Indirect effects on seabirds in northern North Island

POP2017-06 (Milestone 7 Report)

Comparison of availability of food species in fish shoals and how those items are represented in different seabird diets in the region

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Cover photo: (top) Fluttering shearwaters, fairy prions and fish school activity. *Photo: Edin Whitehead;* (bottom) Kahawai and trevally with euphausiids. *Screenshot from video*: NNZST

Figure 1 (above). Australasian gannet with saury. *Photo: Edin Whitehead*

Introduction

This project (POP2017-06) builds on the findings of INT2016-04 (Gaskin 2017). A range of commercial fisheries target aggregations of surface shoaling fish. Purse seining is commonly used to capture these fish schools. The dense fish schools create a phenomenon known as fish workups. These fish drive up prey items to the sea surface and observations suggest that this forms an important food source for a range of seabird species. There is currently poor knowledge of both the diet of surface-foraging seabirds and what prey items are being made available to seabirds from fish workups. This has limited our understanding of the mechanisms through which changes in the distribution and/or abundance of fish workups may be driving seabird population changes (population status and annual breeding success).

POP2017-06 aims to further our understanding of the diet, foraging ecology, breeding success and population status of these species that regularly forage in association with fish workups. The six species identified as feeding in association with fish schools in the northern north island region are red-billed gull, white-fronted tern, Australasian gannet, fairy prion, Buller's shearwater and fluttering shearwaters (Figs 3-8).

Previous reports for POP2017-06 outlined the opportunistic and targeted collection of diet samples from surface nesting and burrow nesting seabirds during chick rearing periods in 2017-2018 and 2018-2019 (Gaskin 2018, 2019); and summarised boat-based activities from 1 May 2018 - 30 December 2018 including cataloguing identification samples collected from September 2017 - April 2018 (Kozmian-Ledward et al 2019).

This report summarises what we have found about the diets of the birds from sampling in colonies and from the at-sea sampling in the fish shoals and background areas across two consecutive seasons. It reviews the sampling programme which has been exploratory in meeting the challenges of zooplankton sampling around fish schools and with limited resources requiring finding supplementary funding for all aspects of the study. It does, however, provide some key findings in terms of the diet of the six species and what is presented when considering the variety of fish shoals and whether prey caught in association of the shoals are likely to contribute a significant part of the natural food fed to adults and chicks or just a portion of the diet. We recommend what new work is needed to build on this preliminary study in the future.

Appended here is a commissioned report (Kozmian-Ledward et al 2019) cataloguing identification of samples collected September 2018 - May 2019 and analysis. It includes a set of macro photography of voucher specimens, zooplankton and larval fish, collected across both seasons of the study. In commissioning these high-quality images, we have in mind an identification guide for the Hauraki Gulf Marine Park, a visual guide of key taxonomic diagnostic features to facilitate future identification of commonly encountered zooplankton species.

Figure 2. Hermit crab larvae, collected 3 May 2019. Photo: Charlie Johnson, School of Biological Sciences, University of Auckland/ NNZST

Table 1. Seabird species observed feeding in association with fish schools in northern New Zealand waters; also included are species observed in association with feeding cetaceans and in other situations (e.g. along current lines). Entries shaded are the six species that are the subject of this study.

Species names		NZTCS	IUCN Red List
Buller's shearwater	*Ardenna bulleri* (= *Puffinus bulleri*) *	At Risk – Naturally Uncommon	Vulnerable
Fluttering shearwater	*Puffinus gavia*	At Risk - Relict	Least Concern
Fairy prion	*Pachyptila turtur*	At Risk - Relict	Least Concern
Australasian gannet	*Morus serrator*	Not Threatened	Least Concern
Red-billed gull	*Larus novaeholllandiae scopulinus*	Nationally Vulnerable	Least Concern
White-fronted tern	*Sterna striata*	At Risk - Declining	Least Concern
Flesh-footed shearwater	*Ardenna carneipes* (= *Puffinus carneipes*) *	Nationally Vulnerable	Near Threatened
White-faced storm-petrel	*Pelagodroma marina*	At Risk - Relict	Least Concern
Black petrel	*Procellaria parkinsoni*	Nationally Vulnerable	Vulnerable
Sooty shearwater	*Ardenna grisea* (= *Puffinus griseus*) *	At Risk - Declining	Near Threatened
Short-tailed shearwater	*Ardenna tenuirostris* (= *Puffinus tenuirostris*) *	Migrant	Least Concern
Grey noddy (grey ternlet)	*Procelsterna cerulea*	Naturally Uncommon	Least Concern
Common diving petrel	*Pelecanoides urinatrix*	Not Threatened	Least Concern
NZ storm-petrel	*Fregetta maoriana*	Nationally Vulnerable	Critically Endangered
Cook's petrel	*Pterodroma cookii*	At Risk - Relict	Vulnerable

* IUCN Red List (2017) lists these species within the *Ardenna* genus, whereas they are listed in the NZ Checklist (2010) and NZTCS (2016) as *Puffinus*.

Figures 4-11. Buller's shearwaters (top left), fairy prions (top right), fluttering shearwater (middle left), Australasian gannet (with squid) (middle right), white-fronted tern (lower left). *Photos: Edin Whitehead*. Red-billed gull (lower right). *Photo: Richard Robinson.* Flesh-footed shearwaters and white-faced storm petrel are also seen in feeding associations. *Photos: Edin Whitehead*








Methods

Details of methods have been covered in earlier milestone reports for POP2017-06 and the appended report here.

Results

Diet sampling within colonies

For identification of prey items for each species please refer to the following reports:

L. Kozmian-Ledward, A. Jeffs & C. Gaskin (2019). **Seabird regurgitation analysis.** Report prepared for the Northern NZ Seabird Trust

E. Doyle & N. Adams (2019). **DNA extraction and amplification of seabird regurgitates from Buller's Shearwater (*Puffinus bulleri*) and Fairy Prions (*Pachyptila turtur*).** Report prepared for the Northern NZ Seabird Trust.

E. Doyle & N. Adams (2019). **DNA extraction and amplification of faecal samples from the White-fronted terns (*Sterna striata*).** Report prepared for the Northern NZ Seabird Trust.

The results of research into the diet of Australasian gannets by N. Adams in 2017 and 2018 were made available to this study (POP2017-06) in recognition of overlapping goals and the resulting collaboration allowed the study to be extended by a further season (December 2018-January 2019).

Gaskin, C.P., Adams, N. (2018). **Summary of activities carried out to collect samples from seabirds 2017-2018 (Milestone 3).** Report prepared for the Conservation Services Programme POP2017-06. Department of Conservation, Wellington.

N. Adams (2019). **Diet and trophic interactions of Australasian Gannet *Morus serrator* – samples collected 2018-2019**. Report prepared for the Northern NZ Seabird Trust.

At-sea zooplankton sampling

For identification of zooplankton including larval fish please refer to the following reports:

Gaskin, C.P. 2019. **Summary of activities carried out to collect samples from fish shoals 2018 (Milestone 5) & overall project update.** Report prepared for the Conservation Services Programme POP2017-06. Department of Conservation, Wellington.

Kozmian-Ledward, A. Jeffs & C. Gaskin (2019). **Summary of zooplankton identification from samples collected 2017-2018.** Report prepared for the Northern NZ Seabird Trust.

Kozmian-Ledward, A. Jeffs & C. Gaskin (2019). **Analysis of zooplankton samples 2018-2019.** Report prepared for the Northern NZ Seabird Trust (NB: this report is appended here).

Seabird fish school feeding associations

Observations made during zooplankton sampling and other trips across both seasons included a wide variety of seabird feeding and fish school activity (Table 2) and feeding associations with marine mammals (Table 3).

Table 2. Fish school/prey types where seabirds have been observed associating or feeding directly. Seabirds for this contract are listed in 'Species' column – study species first, then other species observed in brackets.

	Fish school/prey type	General description of activity	Species
1	Trevally *Pseudocaranyx dentex* (and mixed trevally, kahawai *Arripis trutta*, blue maomao *Scorpis violacea* & kingfish *Seriola lalandii*)	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 in some cases 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. gannets flying low over a school). Shearwaters and prions have been filmed diving in the wake of school activity. Photos, underwater videography.	Buller's shearwater, fluttering shearwater, fairy prion, red-billed gull, white-fronted tern (with sooty shearwater, flesh-footed shearwater, short-tailed shearwater, white-faced storm-petrel, Cook's petrel and grey noddy at some locations).
2	Kahawai	Fast-moving schools, birds moving in 'leap-frogging' formations, shearwaters plunging and diving. Photos, underwater videography Also, tightly packed schools (similar to trevally) separate from trevally schools in the same vicinity.	Fluttering shearwater with white-fronted terns moving with them. Red-billed gull mainly, with some fairy prions and
3	Saury *Scomberesox saurus*	Two instances, 1/ shearwaters and gannets diving on saury, catching fish close to the surface. Out beyond Mokohinau Islands, north of Great Barrier Island. 2/ Between Mokohinau and Chickens Islands, shearwaters and gannets diving and catching fish in association with common dolphins	Australasian gannet and flesh-footed shearwater (with black petrel and sooty shearwater).
4	Jack mackerel *Trachurus novaezelandiae*	Schools most commonly 'seen' by activity of gannets with birds coming to the surface with prey. Sometimes seen breaking the surface, but not frequently during our study.	Australasian gannet
5	Blue (slimy) mackerel *Scomber australasicus*	Very eruptive mobile schools, one minute here, then disappearing to appear somewhere else. Dramatic. Both underwater videography and topside photos	Australasian gannet, fluttering shearwater, Buller's shearwater, fairy prion
6	Baitfish species (e.g. pilchard *Sardinops sagax*, anchovy *Engraulis australis*, koheru *Decapterus koheru*)	Often tightly packed schools, sometimes forming spinning 'bait balls' below the surface. Birds plunging/diving and pursuing prey underwater. Dramatic. Photos	Australasian gannet, fluttering shearwater, Buller's shearwater (with flesh-footed shearwater, white-faced storm-petrel, Cook's petrel) (also common dolphins – see Table 3).

7	Skipjack tuna (*Katsuwonus pelamis*)	Fast moving fish sometimes jumping clear of water. Shearwaters following at speed, leapfrogging from one emergent feeding area to next. Photos, underwater videography.	Buller's shearwaters, also fluttering shearwaters with Australasian gannet and red-billed gull and white-fronted tern on occasion.
8	Crustaceans (no visible fish schools)	Mainly euphausiids (*Nyctiphanes australis*) and salps with birds actively feeding from the surface, often well- spread, occasionally across several sq. kms. Photos	Buller's shearwater, fluttering shearwater, fairy prion, common diving petrel, white-faced storm-petrel, sooty shearwater.
9	Crustaceans, salps, juvenile fish (no visible fish schools)	Current lines with birds actively feeding without prey being visible at the surface. Photos	Fairy prion, fluttering shearwater, white-faced storm-petrel.
10	Squid (no visible schools)	Not observed. Only squid seen have those caught in association with cetaceans (Table 3). However, have turned up as prey items – see next column, this table.	Buller's shearwater, Australasian gannet, white-fronted tern with fluttering shearwater, Cook's petrel, NZ storm petrel and a white-capped albatross

Figure 12. Fluttering shearwaters diving to catch prey above dense school of trevally and kahawai, 26 October 2018. *Screenshot from videography: NNZST*

