Department of Conservation, Conservation Services Programme project BCBC2020-08: Fish shoal dynamics in North-Eastern New Zealand

Final report on fish shoal sampling conducted October 2020- April 2021

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

SCIENCE
SCHOOL OF BIOLOGICAL SCIENCES

NORTHERN NZ SEABIRD TRUST

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The **Addendum: Nutritional Analysis of Seabird Prey Species from the Hauraki Gulf** to this report has been prepared by **Dr Stefan Spreitzenbarth** with **Prof. Andrew Jeffs** (Institute of Marine Science, University of Auckland) and **Lily Kozmian-Ledward** (Sea Lily Ltd.)

August 2021

Figure 1 (above). Fairy prions, Mokohinau Islands. *Photo Edin Whitehead.*

SUMMARY

The aim of this and earlier projects is to better understand the relationship between the diet of surface-foraging seabirds, and what prey items are being made available from fish shoal events (workups) so that we can understand the mechanisms changing the distribution and/or abundance of workups and how that might affect seabird populations.

Survey trips within the Hauraki Gulf area for this contract (DOC CSP BCBC2020-08) are being conducted at locations within the general area of Marsden Point/Whangarei Heads > Marotere/Chickens Islands > Mokohinau Islands > Hauturu/Little Barrier > Bream Tail > Marsden Point during the period October 2020 - April 2021 qualified as spring (Oct-Nov), early summer (Dec), late summer (Jan-Feb) and autumn (Mar-Apr).

After locating a fish shoal, variables recorded included the GPS location, sea-surface temperature, weather conditions and bird species seen foraging. Prey samples were collected using surface trawls (<2m) and preserved where the fish shoals were encountered, and control samples in similar regions where fish shoals were not visible were being collected. It is accepted that presence/absence of shoals is one of the most challenging aspects of sample collection and while preferred, repeat sampling is not always possible. In a selection of fish shoals, individual fish were caught for stomach analysis. Using underwater videography and visual observations of fish at the sea-surface species involved in shoal formation (mixed and/or single species) were identified.

Six field trips (all single day) were made October 2020 to April 2021. COVID-19 restrictions, vessel unavailability and weather conditions meant that no trip was undertaken in March 2021. Two trips were made in April.

Please note: The zooplankton and fish samples collected under this contract are being stored at the Leigh Marine Laboratory, University of Auckland in and at 3°C (zooplankton in 100% ethanol) and -18°C (fish tissue samples) for future analysis (e.g., quantifying species richness and abundance of seabird prey specimens (% mass per sampling period) and will be undertaken together with a review of video footage, as funding permits. This report covers sample collection details and behavioural observations only.

Figure 2. Larval fish amidst dense krill, sample from 3 February 2021. *Photo: Edin Whitehead*

CONTENTS

1 INTRODUCTION

1.1 Background

A notable feature of north-eastern North Island waters are the large numbers of seabirds feeding in "workups" – multi-species feeding aggregations containing zooplankton and fish. There is a need to understand the processes that drive workup formation and dynamics as many seabird species, predominantly red-billed gull (*Larus novaehollandiae scopulinus*), white-fronted tern (*Sterna striata*), Australasian gannet (*Morus serrator*), fairy prion (*Pachyptila turtur*), Buller's shearwater (*Ardenna* (*Puffinus*) *bulleri*), and fluttering shearwater (*Puffinus gavia*), are potentially dependent on shoaling fish to drive smaller prey to the sea surface, making them more accessible to seabirds as a food source. There is poor knowledge of both the relationship between the diet of surface-foraging seabirds, and what prey items are being made available to seabirds from workups. This is limiting our understanding of the mechanisms through which any changes in the distribution and/or abundance of workups may be driving seabird population changes (population status and annual breeding success). For some seabird species that interact with workups, recent population abundance data is incomplete or unknown which limits our assessment of population trends over time (Gaskin et al 2019).

North-eastern North Island waters also support extensive purse-seine fisheries, due to the presence of the large surface shoals of fish, which are also an important part of the food web for seabirds. Fish species targeted by these fisheries predominantly include kahawai (*Arripis trutta*), trevally (*Pseudocaranx georgianus*), skipjack tuna (*Katsuwonus pelamis*), jack mackerel (*Trachurus declivis*), blue mackerel (*Scomber australasicus*), saury (*Scomberesox saurus*), pilchard (*Sardinops sagax*) and anchovy (*Engraulis australis*). By targeting fish species which are also part of workups utilised by various seabird species; purse-seine fisheries potentially negatively impact these seabird populations. However, the degree to which this may occur is unknown, therefore it is important that we better understand the relationship between seabird population trends and changes in abundance and distribution of fish shoals. Note that in this report, fish 'shoal' and 'school' are used somewhat interchangeably. Technically, the term 'shoal' refers to a loose aggregation of fish, sometimes comprising different species, whereas a 'school' is typically a group of fish of the same species swimming together in synchrony (Delcourt & Poncin, 2012).

1.2 Seabird Feeding Associations

Zooplankton occupy a key position in the pelagic food web, transferring the organic energy produced by phytoplankton to higher trophic levels such as fish, seabirds, and baleen whales (Harris et al., 2000; Frederiksen et. al., 2006). Zooplankton abundance and diversity are determined predominantly by oceanographic (e.g., temperature, upwelling zones) and biological factors (e.g., predation) which result in a large amount of spatial and temporal variability (Zeldis & Willis, 2015). The wider Hauraki Gulf area is a highly productive marine ecosystem whose primary productivity is influenced by both wind and current driven circulation. A summary of oceanography of the region is provided in the earlier report for this contract (Taylor & Gaskin 2020).

1.3 Study Area

The study area is located across the northern Hauraki Gulf (Fig. 3). Research on seabird feeding associations and diet has been conducted in this area for several years due to the islands here being important seabird breeding areas for 27 species which breed and forage in the surrounding waters (Gaskin & Rayner 2013; Forest & Bird 2014). Sampling locations in the current project include several of the sites where research work was conducted in previous seasons (POP2017-06, POP2019-02).

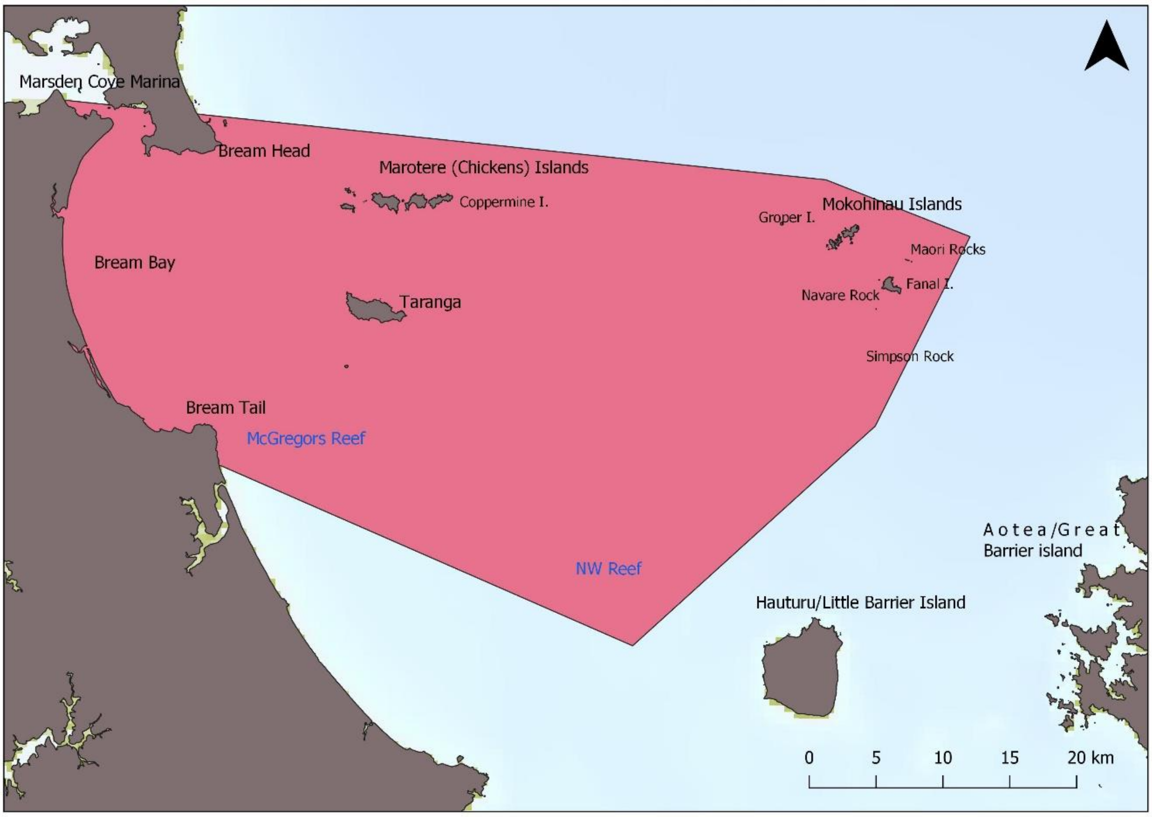

Figure 3. Outer (northern) Hauraki Gulf study area for 2020-2021 season with key locations.

1.4 Covid-19 restrictions

Auckland shifting to Alert Level 3 on 28 February 2021 meant a proposed early March trip was cancelled due to the requirement for people on non-essential duties to 'lock-down' in their homes. By the time Alert Levels were dropped in March the boat charter we had been using was either unavailable or weather conditions discounted getting out on the water. Trips resumed in April 2021.

2 METHODS

In general, the methodology adopted for this sampling season is based on that previously described in POP2019-02. However, some changes were adopted based on some of the recommended changes outlined in Kozmian-Ledward et al (2020). A major change has been to move from a general search for seabird activity over a wide area to following the same basic route with sampling stations determined by activity encountered while vessel cruising. This aimed to provide greater consistency in sampling methods and improve statistical rigour.

2.1 Field Methods

To date, four fieldwork days have been conducted between 6 October 2020 and 3 February 2021. Sampling, videography, and observations were conducted as follows:

- In general, a full suite of data for biological variables (zooplankton, fish, seabirds) was made at each event to allow for full comparisons of all variables.
- The floating camera rig was deployed at sampling locations to ground-truth topside observations of fishes.
- We also trialled a new rig with multiple cameras that could either be set to various depths down the water column or dropped through the water column to record fish and other activity beneath work up activity or at sampling locations.
- Oceanographic data recording – measurements of SST, salinity and water clarity were taken at all sampling events.
- A flowmeter was used to for standardise the zooplankton sampling.
- Seabird data collection included primary species, secondary species, abundance, and behaviours.
- Where possible multiple replicate zooplankton tows at each event were conducted to greater account for characteristic zooplankton patchiness. However, working within a single day and reasonable hours (0800-1800 hrs) the distances covered meant a limited number of tows can be done.
- Control zooplankton tows were undertaken where possible within time constraints.
- Routes and sampling locations are shown in Figure 4.

