No fish school activity. Numbers of FLSH (mainly), CODP, WFSP and some AUGA and FAPR. Again scatered over a large area. A lot birds on the water.
3	21/11/18	1341	-35.97400	174.65318			Whole sample		No fish school, no birds.
1.1-1.4	17/12/18	1814	-35.83670	174.60058			500/2500		6min trawl @ 1.8kns. Kahawai school just outside Bream islands. RBGUs en masse with FLSH, FAPR and a couple of STSH. Noted that salps were plentiful until net was right in front of school, then packed with krill
									Stomach sample from kahawai
2.1-2.3	18/12/18	1020	-35.89960	174.76487			whole sample		8min @ 2.5kns Three schools - few birds. RBGU 10, with BUSH, FAPR, AUGA and WFSP.
3.1-3.3	18/12/18	1045	-35.88177	174.78627			whole sample		Slick line - group of FAPRs close by. Algal slick with salps.
4	18/12/18	1100	-35.87393	174.78803			whole sample	23.3	Random drop - no birds
5	18/12/18	1225	-35.83565	174.65257			whole sample	18.2	Some birds passing slick line - algal slick with salps at surface
6	18/12/18	1345	-35.96413	174.69822					7min trawl at 2.5kns. Just off Dragonmouth Cove. RBGUs c.15 with others further out along slick line. Fish school closer in shore.
7.1-7.2	18/12/18	1537	-35.88273	174.76157			whole sample		5 min trawl at 2.5kns. Just north of gap between Coppermine and Whatupuke. Several schools - FAPR c.1000, RBGU c.500, STSH 2, SOSH 1
8.1-8.3	18/12/18	1552	-35.88273	174.76157			whole sample		same
8.5, 8.6									Two trevally caught, and stomachs sampled
9.1-9.3	18/12/18	1623	-35.88785	174.74535			whole sample		Three fish schools FAPRs RBGU, and one black noddy
11	19/12/18	0837	-35.82691	174.81458			whole sample		Random drop. No fish activity, although a number of birds in vicinity (Sps, PRs, Pes)
12	19/12/18	0932	-35.84612	174.71272			whole sample		AUGAs on water. Large 'blob' on depth recorder midway down (sea floor c.80m)
13	19/12/18	0953	-35.84712	174.69327			whole sample		AUGA c50, FFSH c.50 with common dolphins - trawled through area where birds were seen feeding
14	19/12/18	1029	-35.83580	174.60445			500/2300		8min trawl @ 2.5kns. Big school of kahawai (c.50m across). FLSH, RBGUs in numbers with BUSH, FFSH and STSH.
									one kahawai caught and stoimach sampled
1.1-1.3	29/12/18	0923	-36.13687	174.94353			450/2200		NW Reef - mutiple schools with FAPR, FLSH and BUSH one RBGU
2.1-2.4	29/12/18	0959	-36.14170	174.95230			whole sample		NW Reef - ditto
3.1-3.4	29/12/18	1024	-36.14641	174.95277			whole sample		NW Reef - ditto
4	29/12/18	1435	-35.95878	175.13438			whole sample		Navarre Rock (S of Fanal) - multiple fish schools, very active. Large numbers of RBGU and FAPR, also FLSH
5	29/12/18	1448	-35.96002	175.13340			whole sample		Navarre Rock - ditto
6.1-6.2	29/12/18	1600	-36.00380	175.11312			whole sample		Simpsons Rock - scattered fish activity. FAPR, FLSH and BUSH very mobile, prions espcially shifting between schools

[1] Species names abbreviations (Table 1): Buller's shearwater = BUSH, fluttering shearwater = FLSH, flesh-footed shearwater = FFSH, sooty shearwater = SOSH, short-tailed shearwater = STSH, little shearwater = LISH, fairy prion = FAPR, Cook's petrel = COPE, grey-faced petrel = GFPE, common diving petrel = CODP, white-faced storm petrel = WFSP, New Zealand storm petrel = NZSP, white-capped albatross = WCAL, northern giant petrel = NGPE

Topside photography of seabird and fish activity once again has been key in complementing recording of observations (figs. 5, 8, 9). Likewise, the underwater videography using a floating camera rig capturing fish school action has proved extremely useful for identifying species (especially in mixed species schools).

Figure 5. White-fronted tern dips for prey on the fringes of a trevally school, 26 October 2018. *Photo: Edin Whitehead*

Figure 6. Fluttering shearwaters diving to catch prey above dense school of trevally and kahawai, 26 October 2018. *Screenshot from videography: NNZST*

Figure 7. Dense school of trevally and kahawai (same school as fig. 6), 26 October 2018. *Screenshot from videography: NNZST*

Figure 8. Buller's shearwaters and fairy prions feeding with a mixed trevally and kahawai school, near Maori Rocks, Mokohinau Islands, 26 October 2018. *Photo: Edin Whitehead*

Figure 9. Red-billed gulls, fairy prions and shearwaters feeding with a very active mixed trevally and kahawai school, near Bream Islands, 19 December 2018. *Photo: Edin Whitehead*

Observations of birds with prey

On several occasions birds have been seen and photographed holding prey in their bills – for example, white-fronted terns feeding chicks on Horuhoru Rock during gannet sampling (11 & 12 January 2019) (figs. 11 & 12) and while feeding with fluttering shearwaters (c.50) and little penguins (c.30) in Kawau Bay (3 Jan 2019) (fig. 13. Australasian gannets are commonly seen swallowing their prey after successful plunge dives (fig. 13).

Figure 11. White-fronted tern with anchovy, Horuhoru Rock, 13 January 2019. Photo: Edin Whitehead.

Figure 12. White-fronted tern with anchovy, Horuhoru Rock, 13 January 2019. Photo: Edin Whitehead.

Figure 13. White-fronted tern with what appears to be krill in its bill, Kawau Bay, 3 January 2019. *Photo: Karen Baird*

Birds actively feeding in areas of no fish schools activity

During sampling trips, there were large areas of open water within the study area where birds were not observed feeding. Conversely, large numbers of shearwaters, prions and petrels have been seen actively feeding on a number of occasions in areas of open water where there were no active fish schools or work ups. These observations were made during the previous POP2017-06 sampling season and in previous years during at-sea surveys and bird watching trips. These feeding groups are generally spread over large areas, and while the birds are more scattered than when feeding in association with fish schools, they are still dramatic when encountered. Plankton tows through one of these feeding groups (fluttering shearwaters, common diving petrels and white-faced storm petrels) in the Parry Channel captured euphausiids and larval fish (21 November 2018).

Cetaceans (dolphins) and birds

As reported in the POP2017-06 Milestone 2 report, seabirds were observed feeding in association with cetaceans. More commonly, this relates gannets, and some Procellariiforms most notably flesh-footed shearwaters, feeding on prey that common dolphins (*Delphinus delphis*) pursue, often in frenzied activity. This is not scavenging, rather actively feeding on the fish the dolphins are chasing. However, on one occasion during such activity just west of the Marotere (Chickens) Islands an Australasian gannet was photographed surfacing after a dive with a squid in its bill (fig. 14). Whether this was a discard from common dolphin feeding or the bird caught it swimming underwater is unknown.

Figure 14. Australasian gannet with squid, feeding in association with a common dolphin pod and flesh-footed shearwaters. *Photo: Edin Whitehead*.

Progress on other components of POP2017-06 in current season

Collection of samples from seabirds

Objective 2 of POP2017-06 is to identify food fed to chicks of key seabird species – Australasian gannet, red-billed gull, white-fronted tern, Buller's shearwater, fluttering shearwater and fairy prion. The POP2017-06 Milestone 3 report summarised activities to collect samples from seabirds during the 2017-2018 season, with Australasian gannets conducted through a continuation of a separate project (N. Adams, Unitec Institute of Technology) and trialing techniques for obtaining regurgitations for Buller's shearwaters and fluttering shearwater. Other species (fairy prion, red-billed gull and white-fronted tern) were not sampled in that first season.

Collection of samples from seabirds (i.e. regurgitations, faecal, blood and feather samples) during the current 2018-2019 season, are as follows:

- **Fairy prion** – samples collected during incubation and chick-rearing stages on Tawhiti Rahi, Poor Knights Islands. Geolocators have also been deployed on 20 birds for late-breeding and post-breeding distribution (separate project).
- **Buller's shearwater** – samples collected during pre-lay, incubation stages to date on Tawhiti Rahi, Poor Knights Islands.
- **Fluttering shearwater** – samples collected during incubation and chick-rearing stages on Taranga (Hen Island) and Muriwhenua (Northwest Chickens Islands) (fig. 18).
- **Red-billed gull** – faecal samples and pellets collected during incubation and chick-rearing stages at Tiritiri Matangi Island, Tawharanui and Marsden Point Refinery (figs. 16 & 17).
- **White-fronted tern** – faecal samples collected during incubation and chick-rearing stages at Tiritiri Matangi, Tawharanui and Horuhoru Rock. Photographs have also been taken of birds carrying prey items in their bills (figs 12 & 13).
- **Australasian gannet** – regurgitations, and faecal, feather and preen gland samples collected during chick-rearing stage in December 2018 and January 2019 at Mahuki Island (Aotea Great Barrier Group) (fig. 19 & 20) and Horuhoru (Gannet) Rock (Waiheke Group). GPS loggers (IGotU 120) were deployed in January to study foraging (separate project).