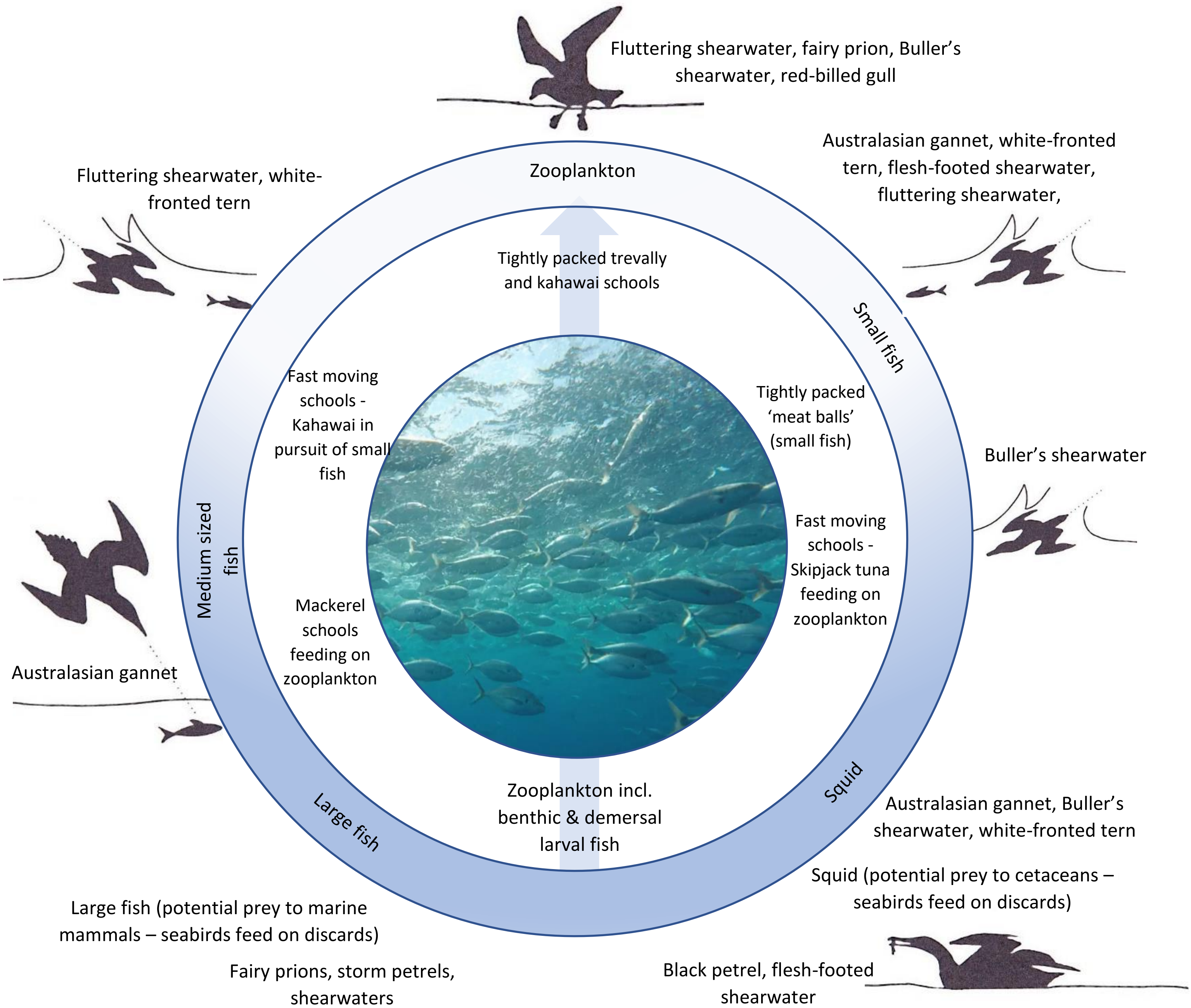
Figure 13. White-fronted tern dips for prey on the fringes of a trevally school near Tara Rocks, Marotere Chickens Islands, 26 October 2018. *Photo: Edin Whitehead*

Figure 14. Red-billed gulls feeding over an active mixed school of kahawai and trevally near the Marotere Chickens Islands, 10 October 2018. *Photo: Edin Whitehead*

Table 3. Other feeding associations recorded during surveys

Marine mammal species	Activity	Birds
Common dolphin *Delphinus delphis*	Generally, very active pursuit by dolphins, sometimes herding or rounding baitfish into tightly packed spinning schools; spectacular with gannets diving, sometimes in very large numbers, also smaller seabirds active amid the action; shearwaters diving in pursuit of prey. Photos.	Australasian gannet, flesh-footed and fluttering shearwater, red-billed gull and white-fronted tern
Common dolphin	In contrast to the above, more sedate feeding activity by the dolphins (although with occasional surges); attendant birds on the surface peering below, sometimes diving in pursuit of prey, or flying to where new action takes place. Photos.	Flesh-footed shearwater, Australian gannet, fluttering and Buller's shearwater
False killer whale *Pseudorca crassidens*, pelagic common bottlenose dolphins *Tursiops trunchatus*	The cetaceans feed at or below the surface; petrels and shearwaters dive underwater to pick up discards; birds often scrapping over food. Storm-petrels have been observed feeding on small scraps and the oily slicks generated by the feeding activity. Photos, underwater videography	Black petrel and flesh-footed shearwater with Cook's petrel, Buller's shearwater, fluttering shearwater, white-faced storm-petrel and NZ storm-petrel
Long-finned pilot whales *Globicephala meias* and pelagic common bottlenose dolphins	Mostly seabirds following the pods which for the most part don't appear to be feeding; however, the birds pay close attention to the cetaceans underwater which occasionally bring squid which the birds pick up and fight over. Photos, underwater videography	Black petrel and flesh-footed shearwater with Buller's shearwater, and white-capped and Campbell albatrosses.
NZ fur seal *Arctocephalus forsteri*	One occasion, NZ fur seal feeding on a John dory at the surface, seabirds in attendance and picking up scraps	Buller's shearwater, fairy prion and white-faced storm petrel

Figure 15. Feeding associations observed during this two-year study – 2017-2018 and 2018-2019. Figures 16 & 17. NZ fur seal feeding on a John Dory with attendant fairy prions (left), and pilot whales with flesh-footed shearwaters.



Discussion

The question this study seeks to answer - does the prey caught by red-billed gull, white-fronted tern, Australasian gannet, fairy prion, and Buller's shearwater and fluttering shearwaters in association with fish shoals contribute a significant part of the natural food eaten by adults and fed to chicks? Our study covers two seasons – 2017-2018 and 2018-2019.

Fluttering shearwater and fairy prion

Fluttering shearwaters and fairy prions are two species that regularly forage with trevally and kahawai schools throughout their breeding season (Cover image and Fig. 17). Also, there appears to be a direct correlation between what the fish are feeding on and what the birds are feeding to their chicks – refer Kozmian-Ledward et al appended here (Appendix 1), also in Kozmian-Ledward et al (2019). In the former case, potential prey, was detected more from the fish stomach contents than zooplankton sampling.

Figure 18. Fairy prions and fluttering shearwaters feeding with trevally and kahawai, 26 October 2018. *Photo: Edin Whitehead.*

Both fluttering shearwaters and fairy prions were also observed feeding away from fish school activity during this study. On one occasion fluttering shearwaters, with white-faced storm petrels and common diving petrels were feeding over a large area west of the Marotere Chickens Islands; zooplankton tows picked up euphausiids, salps and some larval fish with bits of seaweed. Fairy prions were seen on several occasion feeding along current and algal slick lines; in two cases where zooplankton sampling was conducted larval fish, fish eggs and salps were captured.

Of fairy prions, Harper (1976) wrote that 'all [regurgitation] samples, which appeared to have been freshly ingested, comprised euphausiid and amphipod crustaceans in a ratio of approximately 4:1. Coastal species such as *Nyctiphanes australis* and *Parathemisto gracilipes* predominated.' L. Kozmian-Ledward (pers. comm.) notes that there is 'no record of amphipods in the fairy prion samples. However, if amphipods were present in zooplankton samples collected for this project, they have not been all that common in the tows.'

Red-billed gull

Red-billed gulls are the third species in this study regularly observed feeding in large numbers in association with trevally and kahawai schools, at different locations and throughout both seasons (Figs 14 & 19). Their prey is almost certainly euphausiids as revealed in zooplankton sampling and from stomachs of fish caught at these feeding events. However, sampling undertaken in two colonies (Tawharanui and Marsden Point Oil Refinery) did not reflect this, with the pellets (regurgitations) collected showing mostly a terrestrial diet (Kozmian-Ledward et al 2019). Possibly because no parts of zooplankton prey had been retained to regurgitate in pellets. Faecal samples collected at three sites were not forwarded for DNA extraction following unsatisfactory results with samples from other species due to collection issues. In order to provide a more accurate picture of what these birds are feeding on, that is, in relation to fish shoals, sampling from alternative sites is recommended in the future. Red-billed gulls commonly roost on rocky shores a of islands and stacks adjacent to their feeding grounds – for example, the Marotere Chickens Islands, Bream Islands, Mokohinau Islands, and Panetiki Island (The Outpost) at the entrance to Leigh Harbour – and these would provide ideal collection sites for both regurgitations and faecal samples.

Figure 19. Red-billed gulls foraging and roosting on north coast of Coppermine Island, Marotere Chickens Islands, 5 February 2019. *Photo: Edin Whitehead*

White-fronted tern

By contrast, the diet of white-fronted terns appears to be dominated by fish, confirmed through analysis of faecal samples collected at Horohoru Rock in January 2019 (Doyle & Adams 2019), and from photographs taken at colonies of birds carrying prey, mostly anchovy, in their bills (Gaskin 2019). Photography also captured a new diet record for the species, that of a bird carrying a juvenile squid. That, and observations and photographs of terns feeding around the edges of mixed trevally and kahawai schools at the Mokohinau Islands (Fig. 13) suggest a prey range that also includes crustaceans and squid.

Australasian gannet

N. Adams (unpubl.) notes the most consistent signal in the diet samples from Australasian gannets across the years and between Mahuki Island (Outer Hauraki Gulf) and Horuhoru Rock (Inner Hauraki Gulf) colonies has been the persistence of Jack mackerel and anchovy among years and between sites. The importance of Jack mackerel is of additional interest as it is the target of a substantial commercial catch off eastern Northland and the Bay of Plenty. However, the study has also shown that a range of other prey species may be particularly important to Australasian gannets in one season or locality but not the next. Gannets consumed a range of surface shoaling fish and squid and important species included Arrow squid, anchovy (*Engraulis australis*), Jack mackerel, pilchard (*Sardinops sagax*), saury, redbait (*Emmelichthys nitidus*) and blue mackerel. While the restricted sampling schedule suggests some caution in interpretation, there are substantial differences in the diet of birds determined from regurgitation samples at different locations within the gulf and across different years. These likely reflect separation of foraging areas by gannets from the two neighbouring colonies and interannual variation in the availability of particular prey species. Of additional interest is that of secondary prey, detected from remnant DNA recovered from faecal samples and from fish collected as regurgitations. Secondary prey included a range of benthic or demersal and deeper water fish that would be unavailable to gannets. The sizes of ingested primary prey and thus their prey would be small compared to gannets. Accordingly, it is likely that these were consumed as juvenile or larval fish or even eggs. Two crustaceans, krill and swimming crabs (*Liocarcinus corrugatus*), were detected in a least 80 % of all samples suggesting they are common prey of a range of the primary prey consumed by gannets.

Figure 20. Australasian gannet with squid, feeding in association with a common dolphin pod and flesh-footed shearwaters. *Photo: Edin Whitehead*.

Buller’s shearwater

The sixth study species, Buller’s shearwater, presents something of an enigma in the context of this study. Although this species proved to be reluctant regurgitators, samples collected from colonies during breeding included euphausiids, fish and squid (Gaskin 2019, Doyle & Adams 2019, Kozmian-Ledward et al 2019). From observations of their foraging/feeding from October to January across both years revealed vast numbers of Buller’s shearwaters associating with trevally, kahawai and mackerel schools in the outer Hauraki Gulf and along the Northland coast, potentially also along the eastern Coromandel and Bay of Plenty given the large numbers observed moving up the eastern Aotea Great Barrier Island coast on occasion. However, from January through to May they appear to associate less with the tightly packed trevally and kahawai schools, following highly mobile skipjack tuna schools instead, at least along the Northland coast and outer Hauraki Gulf. Whether the birds observed in considerable numbers are predominantly breeding or non-breeding birds is unclear. GPS tracking of breeding birds during chick rearing (March-April) through a related but separate project has revealed a preference for foraging well offshore, with only one of the twelve birds tracked moving inside the Hauraki Gulf during a foraging trip (Gaskin & Zhang unpubl.). These results highlight the need for more intensive tracking, not only for this species, but also the other species within this POP2017-06 study.

Figure 21. Buller’s shearwaters feeding with skipjack tuna, one breaking the surface (splash) centre right. *Photo: Edin Whitehead.*

Flesh-footed shearwater

Although not one of the targeted species for POP2017-06, observations made during our study found flesh-footed shearwaters feeding in association with a variety of fish school types, most notably saury. They were also observed aggressively feeding with gannets and common dolphins, and following other cetaceans, i.e. bottle-nose dolphins, pilot whales and false killer whales, scrapping over discards from their feeding (Fig. 11).