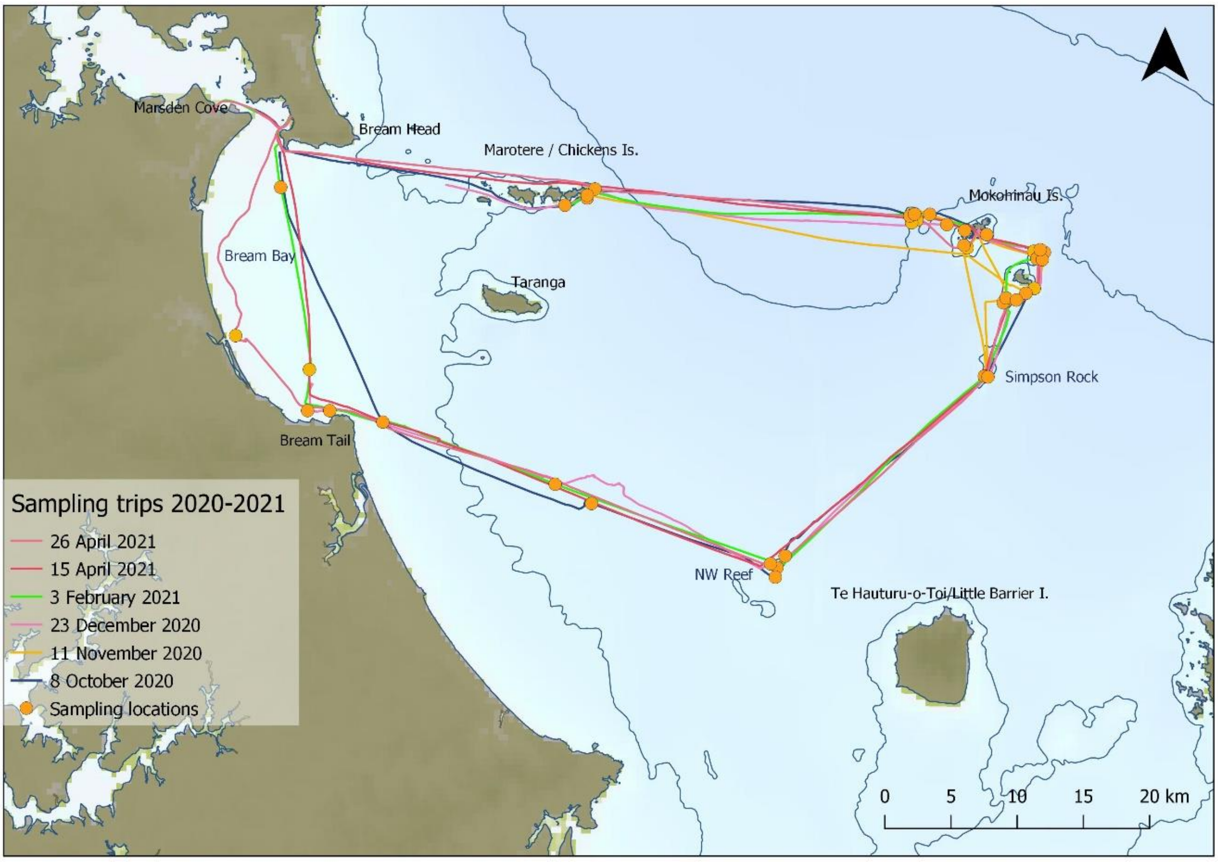

Figure 4. Routes and sampling locations in the outer (northern) Hauraki Gulf, all trips October 2020 to April 2021

Figure 5-10. On-deck activity. Readying the plankton net for towing, and fishing for trevally or kahawai from school; record keeping; reading flowmeter; and topside photography; sieving sample; euphausiid extracted

3 RESULTS

3.1 Zooplankton Sampling

Table 1. Locations where sampling was conducted. Event type relates to fish/seabird activity and the nature of the sampling procedure (either surface tow or control).

Date	Time start	Time stop	Event type	Lat	Long	Location	Description
6/10/2020	9.37	9.43	Current line	-35.88553	174.78914	E. of Coppermine I.	Fish - trevally, kahawai, humpback in vicinity, birds - BUSH, FAPR (dom sp.), RBGU, FLSH
6/10/2020	10.51	10.56	Surface	-35.89826	175.06977	E of Groper I.	Birds only - FAPR 1000s (dom sp.), BUSH 100s, RBGU 50-100, WFTE <10, BBGU 1
6/10/2020	11.30	11.35	Surface	-35.91125	175.11767	Sphinx Rocks	Fish - trevally, kahawai, humpback in vicinity, birds – 200-300 RBGU (dom sp.), c. 100 FAPR, BUSH, FLSH
6/10/2020	12.15	12.20	Surface	-35.92242	175.16630	Maori Rocks	Birds only
6/10/2020	12.50	12.55	Surface	-35.95067	175.15162	S. Fanal I.	Fish - trevally, birds – , 100s FAPR (dom sp.), 10s BUSH, BBGU 1
6/10/2020	14.38	14.43	Control	-36.14134	174.94788	NW Reef	Nothing working, control sample
6/10/2020	15.00	15.05	Surface	-36.14779	174.94655	NW Reef	Fish - trevally, birds – 50-100 RBGU, WFSP, FAPR, FLSH
6/10/2020	15.55	6.00	Surface	-36.10004	174.79118	Jellicoe Channel	Common dolphins, Birds – 100s Gannets (dom sp.), FFSH, SOSH, BUSH, FLSH
20/11/2020	14.07	14.12	Current line	-35.89178	174.7828	Coppermine I.	~500 RBGU (dom sp.) were foraging on arrival, sporadic foraging during sampling, 500m off Coppermine I.
20/11/2020	16.05	16.1	Surface	-35.92751	175.16473	Maori Rocks	~1000 birds, FAPR (dom sp.), RBGU, Maori Rocks, Trevally, Kahawai, Koheru
21/11/2020	11.4	11.45	Surface	-35.89835	175.05696	Groper I.	Intermittent workup. ~1000 FAPR, FLSH, likely mackerel school
21/11/2020	14.14	14.19	Surface	-35.91892	175.09888	S. Atihau I.	FAPR (dom sp.), RBGU, Trevally school. Net cam not working
21/11/2020	15.04	15.09	Control	-36.00776	175.11835	Simpson Rock	Simpsons Rock, no birds or fish present
21/11/2020	15.34	15.39	Surface	-35.95419	175.13509	Navare Rock	FAPR (~1000), FFSH (<10)

Date	Time start	Time stop	Event type	Lat	Long	Location	Description
23/12/2020	6.02	6.07	Control	-36.03998	174.55168	Laings Beach	Few WFTE present, bait ball visible on sounder, Known KAH spot, lots of algae in sample, some salps
23/12/2020	6.35	6.4	Surface	-36.04694	174.61485	McGregor Reef	RBG (~60), FLSH (~60), WFTE, 2x FLSH; KAH school
23/12/2020	7.36	7.41	Surface	-36.08730	174.76035	Jellicoe Channel	~1200 birds, FLSH (dom sp.), BUSH, WFSP, FFSH; MACl or TREV school, very mobile, lots of salps
23/12/2020	8.58	9.03	Surface	-36.13877	174.94238	NW Reef	~400 birds, BUSH dom sp. FLSH, salps, school went down
23/12/2020	10.06	10.11	Surface	-36.00827	175.12133	Simpson Rock	FAPR (~500), WFSP, BUSH; TREV school
23/12/2020	11.21	11.26	Surface	-35.95547	175.14375	Navare Rock	FAPR~1500 (dom sp.), RBG ~30, BUSH & FFSH ~10 each; TREV school
23/12/2020	12.03	12.08	Surface	-35.92076	175.16276	Maori Rocks	FAPR ~80, BUSH ~10, TREV
23/12/2020	14.26	14.31	Surface	-35.90499	175.08419	Groper Rock	FAPR ~1200, SOSH, BUSH,
23/12/2020	15.56	16.01	Surface	-35.88986	174.78275	Coppermine I.	RBG ~2000
3/02/2021	8.49	8.53	Surface	-35.88758	174.52964	Bream Bay	FLSH ~100, FFSH 2x, BUSH 10x, WFTE 5x, fast moving; some fish at surface, KAH, photos of terns taking small fish
3/02/2021	9.52	9.57	Surface	-36.03977	174.57027	Bream Tail	<500 FLSH, <100 BUSH, FFSH <5, WFTE <10, RBGU <5: well spread, KAH
3/02/2021	11.56	12.01	Surface	-36.13330	174.95441	NW Reef	FFSH ~30, BUSH ~200, 1x BLPE, COPE rafting, WFSP ~5, 2x LBPN.
3/02/2021	13.55	14	Surface	-35.95742	175.13279	Navare Rock	RBGU ~1000, BUSH ~100, FLSH ~300, FAPR ~150; 5x TREV schools, camera deployed at Simpsons Rock x2 ~1pm. Bronze whaler shark.

Date	Time start	Time stop	Event type	Lat	Long	Location	Description
3/02/2021	15.09	15.14	Surface	-35.92687	175.16007	Maori Rocks	RBGU 1500+, FAPR 50, BUSH & FLSH ~50 combined, manta at Maori Rocks 2.35pm - Manta ray sighting form submitted.
3/02/2021	15.10	15.15	Surface	-35.90150	175.05283	Groper I.	RBGU 1000s feeding over multiple workups, also many birds roosting on the island.
3/02/2021	16.34	16.39	Surface	-35.89688	174.76428	Near Coppermine I.	RBGU x13, AUGA x2, FLSH, Bronze whaler shark.
15/04/2021	09.20	09.25	Surface	-36.01196	174.55268	Laings Beach	BUSH, WFTE, FLSH ~100 total of all species. Sparse foraging.
15/04/2021	12.04	12.09	Control	-35.90250	175.05907	Navare Rock	KAH/TREV School, no birds.
15/04/2021	13.30	13.35	Surface	-35.95521	175.13449	Near Groper Rock	Workup KOH, RBG ~1200, BLSH ~60
26/04/2021	09.07	09.12	Surface	-35.98961	174.49035	Waipu Cove	Scattered workup, KAH School, RBGU ~50, WFTE ~50, ~100 FLSH showed up later.
26/04/2021	11.52	11.57	Surface	-36.00785	175.11907	Simpsons Rock	TREV school with few birds, ~10 RBGU, ~10 WFTE.
26/04/2021	12.29	12.34	Surface	-35.94727	175.15854	Navare Rock	TREV school, <10 RBGU, shark took fish off the line.
26/04/2021	12.59	13.04	Surface	-35.95675	175.13440	Just South of Fanal Island	TREV school, ~700 RBGU, Octopus in sample?
26/04/2021	13.28	13.32	Surface	-35.92687	175.16007	Maori Rocks	Small school of TREV, RBGU ~100.
26/04/2021	13.56	14.01	Surface	-35.92059	175.10164	Near Burgess I.	TREV school, ~15 RBGU
26/04/2021	14.31	14.36	Surface	-35.90424	175.05468	Groper Rock	TREV school, ~1200 RBGU, ~40 FLSH, ~5FAPR, large crab in sample.

Abbreviations used in Tables 1 and 2: Seabirds: AUGA = Australasian gannet, BLPE = black petrel, BUSH = Buller's shearwater, CODP = common diving petrel, COPE = Cook's petrel, FAPR = fairy prion, FFSH = flesh-footed shearwater, FLSH = fluttering shearwater, GRNO = grey noddy, RBGU = red-billed gull, SOSH = sooty shearwater, STSH = short-tailed shearwater, WFSP = white-faced storm petrel, WFTE = white-fronted tern. Fish: KAH = kahawai, KING = kingfish, KOH = koheru, RED SNAP = red snapper, SNAP = snapper, TREV = trevally.

3.2 Fish Sampling

Table 2: Summary of zooplankton and fish samples collected with 'Original total volume', 'Pres vol' and 'Vol disc'd' representing total volume collected, preserved volume of sample discarded volume respectively. Also, under fish stomach and muscle samples 2X or 3X refers to samples from each separate fish.