Figure 15. Faecal samples collected from fairy prions and Buller's shearwaters, 20-23 October 2018. *Photo: Chris Gaskin*

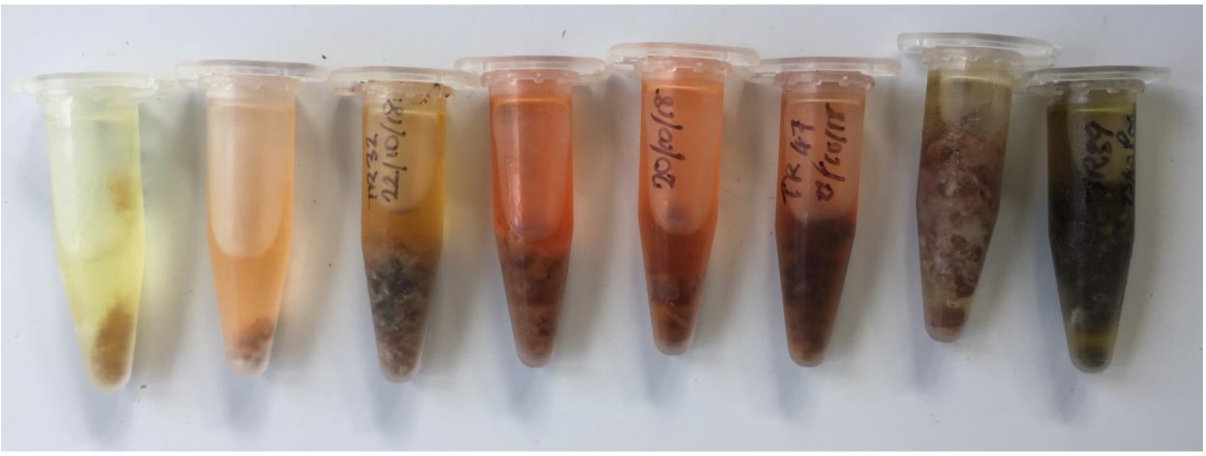


Figure 16. Part of the red-billed gull colony on the banks of the storm water basin within Marsden Point Refinery, late season 18 January 2019. Figure 17 (insert). Collecting red-billed gull faecal samples. *Photos: Andy McCall (Refining NZ)*

Figure 18. Flushing a fluttering shearwater on Muriwhenua, 18 December 2018. *Photo: Chris Gaskin*

Figure 19. Obtaining a regurgitation sample from an Australasian gannet on Mahuki Island, 7 January 2019.
Figure 20 (insert). Jack mackerel regurgitate. *Photos: Chris Gaskin*

Population status of key seabird species

As outlined in the CSP Annual Research Summary report for Objective 4 a very large colony of **fairy prions** was discovered on Tawhiti Rahi in September 2018 adding to known smaller colonies on the same island and Aorangi. The Poor Knights is the only known breeding location for fairy prions in northern New Zealand. During the course of sample collecting and deploying geolocators on fairy prions an accessible study site with marked nest sites has been established for future research with this species, possibly as a Master's degree project through the University of Auckland.

Confirmation of major populations of **fluttering shearwaters** on Taranga (Hen) and Marotere (Chicken) Islands, whereas the large numbers reported from the 1980s for Tawhiti Rahi (Poor Knights Islands) do not appear to be present with only small numbers of this species heard during night counts.

Buller's shearwater surveys to establish a base-line population estimate had been completed prior to the contract start, and analysis, taking account of habitat and topography, has been completed with the write-up in preparation (Friesen et al in prep). The initial estimate indicates a population significantly lower than previously estimated. Permanent plots were established during the population survey and markers remain in situ. Two of these were/will be checked for occupancy during incubation (December 2018) and during chick-rearing (February- April 2019). These plots will used for the deployment of GPS loggers in March and April as part of a separate tracking project.

The aerial survey conducted on 27 November 2017 of **Australasian gannet** colonies in northern New Zealand established trends in populations (refer POP2017-06 Milestone 4 report). During the course of sample collection trips to Mahuki Island and Horuhoru Rock this season, also plankton sampling at Maori Rocks (Mokohinau Islands) and a visit to the Motukawao Islands, a photographic record was made of the status of the colonies (figs. 20, 21 & 22). While not directly comparable to the photographs taken during the aerial survey, i.e. in terms of timing, angle of view and coverage, they are useful in gauging the extent of each colony and breeding success for the 2018-2019 season.

Both **red-billed gulls** and **white-fronted terns** have shown how ephemeral they can be in terms of breeding locations. There is evidence this current 2018-2019 season of redistribution of colonies. For example, red-billed gulls are now breeding in significant numbers on Maori Rocks, a major increase from recent seasons for the Mokohinau Islands (formerly one of the largest colonies of this species was on nearby Burgess Island in 1940s-1980s) from c. 250 pairs to 500-1000 pairs. The colony at Hawere (Goat Island) remains active, as do Marsden Point Refinery, Tiritiri Matangi Island, Tawharanui although the gulls at the latter location have shifted from east of Anchor Bay to Phoenix Rocks west of Anchor Bay this season. With white-fronted terns, two new colonies have emerged this current season – one at Tokatu Point, Tawharanui (c.100 pairs), the other on Horuhoru Rock (300+ pairs). The colony on Tiritiri Matangi remains, and there are small colonies on Hauturu (Little Barrier island) and Maori Rocks.

Figure 20. Maori Rocks Australasian gannet colony (part). *Photo (stitched panorama): Edin Whitehead*

Figure 21. Mahuki Island Australasian gannet colony (part), 7 January 2019. *Photo: Chris Gaskin.*
Figure 22 (insert). One of four gannet colonies on Motukaramarama, Motukawao Islands, 14 January 2019. *Photo: Karen Baird*

Next stages

1 The sampling programme will continue through to mid-April 2019. Samples are to be stored at the University of Auckland's Leigh Marine Laboratory during collection and identification stages.

2 Identification of all plankton samples collected during the current 2018-2019 season will start in early March. This will be on a sub-contract basis with work undertaken at the Leigh Marine Laboratory. Identification of a number of the regurgitations collected in colonies, where prey can be identified by eye, will also be done at the laboratory.

3 DNA extraction and amplification of faecal samples and regurgitations will be undertaken by E. Doyle and N. Adams at Unitec Institute of Technology. Sequencing and bioinformatics to follow and to be undertaken by Auckland Genomics.

4 Voucher specimens to be photographed (high quality macro images) using the University of Auckland School of Biological Sciences technical unit. Ideally, for images of larger plankton stacking multiple images together ('photo-stacking') to get a wider depth of field resulting in higher quality images with everything in focus. Smaller samples to be done under a compound microscope camera rig.

5 Voucher specimens on completion of the project to be deposited into the Auckland Museum collection.

6 Analyses and reports for the POP2017-06 contract to be completed (Milestone 6 – 30 April; Milestone 7 – 20 June; Milestone 8 – 20 June 2019).

APPENDIX 1 – PLANKTON IDENTIFICATION

Summary of zooplankton identification from samples collected 2017-2018

For Indirect Effects on seabirds in northern North Island POP2017-06

This report has been prepared by **Lily Kozmian-Ledward** (Sea Lily Ltd.) with **Prof. Andrew Jeffs** (School of Biological Sciences, University of Auckland) and **Chris Gaskin** (Northern NZ Seabird Trust).

Figure 1 (top). Larval fish and salps.
Figure 2 (bottom): Euphausiids. Photos: Edin Whitehead.

Introduction

The Hauraki Gulf is an internationally significant habitat for seabirds (Forest & Bird 2015, 2016). For example, 27 species breed in the wider Hauraki Gulf, including species endemic to northern New Zealand (Gaskin & Rayner 2013). The Hauraki Gulf is a critical part of northern New Zealand's seabird habitat within which around one third of the world's 350 seabird species have been reported to occur. Despite the importance of the Hauraki Gulf to seabird populations, very little is known about their natural diets and the extent of their reliance on various marine species on which they prey upon. For seabirds, finding suitable food at sea can be challenging given the patchy distribution of possible prey species both temporally and spatially. Seabirds adopt a range of strategies to locate and catch their prey. For example, storm petrels and prions adopt pattering, gannets and terns are renowned for their aerial plunging, shearwaters, petrels, diving petrels, blue penguins and gannets engage in pursuit plunging, petrel species, shearwaters, prions, gulls and terns use surface seizing, while gulls and terns also use dipping. All of these predatory behaviours are likely to result in the capture of different marine prey, but we currently have almost no understanding of what prey species are important to supporting the diet of seabirds in this region. North-eastern North Island waters, including the Hauraki Gulf, are notable for seabirds gathering and feeding at sites of zooplankton and fish concentrations, variously known as a 'fish shoals', 'work ups', 'boil ups', 'bust ups', or 'bait balls'. For this report, they will be described as 'work-ups'. These concentrations of seabird feeding activity have not been well described, as well as the prey species responsible for these events and the dynamic which drives them.