Seabird reliance on fish schools

What this study has revealed is that there is considerable variety in the feeding associations for seabirds, not only in relation to the different types of fish schools and activity (Table 2), but also with marine mammals and their feeding on fish and squid (Table 3). The variety of prey that have been identified from samples collected from the six species further indicates a complex suite of feeding and foraging associations. While the feeding associations that catch the most attention are the highly visible tightly packed shoaling fish schools of trevally and kahawai, and work ups featuring cetaceans, the associations with other prey fish species targeted by the purse seine fishery also need to be better understood. These include jack mackerel, blue mackerel, saury, pilchards, anchovies and skipjack tuna.

While all six species in this study have been observed feeding away from fish school activity, and on occasion in very large numbers spread across large areas, the drawcard of fish school activity, and for some seabirds, marine mammal activity, signals 'fast food' availability for large numbers of these birds, using sight, smell (in the case of Procellariiformes) and potentially sound to home in on these concentrations. If we are to come to terms with the potential impacts from purse seine fishing on seabirds and the marine ecosystems that support them, we need to clarify the trophic interactions at play that may in turn contribute to marine conservation and ecosystem-based management and sustainability of fisheries.

In the case of gannets, which can be both flock and solitary foragers, feeding on small to large fish (<375mm length), Adams (unpubl.) notes that, 'much of the species richness detected in our faecal samples was of secondary prey. Accordingly, analysis of faecal samples from seabirds provide for identification of additional linkages in the food chains that support predatory seabirds. Many of the secondary prey species, at least as adults are benthic, demersal or deeper water fish that are not available to surface feeding gannets. Given the relatively small size of prey taken by gannets it is likely that these secondary prey are ingested as juvenile, larval fish or possibility also as eggs if the period of diet sampling coincides with spawning. At these life stages it is also more likely that they have a wider distribution through the water column than is the case for adult fish. Accordingly, they become available to the surface shoaling fish and squid that comprise the diet of gannets. Such interactions suggest that demersal or benthic fish are linked to seabirds through a single trophic level of the food web that supports gannets.' Krill, also detected as secondary prey in gannet's diet, occur in near surface waters where there are the potential prey not only of fish and squid consumed by gannet but also, as we have seen, a range of other seabirds and also cetaceans such as Bryde's whales (Carroll et al. 2019). Accordingly, krill species appear to support a range of larger predators within the Hauraki Gulf and northern waters.

Figure 22. Euphausiid with eggs, collected 16 January 2019. Photo: Charlie Johnson, School of Biological Sciences, University of Auckland/ NNZST

In conclusion, if changes in the distribution and/or abundance of fish work ups and other activity are driving seabird population changes (population status and annual breeding success), then further examination of fish school dynamics across all those fish species and the seabird associations relating to each is urgently required. Provided future research is planned strategically and over multiple years, the wider Hauraki Gulf region, with its diversity of seabird species and the accessibility to predator-free breeding colonies, offers the perfect system in which to utilise seabirds as indicators of change in the marine environment at different spatial scales.

Recommendations

1. Develop a strategic, long term approach to the study marine food webs within the region, with the focus on seabirds to highlight interactions, especially where they relate to fisheries and other threats. In general, we need to decide what are the key questions, and then design the data collection to answer them. The following are areas of research that could be included:
    - The dynamics of all fish school types to be investigated
    - Diet studies of seabirds (sampling within colonies) to include stable isotope analysis from bloods and feathers, with DNA extraction and sequencing of faecal and regurgitate samples
    - Breeding success of seabird species measured
    - GPS tracking and molecular sexing to be integrated with diet studies
    - The aer-sight (purse-seine spotter plane) database to be updated and a full analysis to be undertaken to provide historical context within an environmental model to the purse seine fishery in north-eastern New Zealand
2. Adopt the following to future zooplankton sampling and analysis (from Kozmian-Ledward et al report appended):
    - High speed zooplankton sampling methods should be tested to determine whether the concentrations of more mobile zooplankton that are important in the diet of seabirds, such as euphausiids, are spatially more concentrated inside workups versus outside workups.
    - Use of underwater camera/video equipment to view the movements of euphausiids in relation to predators (fish and seabirds), and sampling equipment.
    - A flow meter should be incorporated into the zooplankton net to facilitate the standardising of samples by water volume filtered by the net.
    - Volumetric measurements should be used to quickly determine the total zooplankton mass of samples using settled volume.
    - More rigorous subsampling protocols, especially in the field, need to be implemented.
    - The calorific value and biochemical composition of typical zooplankton species consumed by seabirds should be measured and compared.
    - Collect data on oceanographic factors and analyse in GIS to better understand the bottom-up processes influencing zooplankton abundance and distribution.

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Analysis of zooplankton samples collected 2018-2019

For POP2017-06 Indirect Effects on Seabirds in Northern North Island

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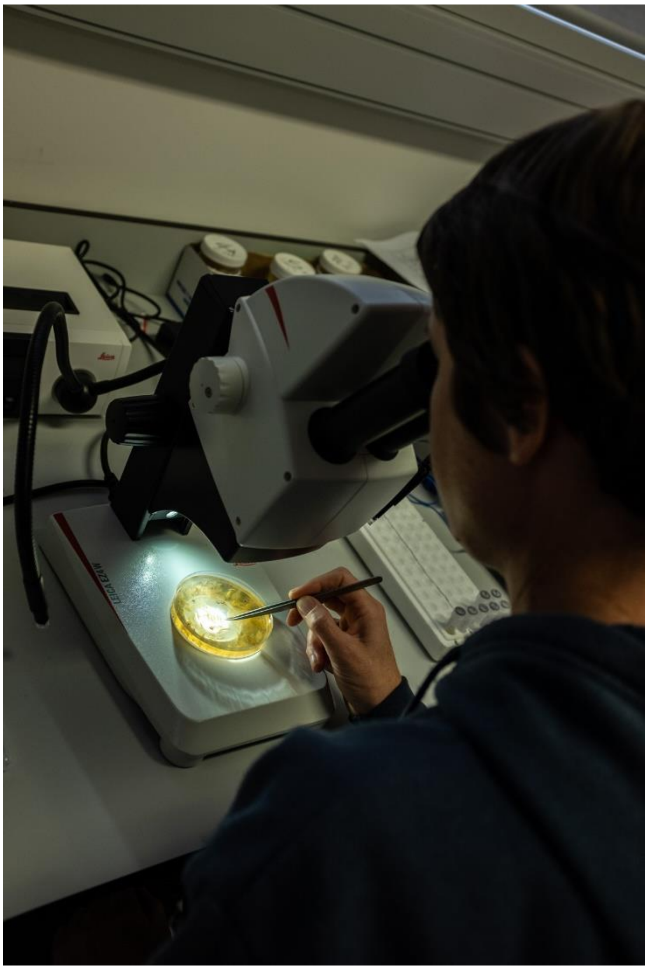

Cover image: Euphausiid carry eggs. *Photo: Charlie Johnson, School of Biological Sciences, University of Auckland/ NNZST*

Figure 1 (this page): Sorting samples at Leigh Marine Laboratory, University of Auckland. *Photo: Edin Whitehead*

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1 Abstract

Marine mesozooplankton form an important part of the diet of a variety of marine predators including seabirds in the waters of the north-east North Island (including the Hauraki Gulf). Zooplankton sampling was undertaken from vessels used for Northern NZ Seabird Trust (NNZST) research trips and also opportunistically from Auckland Whale and Dolphin Safari's (AWADS) commercial tourist trips between August 2018 and May 2019. This sampling effort formed the second season of zooplankton sampling, following on from sampling in 2017-2018. Counts were made of zooplankton in eight major groups and relative proportions determined. 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 fish captured at the same time as zooplankton sampling contained high proportions of Malacostraca and Nauplii, which was different to the zooplankton composition when compared with net samples taken in the same areas. This indicated selectivity of feeding by fish. 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 most likely 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. Comparisons between the two sampling seasons is given in the discussion together with recommendations on future zooplankton analyses.

2 Introduction

Marine mesozooplankton (zooplankton in the size range 0.2 – 20 mm) 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) which result in a large amount of spatial and temporal variability (Zeldis & Willis, 2015).

On the north-east coast of the North Island (including the Hauraki Gulf), offshore winds during the spring can 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 Gulf and the coast are influenced by the warm, nutrient-poor surface waters of the East Auckland Current (EAUC), which are at times 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). In contrast, areas of the inner Hauraki Gulf, such as the Firth of Thames, are supplied by nutrients from agricultural land run off, the release of which generates highly variable seasonal plankton productivity (Zeldis & Swaney, 2018).

This report presents the identification and quantification of zooplankton collected in the 2018-2019 sampling season. It forms a continuation of the zooplankton research conducted in the first sampling season (2017-2018) (Gaskin, 2019). In the first season (2017-2018), 39 zooplankton samples were collected by the Northern New Zealand Seabird Trust (NNZST). Both vertical and horizontal zooplankton tows were undertaken, within and away from shoaling fish schools, visible at the surface, called workups in this report. The sampled zooplankton in 2017-2018 were counted into six taxonomic groups: Copepoda, Malacostraca, Chaetognatha, Appendicularia, Thaliacea and Fish eggs. A seventh group: 'Other', contained all other taxa found. A 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 difference was found in the abundance of any of the zooplankton groups between samples collected in workups versus non workup samples. The data from the two sampling seasons form a part of a larger report, to which this report is appended, looking at the relationships between zooplankton and seabird feeding aggregations in the Hauraki Gulf and north-east North Island waters.

3 Methods

3.1. Field methods: NNZST zooplankton tows and fish captures

Zooplankton sampling was undertaken between 30 September 2018 and 3 May 2019 off the north-eastern North Island, including the northern Hauraki Gulf, between Ti Point in the south and the Bream Islands in the north. The field methodology was conducted in a similar way to the first sampling season (2017-2018) (Gaskin, 2019), but is described below for clarity. Zooplankton sampling generally was combined with other vessel activities due to logistical and financial constraints. Sampling locations were determined by finding areas in which seabirds were seen feeding, also where fish activity was observed to be occurring near the surface of the sea (workups). Sampling was also conducted away from areas of fish school activity for comparison, including in surface current lines. All samples were taken during daylight hours.

At each site, zooplankton were sampled using a conical plankton net (180 µm mesh) with a circular 750 mm diameter opening and a 250 µm mesh cod end (Fig. 2). 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. A dive weight was attached to the cod end to facilitate lowering the net to 30 m. It was then hauled vertically to the surface at a rate of 1 m sec^{-1}. Horizontal tows at the sea surface were conducted using the same net, by towing the net 20 m behind the boat just below the surface at 1.5-2.5 kns for 3-8 mins, aiming across the face of workups, where present, in order to try and include the more mobile zooplankton. A buoy was attached to the rim of the net as protection in case the line broke or knots slipped. At the completion of each net haul the contents from the cod-end were sub-sampled if the sample was large, by mixing the sample in a large jug, then discarding a recorded amount. The remainder was transferred to individual, labelled sample jars and preserved with 70% ethanol, after removing as much seawater as possible. Where the sample was still relatively large, it was split across multiple containers as evenly as possible. In several locations where there were fish workups, trevally (*Pseudocaranx dentex*) or kahawai (*Arripis trutta*) were caught opportunistically using a rod and line, their stomach contents removed and preserved in ethanol (Fig. 3).

Unlike the previous 2017-2018 sampling season, replicate samples were not collected in 2018-2019, partially due to time constraints when out in the field. Only one sample was collected at a time, but samples were sometimes collected within a short distance of one another, particularly when there were multiple attempts to tow the net across the face of a moving workup. Comparisons between replicates taken in season one found that they generally contained similar proportions of zooplankton groups and any differences were caused by larger quantities of fish eggs being present.

3.2. Field methods: AWADS zooplankton tows

Zooplankton samples were collected opportunistically in the Hauraki Gulf during commercial tourist trips on the Auckland Whale and Dolphin Safari vessel between 28 August 2018 and 5 February 2019 (Fig. 4). All samples were collected using a conical plankton net (250 µm mesh, 500 mm diameter by 1900 mm length) towed at the sea surface for 6 mins at 1.5 – 2.0 kts. Samples were collected in areas of workups, often containing cetaceans.

