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Pre-recruit (0+) snapper (*Chrysophrys auratus*) beam trawl and beach seine surveys of East Northland and the Hauraki Gulf (SNA 1)

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Morrison, M.A.; McKenzie, J.; Bian, R. (2019). Pre-recruit (0+) snapper (*Chrysophrys auratus*) beam trawl and beach seine surveys of East Northland and the Hauraki Gulf (SNA 1)

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Stock assessment and management of the SNA 1 stock would benefit from estimates of snapper year-class strength, before these fish recruit into the adult fished populations. The utility of using beam trawl and beach seine surveys to estimate year-class strength of 0+ juvenile snapper was investigated, to determine if acceptable coefficients of variation (CVs) could be produced. A single-phase stratified-random beam trawl survey of the Hauraki Gulf conducted from 21 March to 4 April 2019 with 102 stations returned a year-class estimate of 10.69 million 2019 year-class recruits, with an associated CV of 15.9%. A two-phase stratified random beam-trawl survey in East Northland, conducted from 5 April to 15 April 2019, also with 102 stations, returned a year-class estimate of 634 000 fish (CV 18.7%). These results demonstrate that beam trawl surveys have the potential to generate year class strength estimates for 0+ snapper.

Single phase stratified random beach seine surveys were also conducted (26 February to 6 March 2019) in four East Northland estuaries which support extensive areas of subtidal seagrass. Previous surveys have shown that these sub-tidal seagrass-dominated estuaries consistently hold large 0+ snapper populations. However, very few 0+ snapper were caught in 2019, which was reflected in the population estimates and associated CVs (Parengarenga Harbour, 4359 fish, CV 46%; Houhora Harbour 1449 fish, CV 88%; Rangaunu Harbour 16 459 fish, CV 45%; Whangarei Harbour 4604 fish, CV 79%). The combined estimate for all four harbours was 67 871 fish, with a CV of 58%. This is in stark contrast to a 2013 fish-habitat survey (quasi-random) of Parengarenga and Rangaunu harbours which returned population sizes of 1.081 million (CV 17%) and 1.886 million (CV 34%) respectively. In 2018, sampling of 8 beach seine tows per harbour (excluding Houhora) caught 5270 individuals from Parengarenga, 7847 individuals from Rangaunu, and 1218 individuals from Whangarei; contrasted with the present 2019 survey's catches of 26, 17, and 76 individuals respectively.

1. INTRODUCTION

The northern New Zealand *Kaharoa* trawl survey series was initiated in the early 1980s to monitor snapper (SNA, *Chrysophrys auratus*), with secondary target species of John dory (JDO, *Zeus faber*) and red gurnard (GUR, *Chelidonichthys kumu*). Later in the survey series, the target species shifted to focus on juvenile 1+ and 2+ snapper (Langley 1994, Morrison et al. 2001, 2002a, 2013). This shift in priority reflected the need to have advanced information on the high inter-annual variation in year class recruitment to the SNA 1 stock, which in turn affects the subsequent yield available to the commercial and recreational fishing sectors. The *Kaharoa* trawl surveys were able to quantify this variability 3 to 4 years prior to a year class fully recruiting into the fished component of the SNA 1 stock. These trawl surveys were initially conducted across the three separate SNA 1 sub-stocks: east Northland; Hauraki Gulf; and Bay of Plenty (as well as the west coast SNA 8 stock). Trawl surveys in the Hauraki Gulf and Bay of Plenty regions proved successful in monitoring year-class strength of 1 and 2+ pre-recruit snapper, and were conducted from 1982 through to 1999 on a regular basis. In contrast, the East Northland survey was found to be limited by the large areas of untrawlable foul ground (rocky reefs) occurring in the region, and was consequently discontinued after the completion of two initial surveys in 1992 and 1993.

In 2000, both the Hauraki Gulf and Bay of Plenty *Kaharoa* trawl time series were also discontinued, on the grounds that year-class strength information could be collected more cost-effectively through the sampling of commercial catches in commercial fish sheds. The age structure of the commercial catch, in conjunction with estimates of absolute abundance based on mark recapture programmes, made for reliable assessment of the three SNA 1 biological stocks. Inability to conduct mark-recapture studies since 1994, as a result of high cost and, more recently, food safety concerns, resulted in a decision to reinstate the trawl surveys to provide better information on predicted recruitment strength for stock biomass projections.

Twenty years have passed since the last north-eastern New Zealand *Kaharoa* trawl survey. With the next SNA 1 assessment scheduled for 2021, these new SNA 1 pre-recruit *Kaharoa* trawl surveys are timed to provide year-class strength information, to assist with predicting SNA 1 yield out to 2025.

As noted, previous East Northland *Kaharoa* trawl surveys were stopped due to the presence of large areas of untrawlable ground. An alternative method of estimating juvenile snapper recruitment is needed for this region. Past and recent work conducted as part of Ministry for Business, Innovation and Employment (MBIE) research programmes (Fish usage of estuaries and embayment's (CO1X0222); Coastal Conservation Management (CO1X0907); Juvenile fish-habitat bottlenecks (CO1X1618)) has successfully adapted the use of a small beam trawl (3 m beam), deployed from small coastal vessels, to quantify 0+ snapper distribution and abundance, and habitat-environment relationships. The most recent MBIE study in 2017 and 2018 mapped out the locations of 0+ snapper nurseries in East Northland and the Hauraki Gulf, providing the baseline data needed to develop a formal survey stratification of these two regions. This present project is a pilot to assess whether adequate abundance survey coefficients of variation (CV's) can be obtained using a beam trawl survey within the East Northland region.

Beam trawls offer additional advantages when compared with larger scale *Kaharoa* otter trawl surveys. They have a reduced environmental footprint, sweeping much smaller seafloor extents, and deploy light gear that does not require trawl doors or heavy ground-rope configurations, causing less damage to three-dimensional seafloor habitats (e.g. biogenic habitats). The nets also catch fewer fish, and at smaller sizes, during a life history stage when natural mortality on these fish is thought to be high. These characteristics suggest a potential benefit in ultimately replacing the Hauraki Gulf and Bay of Plenty *Kaharoa* pre-recruit surveys in the long-term with beam trawl surveys. Removing juvenile snapper (1+ and 2+ fish) as target species for those *Kaharoa* surveys would also allow them to be re-optimised for other species, such as adult snapper, red gurnard, John dory and tarakihi. For these reasons, the current project is also a pilot to assess whether adequate abundance survey coefficients of variation (CV's) can be obtained using a beam trawl survey within the Hauraki Gulf region.

The *Kaharoa* will undertake a trawl survey of the Hauraki Gulf in November, which will also sample the 2019-year class. This will allow for a comparison to be made between the two surveys (beam and *Kaharoa* otter trawl) about the strength of the 2019 juvenile snapper year class.

This beam trawl survey research is intended to be the first in an ongoing monitoring programme series. At least four East Northland and Hauraki Gulf beam trawl recruitment surveys will be needed to establish an empirical relationship to adult recruitment success. Likewise, additional *Kaharoa* surveys will greatly improve precision on the stock assessment 5-year projection yield estimates.

In addition to snapper nurseries in the deeper areas of larger estuaries, sheltered bays, and coastal seas (covered by the beam trawl surveys), key 0+ snapper nurseries are also associated with extensive shallow-water sub-tidal seagrass meadows (Morrison et al. 2009, 2014a–c). These occur today in Parengarenga, Rangaunu and Whangarei harbours, and to a lesser degree Houhora Harbour, and are likely to hold a considerable proportion of the overall juvenile population for the East Northland sub-stock. Densities can be several magnitudes higher than those seen in beam trawl catches.

Juvenile 0+ snapper respond positively to subtidal seagrass habitat, with orders of magnitude higher densities than for adjacent non-seagrass/bare sediment, or intertidal only seagrass habitats (e.g. see Rangaunu and Kaipara Harbours, Morrison et al. 2014a–c). Generally, these subtidal seagrass habitats exist as narrow fringes on the edge of channels, often adjacent to intertidal seagrass meadows that may extend for considerable distances up the intertidal flats. At the ‘best’ subtidal seagrass areas (mainly in Rangaunu Harbour), subtidal seagrass may extend down to about two metres below Mean Low Water (MLW), in association with steeper (and narrow) channel slopes. Broader subtidal seagrass expanses/meadow extents also occur in some situations, e.g. in some areas of Rangaunu and Whangarei harbours. Intertidal seagrass habitats are of negligible direct value to 0+ juvenile snapper, with few/no snapper being recovered from sampling in areas where these intertidal beds occur without a subtidal fringe element (Morrison et al. 2014c).

To capture the contributions of these very shallow estuarine habitats, which are not accessible by beam trawling, four beach seine surveys were also undertaken in this project, complementing the deeper water beam trawl surveys. The four survey areas were the East Northland harbours of Parengarenga, Houhora, Rangaunu, and Whangarei.