Zooplankton fill a crucial link between phytoplankton and higher trophic levels, providing an essential source of food for a wide range of marine life including fish, seabirds and baleen whales, both in north-eastern NZ and worldwide. Planktonic organisms can be either holoplanktonic where they spend their entire lifecycle as plankton (e.g. amphipods, krill, copepods and salps) or meroplanktonic which are only in the planktonic phase? for a portion of their lives (e.g. fish eggs and larvae, crayfish larvae and echinoderm larvae). Zooplankton cover a large size range from microplankton (20 – 200 µm) such as single-celled protozoans, which consume the smallest phytoplankton cells in the ocean, up to megaplankton (> 20 cm) which include jellyfish. This study looks at mesozooplankton (0.2 – 20 mm) and larger. While many types of zooplankton just drift with the currents (pleuston), others actively swim (nekton) albeit weakly, some undergoing a diurnal vertical migration from the ocean depths to the surface waters at night to avoid predators and access food.

Given the ecological and fisheries importance of the Hauraki Gulf, the zooplankton ecology is poorly described compared to similar important coastal ecosystems elsewhere in the world. The small number of zooplankton studies undertaken in the Hauraki Gulf indicate marked seasonal changes in zooplankton productivity, abundance and composition, that are largely related to changes in primary productivity (Zelidis and Willis 2015). Furthermore, there is marked spatial variability in zooplankton related to the hydrography of the Hauraki Gulf, and exchange with shelf waters (Zeldis and Swaney

2018, Zeldis et al 2004, 2005, Chang et al 2003). Such processes can also drive significant interannual differences in productivity and zooplankton, which are also likely to greatly influence the feeding opportunities and behaviour of seabirds.

POP2017-06 Objective 2 sets out to identify the range of potential seabird prey species within fish work-ups, to:

- Characterise fish work-ups by identifying and estimating abundance of the suite of predator species and record observations of their feeding behaviour, and
- Quantify the composition of the mesozooplankton community associated with fish work-ups.

In the 2017-2018 season the effectiveness of zooplankton sampling using nets, underwater fish video capture, and seabird behavioural observations, photography and counts, were explored. This first stage provides a more rigorous basis for understanding the connection between seabird feeding concentrations in the Hauraki Gulf and the corresponding presence of zooplankton and fish at these aggregation events. This report presents the identification and quantification of zooplankton collected during at sea sampling in the first season.

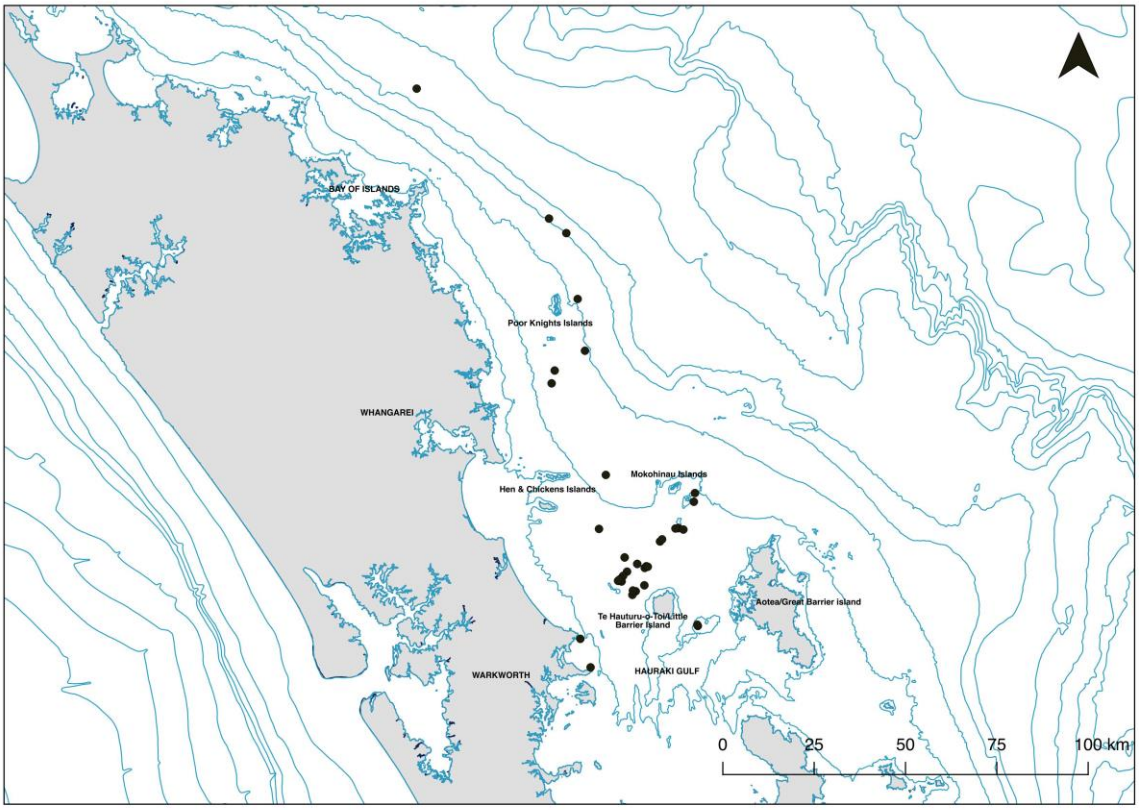
Methods

Field methods

Opportunistic sampling trips were undertaken between 20 September 2017 and 20 April 2018 in the Hauraki Gulf in the area between the Mokohinau Islands to the north and Tokatu Point and Horn Rock in the south. A trip was also conducted between 23-26 April 2018 covering the area between the Bay of Islands and the Hen and Chicken Islands. Sampling locations were determined by locating areas in which seabirds were seen feeding, also where fish activity was observed to be occurring near the surface of the sea. Sampling was also conducted away from areas of fish school activity for comparison. All samples were taken during daylight hours.

At each site, zooplankton were sampled using a net (180 µm mesh) with a circular 750 mm diameter opening and a 250 µm mesh cod end. Zooplankton sampling was conducted in one of two ways: a 30 m vertical haul or by a horizontal surface tow. For the 30 m vertical haul, the net was lowered to 30 m depth and then hauled vertically to the surface at a rate of 1 m sec^{-1} . Horizontal zooplankton net tows at the sea surface were also conducted using the same net by towing the net 20 m behind the boat at 1.8-2 kts for up to 8 mins across the face of work-ups, or in areas where seabirds were observed to be feeding (e.g., along current lines). Up to three replicate hauls (30 m or surface) were conducted at each site, which at times were some distance apart but still within the main body of the work-up location. At the completion of each net haul the contents from the cod-end were sub-sampled if large and then transferred to individual, labelled sample jars and preserved with 90% ethanol (POP2017-06 Milestone 2 report).

Figure 3. Zooplankton sampling locations 2017-2018.



Laboratory processing

The zooplankton samples were stored and processed at the Leigh Marine Laboratory (University of Auckland). A Leica EZ4W dissecting microscope was used to view, identify and count the zooplankton in each sample. Samples which contained a very large number of organisms were subsampled using an 8-way zooplankton subsampling device (Taylor, 1991) with 1/8th or 1/16th of the sample counted depending on the extent of the original zooplankton sample size. Zooplankton were enumerated using a Bogorov counting tray under the microscope at 12.5 to 16× magnification. Further information on the equipment used is given in Appendix C (this report).

There are no comprehensive zooplankton identification guides available for the Hauraki Gulf, and for many of the taxa, a high level of taxonomic expertise is required to reliably distinguish individual species, many of which have subtle diagnostic characteristics. Digital images were taken of many of the voucher specimens using the camera on the Leica EZ4W microscope. Each sample was initially viewed under the microscope in a petri dish and examples of each type of morphologically distinctive species were removed for later expert identification with the aim of producing a set of voucher specimens. Unfortunately, except for the larval fish species identified by T. Trnski (Auckland Museum), no other experts were found who would donate their time for this purpose.

Zooplankton were counted into various taxonomic groups, the level of which was defined by the ease of identification based on obvious morphological differences. With the large number of zooplankton to process and the lack of identification guides, the identification of zooplankton items to species level was not possible, and is probably not particularly useful in terms of characterising the overall zooplankton community that may be responsible for attracting seabirds and fish to feeding aggregations. The major groups of copepods (i.e., calanoid, cyclopoid and harpacticoid copepods) were identified and counted as separate groups. Members of the Malacostraca (i.e., krill, decapods, stomatopods) were initially grouped as they could not be easily identified further. However, adult euphausiids were easy to identify and were counted separately but the identification of the juveniles (i.e., calytopis and furcilla stages) was not possible. Malacostraca individually counted into separate groups were euphausiid adults, stomatopod larvae, isopods, amphipods, brachyura (crab) larvae and lobster phyllosoma, with the remaining material in the Malacostraca grouping counted as a "decapod shrimp" category. Taxa within the "decapod shrimp" group most likely included juvenile euphausiids, mysiid shrimps, anomuran larvae and caridean shrimp larvae. It is likely that there were many euphausiid juveniles present in the samples but without a definitive identification, all unknown "shrimp-like organisms" were counted into a "decapod shrimp" category. Regurgitations obtained from some seabirds in colonies (Gaskin in prep.) indicate that euphausiids represent a potentially important food source.

Of the Cirripedia (i.e., barnacles) their nauplii and cyprid larvae were counted separately. The gastropods were separated into pteropods (those with cone shaped shells), Pterotrachidae and "mollusc larvae". The "mollusc larvae" group included bivalve veligers and misidentified pteropods (those with spiral shells). Other holoplankton was counted into taxonomic units including; Chaetognatha (i.e., arrow worms), Appendicularia (i.e., larvaceans), Cladocera, and Thaliacea. Thaliaceans included salps and doliolids.