Figure 2. NNZST zooplankton sampling locations.

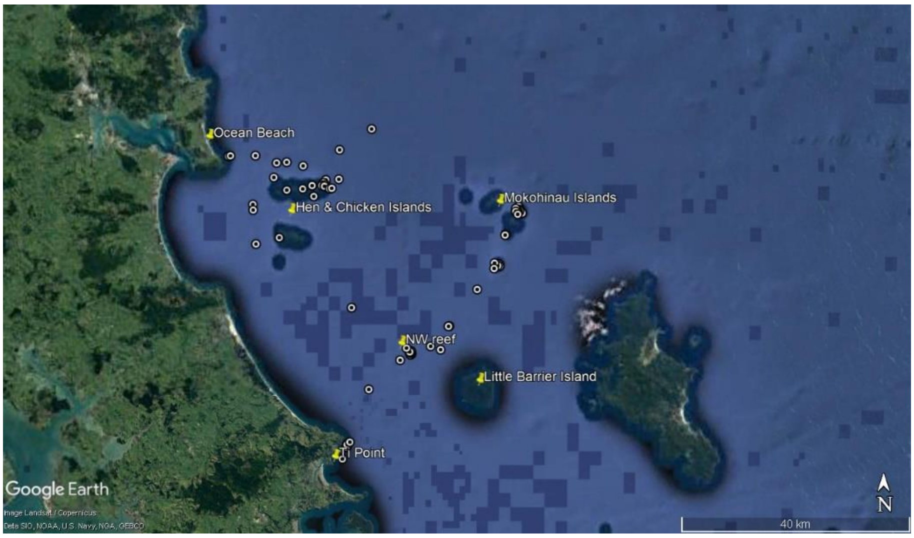


Figure 3. Fish catch locations.

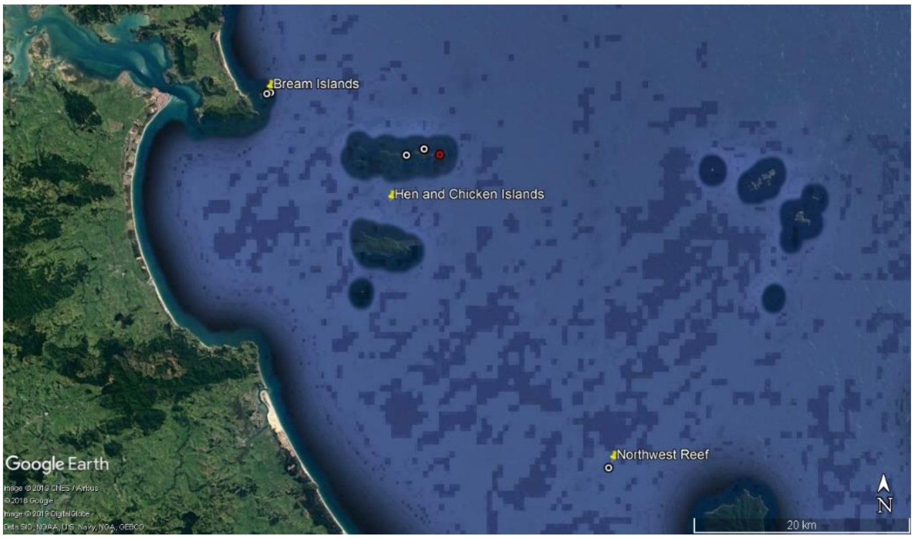
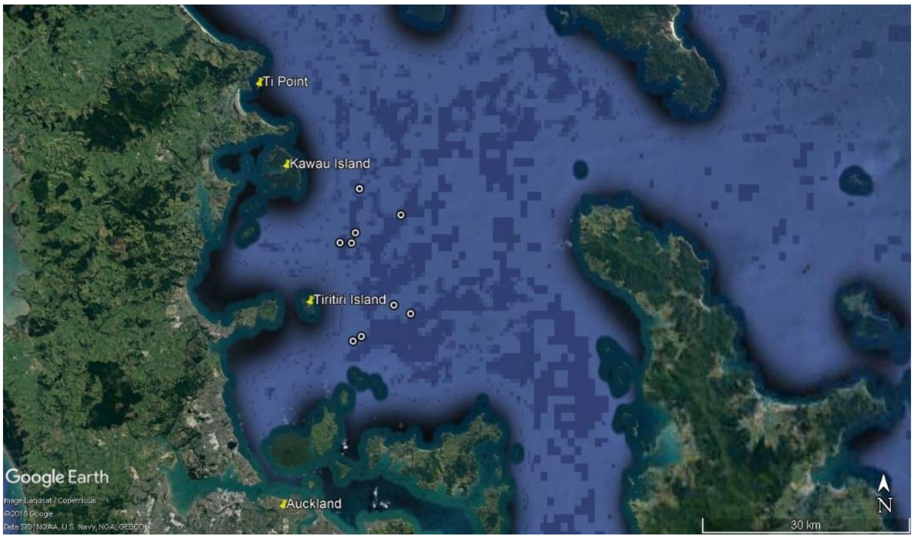


Figure 4. AWADS sampling locations



3.3. Laboratory processing

The zooplankton samples were stored and processed at the Leigh Marine Laboratory (University of Auckland). The laboratory processing was done in a similar way to 2017-2018, however, subsampling was generally conducted to a greater degree and there were some changes in the zooplankton groups that were counted as described below. A dissecting microscope was used to view, identify and count the zooplankton in each sample. Where a sample had been spread across multiple containers at sea, only the first container was analysed, on the assumption that each container contained an equal portion of the original sample. Samples which contained a very large number of organisms were subsampled using an 8-way zooplankton subsampling device (Gaskin, 2019; Taylor, 1991) down to 1/64th of the sample depending on the extent of the original zooplankton sample size. The aim was to obtain at least 200 individuals of the most abundant zooplankton group. Zooplankton were enumerated using a Bogorov counting tray under the microscope at 12.5 to 16× magnification.

Zooplankton were counted into six taxonomic groups: Copepoda, Malacostraca, Nauplii, Appendicularia, Thaliacea, Fish eggs, plus a seventh group, Other, which included all other zooplankton not fitting into the former groups (see Appendix 1 for taxon details of the groups). In 2017-2018 there were also seven groups but instead of a Nauplii group, Chaetognaths were put into their own group. The Nauplii group was added in 2018-2019 in order to differentiate between the very small (< 1 mm) Malacostraca larvae and the larger juveniles and adults. Barnacle nauplii and very small zoeae (< 1 mm) were also included. It was decided to add Chaetognaths to the Other group as they were generally not common and were only separated out in 2017-2018 because of their distinctiveness. Notes were made during the counting process on further types of zooplankton found within the groups, as our taxonomic knowledge and time allowed, including the number of larval fish. Given the large number of zooplankton to process and the relative lack of identification guides, the identification of the majority of zooplankton 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 fish stomach content samples were treated in the same way. The zooplankton had been partially digested within the fish stomachs but were predominately in a good enough condition for counting.

Larval fish were picked out of samples during the counting process, in order for them to be photographed by Dr. Charlotte Johnson (University of Auckland) and identified by Tom Trnski (Auckland Museum). Where a sample portion contained fish larvae, the other parts were also checked for fish as well as the sample remainder after subsampling if applicable, in order to maximise the fish collection.

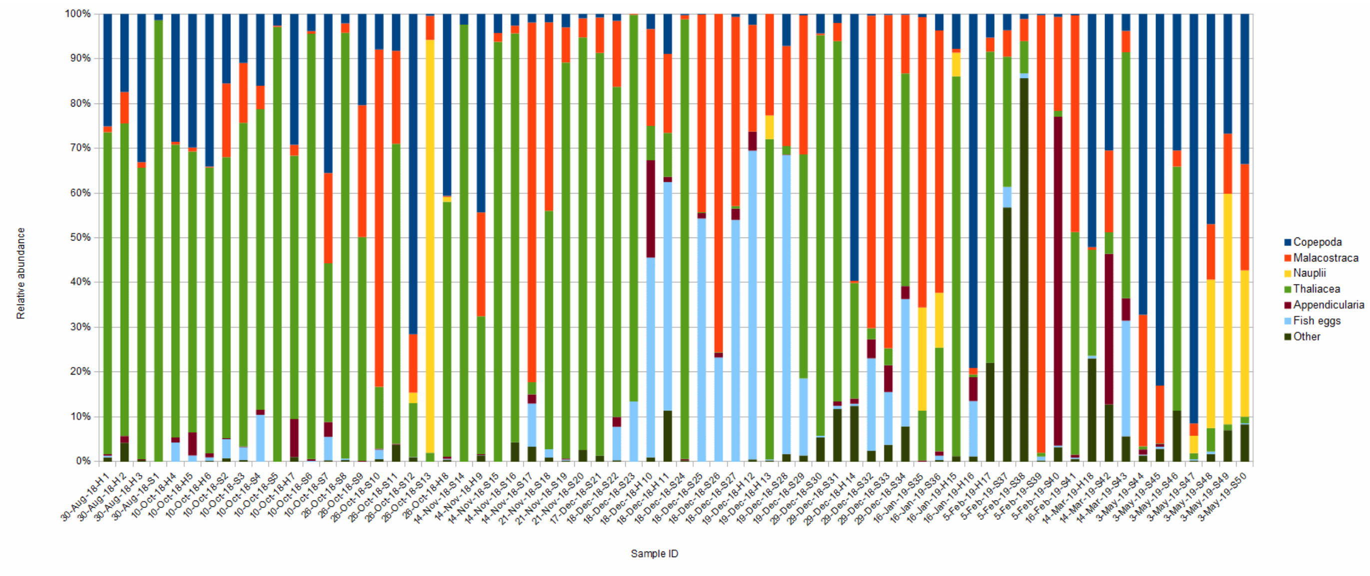
Examples of zooplankton (including larval fish) were photographed over 2 mm squared paper using a Leica MZ95 microscope with integrated camera and Leica Application Suite program at the Leigh Marine Laboratory. Measurements of the zooplankton lengths were taken using the open-source program Image J (Schindelin et al., 2012). High resolution images were taken by Dr. Charlotte Johnson at the School of Biological Sciences, University of Auckland using a Nikon D7200 DSLR camera with adapter connected to a Leica M80 stereo microscope. Images were processed in Adobe Photoshop CC to composite images together (where required), to sharpen and remove chromatic aberration.

4 Results

4.1. NNZST zooplankton tows

A total of 68 zooplankton samples were collected from 30 September 2018 to 3 May 2019 off the north-eastern coast, including the northern Hauraki Gulf (Fig. 2). Fifty surface tows were undertaken: in workups (n=37), away from workups (n=10), and along current lines (n=3). Eighteen vertical hauls were undertaken: in workups (n= 1), away from workups (n=16), and along current lines (n=1).

Figure 5. All zooplankton groups from NNZST sampling 2018-2019.



Most of the zooplankton samples contained a wide variety of taxa, and some seasonal trends were seen (Fig. 5):

- Copepoda were present in 96% of samples and were generally the most abundant during spring and autumn.
- Malacostraca were present in 97% of samples and were generally more abundant during the summer, often comprising 40% or more of the total numeric abundance of zooplankton. Different types of Malacostraca identified included euphausiids of various stages including adults with eggs, decapod shrimp larvae, stomatopod larvae, amphipods, crab megalopa and zoeae.
- Nauplii were present in 16% of samples with the greatest numeric abundance in October and May. The majority of nauplii were of euphausiids but barnacle nauplii dominated the May samples.
- Thaliacea were present in 99% of samples (predominantly salps) and were often the most numerically abundant zooplankton group, particularly from August to December.
- Appendicularia were present in 62% of samples but in relatively low proportions (<10%). They comprised approximately 20% of the zooplankton counts in one December sample, 70% in February and 30% in March samples.
- Fish eggs were present in 71% of samples, mainly in spring and summer. During December, they comprised 40% or more of the zooplankton counts in six samples.
- Zooplankton in the Other group were present in 79% of samples but often at < 5% of the total numeric abundance. There was a peak in February with two samples containing > 55% Other, mainly siphonophores. Other zooplankton taxa identified in the Other counts were cladocera, pteropoda, pteriotrachidae, chaetognatha, larval fish, hydrozoa, polychaeta, and echinoderm larvae.