The overall research objective for the INT201803 project is:

1. To determine the relative abundance of 0, 1, and 2+ pre-recruit snapper in the east Northland, Hauraki Gulf and Bay of Plenty sub-stock regions of SNA 1 using a combination of standard trawl and small beam trawl surveys.

The specific INT201803 project objectives around beam trawl and beach seine surveying are:

Objective 2:
To design a R.V. *Ikatere* small-mesh beam-trawl survey targeting high abundance areas of 0+ snapper in East Northland and Hauraki Gulf coastal and estuarine areas less than 30 m for the purpose of estimating relative annual abundance (year class strength).

Objective 4:
To determine the relative abundance and distribution of 0+ snapper in the Hauraki Gulf and east Northland summer-autumn (February-April) period during the 2018–19 fishing year, by carrying out R.V. *Ikatere* small-mesh beam-trawl surveys over the depth range 3 to 30 m.

Objective 8:
To collect data to underpin the development of assessment and monitoring capabilities for biodiversity and ecosystems.

2. METHODS

2.1 Background on the two beam trawl survey regions, and their stratification

Previous and ongoing MBIE-funded juvenile fish-habitat research has focused on Hauraki Gulf and East Northland 0+ juvenile snapper ecology. This has included large-scale fish-habitat surveys to determine where the nurseries occur, and the habitats and environmental conditions they are associated with. These data were used to stratify the two regions. The survey extent was restricted to soft sediment seafloors, less than 30 m deep as work in the ongoing MBIE Bottlenecks programme has shown that rocky reefs are largely not used by small snapper (under 100 mm) as nursery habitats, and where small snapper do occur, they are found in low densities only on the edges of some reefs.

Large estuaries with a major subtidal area were included as sampling strata (Waitemata, Mahurangi, Whangarei, Whangaruru, and Whangaroa harbours). Stratum delineations were placed to separate out areas of higher and lower catches (based on Bottlenecks programme 2017 data for the Gulf, and 2018 data for East Northland) to maximise catch homogeneity within any given stratum. Within strata, all islands and/or large rock stacks greater than 2000 m^2 were digitized and their spatial area removed from the strata within which they fell.

For the Hauraki Gulf proper, the survey area extended from Tawharanui Point on the north-west side of the Gulf, through Kawau, Whangaparoa, East Coast Bays, Tamaki Strait, the Firth of Thames, and up the western Coromandel, to Colville (Figure 1, Table 1). The inner boundary was the low-tide datum, as could be determined from charts, while the outer boundary was the 30 m depth contour. This included the Noises Islands, the northern coast of Waiheke Island, and the string of small islands along the west Coromandel Peninsula. Greater Omaha Bay was excluded due to low past catch rates, along with the eastern side of Kawau Island due to its exposed nature. The small inlets of Bon Accord Harbour and North Cove at Kawau Island were also excluded, to avoid adverse public reactions as experienced in the 2017 survey (despite informing the harbourmaster and other authorities) and 0+ snapper densities were low. Larger exclusion areas included the power cableway zone from Mullet Point to Kawau Island, the Spark cableway from Takapuna Beach to out past Tiritiri Matangi Island, the main Auckland port area (in Waitemata Harbour), the large mussel aquaculture farming area off West Coromandel, and two marine reserves (Long Bay and Te Matuku).

On the East Coromandel Coast (still part of the Hauraki Gulf Marine Park, but falling in the Bay of Plenty region), snapper nurseries were restricted to more sheltered bays. Here, discrete separate strata were established for inner Mercury Bay, Kennedy Bay and the immediately adjacent coast, and Port Charles. At Great Barrier Island, nursery strata were established for Port Fitzroy, and for three embayments south of this (Whangaparapara, Okupu, and Tryphena harbours; treated as one combined stratum). As this was the first formal survey of Hauraki Gulf snapper nurseries to estimate year-class strength, all areas likely to contribute juvenile snapper were included where possible. Small largely intertidal estuaries were the exception; these are not cost-effective to survey, hold very limited suitable habitat, and have negligible relative recruitment contributions at the Gulf scale (e.g. Francis et al. 2005, 2011).

The East Northland survey was structured differently than the Hauraki Gulf one, with snapper nurseries restricted to harbours and sheltered embayments (Bay of Islands), separated by expanses of exposed coastline that held very few or no fish (Figure 2, Table 2,). The large Taiāpure in the northern Bay of Islands was excluded from sampling, as were the extensive muddy mangrove-lined channels of Waikere Inlet (also a Mātaitai) (the latter unlikely to hold many 0+ snapper).

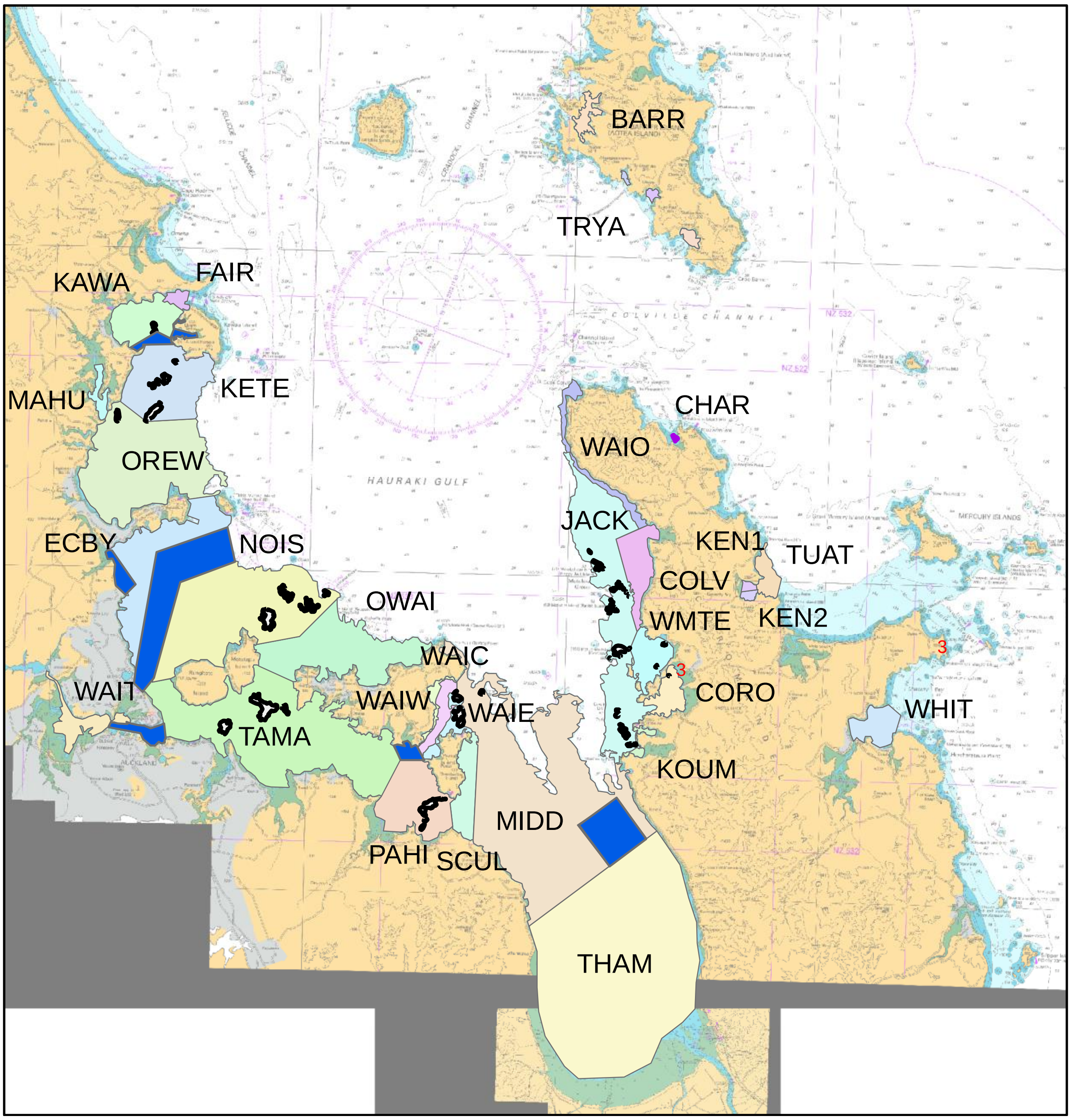


Figure 1: Stratification of the greater Hauraki Gulf. Dark blue polygons are excluded areas (cableways, marine reserves, heavy boat traffic zones, large aquaculture areas). Black polygons within strata denote islands excluded from the strata area. Sourced from LINZ charts NZ523, NZ533.