Results

A total of 39 zooplankton samples were collected at 28 sampling events (i.e., samples from one general location on one day associated with one work-up) from 20 September 2017 - 26 April 2018 from an area 12 nautical miles north of the Poor Knights, south to Tokatu Point and Horn Rock. A total of 13 horizontal surface tows were undertaken; all in areas where birds were observed feeding – in work-ups (n=9), away from work-ups (n=3) and along current lines (n=2). A total of 26 vertical zooplankton hauls were undertaken, within feeding work-ups (n=14), away from work-ups (n=9) and along current lines (n=2).

Zooplankton diversity and seasonal trends

Most of the zooplankton samples contained a wide diversity of zooplankton taxa. The dominant types of zooplankton were organised into six groups: Copepoda, Malacostraca, Chaetognatha, Appendicularia, Thaliacea and fish eggs. A seventh group labelled as 'Other', contained the remaining less abundant taxa including: Hydrozoa, polychaetes, barnacle larvae, cladocerans, mollusc larvae, pteropods, Pterotracheidae, echinoderm pluteus and juvenile fish. The full counts of the raw data are given in Appendix A and example photographs of zooplankton types in Appendix B.

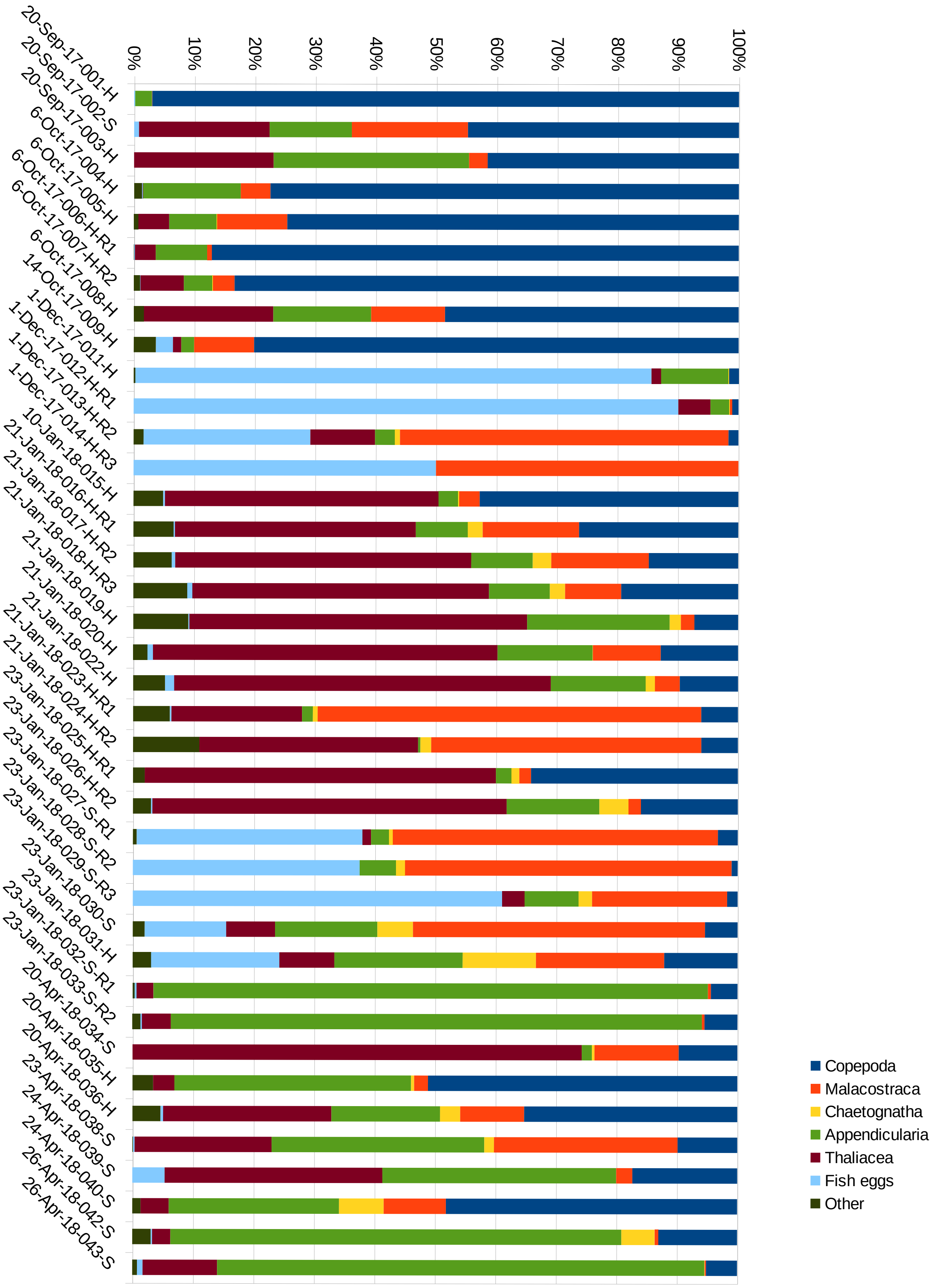
A clear seasonal trend was seen across the zooplankton samples (Fig. 3). Most notably:

- Copepoda were present in 97% of samples and were the most abundant during the spring months, often being the most numerically abundant type of zooplankton in these samples. Copepoda were still an important component of most samples during summer and autumn, comprising around 20% of the total abundance of zooplankton.
- Malacostraca were present in 97% of samples and were generally more abundant during the summer months.
- Chaetognatha were present in 72% of the zooplankton samples, being virtually absent during spring but present in samples from January onwards.
- Appendicularia were present in 93% of the samples and were the most abundant in autumn. They were the most abundant zooplankton type in four samples, two in January and two in April.
- Thaliacea were present in 92% of the zooplankton samples and were generally most abundant during summer, and often comprising 40% or more of the zooplankton counts in samples at this time.
- Fish eggs were present in 79% of the samples with two peaks of high abundance in early December and late January.
- Zooplankton in the 'Other' category were present in 77% of samples and were generally more abundant in samples taken during summer.

In comparing relative abundance of dominant zooplankton types between the two sampling methods; the horizontal surface tows contained four samples with the greatest relative abundance of Appendicularia (>70%) and the vertical 30 m hauls contained six samples with the greatest relative abundance of copepods (>70%). Overall the 30 m vertical hauls also contained a greater abundance of Thaliacea.

On two occasions, both a horizontal surface tow and a 30 m vertical haul were undertaken at a similar location or in similar conditions. Samples 20-Sep-17-002-S and 20-Sep-17-003-H were taken 0.4 nm apart. Both samples had high proportions of copepods, appendicularians and Thaliacea. However, the sample from the horizontal surface tow also had a higher proportion of Malacostraca and a small amount of fish eggs. Samples 23-Jan-18-031-H and 23-Jan-18-032-S-R1 were taken on the same day within schooling skipjack tuna but the zooplankton samples were very different in relative abundances with the former sample having a high diversity of zooplankton types and the latter dominated by Appendicularia.

Figure 4. Relative abundance of dominant zooplankton types across all samples. Sample ID given on x-axis showing date sample collected, sample number, surface tow (S) or 30 m haul (H), and replicate (R1,2, 3) if applicable.



Total number of zooplankton per sample

The total number of individual zooplankton within each sample varied from a minimum of four (1-Dec-17-014-H-R3) to a maximum of 27,106 (1-Dec-17-011-H). The surface tows were only loosely standardised by the tow speed and duration of net tow so the abundance of zooplankton per sample was not representative of the abundance of zooplankton in the water column, but provided a good indication of the proportions of different zooplankton groups that were present (Figs. 5 & 6). For both methods of sampling, there did not appear to be any clear seasonal trend in the total number of zooplankton captured per sample.

Figure 5. Total number of individual zooplankton in samples from horizontal surface tows.