Date	Event #	Original total volume (ml)	Pres vol (ml)	Vol disc'd (ml)	Sample label ID	Fish sp.	Fish length (cm)	Fish stom.	Fish muscle sample	Total # samples
6/10/2020	1	210	150	60	1					3
6/10/2020	2	<50	<50	0	2					3
6/10/2020	3	180	150	30	3					8
6/10/2020	4	100	100	0	4					5
6/10/2020	5	120	120	0	5	TREV 2X	a) 53 b)44	Yes, 2X	Yes x2	7
6/10/2020	6	330	150	180	6					5
6/10/2020	7	550	150	400	7					3
6/10/2020	8	<10	0	<10	8					1
20/11/2020	1	70	70	0	1					1
20/11/2020	2	70	70	0	2	KOH, TREV 2X	a) 45, b) 47 c) 34	Yes, 3X	Yes, 2A, 2B, 2C	7
21/11/2020	3	<50	<50	0	3					1
21/11/2020	4	140	120	20	4					2
21/11/2020	5	<10	<10	0	5					1
21/11/2020	6	<50	<50	0	6	TREV	45	Yes 1X	Yes #6	3
23/12/2020	1	340	240	100	1	KAH	38	Yes 1X	Yes #1	4
23/12/2020	2	2600	240	2360	2					3
23/12/2020	3	10000	240	9760	3					3
23/12/2020	4	10000	240	9760	4					3
23/12/2020	5	2800	240	2560	5	SNAP, KAH, TREV	a) 34 b) 57 c) 38	Yes, 3X	Yes, 5A, 5B, 5C	9
23/12/2020	6	7000	240	6760	6	TREV	44	Yes, 1X	Yes #6m	5
23/12/2020	7	1200	240	960	7	SNAP, TREV	a) 48, b) 43	Yes, 2X	7AM & 7BM	7
23/12/2020	8	1300	240	1060	8	KOH	38	Yes, 1X	8M	5
23/12/2020	9	5000	240	4760	9					3

Date	Event #	Original total volume (ml)	Pres vol (ml)	Vol disc'd (ml)	Sample label ID	Fish sp.	Fish length (cm)	Fish stom.	Fish muscle sample	Total # samples
3/02/2021	1	270	240	30	1	KAH	35	Yes, 1X	1M	2
3/02/2021	2	1800	240	1560	2					2
3/02/2021	3	140	140	0	3	KING	93	3S	3M	4
3/02/2021	4	180	150	0	4	TREV 2X	a & b) 44	4AS, 4BS	4AM, 4BM	6
3/02/2021	5	240	220	0	5	KAH, RED SNAP (r)	53	5S	5M	4
3/02/2021	6	110	110	0	6	TREV	46	6S	6M	3
15/04/2021	1	<10	<10	0	1					1
15/04/2021	2	240	240	0	2	TREV KAH	a)40 b)48	2AS, 2BS	2AM, 2BM	6
15/04/2021	3	<50	<50	0	3	KOH	41	3S	3M	3
26/04/2021	1	<10	<10	0	1					1
26/04/2021	2	<10	<10	0	2	TREV	36	2S		3
26/04/2021	3	80	80	0	3	TREV	38.5	3S	1M	3
26/04/2021	4	<50	<50	0	4	TREV	42.5	4S	4M	3

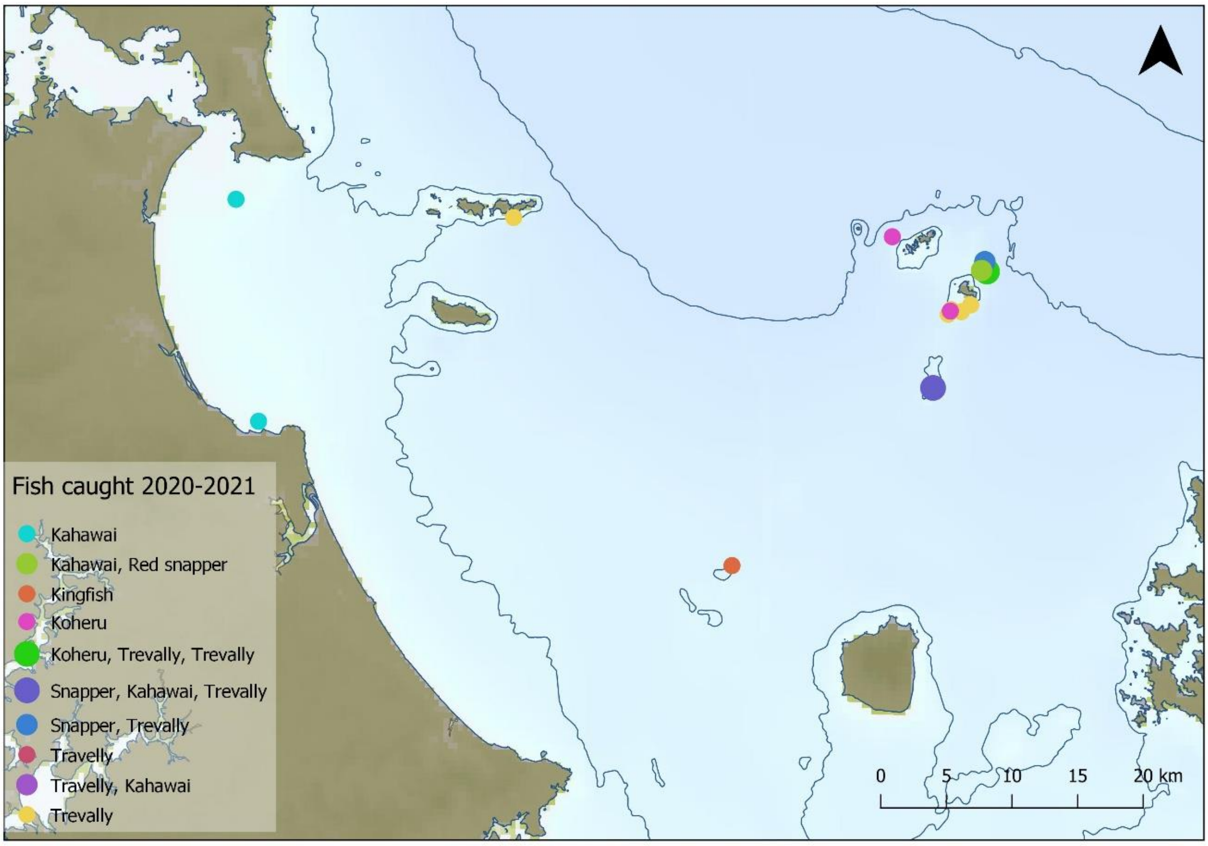

Figure 11. Location of fish captures in the outer (northern) Hauraki Gulf study area during 2020-2021 sampling.

Figure 12. Kingfish, 3 February 2021. *Photo: Kerry Lukies.*

3.3 Fish school dynamics

The sampling sites frequented during this season's fieldwork include seven near islands or over reefs that we have identified as known areas for regular fish shoaling activity and seabird aggregations. At these sites mixed schools of trevally and kahawai prevailed, although on occasion with mackerel spp. joined the schools. In April schools of koheru (*Decapterus koheru*) were encountered (Fig. 14).

In addition, the sites in Bream Bay, varied depending on the seabird/fish activity we encountered. These events added further variety in that they were off a river mouth and long sandy beaches and frequented by large flocks of shearwaters throughout the year. We also encountered activity in the Jellicoe Channel, an open water location between Bream Tail/McGregor Reef and NW Reef on two occasions.

Sites visited:

1. Coppermine Island (Marotere/Chickens Group)
2. Groper Island (Mokohinau Group)
3. Māori Rocks (Mokohinau Group)
4. Navare Rock (Mokohinau Group)
5. Simpson Rock (Mokohinau Group)
6. NW Reef (within Submarine Cable Zone)
7. Jellicoe Channel
8. McGregor Rock (off Bream Tail and Mangawhai)
9. Laings Cove (Bream Bay)
10. Waipu Cove (Bream Bay)
11. Bream Bay

Figure 13. School of kahawai, Groper Rock, 3 February 2021. *Videography screenshot: NNZST*

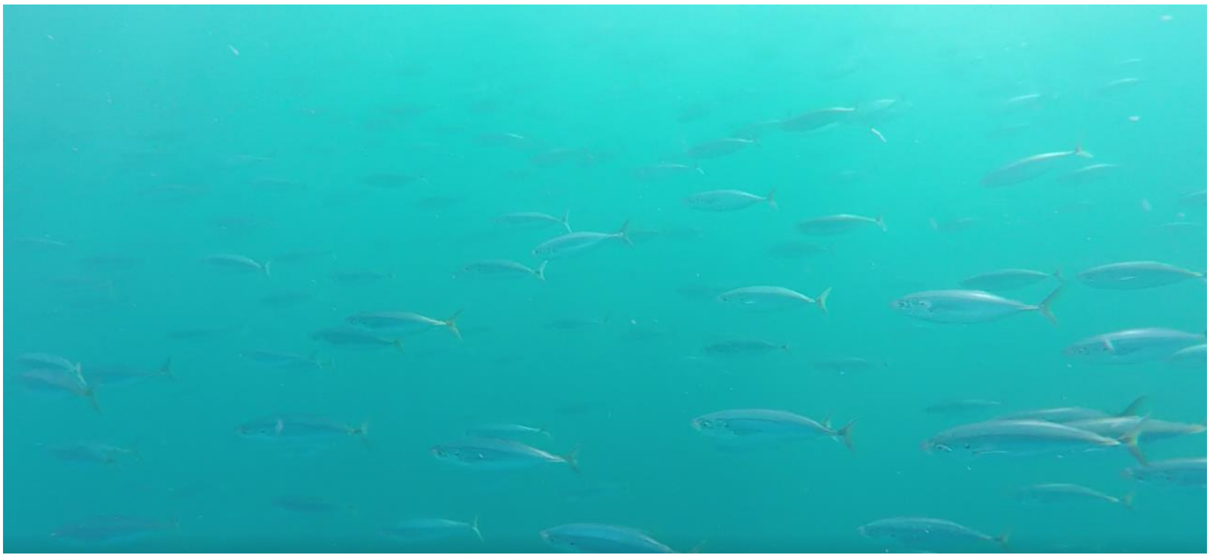

Figure 14. School of koheru, Groper Rock, 15 April 2021. *Videography screenshot: NNZST*

3.4 Seabird Observations

Seabird foraging activity observed this season generally followed the same pattern as previous with most activity relating to birds feeding in association with fish schools (and feeding on prey that the fish were feeding on – predominantly krill) (Fig. 19), and with cetaceans, common dolphins (Figs. 15 & 16). One noticeable difference this season was the lack of tuna schools encountered. Buller's shearwaters make the noticeable shift during the season from feeding in association with tightly packed shoals of trevally, kahawai, and mackerel to following the very mobile tuna schools. This is discussed further below – see Discussion.

Table 1 lists seabirds present at each sampling event.

Figures 15 (top) & 16 (lower). Gannets and flesh-footed shearwaters feeding in association with common dolphins, Jellicoe Channel, 6 October 2020. *Photos: Edin Whitehead*.

There was, however, activity which we had never observed previously, or in fact was not observed directly on the day. It was only when processing photographs that this was picked up, that of krill leaping clear of the water surrounding a foraging fluttering shearwater (Figs. 17 & 18). After a literature search, this appears to be a novel observation of krill avoidance behaviour.