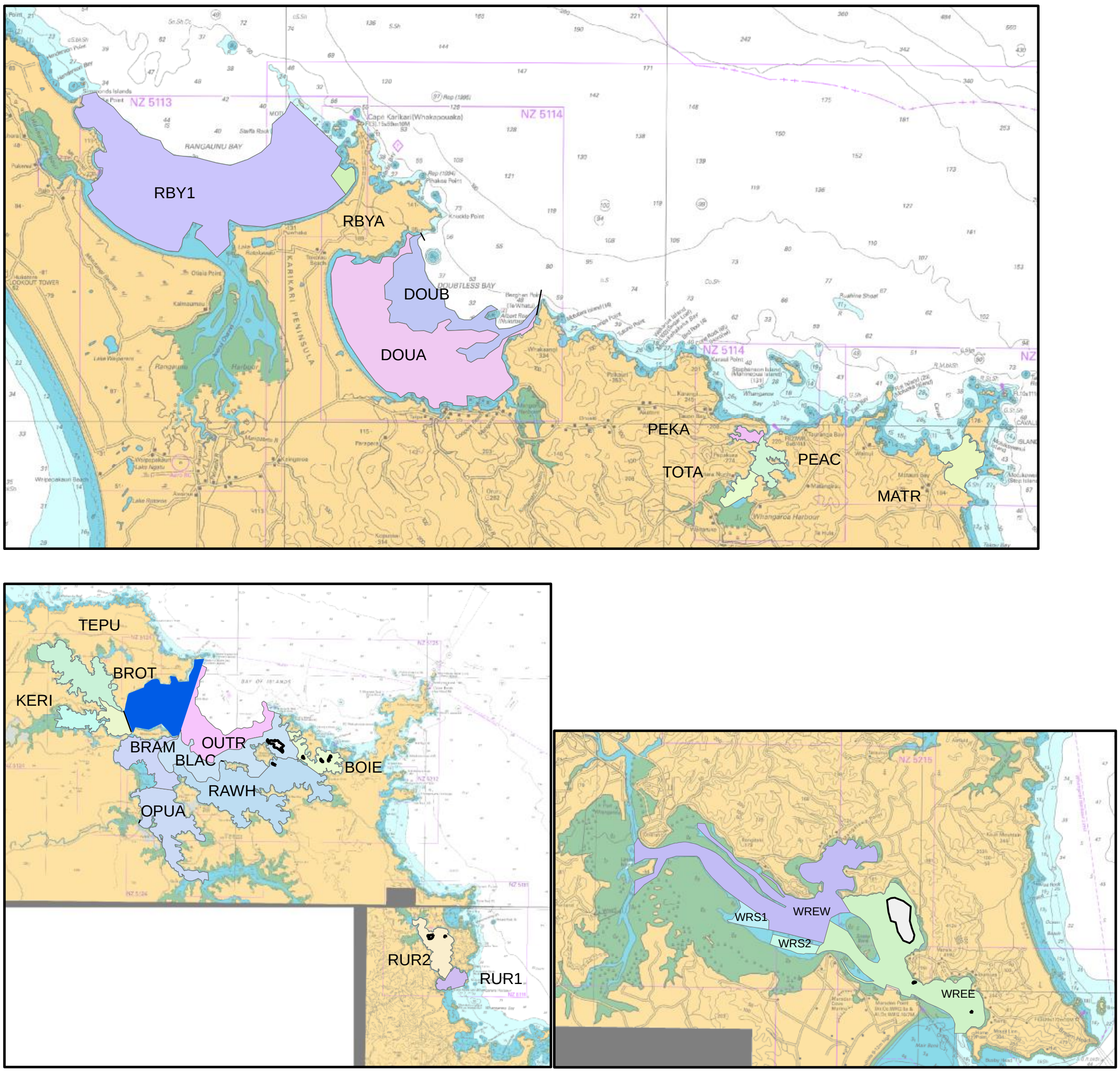


Figure 2: East Northland beam trawl stratification. The dark blue polygon is the excluded area of the Bay of Islands Taiāpure. Black polygons within strata denote islands or large intertidal sand banks excluded from the strata area. Scale varies between images. Sourced from LINZ charts NZ512, NZ521

Table 1: Sampling strata descriptions, and station allocations across the Hauraki Gulf. Prop, areal contribution to overall survey region.

Code	**Identity description**	**Area km^2**	**Prop.**	**Phase I station allocations**
FAIR	Western side of North Channel, between Tawharanui Peninsula and Kawau Island	5.22	0.003	3
KAWA	Kawau Bay, excluding cableway, and North Cove and Bon Accord Inlet, Kawau Island	32.16	0.018	3
KETE	Mullet Point to Big Bay Point, includes Beehive, Motuketekete, Moturekareka, and Moturoa Islands. Out to 30 m depth contour.	68.15	0.038	3
MAHU	Mahurangi Harbour	6.54	0.004	5
OREW	Mahurangi Harbour entrance to Whangaparoa Peninsula, includes Saddle Island. Out to 30 m depth contour	144.33	0.080	5

Code	Identity description	Area km^2	Prop.	Phase I station allocations
ECBY	East Coast Bays, from Tiri Passage down to Takapuna Beach, eastern boundary is the Spark cableway line. Excludes Long Bay Marine Reserve	69.69	0.038	3
NOIS	North end of Rangitoto Channel/east Spark cableway boundary line, across to a line from northeastern Motutapu Island to east of the Noises Islands (included). Out to 30 m depth contour	155.83	0.086	3
WHBR	Waitemata Harbour; subtidal area west of the Auckland Harbour Bridge, and the outer area of Shoal Bay. High boat traffic area of Auckland Port and City excluded	18.51	0.010	3
TAMA	Rangitoto Channel, through Tamaki Strait, to a line from Duder Point across to the south-west corner of Te Makutu Marine Reserve. Includes Motuihe and Sargeant's channels, ending at a line extending from Home Bay Point (Motutapu Island) to south Mātaitai Bay (Waiheke Island)	206.85	0.114	3
OWAI	The north side of Waiheke Island; abuts the NOIS and TAMA strata to the east, and extends out to the 30m depth contour, from the Noises Islands to Tom Thumb Point	90.87	0.050	3
WAIW	The western side of Ponui Channel, flanking east Waiheke Island, from Waiti Bay to the northeast boundary of Te Matuku Marine Reserve. Abuts WAIC at the 10 m depth contour	4.50	0.002	3
WAIC	Ponui Channel proper, extending from the eastern boundary of the Te Matuku Marine Reserve, to north of Pakatoa Island. Flanked by the 10 m depth contour to the west (WAIW) and east (WAIE)	11.72	0.006	3
WAIE	The eastern side of Ponui Channel, including Pakatoa and Rotorua Islands, out to the 10 m depth contour on their eastern sides	9.64	0.005	3
PAKI	The eastern end of Tamaki Strait, enclosing the area between Duder Point (Clevedon) to Te Matuku Marine Reserve, along the southwestern coast of Ponui / Chamberlains Island, and across to Kawakawa Point. Includes Pakihi Island	56.82	0.031	3
SCUL	From the north-eastern tip of Ponui / Chamberlains Island, down its eastern side, and across to Kawakawa Point. The eastern boundary is a line, extending from just south of Ruthe Passage, down to halfway along the coastline between Kawakawa Point and Orere Point	24.48	0.014	3
MIDD	The large area in the middle to outer Firth of Thames, with its southern boundary being a line across the Firth, lying flush with the eastern side of the large mussel aquaculture area. Extends north to the 30 m depth contour, abuts SCUL and WAIE on its west side, and extending to Deadman's Point on the east side	268.85	0.148	3
THAM	The mid to upper Firth of Thames, excluding the very shallow and muddy entrance to the Waihou River	392.25	0.216	10
KOUM	Kouma and Te Manaia Inlets, out to the 10 m depth contour	3.45	0.002	3
CORO	Coromandel Harbour, out to the 20 m depth contour	15.32	0.008	3
JACK	A long stratum, extending from the south from offshore of Te Kouma Inlet, to the north end of greater Colville Bay. The 30 m depth contour is its western boundary; while its eastern side flanks the COLV, WAIO, WMTE, CORO and KOUM strata	129.99	0.072	3
WMTE	The large embayment just north of Coromandel Harbour, bounded by Motuoruhi, Waimate, and Motutapere islands on the west, and a line from Motumorirau Island to Amadeo Bay Point on the north	21.45	0.012	3
COLV	A shallow coastline stratum running from Amadeo Bay Point in the south, to the northern entrance to Colville Bay. Its western boundary is a line starting off Amadeo Bay, and running north-west-west to a point offshore of the southern side of Colville Harbour entrance, and then arcoss to the north side of Colville Bay	14.90	0.008	3

Code	Identity description	Area km²	Prop.	Phase I station allocations
WAIO	A narrow coastline stratum running from Colville Bay, north to Port Jackson Bay. Its western boundary is the 10 m depth contour out to the northern point of greater Colville Bay, and then the 30 m contour up to and including Port Jackson Bay	14.45	0.008	3
CHAR	Port Charles on the upper east Coromandel coast. A small polygon flanked by reef on the east, a mussel farm to the north, and non-nursery bare seafloor to the west. Included as a 'midway area' point between the Hauraki Gulf and Bay of Plenty snapper stock	0.27	0.000	3
KEN1	The northern side of Kennedy Bay	1.86	0.001	3
KEN2	The southern side of Kennedy Bay	1.87	0.001	3
TUAT	The coastal area flanking Kennedy Bay, extending from Tokoroa Rock, south to Anarake Point. Out to 30 m depth contour	10.60	0.006	3
WHIT	Buffalo Bay and inner Mercury Bay. Out to a line extending from Wharekaho Point, across to Motukorure Island, and then along the western boundary of the Hahei Marine Reserve	18.92	0.010	3
BARR	Port Fitzroy, bounded by the northern and western entrances	7.59	0.004	3
TRYA	A combination of three embayments along the south-western coast of Great Barrier Island; Whangaparapara Bay, Blind Bay, and Tryphena Harbour	5.41	0.003	3
		1 812.49		101

Table 2: Sampling strata descriptions, and station allocations across East Northland.