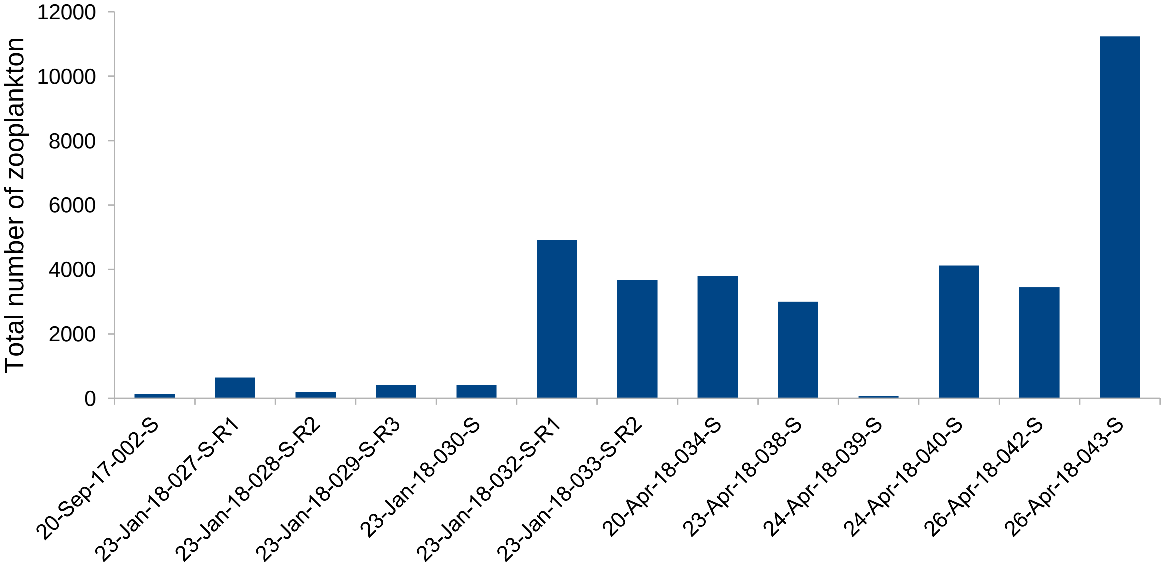
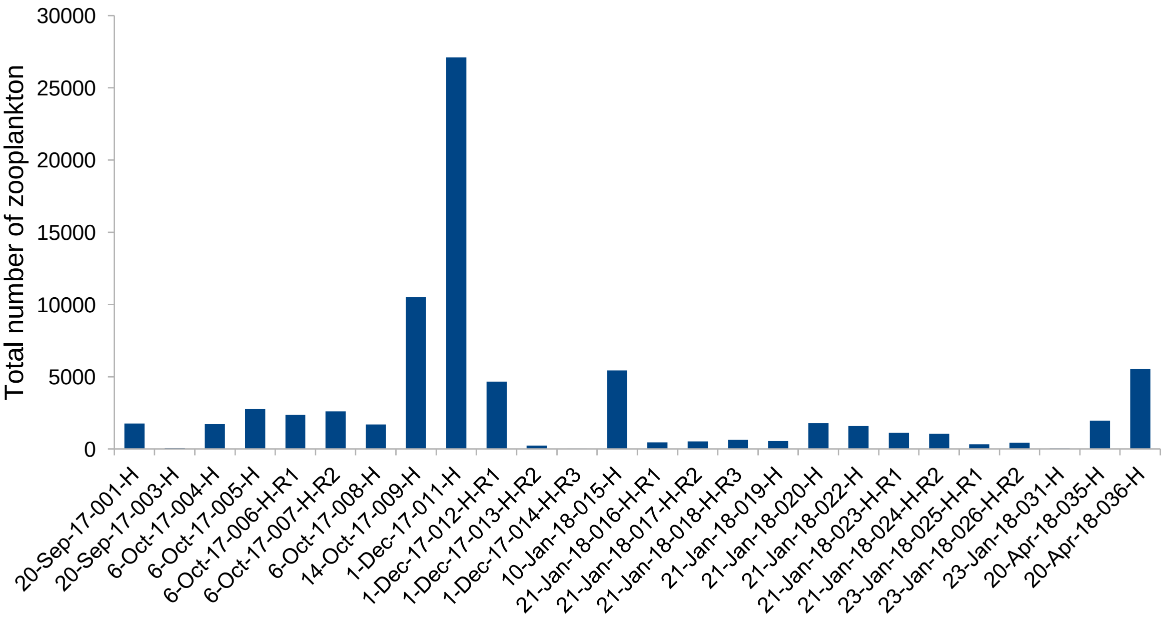


Figure 6. Total number of individual zooplankton in 30 m vertical haul samples.



Replicate sampling

Three replicate horizontal surface tows were undertaken on the 23 January 2018 near Simpson Rock. Replicates one and two had very similar relative abundances of zooplankton with around 37% fish eggs and about 50% Malacostraca. The third replicate was similar but contained a higher proportion of fish eggs (61%) and lower proportion of Malacostraca (22%). Two replicate surface tows on 23 January 2018 taken at a site north of Little Barrier Island were again similar in composition, both being dominated by Appendicularia (>85%) (Fig. 3).

For the 30 m vertical haul samples, replicate sampling events occurred on 6 October 2017 (n=2), 21 January 2018 (n=3) and 23 January 2018 (n=2). In all instances, the replicates from the same sampling event contained similar proportions of zooplankton types and total numbers of zooplankton. For example, the replicates from 6 October 2017 were both dominated by copepods with 87% in 6-Oct-17-006-H-R1 and 83% in 6-Oct-17-007-H-R2 and very similar overall proportions of the remaining zooplankton taxa (Fig. 3).

However, a set of three replicate 30 m vertical haul samples taken on 1 December 2017 were markedly different in zooplankton diversity and total zooplankton count. Replicate one was dominated by an abundance of fish eggs (4200), while replicate two by Malacostraca (243), and replicate three only contained four zooplankton: Malacostraca (2) and fish eggs (2) (Fig. 3).

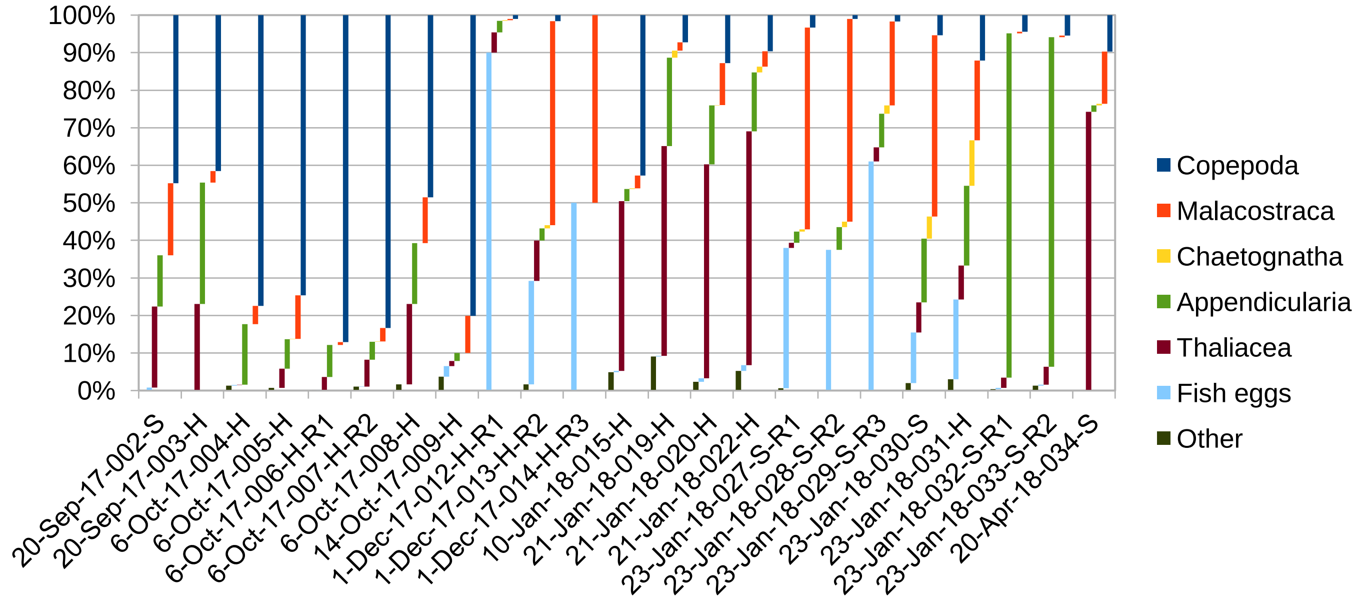
Samples in and out of work-ups

Of the 26 vertical haul samples, 14 were taken in work-ups, 9 were in areas with no work-up, and 2 were in current lines. Of the 13 horizontal tow samples, 9 were in work-ups, 3 outside work-ups, and 2 in current lines.

There is a high degree of variability in the relative abundance of the dominant groups of zooplankton in and out of work-ups, even when they have been taken on the same day in and out of a work-up (Fig. 7). Also, given the seasonal variation in zooplankton discussed above, it is difficult to make comparisons among months other than for January as this is the only month within which several samples were taken both in and out of work-ups. Within the work-ups sampled in January there were slightly greater proportions of Malacostraca and Chaetognatha and a much greater proportion of fish eggs, compared to the non-work-up samples of the four samples taken from current lines: the two taken on the 21 January contained > 50% Malacostraca and > 20% Thaliacea. The two samples from the 26 April both were dominated by Appendicularia (> 70%).

The high degree of variability in the total number of zooplankton also makes it difficult to draw any conclusions from comparisons between samples taken in and out of work-ups (Fig. 8). For surface hauls, the mean total count of zooplankton within a work-up was 1769 (n=8), and with no work-up was 4375 (n=5). For the vertical hauls, the mean number of zooplankton within a work-up was 2395 (n=15) and with no work-up was 3718 (n=11) and there was no significant difference between these means (t test = 0.53, P > 0.60). Although there tended to be fewer eggs in work-ups on average than for samples outside work-ups, there was no difference in the means, i.e., 309 versus 2106 respectively (t test = 1.3, P > 0.2). There tended to be more copepods in work-ups on average than for samples taken outside work-ups, but there was no different between the means, i.e., 1310 versus 520 respectively (t test = 1.3, P > 0.2). There were no other obvious trends in the data for other zooplankton taxa for inside work-ups versus outside work-ups. Samples taken within current lines (no work-up) had a mean of 7340 plankton in surface hauls (n=2) and 1090 in vertical hauls (n=2).

Figure 7. Relative abundance of dominant zooplankton groups from samples in (above) and out of (below) workups. Sample names starting with CL are those taken from current lines.