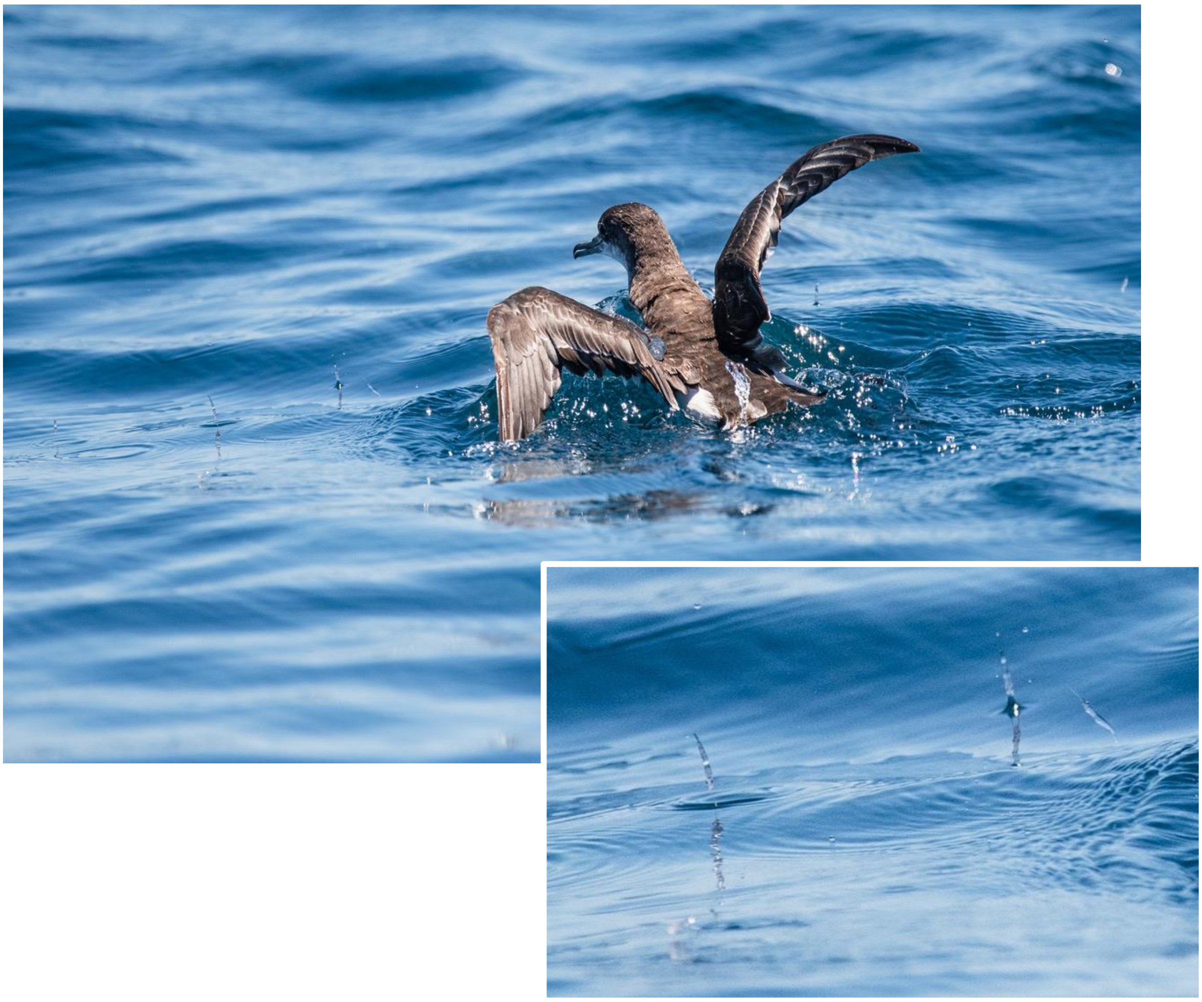

Figure 17 & 18. Fluttering shearwater preying on krill (top image), some of which are visible leaping clear of the water (lower – detail of top), 3 February 2021. *Photos: Edin Whitehead.*

Fish are more commonly observed leaping or flying clear of the water to evade predators, for example, schools of garfish, or, especially dramatic, flying fish when pursued by large fish like tuna, or by dolphins.

In previous seasons we had observed birds, in particular Buller’s shearwaters frenetically chasing prey at or just below the surface (Kozmian-Ledward et al 2020). A repeat of this activity was observed on 3 February 2021 near Bream Tail and while it was not immediately clear what was causing the Buller’s shearwaters’ frenetic activity (Fig. 20), photographs taken show small fish leaping clear of the surface and pursued by the birds (Fig. 21).

Surface schooling fish such as anchovies are taken by terns (Fig. 19), gannets, shearwaters, and gulls.

Figure 19. White-fronted tern with prey, anchovy (*Engraulis australis*), Bream Bay, *3 February 2021. Photo: Edin Whitehead.*

Figure 20. Frenetic activity of Buller's shearwaters, near Bream Tail, *3 February 2021. Photo: Edin Whitehead.*

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Figure 21. Buller's shearwater in pursuit of a small fish (unidentified sp.) leaping clear of the water, *3 February 2021. Photo: Edin Whitehead.*

Figures 22-23. Large numbers of red-billed gulls at Groper Island, Mokohinau Group 3 February 2021. Birds were both roosting en masse on the island and feeding in association with fish schools (mixed trevally and kahawai). *Photos: Chris Gaskin and Edin Whitehead.*

3.5 Marine Megafauna Observations

During the October trip we were treated to a spectacular close encounter with a humpback whale (*Megaptera novaeangliae*) which breached several times (Fig. 24) close to a fish school we had approached, near Sphinx Rocks, stacks adjacent to Burgess and Lizard Islands, Mokohinau Group.

Common and bottlenose dolphins were observed, with one notable occasion of hundreds of Australasian gannets feeding in association with a pod of the former (Figs. 15 & 16). A single manta ray (*Mobula birostris*) was seen close to Māori Rocks, Mokohinau Group during the 3 February 2021 trip. One notable feature extracted from underwater videography were bronze whaler sharks (*Carcharhinus brachyurus*) in amongst the schools of fish that we were targeting (Fig. 26).

Figure 24. Humpback whale breaching close to Sphinx Rocks and Burgess Island, Mokohinau Islands, 6 October 2020. *Photo: Edin Whitehead.*

Figure 25. Pod of bottlenose dolphins, Maori Rocks, Mokohinau Islands 6 October 2020. *Videography screenshot: NNZST*

Figure 26. Mature bronze whaler shark moving through a mixed school of trevally and kahawai, Navare Rock, Mokohinau Islands, 23 December 2020. *Videography screenshot: NNZST*

3.6 Use of the floating/drop camera rig

The first floating camera rig we devised was a set of six GoPro cameras mounted on a circular acrylic platform near base end of a 2.2m carbon fibre shaft. A float is fixed to the top end. This continues to be used with fish shoals to identify species.

This season, we designed, built, and deployed a second floating camera rig with a suspended camera platform that could be set at depths <35m and left floating, or the suspended camera platform dropped from the side of the boat to video through the water column, in some cases to the seafloor.

We tested the rig's effectiveness at several of the bathymetric features where we have consistently observed seabird foraging and fish shoal activity, i.e., the Mokohinau Islands (Māori Rocks and Navare Rock), Simpson Rock (Fig. 34) and NW Reef (Figs. 33 & 35).

These trials gave us snapshots of the fish not evident at the surface. In some cases, fish deeper in the water column were showing up on the boat's depth sounder.

The design of the second rig will be refined for future work, and likely two further camera rigs will be developed – i.e., refinement of the one we tested this year, and a third rig (to be built) that is essentially a weighted drop camera rig that can be lowered down through the water column to the seabed, then hauled back up again.

While more sophisticated rigs can be employed to monitor pelagic, midwater and benthic communities, as undertaken in some of the areas visited during these surveys (see Howarth & Smith 2020), these rigs have been developed to be deployed quickly during or between conducting surface zooplankton tows, other sampling, and seabird foraging observations. The aim is to provide as complete a picture of activity as possible within the sampling period at a particular location, including identification of fish species and sub-surface activity not readily recorded at the surface (Figs. 27-31).

Down the water column

Figure 27. Fairy prions and a Buller's shearwater feeding in association with shoaling trevally and kahawai, Groper Island, 3 February 2021. *Photo: Edin Whitehead*

Figure 28. Mixed school of trevally and kahawai, Coppermine Island, 3 February 2021. *Screenshot from videography: NNZST*

Figure 29. Kingfish *Seriola ladandi* encountered mid-column (c. 15m) at NW Reef, 3 February 2021. *Screenshots from videography: NNZST*

Figure 30. Blue maomao *Scorpis violaceus* and demoiselles *Chromis dispilus* near surface, Simpson Rock, 3 February 2021. *Screenshot from videography: NNZST*

Figure 31. Sweep *Scorpis lineolate* at 30m depth, NW Reef (top of reef visible at bottom of image), 3 February 2021. *Screenshot from videography: NNZST*

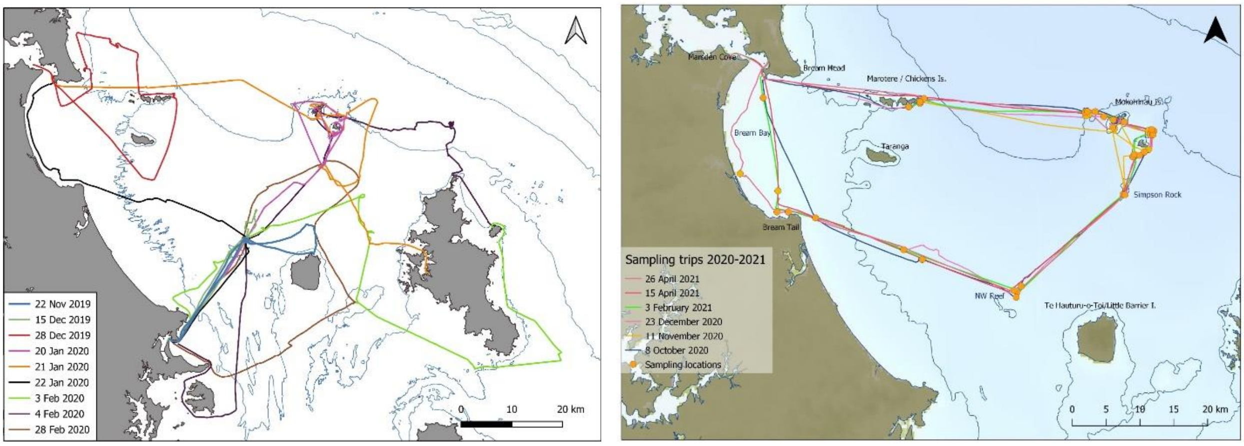
4 DISCUSSION

In general, seabird activity observed during this study followed a similar pattern to previous seasons, with Buller's and fluttering shearwaters, fairy prions, red-billed gulls, and to a lesser extent white-fronted terns, and sooty and flesh-footed shearwaters associating strongly with shoaling fish – principally mixed schools of trevally, kahawai, and mackerel spp. Fluttering shearwaters are the dominant species inshore, i.e., in Bream Bay and the Parry Channel (immediately offshore from Bream Head, Whangarei Heads), and from early February (post-breeding) following kahawai schools.

A major difference from earlier seasons is that we did not encounter tuna schools during our trips within the Hauraki Gulf, neither skipjack nor albacore tuna. Usually these enter the outer Gulf in the second half of January as offshore conditions change, SST rising through the summer, water clarity improving, and colour shifting from green/khaki or blue green to deep blue. In Gaskin (2017) it was first noted that Buller's shearwaters make the noticeable shift from feeding in association with tightly packed shoals trevally, kahawai, and mackerel to following the very mobile tuna schools, activity that coincides with the start of raising chicks, also referred to in Gaskin et al (2019) and Kozmian-Ledward et al (2020). It should be noted that on a separate research trip later in the month (19 February 2021) unrelated to this study, large numbers of Buller's shearwaters were seen active over a tuna school outside the study area at the Bay of Islands (author, pers. obs.).