When comparing the relative abundance of zooplankton groups between the two sampling methods; the horizontal surface tows generally contained higher proportions of Malacostraca and Nauplii in comparison to the vertical 30 m haul samples. Where a vertical haul (H14) was undertaken in the vicinity of two surface tows (S30, S31); H14 contained 60% copepods whereas S30 and S31 had <5%. The two surface tows were very similar to each other, with much higher proportions of Thaliacea (>80%) than the vertical haul. Other samples were also collected close to one another and often had similar proportions of zooplankton groups (Fig. 2); they are listed below:

- 10 October 2018: H4, H5 and H6 were all taken in the vicinity of Northwest Reef, no workup.
- 10 October 2018: S3 and S4 were taken in a workup around the Mokohinau Islands.
- 26 October: S11, S12 and S13 were taken a little distance apart, around the Mokohinau Islands, while following fish school activity and were quite different in composition. Of the three samples, S11 contained the highest proportions of Thaliacea (67%), Malacostraca (21%) and Other (4%). S12 had the highest proportion of Copepoda (72%), while S13 was dominated by Nauplii (92%). By volume (eye-balling the sample container), S13 was predominately comprised of euphausiids, but the sheer number of their nauplii dominated the counts.
- 14 November 2018: S15 and S16 were taken in a workup in the vicinity of Northwest Reef.
- 21 November 2018: S18 and S19 were taken near the Hen and Chicken Islands; no workup. S18 had a much greater proportion of Malacostraca; 42% versus 8%.
- 18 December 2018: S25 and S26 were taken in a workup near the Hen and Chicken Islands. S26 had a greater proportion of Malacostraca (76%), mainly euphausiids, while S27 had a greater proportion of Fish eggs (54%).
- 29 December 2018: S32 and S33 were obtained in a workup at Navarre Rock (Mokohinau Islands). Both samples contained around 70% Malacostraca, most of which were euphausiids.
- 16 January 2019: S35 and S36 were obtained in a workup at the eastern end of Coppermine Island (Hen and Chickens). Both samples were fairly similar with around 60% Malacostraca, mainly euphausiids.
- 3 May 2019: S47 and S48 were collected in a workup containing kahawai off Leigh. S47 contained a much greater proportion of Copepoda (92%) than S48.

The 30 m vertical haul samples were undertaken in a consistent manner, however, on two occasions (H1 & H16) where the vessel was drifting too fast in strong winds, the haul became oblique rather than vertical (Fig. 5). This may have increased the zooplankton catch due a greater volume of water passing through the net. The total number of zooplankton varied from a minimum of 95 (H17) to a maximum of 10,750 (H10).

4.2 Samples in and out of workups

Of the 50 surface tow samples, 37 were taken in workups, 10 in areas with no workups and 3 in current lines. Of the 18 vertical haul samples, 1 was taken in a workup, 16 where no workup and 1 in a current line.

There was a high degree of variability in the relative abundance of the zooplankton groups in and out of workups, even on the same sampling days (Fig. 7A & 7B). In general, samples obtained within workups had higher proportions of Malacostraca and Nauplii. Workup samples had a higher proportion of Appendicularia in February, while outside of workups, the Other category was more abundant in February, comprising mainly siphonophores. A valid statistical comparison was unable to be made on the vertical haul zooplankton counts in and out of workups due to only one sample being taken in a workup. The horizontal tow samples were not undertaken in a standardised manner so total counts were not able to be used for comparison. However, the percentage proportion of each zooplankton group in and out of workups was calculated for the surface tows and compared using t-tests after transforming the percentage data with an arcsine transform. Of the seven zooplankton groups only the Other group showed a significant difference with more than double the proportion of Other zooplankton outside of workups versus inside (t=2.52, P=0.015).

Figure 7A. Samples collected at work-ups.

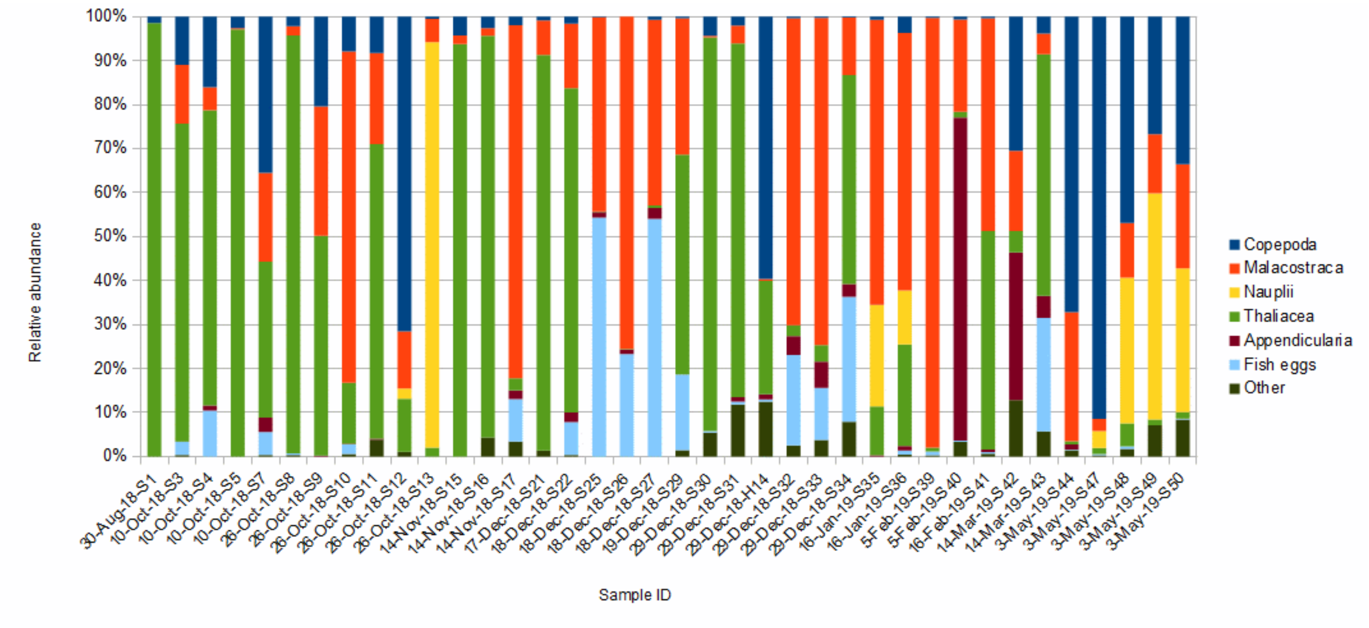
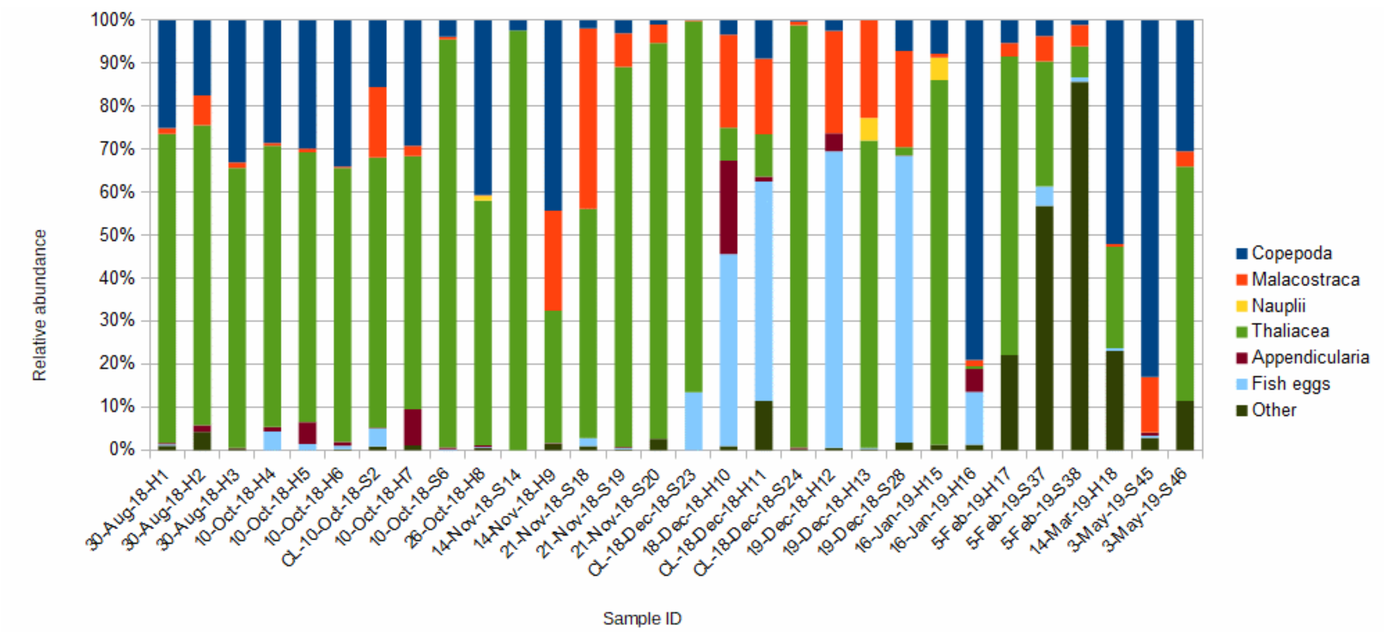


Figure 7B. Samples collected away from work-ups.

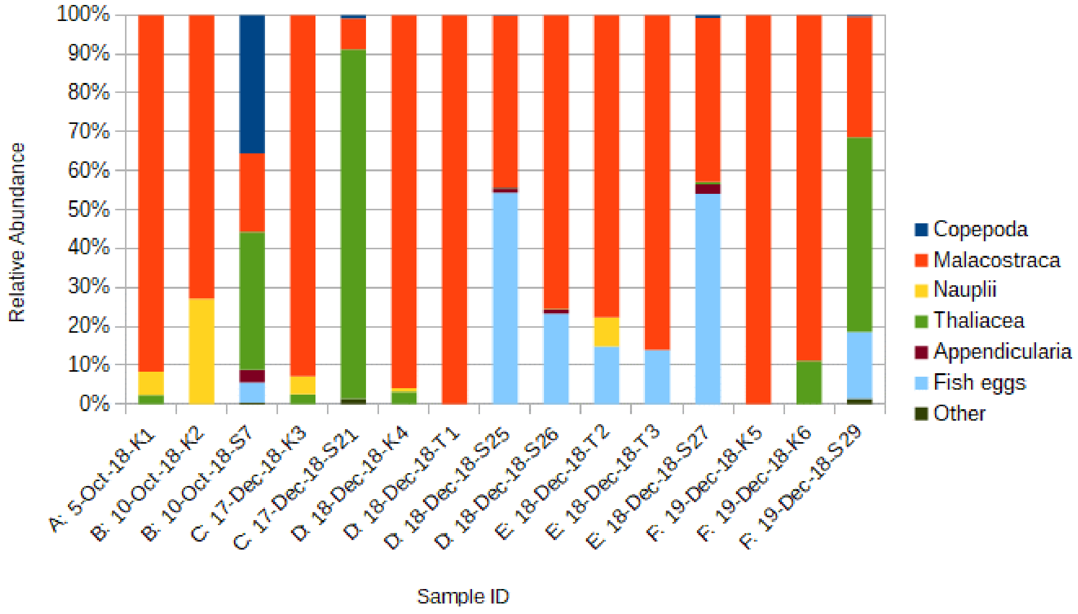


Of the four samples collected along current lines (CL) (Fig. 7B), S2 tended to have a greater proportion of Malacostraca and less Copepoda than other non-workup samples collected on the same day. S23 and S24 taken on 18 December 2018 both contained relatively high proportions of Thaliacea, whereas H11, taken on the same day had a relatively high proportion of Fish eggs and Other in comparison with the other non-workup samples on that day.

4.3 Fish stomach contents

Eight fish (five kahawai and three trevally) were caught opportunistically in conjunction with six surface zooplankton tows between 10 October and 19 December 2018 (Fig. 8). One kahawai was also caught on 5 October 2018 before zooplankton sampling commenced for the season. The most abundant zooplankton group in the fish stomach contents was Malacostraca (73 – 100%) and these were predominantly euphausiids which included females carrying eggs. Nauplii (euphausiid) were found in five fish comprising 1 – 27% of the total abundance. Thaliacea were found in four kahawai at 2 – 11%. It is possible that there were more Thaliacea present but they could have been too degraded to reliably identify. Fish eggs were found in two trevally only, at 14 and 15 % of total gut content. The zooplankton groups Copepoda, Appendicularia and Other were not found in any of the fish gut contents.