Code	Identity description	Area km²	Prop.	Phase I station allocations
RBY1	Rangaunu Bay, from Grenville Point to the Moturoa Islands. Bounded by the 30 m depth contour	145.29	0.322	3
RBYA	Rangaunu Bay area of macroalgae (reds, *Caulerpa*, rhodoliths) on coarser shell sediment	2.69	0.006	4
DOUA	Doubtless Bay, out to 20 m contour	87.21	0.193	3
DOUB	Doubtless Bay, 20 to 30 m depth zone	32.79	0.073	3
PEKA	Whangaroa Harbour – Pekapeka Bay	2.16	0.005	3
PEAC	Whangaroa Harbour – inside entrance, up to a line running north-west-west arcoss the harbour from the headland just north of Whangaroa village	5.65	0.013	3
TOTA	Whangaroa Harbour – upper harbour zone, abuts PEAC	3.98	0.009	3
MATR	Cavalli Passage, to the 10 m depth contour west and east	8.91	0.020	3
TEPU	Bay of Islands – Te Puna Inlet	15.23	0.034	4
KERI	Bay of Islands – Kerikeri Inlet	4.74	0.011	3
BROT	Bay of Islands – the area where Te Puna and Kerikeri Inlets merge	4.21	0.009	3
OUTR	Bay of Islands – deeper central/south area of the bay, 30–40 m zone	16.74	0.037	3
BLAC	Bay of Islands – 20 to 30 m depth zone, running from Black Rocks across to Te Nunuhe (Whale Rock). Includes Motuarohia, Moturoa, and Motukiekie islands	10.55	0.023	4
BRAM	Bay of Islands – area east and north of Brampton Bank, out to 20 m depth contour	11.06	0.025	3
OPUA	Bay of Islands – Opua Inlet, from Brampton Bank, up to the start of Waikere Inlet	18.10	0.040	7
RAWH	Bay of Islands – Te Rawhiti Strait, from Tapeka Point to Poroporo Island, and Omakiwi Cove. Includes coastal embayments on its southern side	33.23	0.074	9

Code	Identity description	Area km^2	Prop.	Phase I station allocations
BOIE	Bay of Islands – eastern inside entrance, and south and western side of Urapukapuka Island	5.63	0.012	3
RUR2	Whangaruru Harbour proper, to a line extending from Oakura across to Black Rocks	7.56	0.017	3
RUR1	Whangaruru Harbour outer entrance, out to Motutara Island, and south to Bland Rocks	2.81	0.006	6
WREW	Whangarei Harbour – western channel area, from north-western Snake Bank to Limestone Island, Includes Parua Bay	18.06	0.040	3
WREE	Whangarei Harbour – eastern channel area, from north-western Snake Bank out to the harbour entrance (Urquharts Bay)	11.65	0.026	3
WRS1	Whangarei Harbour – area of subtidal seagrass > 1.5 m water depth at low tide, on western Takahiwai Reach	1.39	0.003	3
WRS2	Whangarei Harbour – area of subtidal seagrass >1.5 m water depth at low tide, on eastern Takahiwai Reach	1.12	0.002	3
		450.76		88

2.2 Beam trawl station allocation

Both beam trawl surveys were designed as two-phase stratified surveys (according to Francis 1994). From the total number of stations available, 80% were assigned to Phase I, and 20% to Phase II.

For the Hauraki Gulf, all strata held previous quasi-random stations from the 2017 MBIE Bottlenecks beam trawl survey, except for Mahurangi Harbour. Each stratum was initially assigned 3 stations, and then additional stations assigned iteratively using the ALLOCATE function, where stations were sequentially assigned to the stratum that returned the greatest reduction in the estimated CV (Francis 2006). The Mahurangi Harbour strata was arbitrarily assigned 5 stations, based on past knowledge of its snapper nursery function (Morrison & Carbines 2006, Usmar 2009) (Table 1)

For East Northland, less past survey data was available. All strata were allocated an initial three stations. For those strata with data, the ALLOCATE function was used to assign the available remaining stations. For those strata not previously surveyed, their station assignment was left at three; aside from the outer deep stratum in the Bay of Islands (OUTR, 40–50 metres), which was assigned four stations (Table 2).

2.3 Beam trawl sampling approach

A beam trawl was used to sample small snapper and other fish species. This net consisted of a 3-m long hollow steel bar (the beam) from which was slung the net proper, effectively a sock with headline and ground-line ropes (see Appendix 1 for the net plan). The net mesh was a thick 9 mm stretched mesh (identical to that of the beach seine). Tows were conducted during the hours of daylight (usually between 0730 and 1800 NZST). If the station fell over foul or other untrawlable ground (e.g. marine farms), suitable ground within 500 m of the station in the same stratum was searched for. If a suitable replacement was not found, then the station was abandoned and the next station on the list selected as a replacement. A standard tow length of 200 m was used, as measured by GPS (for the first two days of the Hauraki Gulf survey, 400 m tows were used). For each beam trawl, the randomly allocated station coordinates were used as the midway point of the tow, and a tow deployed through it, with tow direction determined by wind and tide conditions on the day. Warp to depth ratio was 5:1 at stations in less than 10 m water depth; and 4:1 at stations 10 m water depth or greater. The net spread was assumed constant and to effectively fish a 2.5 m width, as set by the 3-m bar and the bridle ropes attaching the net to the bar ends. Two GoPro cameras were attached to the beam itself, one facing forward and down to image the seafloor, and one facing back to the net to visualise gear performance (height, spread, bottom contact). For some areas of more turbid waters (e.g. Firth of Thames, and strata in upper harbour zones), visibility was too poor for the cameras to see anything.

Before deploying the beam trawl, the GoPro cameras were turned on, and the station details recorded by holding a white board with the details in front of each camera. The net and bar were then deployed from the vessel, with the tow warp being let out to the required warp to depth ratio. Given the slow speed of the vessel's winch (both in and out), fishing was considered to have started once the net touched the seafloor, when the 'feel' of the winch changed, as well as the vessel. A GPS position was taken at this time. This was a change from past surveys, where the net was dropped to the seafloor with loose warp being spooled out, and then the vessel steamed forward slowly until the warp came up hard on the net (when fishing was taken to commence, and a GPS position taken). The winch drum speed was also much slower than in past surveys. Given this, the net will have 'fished' longer both on its way down to the seafloor, and back up, than in past surveys. This will not have affected the demersal fish catch rates (with 0+ snapper as the target species) but is likely to have inflated the catch of anchovies. This species is problematic regardless, due to its unknown vertical availability, and because many individual fish are thought to pass through the 9 mm braid mesh so catches of this species are not used quantitatively.

Once on the seafloor and fishing, the net was hauled at a constant speed over the ground at between 1.3 and 2 knots, depending on current and wind conditions. Speeds faster than this were avoided to prevent the net losing contact with the seafloor and 'flying' in the water column. At the 200-metre mark, hauling commenced and the position recorded as the end of the tow (average station tow length as recorded by the start and end GPS positions was 210.5 m). On retrieval, the tow was given a gear performance score, indicating whether it was suitable for inclusion in subsequent analyses. On occasions where it was apparent that the net had flipped upside down during its deployment or had encountered debris such as large branches/small logs, the net was cleared, and the tow repeated 50 m or more to one side of the initial tow.

The GoPro cameras with battery packs, and memory cards, were swapped out through the day as needed. The video files were transferred over to an external hard drive and given appropriate file names. Videos were visually checked at regular intervals to ensure that the net was functioning well.

If the net was loaded up with mud on retrieval, it was towed at the surface behind the vessel to wash out mud, until the sediment plume trail disappeared. The net was then lifted on board, and the catch removed and spread out on a sorting table (perforated aluminium base with 2 mm holes for drainage). A deck hose was used as necessary to further wash and clean the catch to allow it to be visually sorted by hand. All finfish were removed, the snapper catch weighed (down to the nearest 0.001 gram) and fish individually measured for length down to the nearest millimetre. Juvenile 0+ snapper were retained, with larger individuals released alive back into the sea. The weighing of snapper catches was undertaken to conform with data collection protocols for standard trawl surveys but all analyses in this report use fish numbers only as biomass is not relevant in the current context.