4.1 The shift to a set route

As noted above, in previous seasons (2019-2020) we conducted general searches to locate seabird and fish shoal activity over sometimes very wide areas (Fig. 32). This season we made the change to a series of day trips following similar routes (Fig. 33). Sampling stations were largely determined by activity encountered along that route. This change provided a more structured approach to the sampling programme, i.e., within the constraints of budget, which determined the number of trips, distance travelled, and time spent at each station. In the event, the most consistent seabird foraging and fish shoal activity was close to islands and prominent reefs.



Figures 32 & 33. Vessel track-lines for each fieldwork day conducted in 2019-2020 and 2020-2021.

4.2 Significance of aggregations

The aim of this and earlier projects is to better understand the relationship between the diet of surface-foraging seabirds, and what prey items are being made available from fish shoal events (workups) so that we can understand the mechanisms that drive changes in the distribution and/or abundance of workups and how that might affect seabird populations.

Findings from this and previous DOC CSP contracts investigating seabirds associating with fish shoals and fish school dynamics (INT 2016-04 and POP2019-02) have highlighted the importance of the Gulf itself for seabirds breeding in the wider Hauraki Gulf region, species such as Buller's shearwaters, fairy prions and flesh-footed shearwaters on Northland offshore islands (e.g., the Poor Knights Islands) (Gaskin & Rayner 2013, Gaskin 2017). It also serves to highlight that, despite significant and obvious ecological values at the locations surveyed during this and previous studies, there is much to learn about the dynamics that trigger and sustain major aggregations of marine activity. The findings from those studies also serve to highlight that major aggregations of marine activity are not confined to areas around islands or over major reef systems – i.e., seabirds feeding in association with cetaceans and highly mobile tuna, mackerel and kahawai schools, and krill swarms. These can be highly ephemeral in nature across pelagic areas and the outer Hauraki Gulf, and driven by processes that remain largely unknown.

4.2.1 Shifting seabird populations

A significant feature of this season's observations with respect to occurrence of seabirds across the study site has been the changing distribution pattern of red-billed gulls.

During 2014-2016 Birds New Zealand, in conjunction with DOC, carried out a national survey to establish the current size of the red-billed gull breeding population (Frost & Taylor 2016). The authors' suggested, together with Birds New Zealand, DOC and others, there was the need to identify several representative colonies around the country, for future monitoring over many years using comparable and consistent methods. One of the key sites is the Mokohinau Islands, formerly one of New Zealand's largest breeding sites for this species at an estimated 13,000 birds on Burgess Island in 1945 (Fleming 1946, Buddle 1947, Gurr & Kinsky 1965).

Gaskin (2017) referred to concerns raised about the potential impact of the purse-seine fishery noting marine ecology including seabirds' foraging. Anecdotal historical accounts reported diminishing fish school size and frequency, particularly of the formerly 'vast' trevally schools from northern waters (R. Walter, W. Doak, R. Grace pers. comms.). The cause of the decline in red-billed gulls on the Mokohinau Islands had potentially been attributed to the diminishing fish schools and their reliance on feeding in association with these schools (Frost & Taylor 2018).

Since 2005 researchers visiting the islands have kept track on gulls nesting there, in fluctuating numbers and moving from site to site. From 2013 to 2018 numbers remained steady at around 250 pairs, although during winter months red-billed gull numbers would escalate to the low thousands with flocks of birds seen feeding over fish schools active around the islands. In 2018-2019 red-billed gulls were found to be breeding in greater numbers on Māori Rocks (now absent on Burgess Island itself), approximately 500 pairs. While the breeding population at the Mokohinau Islands appears to be remaining steady at the 2018-2019 estimate, the numbers of birds congregating around the Mokohinau Islands post-breeding appear to be increasing. The Marotere (Chickens) Islands is another hotspot for this species through this period.

Our records of red-billed gulls through this season reflect this. On the 3 February trip thousands of gulls were seen feeding at three sampling locations in the Mokohinau Group (Navare Rock, Māori Rocks and Groper Island), and off Lady Alice Island (Figs. 23-25). Red-billed gulls where again encountered in large numbers at the Mokohinau Islands and off the Marotere (Chickens) Islands during the 15 and 24 April trips.

4.2.2 Fragmentation

The question these observations raise is where these large numbers of red-billed gulls are coming from, given the relatively small breeding population at the Mokohinau Islands. Has there been a fragmentation of the original colony on Burgess Island, estimated at 5,000-10,000 birds by Fleming (1946) and 13,000 birds by Buddle (1947)? However, the only recorded colony of significant size in the region is at the Marsden Point Oil Refinery, one of Aotearoa New Zealand's largest colonies of red-billed gulls (1,190 pairs, 2014-2106) (Frost & Taylor 2018). While more accurate counts over multiple years of the both colonies (breeding birds) and non-breeding congregations across the region would shed light on this, the presence of high numbers at the Mokohinau Islands from late January through to September-October highlights the importance of the islands and surrounding waters for this species.

4.2.3 Colony displacement

As noted above, the Marsden Point Oil Refinery has a major colony of red-billed gulls within its confines. During breeding these gulls are regularly seen flying out beyond Bream Head to forage around the Bream Islands, and likely the Marotere/Chicken Islands) and possibly beyond (CG, pers. obs). Post-breeding, it is likely many red-billed gulls regularly congregating around both the Marotere (Chickens) and Mokohinau Islands are from the oil refinery colony. Although, it should be noted, that during autumn and winter months flocks of gulls are also regularly seen feeding in paddocks in the Ruakaka area inland from Marsden Point. A consequence of the proposed scaling back of the Marsden Point Oil Refinery to an import-only terminal (RNZ Checkpoint programme 16 June 2021) could be the disruption of this population.

4.3 Facing a decline – Sea Change and the Hauraki Gulf

Tai Timu Tai Pari – Sea Change – Hauraki Gulf Marine Spatial Plan was released in April 2017 after several years of consultations aiming to improve the health of the Hauraki Gulf Marine Park for future generations and included proposals for marine protection and fisheries management. Following the Government commitment in 2020 to continue working on the Sea Change project, **Revitalising the Gulf – Government Action on the Sea Change Plan** was released (DOC and FNZ, 2021a). To support the recovery of species and habitats, new marine protected areas have been proposed in what are considered some of the most biodiverse regions in the Gulf, with complementary sustainable fisheries management measures, including harvesting controls and restrictions on trawling.

In highlighting priority research on protected species in the Gulf the Strategy identifies that various research and monitoring that is required to improve understanding of protected marine species in the Gulf, their threats, and the effectiveness of our interventions. New research and monitoring initiatives must consider the ecosystem effects of changes in the distribution, behaviour, and abundance of protected species, as well as changes in the food webs of which they are a component, thus, enhancing understanding of the waiora of the Gulf ecosystem (DOC and FNZ 2021a).

Priority research for protected species identified in the Strategy includes:

- The influence of long-term trends in pelagic primary and secondary productivity on the behaviour, distribution and reproductive success of seabirds and cetaceans inhabiting the Gulf,
- The biology and ecology of bait fishes (particularly anchovy, pilchard, sprats and mullet),
- The terrestrial habitats of shorebirds and seabirds (for example, burrow-nesting seabirds, such as petrels, shearwaters, and little penguins) and improving our understanding of these habitats, including whether changes in vegetation at breeding sites are adversely affecting shorebird species,
- The effects of suspended sediments on foraging behaviour,
- The establishment of population trends of seabirds and shorebirds, and sustainable levels of harvest (DOC and FNZ 2021a).

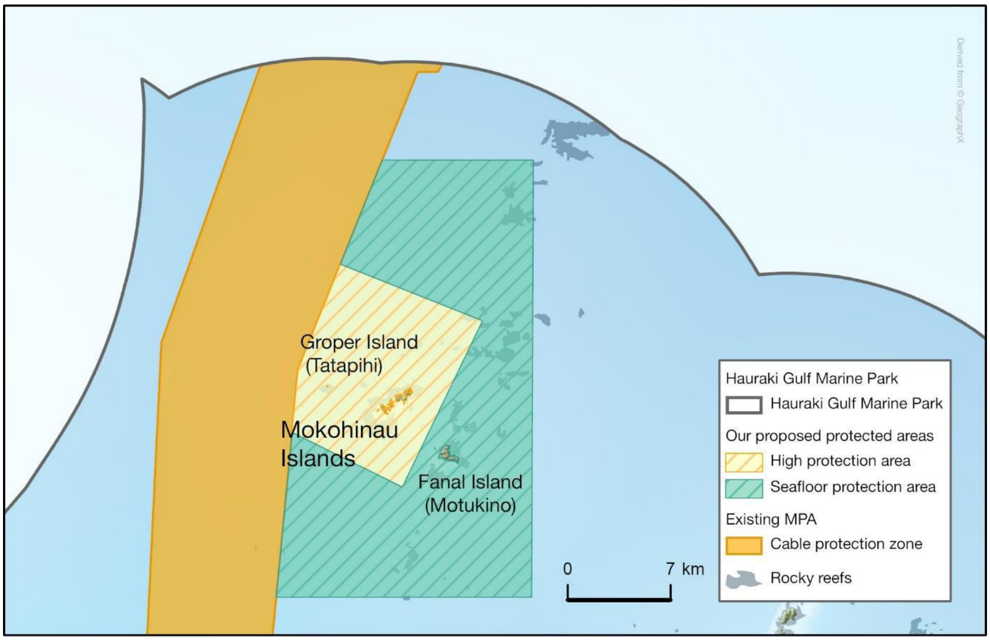


Figure 34. Preferred option for the Mokohinau Islands (DOC and MPI 2021b).

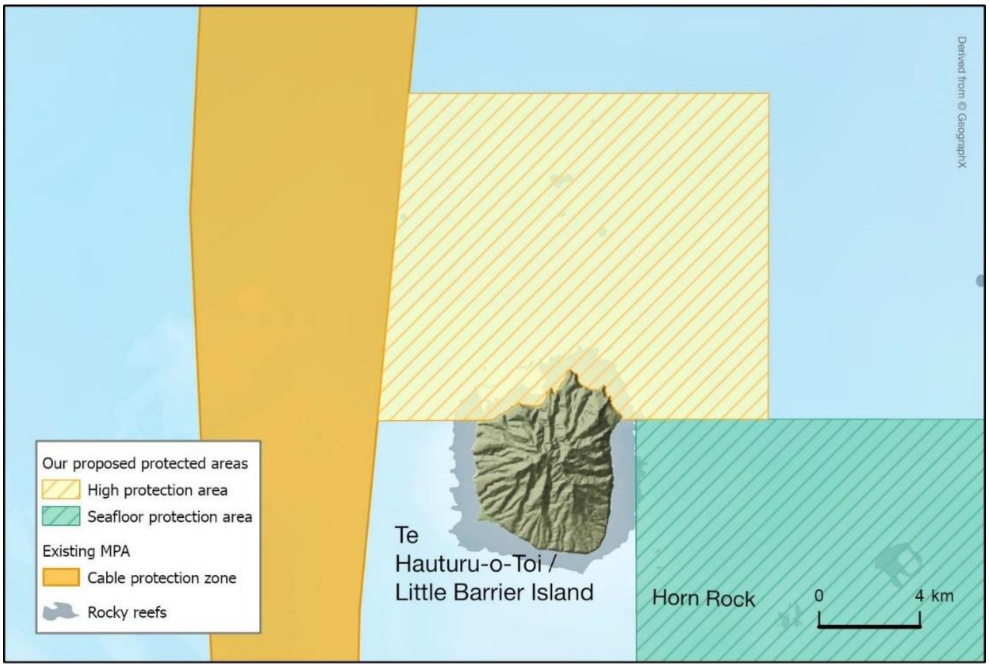


Figure 35. Preferred option for Te Hauturu-o-Toi/Little Barrier Island high protection area. Proposed Type 2 MPA at Cradock Channel (DOC and MPI 2021b).