Figure 8. Fish stomach contents.



Where fish were caught in conjunction with zooplankton surface tow samples, the contents of their stomachs were markedly different to that obtained by the surface tow. The surface tows generally had a greater number of zooplankton groups present. Comparisons with the fish stomach contents and associated surface tows are given below:

- Fish/tow B: Kahawai 2 (K2) was caught in conjunction with surface tow 7 (S7) on 10 October 2018. K2 had 72.9% Malacostraca and 27.1% Nauplii whereas S7 had 35.5% Copepoda, 20.2% Malacostraca, 35.4% Thaliacea, 3.3% Appendicularia, 5.2% Fish eggs and 0.3% Other.

- Fish/tow C: K3 was caught in conjunction with S21 on 17 December 2018. K3 had 92.9% Malacostraca, 4.5% Nauplii and 2.6% Thaliacea. S21 had 0.8% Copepoda, 7.9% Malacostraca, 89.9% Thaliacea and 1.4% Other.

- Fish/tow D: K4 and T1 were caught in conjunction with S25 and S26 on 18 December 2018. K4 had 95.9% Malacostraca, 0.9% Nauplii and 3.2% Thaliacea while T1 contained 100% Malacostraca. The surface tows contained <0.1% Copepoda, 44.2 – 75.6% Malacostraca, <0.3% Thaliacea, 1.0 – 1.2% Appendicularia, and 23.3 – 54.3% Fish eggs.

- Fish/tow E: T2 and T3 were caught in conjunction with S27 on 18 December 2018. These trevally contained 77.8 – 86.1% Malacostraca, 0 – 7.4% Nauplii, and 13.9 – 14.8% Fish eggs. S27 had 0.7% Copepoda, 42.2% Malacostraca, 0.6% Thaliacea, 2.5% Appendicularia, and 54% Fish eggs.
- Fish/tow F: K5 and K6 were caught in conjunction with S29 on 19 December 2018. These kahawai had 88.9 – 100% Malacostraca and 0 – 11.1% Thaliacea. S29 had 0.3% Copepoda, 31.0% Malacostraca, 50.0% Thaliacea, 17.2% Fish eggs and 1.4% Other.

4.4 AWADS zooplankton tows

Thirteen zooplankton samples were collected by the AWADS vessel in the Hauraki Gulf between 28 August 2018 and 2 February 2019; all were surface tows (Fig. 9). All samples were taken in the vicinity of workups (Table 1). These zooplankton samples were generally much smaller in volume (visually) than the NNZST ones.

Figure 9. AWADS zooplankton sampling.

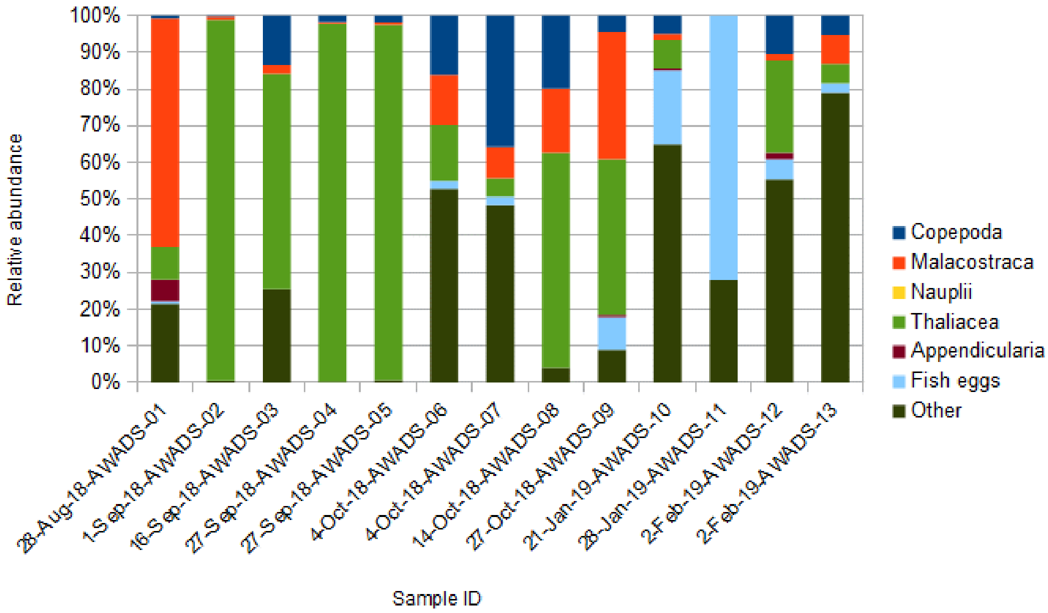


Table 1. Field notes from AWADS sample collection. Seabird codes: AUGA – Australasian gannet (*Morus serrator*); BBGU – Black-backed gull (*Larus dominicanus dominicanus*); BUSH – Buller's shearwater (*Puffinus bulleri*); FFSH – flesh-footed shearwater (*Puffinus carneipes*); FLSH – fluttering shearwater (*Puffinus gavia*); SH – unidentified shearwater species; WFTE – white-fronted tern (*Sterna striata*); WFST – white-faced storm petrel (*Pelagodroma marina*).

Sample ID	Field notes: fish, seabird and cetacean species present
28-Aug-18-AWADS-01	Large work up, kahawai, common dolphins (*Delphinus delphis*), AUGA, WFTE, BBGU
1-Sep-18-AWADS-02	Fish boiling, BBGU, AUGA, FLSH
16-Sep-18-AWADS-03	Small workup: AUGA, WFTE with kahawai. No dolphins
27-Sep-18-AWADS-04	Work up: Common dolphins with AUGA, SHs, WFTE
27-Sep-18-AWADS-05	Same as above. WFTE, BUSH, WFSP, AUGA
4-Oct-18-AWADS-06	Work up with common dolphins, AUGA, BUSH, FFSH
4-Oct-18-AWADS-07	Red coloured water, possible algal bloom. Less birds feeding than at #06. Work up with common dolphins (600-1000), AUGA (similar number), BUSH, FFSH. Bryde's whale (*Balaenoptera edeni* brydei) feeding nearby

14-Oct-18-AWADS-08	Work up with common dolphins, AUGA, SHs
27-Oct-18-AWADS-09	No information available
21-Jan-19-AWADS-10	Big feeding event. AUGA (c.100), SHs with predatory fish
28-Jan-19-AWADS-11	Common dolphins, AUGA, FLSH, FFSH
2-Feb-19-AWADS-12	Kahawai work up, AUGA (c.500), FFSH, FLSH
2-Feb-19-AWADS-13	Kahawai + kingfish (*Seriola lalandi lalandi*), FFSH, FLSH

The general trends seen in the relative proportion of zooplankton groups is given below:

- Copepoda were present in 92% of samples and generally most abundant in the first half of October, comprising 16 – 36% of a total sample.
- Malacostraca were present in 92% of samples; comprising 62% of sample 01; 9 – 35% in the October samples and otherwise at relatively low proportions. Common taxa in the Malacostraca group were euphausiids, crab larvae and various decapod shrimp larvae.
- No Nauplii were found in these samples.
- Thaliacea were present in all the samples, comprising 59 – 98% in the September samples and 43 – 59% in two of the October samples (08 and 09).
- Appendicularia were present in 31% of samples in small proportions (< 6%).
- Fish eggs were present in 62% of samples and most abundant in the January samples comprising 72% of sample 11.
- Zooplankton from the category "Other" were found in all samples and at high proportions (> 48% in 5 of the samples). Common zooplankton taxa in this group were cladocerans, medusae and siphonophores.

4.5 Larval fish

Larval fish were found in 24% (n = 16) of the NNZST samples, between October and May, comprising < 1% of the total counts. Of these samples, 25% were vertical hauls and 75% surface tows (Table 2). In the AWADS samples, larval fish were found in 15% (n = 2) of samples, In October only, also < 1% of the total counts. No larval fish were found in the kahawai or trevally stomach contents.

Table 2. Larval fish collected between October 2018 and May 2019; identifications by T. Trnski, Auckland War Memorial Museum. See Appendix 3 for macro-photographs.

Station #	Fish #	Family	Taxon	#: size	Notes	
AWADS-06	1	Clupeidae	*Sardinops sagax*	1: 6mm TL		
AWADS-07	2	Clupeidae	*Sardinops sagax*	1: 4mm TL	Yolksac stage	
AWADS-07	3	Clupeidae	*Sardinops sagax*	1: 4mm TL		
-008-T	4	Bothidae	*Lophonectes mongonuiensis*	1: 6mm TL		
-009-T	5	Scorpaenidae	Scorpaenidae	1: 5mm SL		
-014-T	6	Monacanthidae	*Meuschenia scaber*	2: 8-9mm SL		

-014-T	7	Unidentified	Unidentified	1	Head and tail missing	
-025-T	8	Clinidae	*Cristiceps aurantiacus*	1: 16mm SL		
-026-T	9	Creediidae	Creediidae	1: 12mm SL		
-026-T	10	Sparidae	*Chrysophrys auratus*	1: 5mm TL		
-026-T	11	Clupeidae	*Sardinops sagax*	2: 5-5mm TL		
-026-T	12	Carangidae	*Trachurus*	1: 4mm TL		
-026-T	13	Percoidei	Percoidei	2: 5-5mm TL	2 species, poor condition	
-026-T	14	Carangidae	*Trachurus*	1: 2mm TL		
-026-T	14	Sparidae	*Chrysophrys auratus?*	1: 3mm TL		
-027-T	15	Scorpididae	*Scorpis*	2: 3-5mm TL		
-027-T	15	Cheilodactylidae	*Cheilodactylus?*	1: 4mm TL		
-028-T	16	Monacanthidae	*Meuschenia scaber*	1: 9mm SL		
-029-T	17	Cheilodactylidae	*Cheilodactylus?*	2: 4-4mm TL		
-029-T	18	Cheilodactylidae	*Cheilodactylus?*	1: 5mm TL		
-030-T	19	Carangidae	*Pseudocaranx georgianus*	1: 8mm SL		
-033-H	20	Carangidae	*Trachurus*	3: 2-2mm TL		
-033-H	21	Carangidae	*Trachurus novaezelandiae?*	2: 20-22mm SL		
-039-H	22	Carangidae	*Trachurus*	3: 3-3mm TL		
-042-T	23	Carangidae	*Pseudocaranx georgianus*	1: 5mm TL		
-046-T	24	Engraulidae	*Engraulis australis*	2: 13-13mm SL		
-6.2	25	Carangidae	*Trachurus*	1: 8mm SL		
-049-T	26	Engraulidae	*Engraulis australis*	1: 18mm SL		
-049-T	27	Carangidae	*Pseudocaranx georgianus*	2: 8-8mm SL		
-050-T	28	Rhombosoleidae	Rhombosoleidae	1: 15mm SL		
-050-T	29	Blenniidae	*Parablennius laticlavius*	1: 16mm SL		
-050-T	30	Carangidae	*Trachurus*	3: 12-16mm SL		
-050-T	31	Blenniidae	*Parablennius laticlavius*	1: 8mm SL		
-2.2	32	Rhombosoleidae	Rhombosoleidae	2: 15-17mm SL		
-2.2	33	Engraulidae	*Engraulis australis*	1: 23mm SL		
-2.2	34	Blenniidae	*Parablennius laticlavius*	1: 11mm SL		
-2.2	35	Carangidae	*Pseudocaranx georgianus*	2: 10-10mm SL		

-2.2	35	Scombridae	*Scomber australasicus*	1: 12mm SL		

4.6 Size ranges of zooplankton

A selection of zooplankton from each group and across a variety of NNZST samples were measured (Table 3). Malacostraca measurements were of euphausiids (n = 22), amphipods (n = 5), crab larvae (n = 12), stomatopod larvae (n = 8) and miscellaneous other decapod shrimp larvae (n = 12). Nauplii comprised euphausiid (n = 6) and barnacle (n = 4) nauplii. The Other group comprised only measurements of siphonophores (n = 5) and chaetognaths (n = 8). Larval fish total length (TL) was measured from a selection of fish.