All non-target finfish species were either counted, measured and released alive if larger individuals (e.g. flatfish) and/or easily handled (spotty); or bagged, frozen, and later fully processed back on land. Greasy-backed (green-tail) prawn (*Metapenaeus bennettae*), a Non-Indigenous Species, were also counted, and measured when caught, and frozen for potential use in other research projects. A summary of all fish catch by method and survey area is provided in Appendix 2. The catches of these species are not commented on further in this report, as they fall outside the objectives of the project.

Larger non-fish by-catch was sorted into Operational Taxonomic Units (OTU's) as either habitat-formers (e.g. horse mussels, sponges, macro-algae, large tubeworms) or other species (e.g. cushion stars, sand dollars, scallops), and their volume estimated by eye, with the aid of marked plastic bins, to the nearest 50 ml, as well as being weighed to the nearest 0.001 gram. Each catch was photographed, initially in 'raw' unsorted form, and once sorted into OTU's, using the labelled GoPro camera whiteboard as a station identifier. Smaller species such as whelks, hermit crabs and shrimps (except for greasy-backed prawns) were not enumerated. These data have been recorded in the TRAWL database but are not reported on further in this report, as their analysis, along with the GoPro video recorded, falls outside the objectives.

Data were initially recorded on pre-printed customised waterproof data-forms, with the snapper catch being punched into a suitable spreadsheet to allow for Phase II calculations. Back in the office, all data were punched, along with the additional non-target fish species data, generated from lab processing of samples.

At each station, water clarity was measured from the surface using a Secchi disk.

2.4 Background on the beach seine survey harbours, and their stratification

Four East Northland harbours (Parengarenga, Houhora, Rangaunu, and Whangarei) are known to still contain significant subtidal seagrass habitat extents and associated 0+ snapper densities. These were selected for survey using beach seines. Stratifying these harbours required a different approach than that taken for beam trawling.

Beach seine sampling is undertaken 2.5 hours either side of low tide, when most subtidal seagrass is shallow enough to be accessed on foot, and where small fish are forced to leave the intertidal flats and are concentrated along the subtidal edge (Morrison et al. 2002b). Juvenile 0+ snapper are thought to remain in subtidal seagrass habitat across the tide cycle, but these habitats are only accessible to beach seining over low tide periods. Juvenile 0+ snapper occupy a ‘narrow ribbon’ of subtidal seagrass habitat extending along the channel edge. The outer boundary (seagrass/bare sediment) of this habitat is clear on good aerial and satellite imagery, but the inner (shoreward) boundary is usually not, as most subtidal seagrass grades continuously into intertidal seagrass, which can them extend hundreds, sometimes thousands, of metres up the shore.

Aerial/satellite imagery does not provide water depth information, and is seldom, if ever, taken exactly at low tide. High resolution bathymetric data/maps do not exist for these harbours, and even the coarse channels marked outside of main navigation areas can be significantly in error. Even if an arbitrary maximum low water boundary could be mapped out, in reality the subtidal/intertidal boundary is fluid and continuously changing with the tidal cycle and moon state, with additional influences from barometric pressure (up to 15 cm water level change), coastal swells, freshwater inputs, and wind speed and direction, which can lower water levels on one side of the estuary and raise it on the other. Combined, these made defining the inner boundaries (low tide line) required for two-dimensional strata problematic. An alternative to the usual two-dimensional fixed-area stratification approach was needed.

To solve this, we adopted a one-dimensional stratification approach, where the low tide shoreline (as best as could be approximated) was broken into habitat segments (e.g. subtidal seagrass / not subtidal seagrass), and then treated as a string, along which sampling stations were randomly allocated. Any given habitat stratum might consist of multiple ‘string’ segments, interspersed with the segments from other strata. The sampling unit was defined as the catch from a beach seine tow starting 5 m to seaward of the subtidal seagrass boundary and towed straight into the low-tide line. Each tow was assumed to have a 9 m wide net width sweep and treated as having sampled a 9 m segment of the overall stratum (string) length. Tow length was by default ‘collapsed’ into the one-dimensional strata, with the assumption that tow lengths varied randomly from station to station, if stations were randomly selected from the ‘pool’ of all possible tow lengths possible [for all stations sampled, actual tow lengths were still recorded as important data, using a hand-held GPS, but were not included in the data analysis]. Similar to the two-dimensional area-swept approach, the sampled station net-widths (9 metres per station) were scaled up by the total length of the stratum (‘string’ length) to derive an overall abundance estimate for each stratum. Other than the scalar unit used, the station allocation and variance calculation methods for the one and two-dimensional sampling designs were identical (Section 2.8).

To create these one-dimensional ‘string’ habitat strata, available aerial imagery for each harbour was uploaded from the LINZ web-site, for imagery taken over low-tide periods. As the imagery was sometimes quite variable in its quality (issues of water clarity, sun-strike, poor substrate contrasts), we worked across several different time periods as necessary to firstly digitise the channel boundaries as continuous lines. Google Maps/Earth satellite imagery, as publicly available on the web, was also used for additional guidance. These initial low-tide channel delimitations extended from the inside of harbour entrances, to the upper harbour extent, ending where the water became very shallow at low tide (less than about 20 cm), and/or graded into turbid mangrove channel systems; both of which are known to hold few or no 0+ snapper based on past extensive sampling of estuarine fish assemblages (e.g. Morrison et al. 2002b, Francis et al. 2005, 2011; Lowe 2012, Morrisey et al. 2010).

Using the available imagery, it was possible to identify regions of sub-tidal seagrass presence/absence along the low-tide channel lines (‘strings’). We segmented these continuous low-tide channel lines into two habitat strata (subtidal seagrass / not subtidal seagrass) (Figures 3–6). For Parengarenga Harbour, these were further divided into northern and southern harbour components (Table 3, Figure 3). It is important to note that any given stratum was the sum of multiple spatially separated segments, either interspersed by segments of alternative habitat strata, or by intersecting channel breaks (as well as each channel having two sides) (Figure 3–6).

In Rangaunu and Whangarei harbours there were several areas of expansive subtidal seagrass extent/meadows, too wide to suit this one-dimensional approach. These larger subtidal seagrass areas had to be treated as standard two-dimensional strata, with snapper abundance estimated using the standard area-swept two-dimensional method. In Rangaunu Harbour, the subtidal area existed as a lagoon like feature, surrounded by intertidal sand banks, with several water flow entrances (RLAG stratum, Figure 5). It was treated as a discrete two-dimensional feature. For Whangarei Harbour, an area of extensive subtidal seagrass patches existed, adjacent to very extensive intertidal seagrass habitat. For the deeper elements (too deep for beach seining), two beam trawl strata were allocated (see beam trawl section). The remaining extent was split into two beach seine strata, one running along a shallow subtidal bank, and one adjacent to it, and assigned an arbitrary inner stratum boundary based on available imagery (WDPA and WDPB, Figure 6).