Highly visible seabirds, their foraging, and the shoaling fish they associate with are a major feature of north-eastern North Island waters, including the Hauraki Gulf as our research over several seasons has shown (Gaskin 2017, Kozmian-Ledward et al 2020). They are also a regular feature of two of the proposed MPA in the Sea Change Strategy, the Mokohinau Islands and Te Hauturu-o-Toi (Little Barrier Island)/Cradock Channel (Figs. 34 & 35), designated primarily to protect reef and benthic biodiversity (DOC and MPI 2021b). Significant bathymetric features such as the Mokohinau Islands, including Māori, Navare and Simpson Rocks, NW Reef northwest of Hauturu, and Horn Rock in the Cradock Channel, generate conditions favourable for shoaling fish and at times vast aggregations of seabirds, as further evidenced by results at our sampling locations 2020-2021 (Fig. 33). The authors consider that full recognition of surface to benthic biodiversity (Figs. 27-31) should be used to further inform decision making around 'static' MPA such as for Mokohinau Islands and Te Hauturu-o-Toi (Little Barrier Island)/Cradock Channel.

However, as has also been shown above and in earlier reports, the seabird species that regularly associate with fish shoals are not, to a greater or lesser degree, dependent on that association. Some, also feed in more pelagic or open waters following cetaceans, both dolphins and whales, or highly mobile tuna and mackerel species. They can feed on krill swarms where no surface fish shoaling is evident and along current and tide lines. There are also species (e.g., petrels, storm petrels, diving petrels) which rarely feed in association with fish shoals.

For highly mobile seabirds with a range of feeding strategies and changes in distribution and occurrence, the authors also consider that the Sea Change Strategy with its comparting to fixed benthic habitats may do little to address ecosystem-wide pressures for seabirds, other than to recognise priority research areas as noted above.

Figure 35. Buller's and fluttering shearwaters, and fairy prions active over mackerel schools north of Hauturu (Little Barrier Island). *Photo: Edin Whitehead*

Our study area extends beyond the Hauraki Gulf Marine Park, the region covered by the Sea Change Strategy. Unlike the original Hauraki Gulf Maritime Park which extended from the Poor Knights Islands to the Te Ruamāhua (Aldermen Islands), the Marine Park established in 1992 does not include the East Northland offshore islands, coast, and catchments. While definitions of what geographically constitutes the 'Hauraki Gulf' vary, there is one certainty, seabirds know no geographical boundaries, whether they breed within the Marine Park or on islands adjacent.

For many of the seabirds of the Hauraki Gulf, including those breeding on Northland Islands (i.e., Poor Knights, Taranga (Hen) and Marotere (Chickens) Islands, the productivity of the outer Hauraki Gulf and east Northland waters helps sustain their populations. Currently, with our 'snapshot' approach to monitoring, while providing us with a wealth of observational information about seabird foraging and shoaling fish, and zooplankton sampling data, does not enable us to account for trends in productivity across this critical area.

4.4 Looking Ahead and recommendation for future research

An update of this report will be released in August 2021 and will include:

- Energy analysis for both POP2019-02 and this contract (BCBC2020-08)
- Investigation of the relationship between historical fish school formation and oceanography. The aer-sight (spotter plane) database will be used to characterise changes in schooling aggregations over time (i.e., size of schools, tonnage of sightings, number of schools) analyses.

Subject to funding under a separate contract, zooplankton samples collected will be identified, counted, and a complete analysis will be undertaken.

Long-term monitoring for the wider Hauraki Gulf region is essential to guide future management of this region's marine environment. To adequately assess the condition of the ecosystem, we must establish a set of long-term monitoring stations across the wider Hauraki Gulf with seabirds as our indicators for marine health, a maritime take on the 'canary in the coalmine' scenario[1], together with research conducted on the islands (examples – population surveys, health assessments etc) would inform future marine management. Such a proposal would draw on the findings from previous recent research, both at-sea and on islands, to create a structured programme and develop a viable and cost-effective tool for assessing long term changes with the Gulf's marine ecosystem. While such a network would be across the whole Hauraki Gulf, from Northland through to the east Coromandel islands, there is particular emphasis on the outer reaches of the Gulf to provide balance to the ongoing debate about marine protection and management issues.

5 ACKNOWLEDGMENTS

This project was funded by the Marine Species Team, Department of Conservation project BCBC. The authors would like to thank Dr Karen Middlemiss, Graeme Taylor and Ian Angus (Department of Conservation); Pete Mitchell for fish captures, Edin Whitehead for topside photography; and skipper Trevor Jackson for his manoeuvring skills, thoughtful assistance and maintaining one of

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[1] An allusion to caged canaries (birds) that miners would carry down into the mine tunnels with them. If dangerous gases such as carbon monoxide collected in the mine, the gases would kill the canary before killing the miners, thus providing a warning to exit the tunnels immediately.

the cleanest charter vessels around; and to Trevor's wife Leanne for the wonderful supply of freshly baked date loaf on every trip.

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Addendum: Nutritional Analysis of Seabird Prey Species from the Hauraki Gulf

This report has been prepared by **Dr Stefan Spreitzenbarth** with **Prof. Andrew Jeffs** (Institute of Marine Science, University of Auckland) and **Lily Kozmian-Ledward** (Sea Lily Ltd.) for the Department of Conservation (DOC), Conservation Services Programme (CSP) and managed by DOC marine science advisor Dr. Karen Middlemiss.

August 2021

SUMMARY

Surveys of fish shoals were undertaken for the contract (DOC CSP BCBC2020-08) conducted at locations within the general area of Marsden Point/Whangarei Heads > Marotere/Chickens Islands > Mokohinau Islands > Hauturu/Little Barrier > Bream Tail > Marsden Point during the period October 2020 - April 2021 qualified as spring (Oct-Nov), early summer (Dec), late summer (Jan-Feb) and autumn (Mar-Apr). Zooplankton nets and line fishing methods were deployed in fish shoals to identify the dominant composition of marine species contributing to the fish shoaling, and potentially providing prey species for seabirds that were frequently feeding in association with the fish shoals. In addition, a preliminary study was undertaken to determine the nutritional composition of samples of krill, small pelagic fish and squid by analysing their ash, protein, lipid and overall calorific (energy) content.

1 INTRODUCTION

Globally seabirds are a highly threatened group which mostly rely on mix of prey species, frequently foraged from large areas of the sea. Seabirds typically feed on abundant and highly nutritious prey species because of the high energy requirements of their lifestyle (Kooijman 2020). For example, seabirds frequently prey on krill because they form dense aggregations at the surface of the sea, and have a high lipid and protein content compared to many other zooplankton. Despite the importance of feeding to the success for seabirds the foraging ecology of most species of seabird remains poorly understood. This is of importance because changes in ocean ecosystems due to human impacts can detrimentally impact the prey availability and quality for seabirds, which in turn can place seabird populations under nutritional stress.

The Hauraki Gulf is an important feeding habitat for a variety of seabirds, a significant proportion of which are under some conservation threat. The marine ecosystem of the Hauraki Gulf has been considerably impacted by human activities, especially through extensive fishing activity (MacDiarmid et al. 2012, 2015, 2016). There is a priority for research to better understand the feeding ecology of seabirds in the Hauraki Gulf, to provide a stronger basis for managing potential trophic stress for seabirds.

To this end, over the past two years the Conservation Services Programme has funded some initial surveys of fish shoaling events that are often associated with active seabird feeding in the wider Hauraki Gulf. The surveys have identified the major marine species associated with fish shoaling and bird feeding events, and generated some initial indication of potential diet of some seabird species.

This report outlines the results of some preliminary laboratory analyses to determine the nutritional composition (ash, protein, lipid and energy content) of important prey species for seabirds in the Hauraki Gulf. Analyses were conducted on two types of samples: 1) krill from zooplankton tows conducted in the 2019-2020 and 2020-2021 survey seasons, and 2) samples of whole prey species recovered intact from Australasian gannet regurgitations collected in 2018-2019.

2 METHODS

2.1 Krill samples

Besides describing the overall nutritional composition of the content of krill from the surveys, a secondary aim was to attempt to assess whether there was variation in the nutritional content of krill collected in the vicinity of the Mokohinau Islands area over the two survey seasons to look at potential differences in energy and macronutrient content between months and years. Whilst extensive studies have been conducted on energy and chemical composition of krill in other parts of the world, such as the Southern Ocean, to our knowledge there are no reports of the nutritional composition of krill from the temperate waters of New Zealand.

Zooplankton sampling tows were conducted as described in Lukies et al. (2021) for the 2020-2021 season and in Kozmian-Ledward et al. (2020) for the 2019-2020 season. Unless the resulting zooplankton sample was very small (< 20 ml), a small representative portion of each sample (approx. 20 ml) was stored in a container without ethanol and kept frozen at -18 °C for subsequent energy and proximate analysis. Krill were subsequently sorted from a selection of the frozen samples from zooplankton tows taken around the Mokohinau Islands for nutritional analyses.

From each frozen zooplankton sample that contained sufficient krill for analyses, the sample was defrosted and individual krill were picked out using forceps to make a total of ~1 g wet weight. The number of krill were recorded and a digital photograph was taken to enable length measurements of krill to be taken using Image J. Approximately 40 krill from each sample were measured from the anterior of the eye to the end of the telson (Standard 1 method, Mauchline 1980). Each krill sample was then stored in a small labelled vial in a -80 °C freezer.

A smaller total number of krill samples (13) than hoped for were obtained from the Mokohinau Islands (Table 1). In the 2019-2020 season, fieldwork was only conducted at the Mokohinau Islands in January and February, with the February zooplankton samples being either too small to retain a portion for energy and proximate analysis or where the zooplankton samples were frozen, the samples did not contain enough krill for analyses. In the 2020-2021 season, no fieldwork was conducted in January or March, while zooplankton tow samples obtained from the Mokohinau Islands in April were too small to retain a portion for energy and proximate analysis.

Table 1. Details of krill samples.

Sample date	Sample ID	Sample location	Wet weight (g)	Number of krill	Average length (mm)
20 Jan 2020	K9	Navire Rock	0.912	119	12.863
20 Jan 2020	K10	Groper Island	1.985	106	10.417
20 Jan 2020	K11	Maori Rocks	1.058	60	13.275
20 Jan 2020	K12	Maori Rocks	0.715	400	5.763
21 Jan 2020	K13	Sth side Flax Islands	1.218	54	12.396
6 Oct 2020	K1	Groper Island	1.041	177	8.777
6 Oct 2020	K2	Sth side Flax Islands	0.702	81	9.477
6 Oct 2020	K3	Sth side Fanal Island	0.575	72	9.917
21 Nov 2020	K4	Sth side Flax Islands	1.374	106	10.273
23 Dec 2020	K5	Maori Rocks	1.045	49	13.452
23 Dec 2020	K6	Groper Island	1.219	60	13.835
3 Feb 2021	K7	Navire Rock	1.101	60	13.716
3 Feb 2021	K8	Maori Rocks	1.086	75	11.146

2.2 Gannet regurgitation samples

Regurgitations were collected from gannets at Mahuki Island in the outer Hauraki Gulf and Horuhoru Rock in the inner Hauraki Gulf during the 2019-2019 breeding season (Adams 2019). One whole specimen of each of four prey species that had recently been ingested and was still intact was selected for the energy and proximate analysis (Table 2). Total length of the prey items (fish - nose to fork; squid – top of head to end of outstretched tentacles) was measured with a ruler and wet weight was measured with a scale. A ~1 g sample of tissue was excised with a scalpel from the body of each sample.