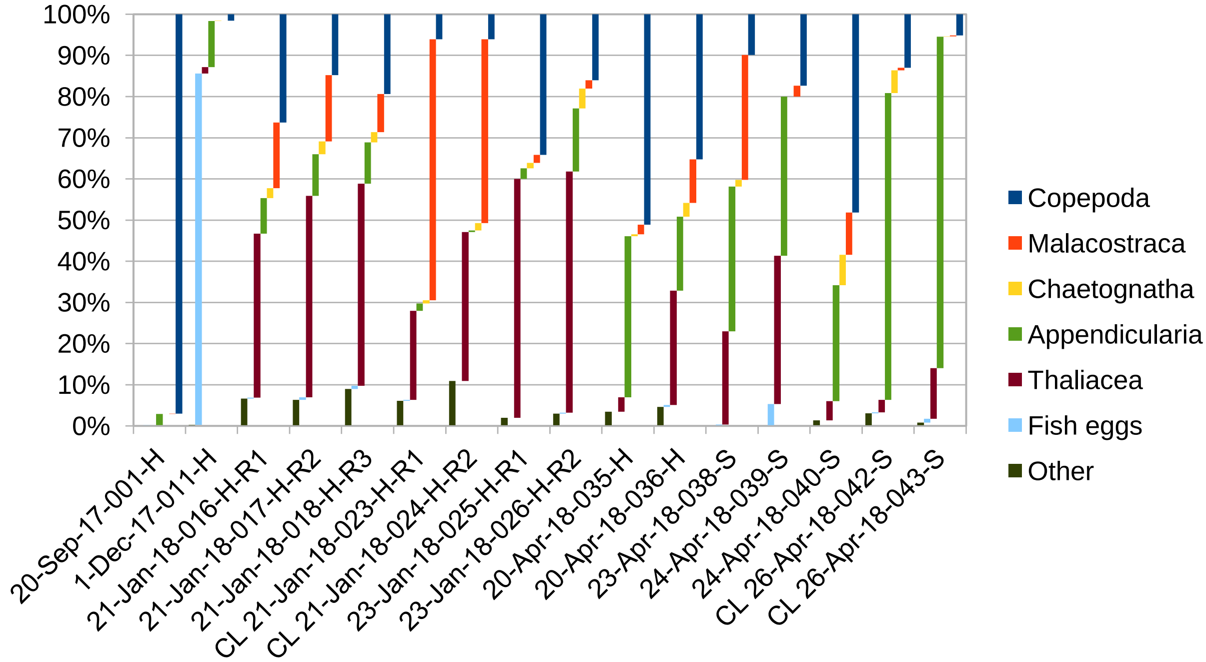
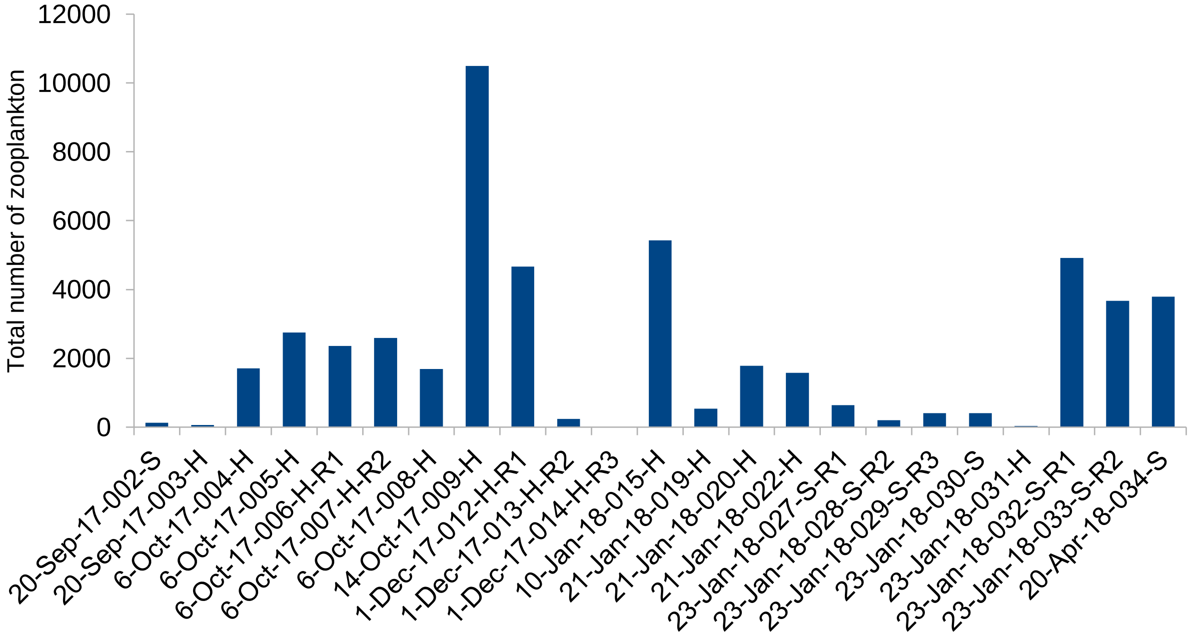
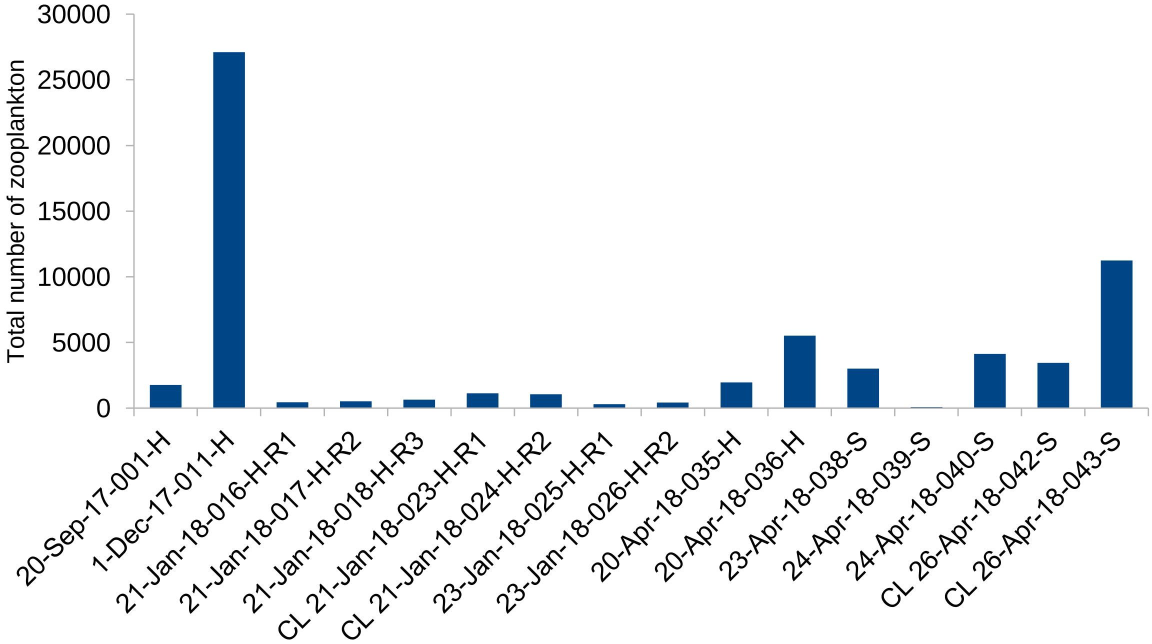


Figure 8. Total number of zooplankton in (above) and out of (below) work-ups. Sample names starting with CL are those taken from current lines. Note the different scales on the y-axis.





Larval fish identification

Larval fish were found in 46% of the total samples, 31% of the surface tow samples and 54% of the 30 m vertical haul samples, but usually in relatively low numbers. Nine types of larval fish were identified, mostly to species level by T. Trnski (Auckland Museum) (Table 1). Photos are given in Appendix B.

The highest numbers of larval fish were found in samples 1-Dec-17-011-H (n = 54, NW reef), 21-Jan-18-022 (n = 48, NW reef), 23-Jan-18-033-S-R2 (n = 32, N of LBI), 20-Apr-18-036-H (n =

40, NW reef), and 26-Apr-18-042-S (n = 37, N of Poor Knights). All other zooplankton samples that contained larval fish had nine or less individuals.

Table 1. List of larval fish voucher specimens found in zooplankton samples. Table modified from T. Trnski pers. com. Common names taken from Roberts et. al. 2017.