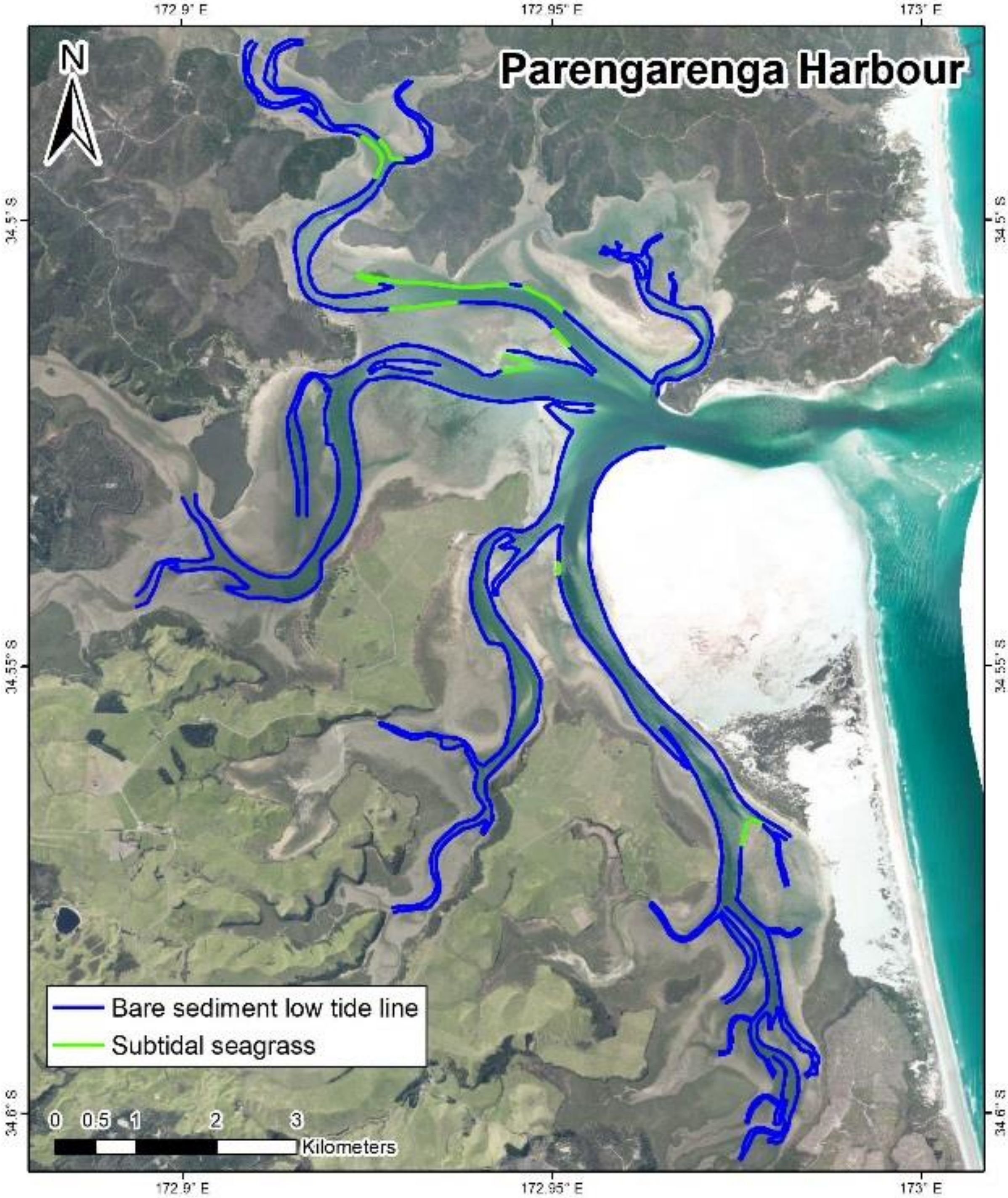


Figure 3: The one-dimensional (blue and green lines) beach seine survey strata for Parengarenga Harbour. Note that the backdrop is recent satellite imagery from Google Earth, provided for illustrative purposes only. It is not the LINZ aerial photographic imagery used to generate the strata; nor necessarily taken at low tide. Image from Google Earth; Image ©2019 CNES /Airbus © Google. Data SIO, NOAA, US Navy, NGA GEBCO. Image © Terrametrics.

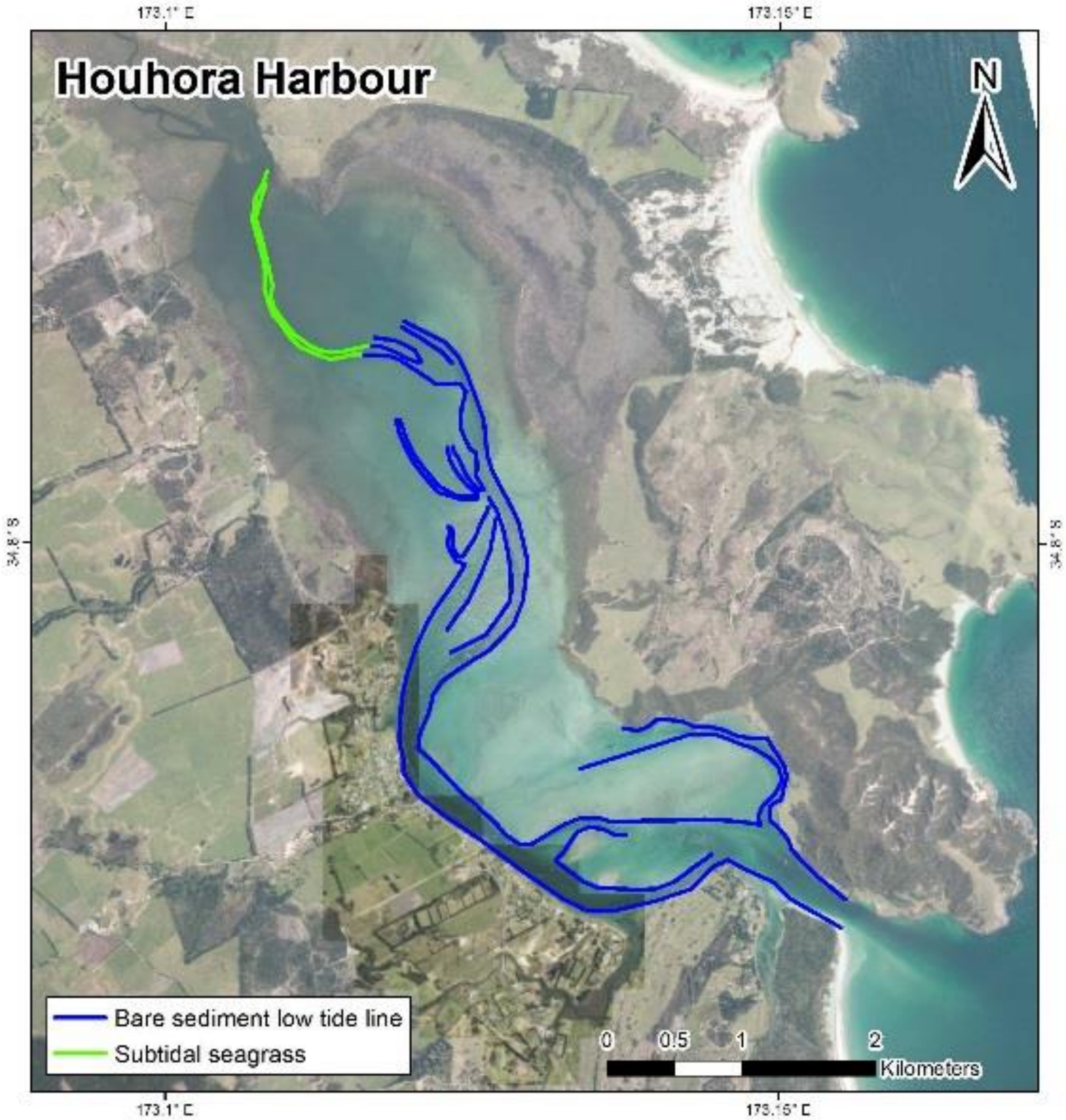


Figure 4: The one-dimensional (blue and green lines) for Houhora Harbour. Note that the backdrop is recent satellite imagery from Google Earth, provided for illustrative purposes only. It is not the LINZ aerial photographic imagery used to generate the strata; nor necessarily taken at low tide. Image scale varies between the four harbours. Image from Google Earth; Image ©2019 CNES /Airbus © Google. Data SIO, NOAA, US Navy, NGA GEBCO. Image © Maxar Technologies.