Table 3. Measurements of the zooplankton groups. Lengths are in mm. The number of individual zooplankton measured is given in the last column as 'n'.

Zooplankton Group	Min.	Max.	Mean	SE	n
Copepoda	0.51	3.79	1.64	0.18	27
Malacostraca	1.32	17.43	8.42	0.61	59
Nauplii	0.34	0.62	0.44	0.03	10
Thaliacea	1.69	12.79	7.30	0.81	20
Appendicularia	1.16	4.45	2.61	0.21	24
Fish eggs	0.78	1.38	1.10	0.06	11
Larval fish	2.48	22.39	10.03	0.84	37
Other	3.01	15.08	10.34	1.01	13

5 Discussion

5.1 NNZST zooplankton samples: interannual comparison

Nearly twice as many net samples were collected in 2018-2019 (n = 68), compared to 2017-2018 (n = 39). Proportionally more surface tows were conducted in 2018-2019 to try and capture zooplankton during mobile feeding workups. The proportions of zooplankton within each group across the season was very different between the two sampling years. In 2017-2018, spring samples were generally dominated by Copepoda whereas in 2018-2019, Thaliacea dominated. In summer, Appendicularia were highly abundant in 2017-2018 but, aside from one sample in 2018-2019, this group was not common. Malacostraca were more common in 2018-2019 during the summer and also siphonophores in the Other group. High proportions of Fish eggs did feature in the summer of both sampling years. The autumn samples of 2017-2018 had generally greater proportions of Appendicularia and Thaliacea, while in 2018-2019 they were commonly dominated by Copepoda and Nauplii which were not counted in 2017-2018. In 2017-2018, mature euphausiids with eggs were relatively rare and associated nauplii were not seen or else not identified as such. The variety of zooplankton within the Malacostraca group appeared to be greater in 2018-2019 and crab larvae appeared to be more common. Many samples appeared to be dominated by euphausiids in 2018-2019 and on closer inspection often contained large numbers of nauplii.

These differences in relative proportions of the zooplankton groups between the two years of sampling highlight the inherent variability in zooplankton assemblages that can occur between years. This variation can be caused by a variety of oceanographic and biological factors. Improvements to sampling techniques in 2018-2019 will have also caused some sample variation, partly by a greater number of surface tows being conducted to obtain zooplankton from often mobile and patchy workups. No attempts were made during this study to look at differences in zooplankton composition in terms of sample location or factors such as tides, sea surface temperature and salinity.

Only relatively minor differences were found in the composition of zooplankton groups between samples collected in workups and away from workups for both sampling years. This was despite a specific focus in the field sampling of 2018-2019 to target the active face of workups in order to catch more mobile zooplankton species that may have been missed by sampling efforts in the previous year. However, there was a lack of any major differences in the zooplankton communities for workups versus outside workups which could be due to the high variability in zooplankton between sampling events. Such variability is likely to be due to the inherent spatial and temporal variability of zooplankton. However, it could also be caused by the method of sample analysis used in this study because standardised zooplankton counts were not able to be undertaken due to the unknown volume of water sieved by the plankton net so therefore the relative proportions calculated do not give an indication of the total number of zooplankton present. Regardless, in 2017-2018 comparisons of standardised vertical hauls found no differences in the zooplankton groups for within workup versus outside workups. Observations of underwater video footage taken at workups suggest that more highly mobile zooplankton species, like euphausiids, may form highly localised intense concentrations that last for only short periods as a result of being corralled by schooling fishes, before dispersing again. Such temporary concentrations of euphausiids may provide prey for predatory fishes and seabirds, but would be difficult to sample with a relatively slow moving zooplankton net.

Additional data was collected in 2018-2019 through the analysis of fish stomach contents, caught in workups where zooplankton samples were also collected. The stomach contents showed that the kahawai and trevally appear to have been targeting euphausiids within the more diverse range of taxa seen in the zooplankton in these areas. The recorded diet of both these fish species includes euphausiid shrimp and other planktonic crustaceans in the surface waters (Doak, 1984; Francis, 2001).

5.2 AWADS samples

The zooplankton samples collected by the AWADS vessel were obtained in the inner Hauraki Gulf and in workups seen while looking for cetaceans. The composition of these samples were generally quite different to those collected by the NNZST and this could be due to the different location within the Hauraki Gulf and the different types of workups targetted. The AWADS samples generally contained much lower numbers of zooplankton, with the Malacostraca group often consisting of a large number of crab larvae, although some euphausiids were present. In the Other group, small hydrozoan medusae were common together with siphonophores and cladocerans, all of which were rarely seen in the NNZST samples.

5.3 Ecological importance of zooplankton

Mesozooplankton are a valuable food source for a wide range of marine life including fish, seabirds and baleen whales. The estimated mean energy content of crustacean zooplankton such as euphausiids (23.5 kJ g^{-1} of dry mass) and copepods (29.8 kJ $g^{-1)}$, is much greater, compared to the gelatinous Thaliacea (4.1 kJ g^{-1} of dry mass) (Wang & Jeffs, 2014). Furthermore, much of this food energy is composed of high quality protein and lipid which is ideal for provisioning seabirds and fast swimming fishes. Fish eggs also have a high energy content, for example, Hislop & Bell (2006) calculated a mean of 23.2 kJ g^{-1} for the eggs of some demersal fish species from British waters.

Given the ecological and fisheries importance of the north-eastern North Island and 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 (Zeldis & 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.

The Hauraki Gulf is an internationally significant habitat for seabirds (Forest & Bird, 2015). However, much information is lacking on the food web links between primary productivity, zooplankton, fish and seabirds. More research is needed in order to protect and conserve this valuable taonga.

5.4 Recommendations for future zooplankton analysis and field work

- High speed zooplankton sampling methods should be tested to determine whether the concentrations of more mobile zooplankton that are important in the diet of seabirds, such as euphausiids, are spatially more concentrated inside workups versus outside workups.
- Use of underwater camera/video equipment to view the movements of euphausiids in relation to predators (fish and seabirds), and sampling equipment.
- A flow meter should be incorporated into the zooplankton net to facilitate the standardising of samples by water volume filtered by the net.
- Volumetric measurements should be used to quickly determine the total zooplankton mass of samples using settled volume.
- More rigorous subsampling protocols, especially in the field, need to be implemented.
- The calorific value and biochemical composition of typical zooplankton species consumed by seabirds should be measured and compared.
- Collect data on oceanographic factors and analyse in GIS to better understand the bottom-up processes influencing zooplankton abundance and distribution.

6 Acknowledgements

Huge thanks go to volunteers Olivia Lord and Alyssa Ward for their assistance with processing the zooplankton samples. Thanks to the Leigh Marine Laboratory staff and students for, as always, creating a great place to work. Thanks to Tom Trnski (Auckland Museum) for his enthusiasm in identification of larval fish specimens and to Dr. Charlotte (Charlie) Johnson (School of Biological Sciences, University of Auckland) for taking beautiful, high resolution photographs of zooplankton specimens. Thanks also to the crew of the Auckland Whale and Dolphin Safari vessel for providing zooplankton samples.

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Resources used for zooplankton identification and classification

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8 Appendices

Appendix 1 Taxonomy of zooplankton groups

Taxonomic order from World Register of Marine Species (www.marinespecies.org)

This list includes the taxon details of zooplankton included in each of the seven groups used in this report. It is not an exhaustive list but gives an idea of the wide range of diversity found in the plankton samples.

COPEPODA

Phylum: Arthropoda
Subphylum: Crustacea
Class: Hexanauplia
Subclass: Copepoda

- **Order:** Calanoida
- **Order:** Cyclopoida
- **Order:** Harpacticoida

MALACOSTRACA

Phylum: Arthropoda
Subphylum: Crustacea
Class: Malacostraca

- **Order:** Isopoda (isopods)
- **Order:** Amphipoda (amphipods)
- **Order:** Mysidacea (mysiid shrimp)
- **Order:** Euphausiacea (krill)
- **Order:** Stomatopoda (mantis shrimp larvae)
- **Order:** Decapoda
    - **Infraorder:** Anomura (“false” crabs, including hermit, porcelain larvae)

    - **Infraorder:** Caridea (shrimp larvae)
    - **Infraorder:** Brachyura (true crab larvae)
    - **Infraorder:** Achelata
        - **Family:** Palinuridae (crayfish larvae)
    - **Infraorder:** Gebiidea
        - **Family:** Laomediidae. *Jaxea* sp. (shrimp)
    - **Suborder:** Dendrobranchiata
        - **Family:** Luciferidae (planktonic shrimp)

NAUPLII

Order: Euphausiacea (krill) nauplii
Infraclass: Cirripedia (barnacle) nauplii
Infraorder: Anomura (false crab) zoae < 1 mm

APPENDICULARIA

Phylum: Chordata
Subphylum: Tunicata
Class: Appendicularia (larvaceans)

THALIACEA

Phylum: Chordata
Subphylum: Tunicata
Class Thaliacea (salps)

- **Order:** Salpida
- **Order:** Doliolida

FISH EGGS

Phylum: Chordata
Subphylum: Vertebrata
Class: Actinopterygii (ray-finned fish eggs)

OTHER

Phylum: Cnidaria (jellyfishes)

- **Class:** Hydrozoa
    - **Order:** Anthoathecata (athecate hydroid)
    - **Order:** Leptothecata (thecate hydroid)
    - **Order:** Siphonophorae (siphonophores)
- **Class:** Scyphozoa (jellyfish)

Phylum: Annelida (worms)
Class: Polychaeta

Phylum: Arthropoda

Subphylum: Crustacea

- **Class:** Hexanauplia
  - **Infraclass:** Cirripedia (barnacle cypriid)
- **Class:** Brachiopoda
  - **Superorder:** Cladocera (cladoceran)
- **Class:** Ostracoda (ostracod)

Phylum: Mollusca (snails)
Class: Gastropoda

- **Order:** Pteropoda (sea butterfly)
- **Order:** Littorinimorpha
  - **Family:** Pterotracheidae

Phylum: Echinodermata (sea urchins and sea stars)

- **Subphylum:** Echinozoa
  - **Class:** Echinoidea (sea urchin larvae)
- **Subphylum:** Asterozoa
  - **Class:** Asteroidea (starfish larvae)
  - **Class:** Ophiuroidea (brittle-star larvae)

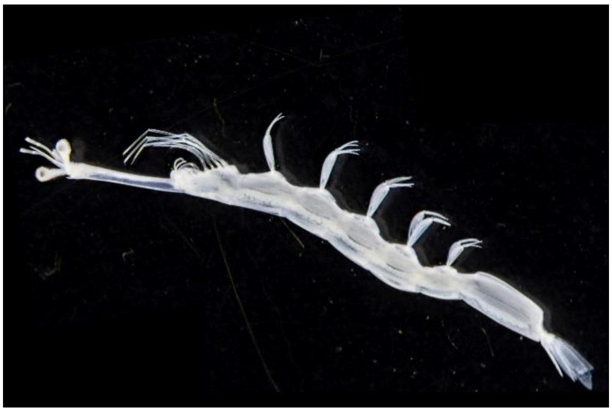
Phylum: Chaetognatha (arrow worm)

Phylum: Chordata
Subphylum: Vertebrata
Class: Actinopterygii (ray-finned fish larvae)

Appendix 2 Macro photography of voucher specimens – zooplankton

High resolution images were taken by Dr. Charlotte Johnson at the School of Biological Sciences, University of Auckland using a Nikon D7200 DSLR camera with adapter connected to a Leica M80 stereo microscope. Images were processed in Adobe Photoshop CC to composite images together (where required), to sharpen and remove chromatic aberration.

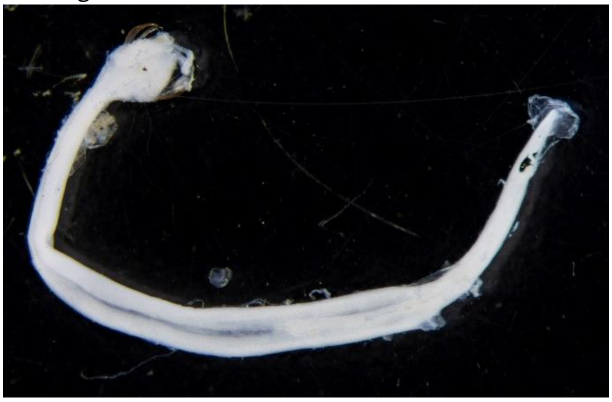
Malacostraca, *Lucifer* sp.