Sample ID	**Voucher ID**	**Family**	**Taxon**	**Common name**	**No: size mm SL**
1-Dec-17-013-H-R2	013/#1	Moridae	*Lotella*	Morid cod family	1: 19
10-Jan-18-015-H	018/#2	Carangidae	*Pseudocaranx georgianus*	Trevally	4: 3-4
21-Jan-18-022-H	022/#3	Carangidae Scombridae	*Pseudocaranx georgianus* *Scomber australasicus*	Trevally Blue mackerel	2: 3-4 2: 4-4
23-Jan-18-031-H	031/#4	Exocoetidae	Unknown	Flying fish family	1: 6
20-Apr-18-036-H	036/#5	Neoscopelidae?	*Neoscopelidae* sp.?	Blackchin family?	1: 4
20-Apr-18-036-H	036/#6	Cepolidae	*Cepola haastii*	Red bandfish	1: 4
26-Apr-18-042-S	042/#7	Scomberosocidae	*Scomberesox saurus*	Saury	2: 15-16
26-Apr-18-042-S	042/#8	Scomberosocidae	*Scomberesox saurus*	Saury	2: 8-9
26-Apr-18-042-S	042/#9	Macroramphosidae	*Macroramphosus scolopax*	Snipefish	1: 6
26-Apr-18-042-S	042/#10	Kyphosidae	*Kyphosus* sp.	Drummer family	1: 6
26-Apr-18-042-S	042/#11	Carangidae	*Pseudocaranx georgianus*	Trevally	1: 19

Size range of the zooplankton collected

The sizes of zooplankton were not measured during the laboratory processing. Estimated average size ranges for the dominant species groups are below (Jillett, 1971; Swadling et al., 2013):

- Copepoda: 0.5 – 3.5 mm (copepodites (immature copopod) are smaller but were not counted separately).
- Malacostraca: 0.5 – 20 mm
- Chaetognatha: 20 – 40 mm
- Appendicularia: 2- 5 mm
- Thaliacea: up to 20 mm

Relationships between seabird feeding in association with shoaling fish

Understanding the diet of seabirds which commonly associate with shoaling fish and the potential prey made available by this intense fish activity is the main thrust of this project (POP2017-06: Indirect Effects on seabirds in northern North Island). Discussion on these complex and poorly understood relationships will be explored in companion reporting for this project, and to which this identification report will be appended.

Discussion

There have been several studies on zooplankton in the Hauraki Gulf and north-eastern New Zealand (e.g. Jillett, 1971; Kingsford, 2013; Zeldis & Willis, 2015). However, none of these have looked at the relationship between zooplankton and work-ups, or zooplankton as a food source for seabirds. Some studies have been conducted in Otago waters looking at the distribution of zooplankton and planktivorous seabirds in Otago shelf waters where swarms of euphausiids (*Nyctiphanes australis*), and galatheid crab larvae (*Munida gregaria*) occur in summer (McClatchie et al., 1989; Richard et al., 1998). There does not appear to be any similar studies conducted in northeast New Zealand before this current study which makes it significant in terms of beginning to better understand the relationship of the zooplankton communities with seabird feeding.

It could be expected that there would be significant differences in zooplankton composition and/or abundance in areas of work-ups and to a lesser degree at current lines and upwelling areas when compared to other areas. However, the results of this study do not provide evidence for differences in total abundance of zooplankton, or relative abundance of dominant zooplankton groups, from sampling taken within and away from work-ups. This lack of apparent differences could be due to the high degree of variability in zooplankton among sampling events, which is likely to due to the inherent spatial and temporal variability of zooplankton. A more highly structured sampling programme is required to address this question, which incorporates a higher degree of replication inside and outside individual work-ups

Previous studies have found differing zooplankton communities in the inner and outer Hauraki Gulf (e.g. Jillett, 1971; Zeldis & Willis, 2015), with generally less variety in the inner Gulf but more larval species, and more of an offshore influence in the outer Gulf. However, Zeldis & Willis (2015) found that zooplankton abundance was much greater within the Hauraki Gulf than at sites to the north, likely due to the greater amounts of nutrient availability within the Gulf. This study did not look at differences in zooplankton composition and abundance between different locations but these previous studies show that there can be differences when moving from semi-enclosed coastal areas out to more oceanic realms.

The aim of this current study was to obtain a general picture of zooplankton types and abundance in northeastern North Island waters and its potential relationships with seabirds and determine the best methods (field and laboratory) to achieve this.

Recommendations are given below for potential improvements for the next (2018-19) season.

Recommendations

The work completed so far, i.e. establishing and refining methodology and gathering suitable resources to facilitate identification will mean samples from the 2018-2019 season will be analysed more efficiently. However, improvements could be made to further streamline the sample processing. Recommendations for the fieldwork are given in the main report.

1. **Subsampling.** Could be done to a greater degree to reduce the amount of material to process. Only the larger samples in this study were subsampled. The method used in this study (8-way splitter) potentially produced artificially inflated final counts. Other subsampling devices (e.g. Folsom plankton splitter or Hensen Stempel pipette) could be tested for improved accuracy and efficiency of processing samples.
2. **Measuring zooplankton biomass.** Determining the biomass of zooplankton in each sample would allow comparisons between the amount of potential food available to seabirds (and other planktivores) in and out of work-ups and spatially in relation to hydrographic features. Comparisons could also be made with previous research. In order to define this, the volume of water passing through the net would need to be measured. Biomass in samples can be determined in displacement volumes of zooplankton or by measuring settled volume in a measuring cylinder (McClatchie et al., 1989).
3. **Zooplankton size classes.** Specific details on which zooplankton types may be important for seabirds, as prey is not yet known, however, zooplankton size may be important to seabirds actively targeting zooplankton. Within the zooplankton groups used in this study, separating the species into size classes using sieves would likely be more useful than trying to identify zooplankton further to family or species level. Then identifying dominant taxa within each size class would enable the sample to be quickly characterised.
4. **Euphausiid abundance.** Euphausiids are thought to be an important food source for many species of seabirds (e.g. McClatchie et al.,1989) and can form dense swarms, sometimes isolated from fish activity (CG pers. obs.). They also occur in large areas away from fish school activity but where seabirds have been seen feeding. Identifying and counting euphausiids (all life stages) separate from the Malacostraca group may provide some useful information.
5. **Photography.** Obtaining good quality images using the camera on the Leica dissecting microscope was difficult. Creating a set of high-quality images to illustrate the different zooplankton types would be beneficial as a resource for other researchers. The School of Biological Science at the University of Auckland has microscope camera equipment that could be used for this purpose in future.

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APPENDICES

Appendix A: Raw data

Zooplankton counts. The "decapod shrimp" category includes euphausiid juveniles, mysiid shrimps, as well as anomuran and caridean shrimp larvae. The "mollusc larvae" category includes bivalve veligers, and misidentified pteropods with spiral shells.

			Class Hydrozoa			Subclass Copepoda			Infraclass Cirripedia		Class Malacostraca									Class Gastropoda		
Sample ID	Location	Subsampled?	Hydrozoan	Siphonophore	Polychaete	Calanoida	Cyclopoida	Harpacticoida	Barnacle cyprid	Barnacle nauplis	"Decapod shrimp"	Adult euphausid	Isopod	Amphipod	Crab larvae	Crayfish philosoma	Stomatopod larvae	Cladocera	Chaetognatha	"Mollusc larvae"	Pteropod	Pterotracheidae
20-Sep-17-001-H	NW reef	N	0	0	0	1621	96	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
20-Sep-17-002-S	SW of Simpson rk	N	0	0	0	33	23	0	0	0	8	15	0	0	0	0	1	0	0	0	0	0
20-Sep-17-003-H	SW of Simpson rk	N	0	1	0	25	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
6-Oct-17-004-H	NW reef	N	0	1	0	1243	68	14	4	7	82	0	0	0	2	0	0	0	0	12	0	0
6-Oct-17-005-H	Nw of LBI	N	0	3	0	1967	79	7	6	3	315	1	0	4	2	1	0	0	2	5	0	1
6-Oct-17-006-H-R1	Nw of LBI	N	0	1	0	1999	51	6	2	0	15	0	1	0	1	0	1	0	0	0	0	0
6-Oct-17-007-H-R2	Nw of LBI	N	0	1	0	2097	62	3	2	0	90	0	0	12	3	0	0	0	2	13	0	0
6-Oct-17-008-H	nr NW reef	N	1	3	0	751	65	3	1	6	204	0	0	4	1	1	0	0	0	17	0	0
14-Oct-17-009-H	NW of LBI	Y	0	24	0	7328	752	328	40	24	960	77	2	8	1	0	0	8	0	304	0	0
1-Dec-17-011-H	NW reef	Y	2	16	0	344	80	0	0	0	0	0	0	0	0	0	0	10	24	8	0	0
1-Dec-17-012-H-R1	Simpson Rk	Y	40	16	0	24	24	0	0	0	16	0	0	0	0	0	0	0	8	0	0	0
1-Dec-17-013-H-R2	Simpson Rk	N	11	3	0	2	2	0	0	0	5	126	0	2	1	0	0	0	2	0	0	0
1-Dec-17-014-H-R3	Simpson Rk	N	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
10-Jan-18-015-H	Mokes	Y	0	104	0	2217	104	0	8	18	152	24	0	0	0	0	8	0	8	40	0	0
21-Jan-18-016-H-R1	NW reef	N	3	7	1	117	1	1	0	1	65	0	0	1	6	1	0	0	11	0	4	0
21-Jan-18-017-H-R2	NW reef	N	8	13	1	77	0	0	1	1	80	0	0	0	3	0	1	0	16	1	0	0
21-Jan-18-018-H-R3	NW reef	N	10	12	1	122	1	0	1	0	53	0	2	2	0	1	3	0	16	2	2	1
21-Jan-18-019-H	nr NW reef	N	8	22	0	37	2	0	1	0	5	0	0	1	2	0	5	0	10	3	0	4
21-Jan-18-020-H	NW reef	Y	8	240	0	224	4	0	0	0	184	0	0	16	16	0	0	0	1	8	0	2
21-Jan-18-022-H	NW reef	Y	8	128	0	152	0	0	0	0	48	0	0	1	16	0	1	0	24	0	0	2
21-Jan-18-023-H-R1	Horn Rk	N	3	16	0	60	8	0	0	2	702	1	0	0	8	0	0	0	9	3	1	0
21-Jan-18-024-H-R2	Horn Rk	N	11	13	2	59	4	1	0	1	462	0	0	0	9	0	2	0	19	3	1	0
23-Jan-18-025-H-R1	N of LBI	N	1	4	0	106	0	0	0	0	5	0	0	2	1	0	0	0	4	1	2	0
23-Jan-18-026-H-R2	N or LBI	N	6	5	0	68	2	0	0	0	9	0	0	7	0	0	0	0	21	1	5	0
23-Jan-18-027-S-R1	Simpson Rk	N	0	0	0	21	0	0	0	4	317	27	0	0	0	0	0	0	4	0	0	0
23-Jan-18-028-S-R2	Simpson Rk	N	0	0	0	2	0	0	0	0	67	39	0	0	1	0	1	0	3	0	0	0
23-Jan-18-029-S-R3	Simpson Rk	N	0	0	0	6	1	0	0	0	50	36	0	0	3	0	1	0	9	0	0	0
23-Jan-18-030-S	Mokes	N	0	0	1	20	2	0	0	0	41	143	0	5	13	0	0	0	24	0	0	0
23-Jan-18-031-H	Simpson Rk	N	0	0	0	3	1	0	0	0	4	3	0	0	0	0	0	0	4	0	0	0
23-Jan-18-032-S-R1	N of LBI	Y	0	32	0	168	48	0	0	0	16	8	0	0	0	0	0	0	0	8	0	1
23-Jan-18-033-S-R2	N of LBI	Y	0	16	0	168	32	0	0	0	8	0	0	16	8	0	0	0	0	0	0	0
20-Apr-18-034-S	Leigh reef	Y	0	0	0	240	128	0	0	0	496	0	0	0	16	0	16	0	16	0	0	0
20-Apr-18-035-H	NW reef	N	1	4	12	808	192	5	0	2	44	0	0	0	1	0	0	38	10	3	9	2
20-Apr-18-036-H	NW reef	Y	0	0	0	10	1936	0	72	24	536	0	0	0	32	16	0	8	184	8	56	8
23-Apr-18-038-S	off Tutukaka	Y	0	0	0	208	88	0	0	0	904	0	0	0	8	0	0	0	48	0	3	0
24-Apr-18-039-S	btn Chicks and Mokes	N	1	0	0	13	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
24-Apr-18-040-S	S of Poor Knights	Y	32	8	8	1496	448	40	0	0	424	0	0	8	0	0	0	0	304	8	32	0
26-Apr-18-042-S	N of Poor Knights	N	0	124	0	345	103	1	12	3	20	0	1	4	1	0	0	9	189	7	33	0
26-Apr-18-043-S	N of Poor Knights	Y	0	0	0	400	168	8	0	72	16	8	0	8	0	0	0	0	8	16	0	0
		TOTALS >>	155	817	26	24581	4577	417	150	168	6407	510	6	101	155	20	41	73	980	471	148	21