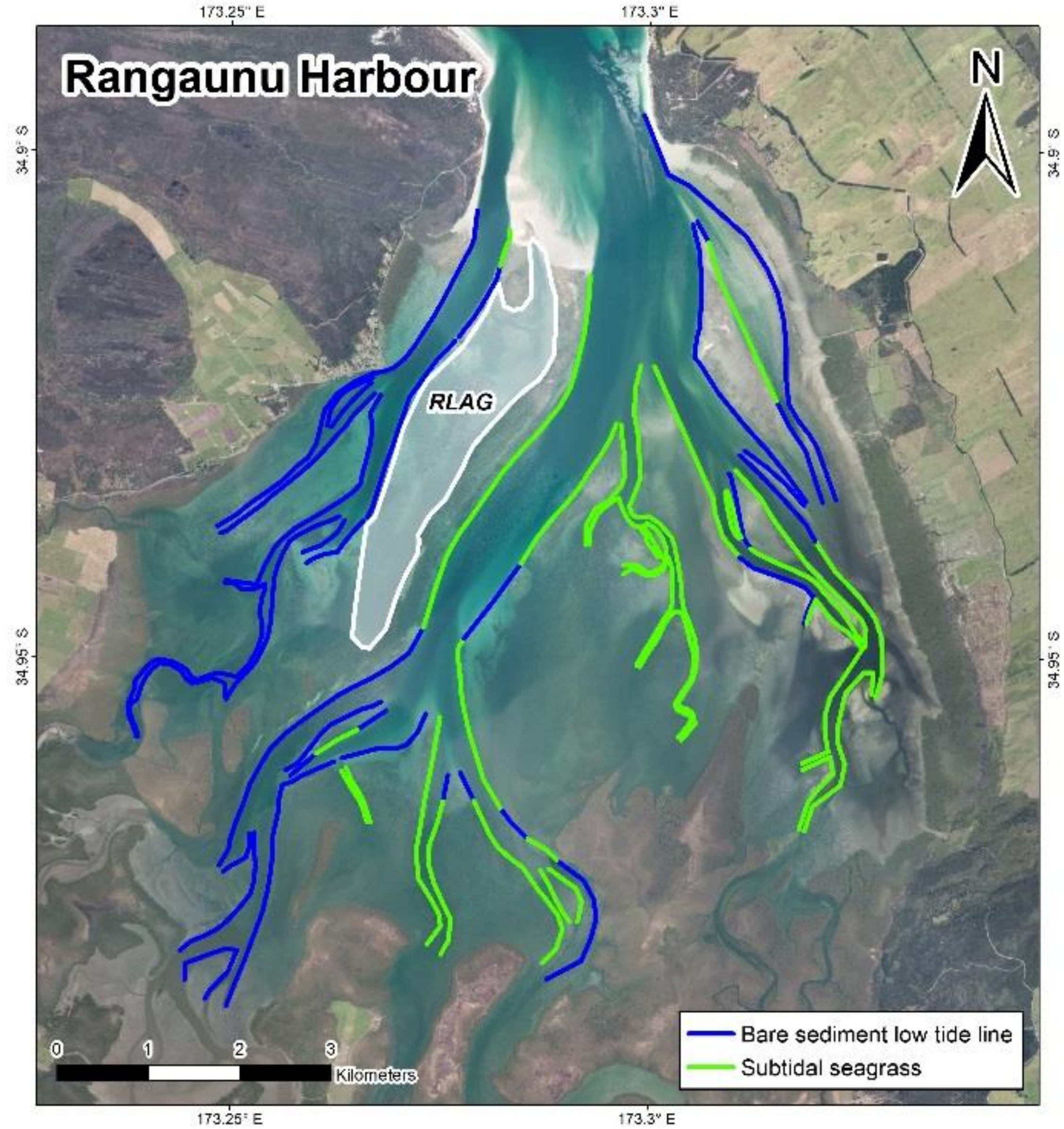


Figure 5: The one-dimensional (blue and green lines) and two-dimensional (white polygons) beach seine survey strata for Rangaunu Harbour. Note that the backdrop is recent satellite imagery from Google Earth, provided for illustrative purposes only. It is not the LINZ aerial photographic imagery used to generate the strata; nor necessarily taken at low tide. Image from Google Earth: Image © 2019 Terrametrics, Image © 2019 CNES / Airbus, © 2018 Google; Image © 2019 Maxar Technologies.

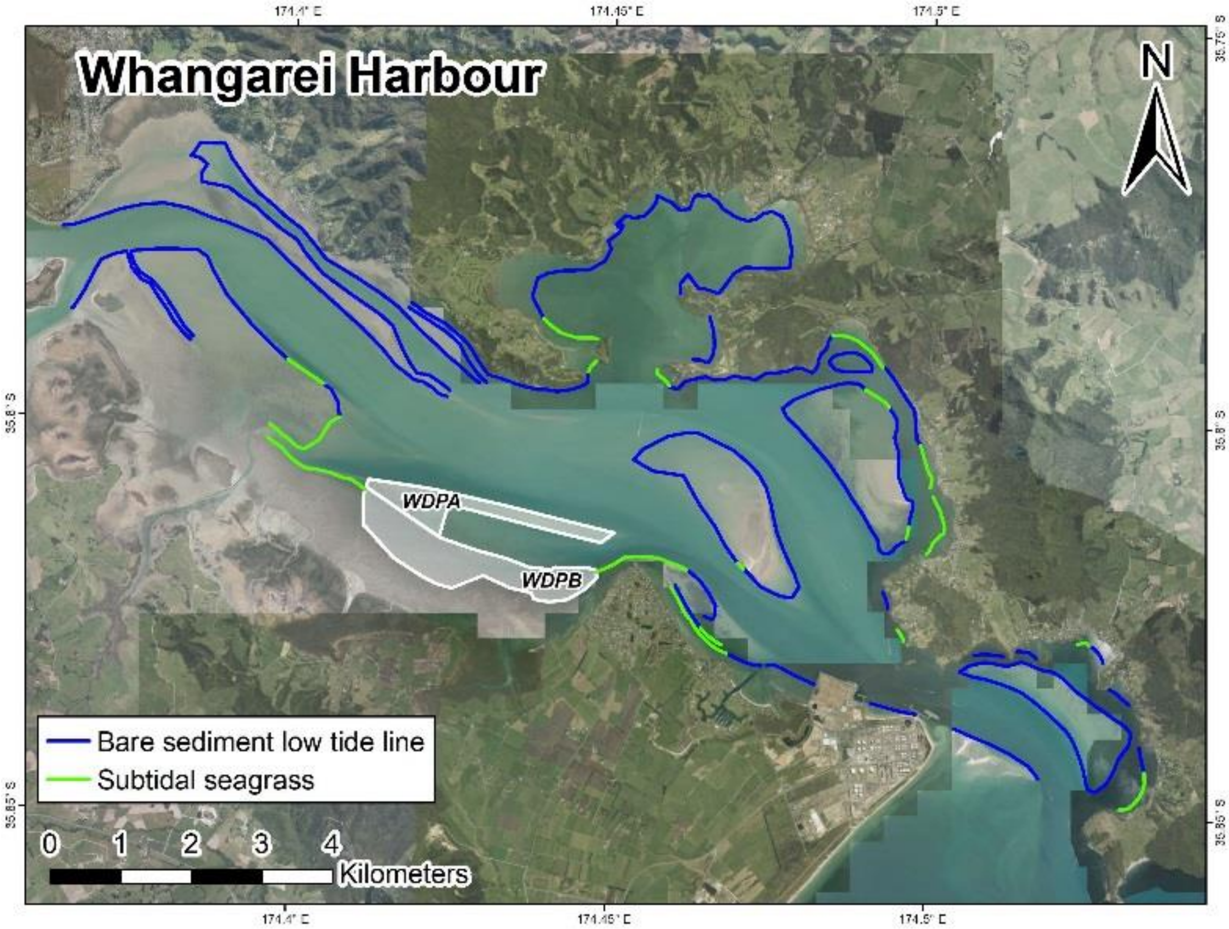


Figure 6: The one-dimensional (blue and green lines) and two-dimensional (white polygons) beach seine survey strata for Whangarei Harbour. Note that the backdrop is recent satellite imagery from Google Earth, provided for illustrative purposes only. It is not the LINZ aerial photographic imagery used to generate the strata; nor necessarily taken at low tide. Image from Google Earth: Image © 2019 Maxar Technologies, data SIO, NOAA, US Navy, NGA, GEBCO, © 2018 Google, image © 2019 CNES / Airbus

In developing a time series of juvenile 0+ snapper abundance, the requirement that the overall sampling extent remains constant over the different survey years holds for both the one- and two-dimensional sampling approaches. In combining the two approaches to calculate an overall number of fish present, the statistic of interest is simply the total scaled number of juvenile snapper, calculated by combining the individual survey strata population estimates. The unit of measurement used to calculate each of these individual stratum estimates (i.e., fish per unit length (one-dimensional) or fish per unit area (two-dimensional)) is irrelevant. This allows us to statistically combine area and linear strata estimates together, producing results comparable to a standard stratified survey.

2.5 Beach seine station allocation

The overall number of sampling stations available for allocation was 56, set by the project resourcing available. As seagrass strata can 'move' over time as subtidal seagrass dynamics change (seagrass disappears in some areas, establishes in others), older survey data (from 2013) was not used to allocate stations to strata. A cost-benefit constraint on sampling was that on an average survey day, eight stations can be completed by a survey team during the low tide window available, and it is not possible to move between two different estuaries within one low-tide sampling event. Therefore, sampling effort was allocated in multiples of eight, with Parengarenga, Rangaunu, and Whangarei harbours each receiving 16 stations, and Houhora Harbour eight stations, due to its smaller size. As catch processing is laborious and time-consuming, and the overall station number limited, these four surveys were run as single-phase surveys. Most strata were allocated four random stations; for Parengarenga Harbour the very limited subtidal seagrass area in the southern harbour was allocated three stations, and the large surrounding bare stratum five stations; while in Rangaunu Harbour the large subtidal-seagrass strata was allocated eight stations, and the other two strata, four stations each (Table 3).

For the one-dimensional strata, random station positions were allocated by summing up the total combined length of string segments that formed a given strata, and then assigning stations to random distances along that string using the Excel Function 'RANDBETWEEN', which generates a random number between two boundary numbers. Stations were given a minimum separation distance of 50 metres. These randomly assigned distances were then measured out along the combined stratum string segments in GIS, to find where a given station fell along that overall strata line, and a station position (latitude, longitude) extracted. For the two-dimensional strata, stations were allocated using the ALLOCATE function, as for the beam trawl strata.

Table 3: Sampling strata descriptions, and station allocations, for the four beach seine surveys (Parengarenga, Houhora, Rangaunu, and Whangarei harbours).