Table 2. Details of gannet regurgitation samples.

Sample date	Species	Length (mm)	Wet weight (g)	Sample location	Sampled bird status
29 Jan 2018	Anchovy *Engraulis australis*	80	3.0	Horuhoru	Chick
27 Nov 2019	Pilchard *Sardinops sagax*	170	45.8	Mahuki	Adult
6 Dec 2019	Jack mackerel *Trachurus* spp.	175	51.6	Mahuki	Adult

7 Dec 2019	Arrow squid *Nototodarus gouldi*	105	10.0	Mahuki	Adult

2.3 Laboratory analyses

The ~1 g samples of all prey material were lyophilised (freeze dried) and then dry weight of the samples determined with scales to allow the calculation of the proportion of moisture in the sampled. The lyophilised samples were then ground to a fine powder for subsequent sub-sampling for further analyses.

Total lipid content of a measured single subsample of krill and three replicate subsamples of the larger prey items were measured gravimetrically using a modified Bligh & Dyer (1959) extraction. In short, methanol, chloroform and deionised water were added to the lyophilized powdered prey, vortexed and centrifuged for 10 min at 1000 g. The chloroform/lipid mixture was removed and transferred to a tared vial in a thermal block (36 °C), where nitrogen gas (BOC, 100%) was gently blown onto the lipid and solvent mixture to remove chloroform leaving the only residual lipid in the vial, which was then weighed.

Total protein content of a measured single subsample of krill and three replicate subsamples of the larger prey items were incubated in 0.1 M NaOH for 16 h at 50 °C. The incubated samples were then centrifuged at 10,000 rpm at 4 °C for 10 min. Protein was quantified by BCA (bicinchoninic acid) method (Smith et al. 1985) using a micro BCA protein assay kit (ThermoFisher Scientific, USA) and read against bovine serum albumin (BSA) standard at 562 nm.

The total ash content of a measured single subsample of krill and three replicate subsamples of the larger prey items were determined by burning off the organic content in a muffle furnace (Nabertherm LT15/11 B410, Germany) at 450 °C for 4 h. The remaining ash from the sample was then weighed to establish the quantity of inorganic material (ash) and this was used to calculate the proportion of ash free dry weight (AFDW) to total dry weight, i.e., organic content of the sample. One krill sample (K9) had insufficient sample material to determine ash content.

The energy content of a measured three replicate subsamples of krill and three replicate subsamples of the larger prey items were determined with a semi-micro calorimeter (Parr 6725, Parr Instrument Company, USA). The calorific value per gram of dry mass of each prey subsample was then calculated. Krill samples K1-3 and K12 could not be analysed because of insufficient sample material.

3 RESULTS

3.1 Krill size

The length of the krill sampled from the Hauraki Gulf ranged between 4.0 mm and 18.6 mm in krill samples K12 and K9, respectively. Krill sampled at five different sites (K9-13) around the Mokohinau Islands on two consecutive days (20 & 21 January 2020) had different mean lengths among the five sites (ANOVA, F=92.7, P<0.00001). Likewise, there were no differences in the mean lengths of krill for samples collected on six different dates from around the Mokohinau Islands, regardless of site of collection (ANOVA, F=38.2, P<0.00001). There were insufficient samples to make inferences about possible seasonal or interannual variation in the length of krill.

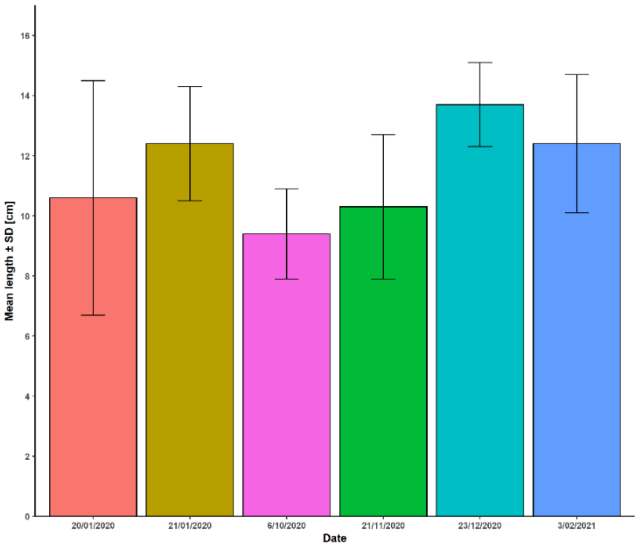

Figure 1. Mean length of krill sampled from around the Mokohinau Islands for six different dates.

3.2 Prey moisture content

The moisture content of the five prey species for seabirds from the Hauraki Gulf ranged between 63.0% and 96.0%, both in krill samples, K11 and K2, respectively. Krill sampled at four different sites (K9-12) around the Mokohinau Islands on the same day (20 January 2020) were highly variable in their moisture content, ranging from 63.0 to 93.9% moisture. The moisture content did not appear to vary with the differences in the size of krill observed among these four sites. There were no differences in the mean moisture content for samples collected on four different dates around the Mokohinau Islands (ANOVA, F=1.07, P=0.41). There were insufficient samples to make inferences about possible seasonal or interannual variation in the moisture content of krill. On average the moisture content of all the krill samples tended to be higher than the other four prey species.

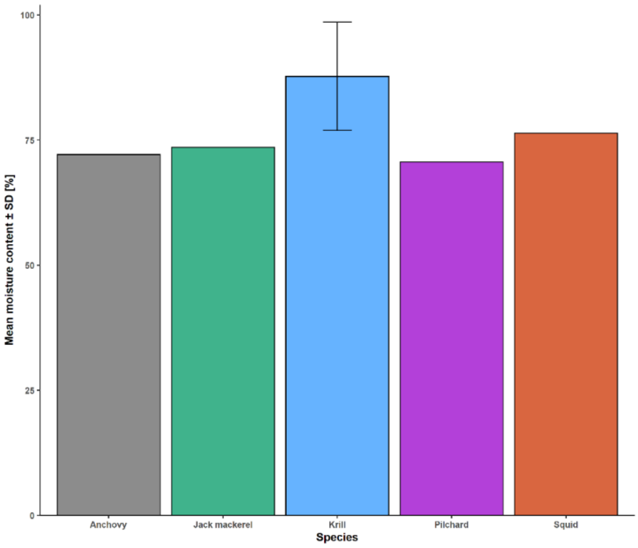

Figure 2. Mean moisture content of five prey species of seabirds from the Hauraki Gulf.

3.3 Prey lipid content

The lipid content of the five prey species for seabirds from the Hauraki Gulf ranged between 6.5% of dry weight in one jack mackerel subsample and 21.2% in one krill (K1) sample. The lipid content of the 13 krill samples ranged from 8.1% (K8) to 21.2% (K1). Krill sampled at four different sites (K9-12) around the Mokohinau Islands on the same day (20 January 2020) were highly variable in their lipid content, ranging from 9.9 to 20.1% of dry weight. The lipid content did not appear to vary with the differences in the size of krill observed among these four sites. There were also differences in the mean lipid content for samples collected on four different dates around the Mokohinau Islands (ANOVA, F=8.25, P<0.008). There were insufficient samples to make inferences about possible seasonal or interannual variation in lipid content of krill. On average the lipid content of all the krill samples tended to be higher than the other four prey species.

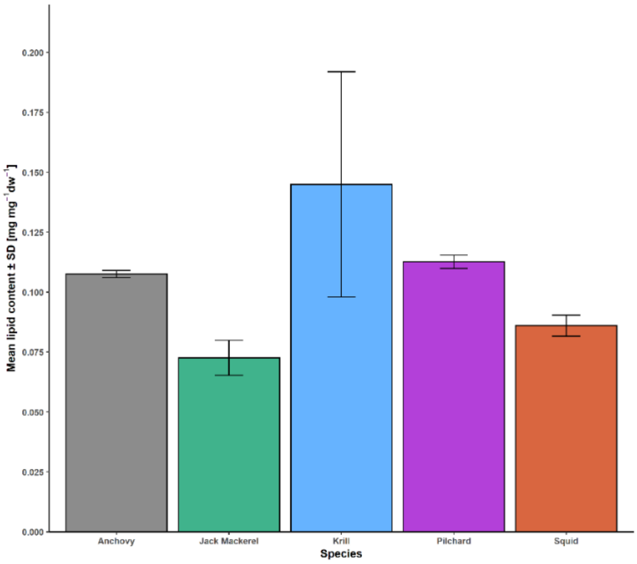

Figure 3. Mean lipid content of five prey species of seabirds from the Hauraki Gulf.

3.4 Prey protein content

The protein content of the five prey species for seabirds from the Hauraki Gulf ranged between 25% of dry weight in one krill sample (K10) and 85% in one jack mackerel subsample. The protein content of the 13 krill samples ranged from 25% (K10) to 80% (K4). Krill sampled at four different sites (K9-12) around the Mokohinau Islands on the same day (20 January 2020) were highly variable in their protein content, ranging from 25 to 52% of dry weight. The protein content tended to be lower in samples with the smaller sized krill observed among these four sites. There were also differences in the mean protein content for samples collected on four different dates around the Mokohinau Islands (ANOVA, F=5.76, P<0.03). There were insufficient samples to make inferences about possible seasonal or interannual variation in protein content of krill. On average the protein content of all the krill samples tended to be lower than the other four prey species.

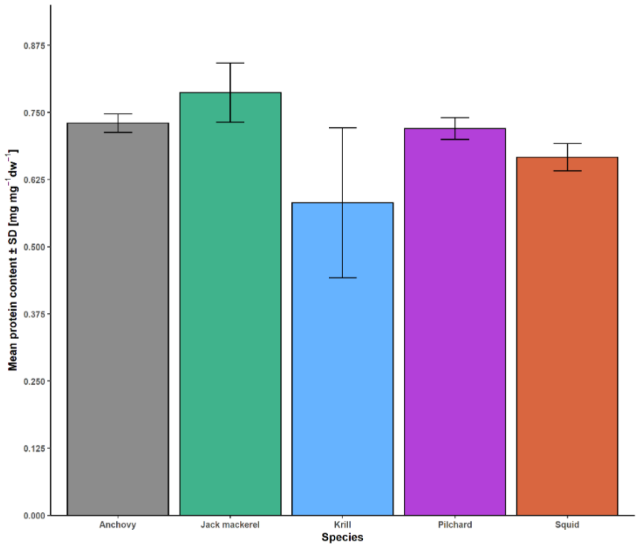

Figure 4. Mean protein content of five prey species of seabirds from the Hauraki Gulf.

3.5 Prey energy content

The energy content of the five prey species for seabirds from the Hauraki Gulf ranged between 1054.2 calories per g of dry weight in one krill sample (K10) and 3061.8 in one jack mackerel subsample. The energy content of the 8 krill samples ranged from 1054.2 calories per g of dry weight (K10) to 2252.1 (K4). Krill sampled at three different sites (K9-11) around the Mokohinau Islands on the same day (20 January 2020) were highly variable in their measures of energy content, ranging from 1054.2 calories per g of dry weight to 1886.4. The energy content tended to be lower in samples with the smaller sized krill observed among these three sites. There were insufficient samples to make reliable comparisons or inferences about possible spatial, seasonal or interannual variation in the energy content of krill. On average the energy content of all the krill samples tended to be considerably lower than the other four prey species.