Appendix B: Examples of zooplankton found in this study.

Figure B1: Photographs showing examples of zooplankton and their taxonomy found in this study.

Subphylum Crustacea - Subclass Copepoda – Order Calanoida

Subphylum Crustacea - Subclass Copepoda – Order Calanoida

Subphylum Crustacea - Subclass Copepoda – Order Cyclopoida – *Sappharina* sp.

Subphylum Crustacea - Subclass Copepoda – Order Cyclopoida, upper one with eggs

Subphylum Crustacea - Class Malacostraca – Order Amphipoda

Subphylum Crustacea - Class Malacostraca – Order Decapoda - *Jasus edwardsii* (crayfish) phyllosoma


Subphylum Crustacea - Class Malacostraca – Order Euphausidae (with eggs)


Subphylum Crustacea - Class Malacostraca – Order Decapoda – *Lucifer* sp. larvae

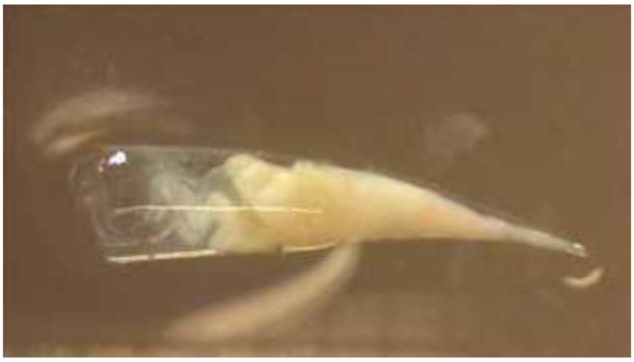

Subphylum Crustacea - Class Malacostraca – unknown “shrimp” - possibly euphausiid furcella


Subphylum Crustacea - Class Malacostraca – Order Mysidacae


Subphylum Crustacea - Class Malacostraca – Order Decapoda – Infraorder Brachyura (crab) - larvae

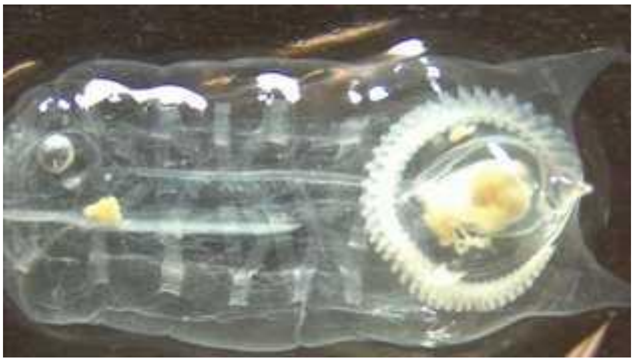

Subphylum Crustacea - Class Malacostraca – Order Stomatopoda (mantis shrimp)- larvae

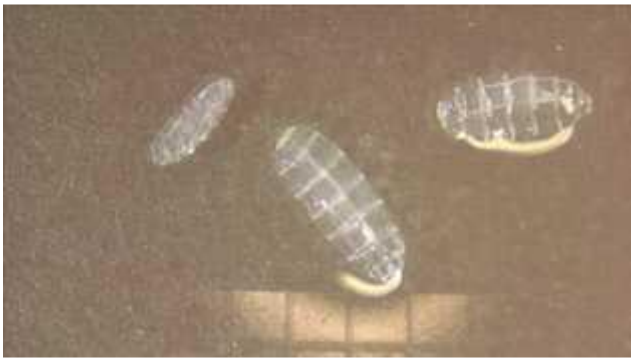

Phylum Chaetognatha (arrow worm)


Phylum Mollusca - Class Gastropoda – Order Pteropoda


Phylum Echinodermata - plutus


Subphylum Tunicata - Class Appendicularia


Subphylum Tunicata – Order Salpidae – *Thalia* sp.


Subphylum Tunicata – Order Doliolida

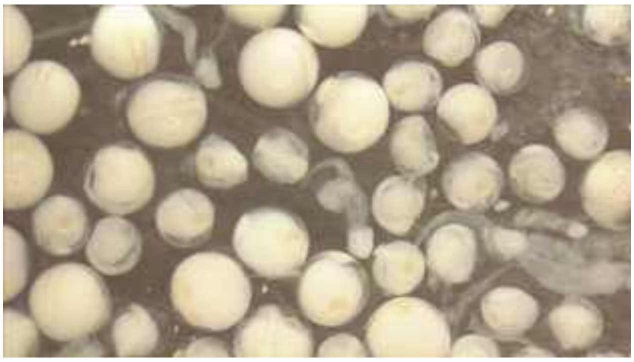
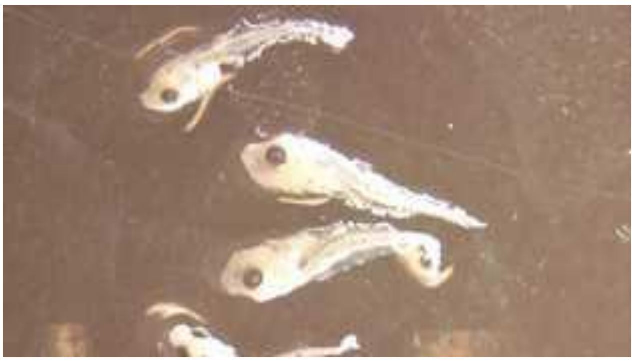

Phylum Chordata - Fish eggs – unknown species.
With Appendicularia

Figure B2: Photographs of some of the larval fish found in this study



Psuedocaranx georgianus juvenile

Family Exocoetidae juvenile.

Possible Neoscopelidae sp. juvenile.

Cepola haastii juvenile.

Scomberesox saurus juvenile.

Appendix C: Equipment used during the zooplankton identification process

Equipment used included: squirt bottles of ethanol and water, small sieves, various containers, counters, Bogorov tray, forceps, petri dishes.

Leicia EZ4W microscope with external lighting, Bogorov tray with black paper underneath.

The 8-way sample splitter. L to R: bucket with eight bunged holes in the base, eight-vane plunger and weighted (5.6 kg) collar.

Sample splitter in use.

Using the sample-splitter (Taylor, 1991).The sample to be split was poured into the bucket, diluted with about 1 L fresh water, and vigorously agitated for several seconds using a stirring rod. The plunger was then forced into the bucket with the neoprene seals on the sides and bottom of the vanes forming eight compartments. The weighted collar was placed on top to ensure a tight seal. The contents of one of the compartments was emptied into a container by removing the bung. In practise, the seals between the compartments were not always 100% watertight and may have allowed some transfer of small zooplankton between compartments.