Malacostraca, crab megalopa

Malacostraca, crab larvae

Chaetognath



Appendicularia

Thaliacea

Malacostraca, stromatopod larvae

Malacostraca, crab zoaea

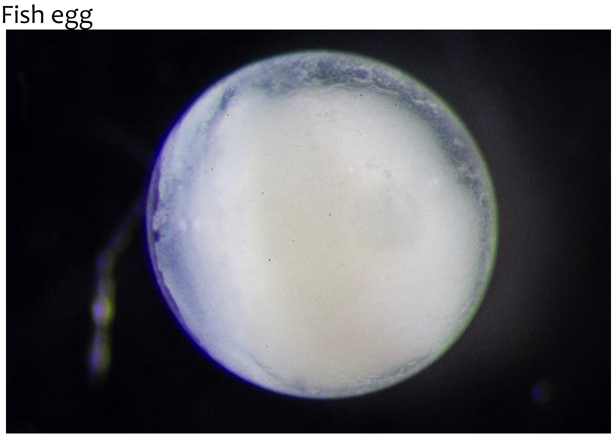
Malacostraca, hermit crab larvae

Malacostraca, decapod shrimp larvae

Malacostraca, *Jaxea* sp

Calanoid copepod

Fish egg



Malacostraca, Euphausiid

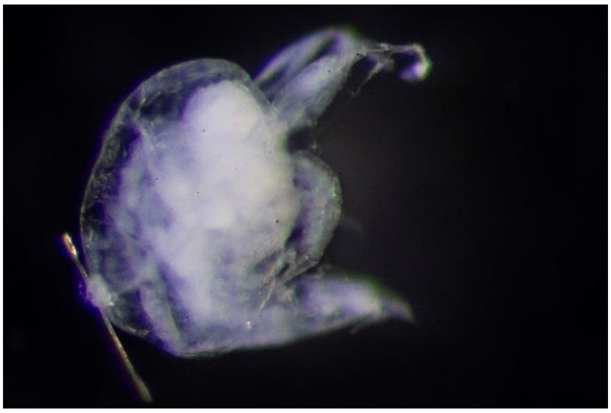
Malacostraca, Euphausiid with eggs

Calanoid copepod

Isopod

Barnacle nauplii

Crab, early zoaea

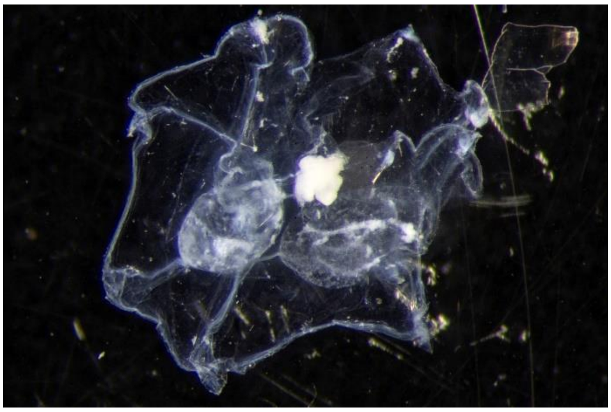


Amphipod

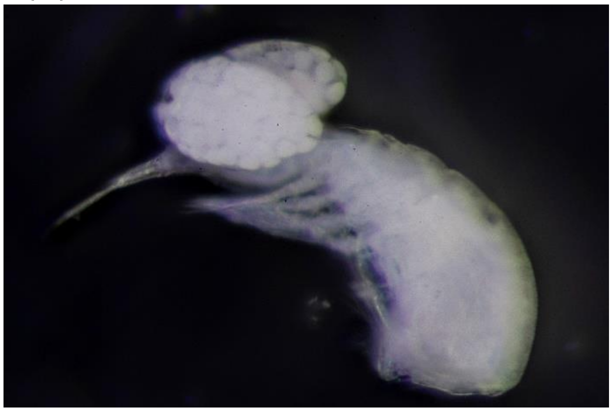
Pteropod

Cladocera

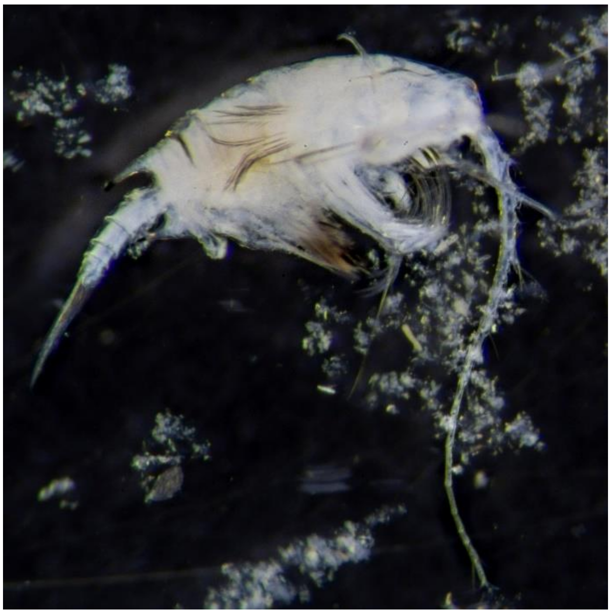
Siphonophore



Copepod



Copepod

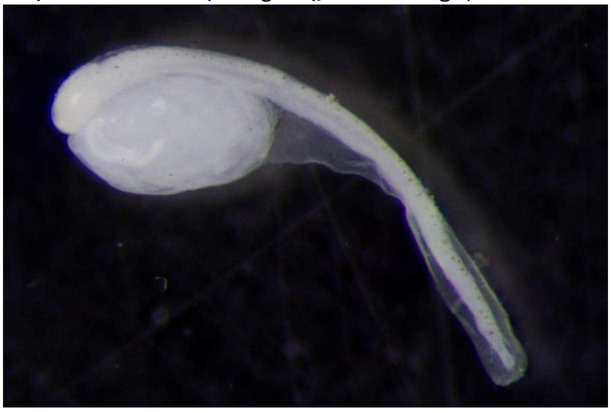


Appendix 3 Macro photography of voucher specimens – larval fish

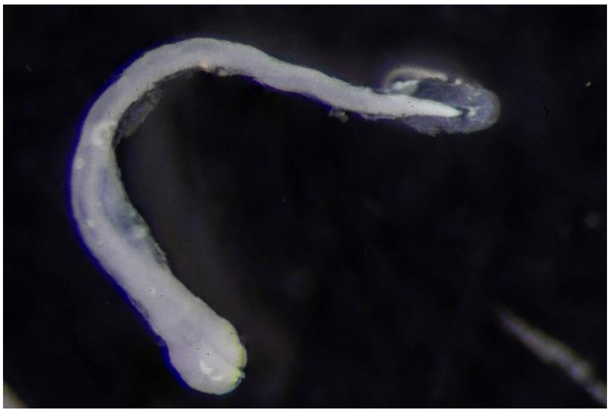
High resolution images were taken by Dr. Charlotte Johnson at the School of Biological Sciences, University of Auckland using a Nikon D7200 DSLR camera with adapter connected to a Leica M80 stereo microscope. Images were processed in Adobe Photoshop CC to composite images together (where required), to sharpen and remove chromatic aberration.

Clupeidae, *Sardinops sagax*

Clupeidae, *Sardinops sagax* (yolksac stage)



Clupeidae, *Sardinops sagax*



Bothidae, *Lophonectes mongonuiensis*

Unidentified, head and tail missing

Clinidae, *Cristiceps aurantiacus*

Scorpaenidae, Scorpaenidae

Monacanthidae, *Meuschenia scaber*

Creediidae, Creediidae

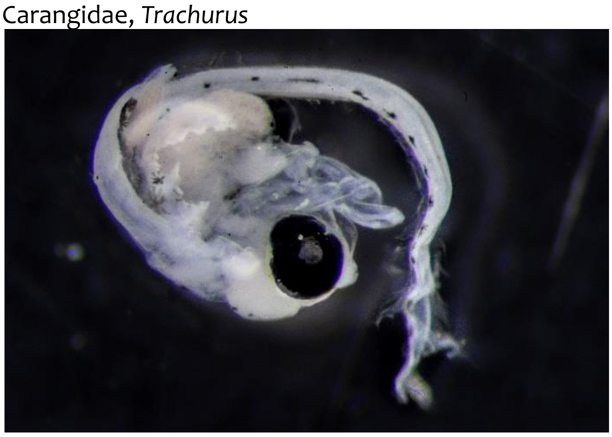
Sparidae, *Chrysophrys auratus*

Clupeidae, *Sardinops sagax*

Carangidae, *Trachurus*

Percoidei, Percoidei

Carangidae, *Trachurus*



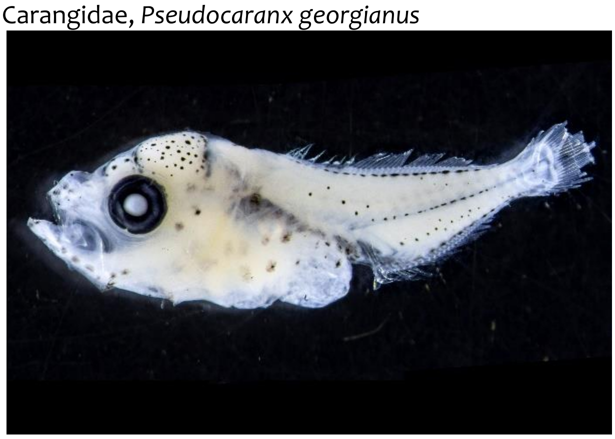
Scorpididae, *Scorpis*

Monacanthidae, *Meuschenia scaber*

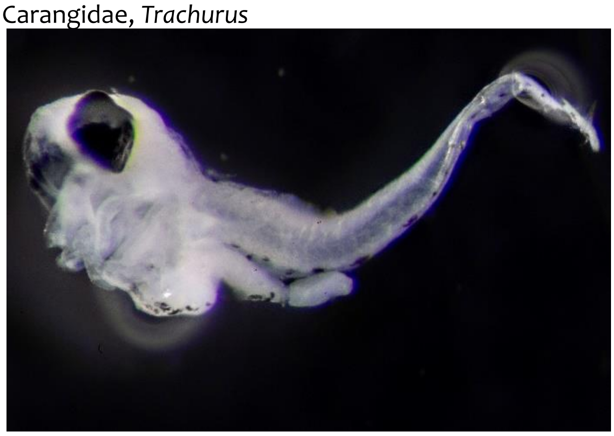
Cheilodactylidae, *Cheilodactylus*?

Cheilodactylidae, *Cheilodactylus*?

Carangidae, *Pseudocaranx georgianus*



Carangidae, *Trachurus*



Carangidae, *Trachurus novaezelandiae*?

Carangidae, *Trachurus*

Carangidae, *Pseudocaranx georgianus*

Engraulidae, *Engraulis australis*

Carangidae, *Trachurus*

Engraulidae, *Engraulis australis*

Carangidae, *Pseudocaranx georgianus*

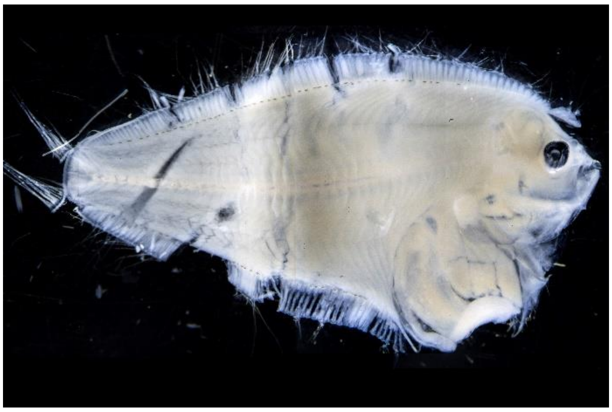
Rhombosoleidae

Blenniidae, *Parablennius laticlavius*

Carangidae, *Trachurus*

Blenniidae, *Parablennius laticlavius*

Rhombosoleidae



Engraulidae, *Engraulis australis*

Blenniidae, *Parablennius laticlavius*

Scombridae, *Scomber australasicus*