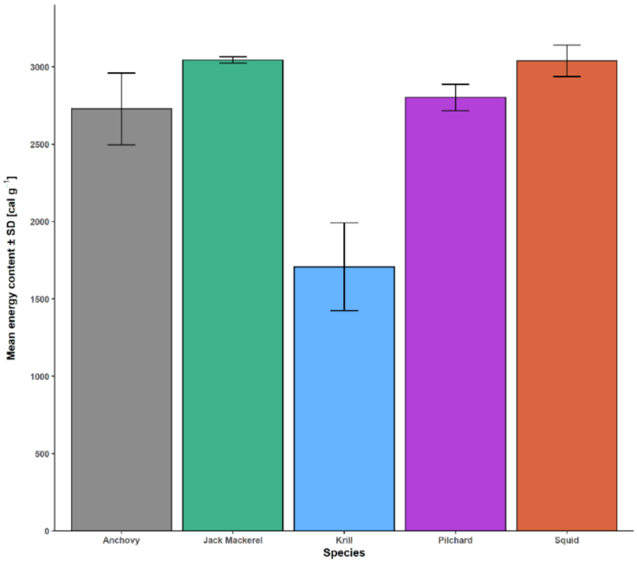

Figure 5. Mean energy content of five prey species of seabirds from the Hauraki Gulf.

3.6 Prey ash content

The ash (i.e., inorganic) content of the five prey species for seabirds from the Hauraki Gulf ranged between 0.7% of dry weight in one krill sample (K1) and 30.6% in another krill sample (K10). Krill sampled at three different sites (K10-12) around the Mokohinau Islands on the same day (20 January 2020) were highly variable in their ash content, ranging from 14.9% to 30.6% of dry weight. The ash content of krill did not appear to be related to differences in the overall size of krill sampled at different sites on the same day. There were also differences in the mean protein content for samples collected on four different dates around the Mokohinau Islands (ANOVA, F=15.5, P<0.004). There were insufficient samples to make inferences about possible seasonal or interannual variation in the ash content of krill. On average the ash content of all the krill samples tended to be mid-range of those measured for samples of the other four prey species.

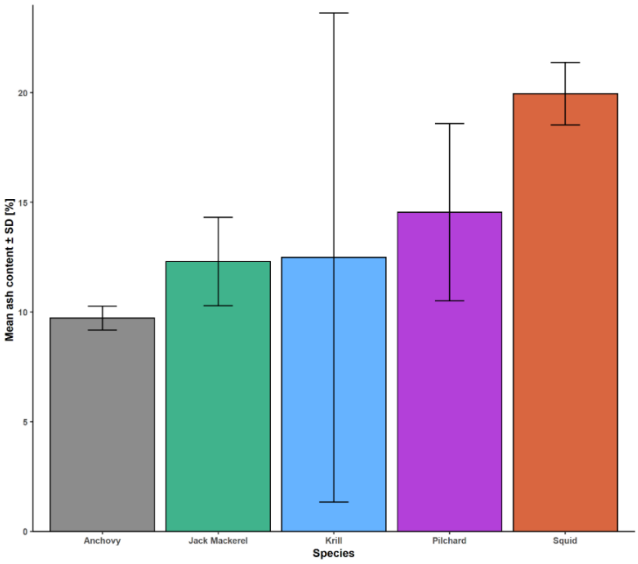

Figure 6. Mean ash content of five prey species of seabirds from the Hauraki Gulf.

4 DISCUSSION

The nutritional analyses of the five prey species from seabirds in the Hauraki Gulf all have moderate moisture content (63.0 - 96.0%), high lipid (6.5 – 21.2%) and protein content (25 - 85%), mostly low ash content (0.7 – 30.6%), and consequently relatively high energy content (1054 – 3062 calories g^{-1}). The relatively high nutritional value of these species, as well as their availability in the Hauraki Gulf, is likely to be the major reasons why these species are targeted as prey. In contrast, 54 samples of 30 species of macrozooplankton caught off the east coast of New Zealand had comparative ranges of 79.2 – 98.1% of moisture content, 0.1 – 27.9% for lipid, 1.9 – 54.2% for protein, and 3.9–76.4% for ash (Wang et al. 2013). A wider review of the nutritional composition of macrozooplankton species found that crustacean species protein on average was higher than in most other groups of zooplankton (i.e., 46.7 ± 6.0% mean ± SE) and so too was average lipid content higher than for other zooplankton groups (i.e., 23.8 ± 4.5%) (Wang and Jeffs 2014).

The fish and squid prey species of seabirds (6.5 - 11.5%) also had characteristically high lipid content. In comparison an analysis of 142 fish species from Australian waters found an average of 1% of wet weight as lipid (~3.5% of dry weight) in their tissues (Nichols et al. 1998; Brown et al. 1989). Only a relatively small number of pelagic fish species in these Australian studies had higher lipid content. Likewise, adult arrow squid in Australian study were found to have relatively low lipid content unlike in the present study, i.e., ~3.5% of dry weight (Nichols et al. 1998).

Fish flesh protein content is typically between 10 and 30% of wet weight, i.e., ~25 – 80% by dry weight (Lozano & Hardisson 2003). In comparison, the fish and squid prey species of seabirds (64 - 76%) had characteristically high protein content.

Krill are a group of small crustacean species belonging to the order Euphausiaceae, which are an important component of zooplankton communities, particularly in the pelagic ecosystem of the Southern Ocean. Krill are effective grazers on phytoplankton, often forming large aggregations, which make them important prey for many species, including commercially important fish, seabirds and whales, (Smith 1991; Byrd et al. 1997; Shuntov et al. 2000). Studies of the nutritional composition of different species of krill show they can differ among males, females and juveniles, and with their overall size (Färber-Lorda et al. 2009). Lipid content of krill also ranges widely from 12 to 50% of dry weight due to seasonality (Saether et al. 1986). There is a simulated seasonal cycle of lipid variation in adult krill, with low lipid concentrations in spring and a strong increase in lipid values until autumn (Falk-Petersen et al. 2000).

For all reported analyses of different species of krill the lipid content is highly variable ranging from 5.2 - 46.6% of dry weight, with a mean (±S.E.) of 22.2 ± 2.8% (Wang & Jeffs 2014), which was comparable to the results in the current study (8.1 - 21.2%). Krill also have consistently been found to have a high protein content, which is 36.1 – 62.4% of dry mass and mean (±S.E.) of 49.0 ± 2.1% (Wang & Jeffs 2014), which is also comparable to the current study (25 – 80%). The overall mean energy content of krill reported in previous studies is 5616 calories g^{-1} of dry mass (Wang & Jeffs 2014) which is higher than for the current study (1054.2 – 2252.1 calories g^{-1}).

In the current study, the size and nutritional quality of krill sampled from the zooplankton around the Mokohinau Islands varied markedly with sampling event and sampling location. Such high variability in the nutritional condition of krill would be likely to affect seabirds with a high reliance of foraging for krill. Unfortunately, there is very little information about krill ecology in the Hauraki Gulf from which to draw any other conclusions. Further research into krill biology in the

Hauraki Gulf is therefore warranted given a number of studies overseas have found that fishing pressure and natural variability in krill populations can have a significant effect on the performance of seabird populations with a high reliance on them as a food resource (Santora et al., 2017; Scopel & Diamond 2018; Krüger et al., 2021).

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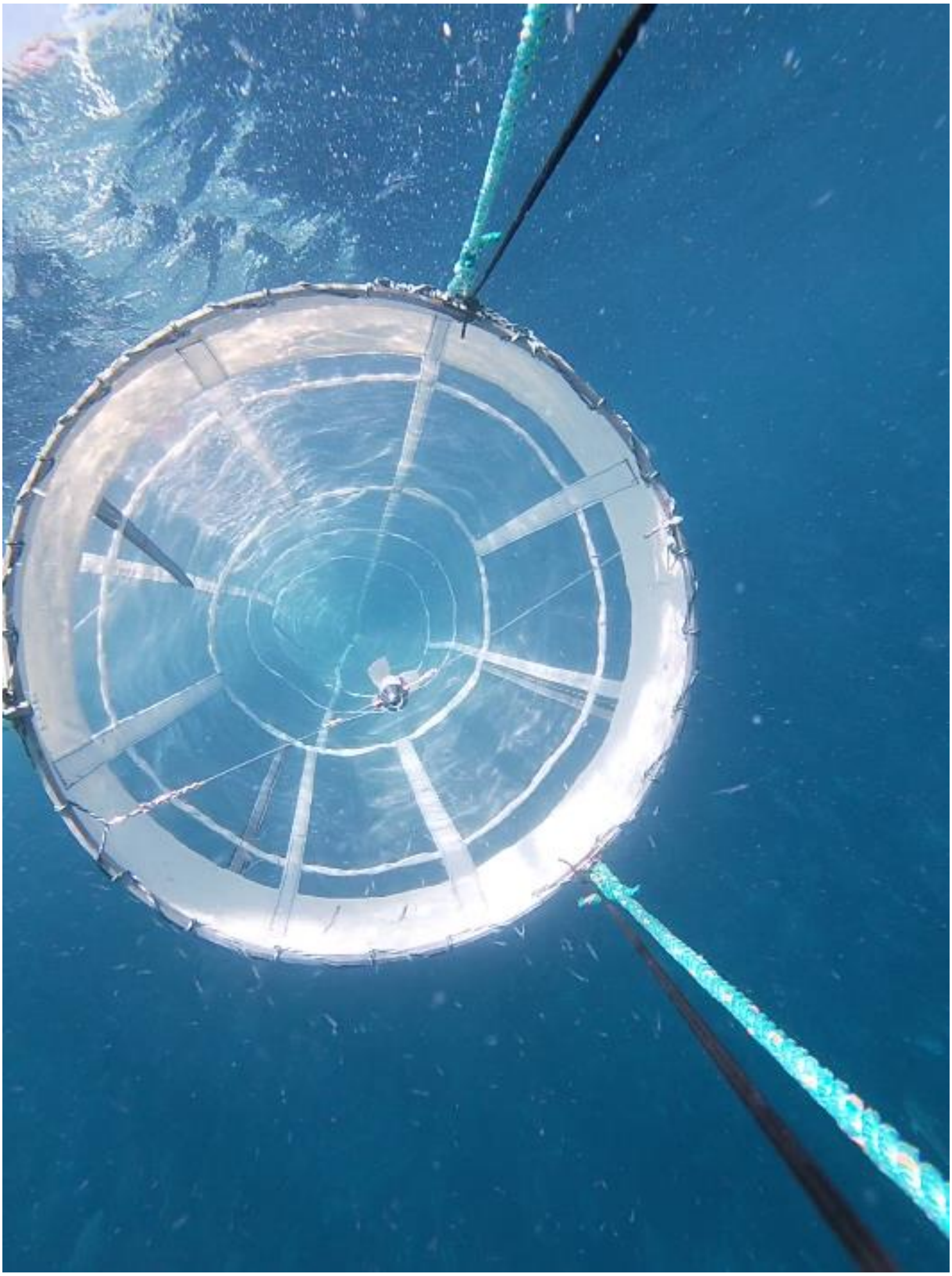

Plankton net during tow showing flowmeter, krill entering the net, and a fish school in the lower background. *Videography screenshot: NNZST*