Code	Identity description	Linear extent (m)	Area km^2	Station allocation
	Parengarenga Harbour			
PBAN	Bare sediment low tide line – North	53 107		4
PBAS	Bare sediment low tide line – South	55 762		4
PSEN	Subtidal seagrass low tide line – North	5 682		5
PSES	Subtidal seagrass low tide line – South	476		3
	Totals	115 027		16
	Houhora Harbour			
HBAR	Bare sediment low tide line	27 440		4
HSEA	Subtidal seagrass low tide line	3 726		4
	Totals	31 166		8
	Rangaunu Harbour			
RBAR	Bare sediment low tide line	49 289		4
RSEA	Subtidal seagrass low tide line	55 490		8
RLAG	Subtidal seagrass lagoon area		2.95	4
	Totals	104 779	2.95	16
	Whangarei Harbour			
WBAR	Bare sediment low tide line	81 757		4
WSEA	Subtidal seagrass low tide line	8 312		4
WDPA	Deep subtidal seagrass polygon A, eastern Takahiwai Reach		1.30	4
WDPB	Deep subtidal seagrass polygon B, western Takahiwai Reach		1.68	4
	Totals	90 069	2.98	16

2.6 Beach seine sampling approach

Beach seine sampling was undertaken within the 2.5-hour time window each side of low tide, when the intertidal flats are exposed, and the water depths shallow enough for beach seines to be deployed and towed on foot. Where the subtidal seagrass edge was shallower than about 1.3 m, the net was set parallel to the habitat edge 5 m seaward, and then hauled to shore until the intertidal was reached and the net hauled clear of the water; or pursed together in very shallow water (more than 10 cm deep, in the intertidal). Non-seagrass tows were arbitrarily started at around 1.3 m water depth (or deeper if the station fell on a steeper channel edge). Where the water depth was too deep for hand setting (steep channel drop-offs), a 'boat' set was used, where one person was dropped on the channel bank holding one warp rope end, the net warp run straight offshore, the net then set perpendicular to shore, the second net warp run back to shore, and then the net hauled by hand up the bank by the two net haulers. The net height fully stretched is 3.5 m, and in boat sets, the net fishes from the seafloor up to this height, reducing in height once the headline sits on the water surface. In these sets, the tow distance was fixed by the 25 m length of the net warps, plus the short distance the haulers walked backwards to the intertidal line as they hauled in the net. For all tows, in both one and two-dimensional strata, each station's start and end coordinates were recorded using a hand-held GPS.

Once the net tow was completed, the bag/cod end was emptied of its catch, with larger debris being discarded as far as practical (e.g., drift algae, sticks, rubbish), and then the entire catch plus assorted fine debris (e.g. dead cockle shells, etc) placed into a labelled plastic bag for storage, and frozen once back on shore. As far as possible, larger individual fish such as eagle rays, flounders, and kahawai, were measured and released alive back into the sea. In Parengarenga Harbour, large volumes of an unknown green slimy algae prevented field sorting, and it was necessary to bag the entire catch. Similar issues were encountered with two non-indigenous species of bryozoans at Whangarei Harbour stations (*Amathia verticillate*, and *Thalamoporella californica*).

Back in the lab, all samples were unfrozen and carefully picked through to separate all fish. All snapper, as the objective target species, were counted and measured to the nearest mm in length. Non-target fish were also sorted to species, counted and measured, but are not reported on further in this report, aside from a summary catch table. No substantive habitat forming bycatch species were encountered.

2.7 Numerical analysis

Although SurvCalc is the preferred software tool for Fisheries New Zealand survey analyses conducted by NIWA, the current version of SurvCalc does not accommodate small length measurements in the 1–10 cm range and sample weights less than 1 kg. Our survey population estimates, and bootstrap CVs were instead derived using the following formulation coded in R. We note that SurvCalc calculates CVs using parametric equations, whereas here we use a boot-strapping approach. Independent parametric estimates made using R returned virtually identical estimates as those from boot-strapping, giving confidence that the two different approaches produce the same CV outcomes.

Expected number of snapper in the total survey

The expected total number of snapper over all harbour strata (E) is given by:

$$E[total\ number\ of\ snapper\ over\ all\ strata] = \sum_{h=1}^{L} r_h \bar{x}_h$$

Where:

r_h = sample unit scalar (i.e. either area or linear distance) for stratum h

$\bar{x}_h$ = sample mean of stratum h

L = number of strata

Standard error on the expected number of snapper in the total survey

The standard error (SE) of E was derived from 1000 bootstrap random draws (with replacement) from the individual stratum tow data as follows:

Let $h_{i(k)}$ denote the i^{th} tow drawn at the k^{th} draw from n-1[1] draws from a total of n stratum h tows.

Then $\bar{x}_{h_j}$ the j^{th} bootstrap sample mean of stratum h is given by:

$$\bar{x}_{h_j} = \frac{\sum_{k=1}^{n-1} h_{i(k)}}{n-1}$$

Then E_j, the expected total number of snapper over all harbour strata for the j^{th} bootstrap is given by:

$$E_j[total\ number\ of\ snapper\ over\ all\ strata] = \sum_{h=1}^{L} S_h \bar{x}_{h_j}$$

Let **E** be the vector of bootstrap expected values such that

$\mathbf{E} = (E_{1,} E_{2,} \ldots, E_{1000})$

Then the standard error (SE) of $E[total\ number\ of\ snapper\ over\ all\ strata]$ is approximated by the standard deviation (sd) of **E** such that:

$SE[total\ number\ of\ snapper\ over\ all\ strata] \cong \text{sd}\ \mathbf{E}$

The coefficient of variation (CV) on the survey estimate is therefore:

$$CV = \frac{SE[total\ number\ of\ snapper\ over\ all\ strata]}{E[total\ number\ of\ snapper\ over\ all\ strata]}$$

Survey length frequency estimation

The expected total number of snapper over all strata within each length class (survey length frequency) and associated standard errors were also derived as above, subscripted by length-class. Note: in accordance with accepted statistical theory the individual tow length frequency data were not additionally bootstrap resampled with each bootstrap stratum tow draw.

For plotting and visualisation purposes, both beam and beach seine catches were expressed as either fish per km^2 (2-dimensional strata), or as fish per km of channel edge (1-dimensional strata).

[1] Note: number of draws was n when number of stratum tows was less than 3. In these instances, the SE will be slightly under-estimated

Snapper length frequency distributions are presented in 1 cm length bins to provide consistency with other fisheries reports.

2.8 Other data sets

For comparative purposes, summary data from previous beam trawl and beach seine surveys in East Northland and the Hauraki Gulf are included in the results section. Table 4 below briefly explains their context and provenance. It is important to note that these surveys were quasi-random only and not designed to estimate total population sizes; but rather were aimed at capturing as much fish–habitat–environmental variation as possible, to investigate fish-habitat relationships. No stratification was employed, beyond spreading sampling effort across the sampling regions equally. As such, they are less statistically robust that the 2019 survey data, in terms of estimation of 0+ snapper population size. Size frequency distributions from these earlier surveys are presented as raw length summaries and have not been proportionally scaled by stratum areas.

Table 4: Past survey data sources used for comparative purposes in this report.

Year	Type	Description
2004 Rangaunu Harbour	Beach seine tows collected as part of MPI Biodiversity Research Advisory Group (BRAG) project ZBD200408	Limited tows (16 in all) across subtidal seagrass (4), intertidal seagrass (8), and bare habitats (4). Tows were run parallel to the shore to stay within the optimal habitat zone, and in small blocks (4 tows, spaced 50 m apart), in contrast to later beach seine surveys. See Morrison et al. 2014c.
2013 Parengarenga and Rangaunu harbours	Beach seine survey to quantify fish-habitat (seagrass) relationships, as part of NIWA post-doc project and MBIE Coastal Conservation Management programme (CO1X0907)	Tows spread over putative environmental gradients, using aerial photography to help in station selections Parengarenga 33 stations, Rangaunu 57 stations
2014 East Northland	Beam trawl survey across parts of East Northland to identify 0+ snapper nurseries, as part of NIWA post-doc project and MBIE programme (CO1X0907)	Not all nurseries were covered / discovered in this survey. Random tows across likely areas, including the open coastal zone where 0+ snapper were seldom encountered (low numbers were captured in Cavalli Passage)
2017 Hauraki Gulf	Beam trawl survey across the greater Hauraki Gulf to locate juvenile 0+ snapper nurseries, as part of MBIE Juvenile fish-habitat bottlenecks programme (CO1618)	Extensive sampling (334 stations), including some exposed open coastal areas where 0+ snapper were not encountered
2018 Parengarenga, Rangaunu, Whangarei harbours	Limited beach seine sampling of subtidal seagrass, along with intensive sampling of invertebrates (pelagic, benthic) and environmental variables. MBIE Bottlenecks (CO1618) programme	Eight stations per harbour spread over putative habitat/environmental gradients. Parengarenga and Rangaunu stations largely a subset selected using 2013 survey data
2018 East Northland and Hauraki Gulf	Sampling of subtidal coastal habitats, along with intensive sampling of invertebrates (pelagic, benthic) and environmental variables. MBIE Bottlenecks (CO1618) programme	Stations largely identified from the 2013 East Northland and 2017 Hauraki Gulf beam trawl surveys. Selected to span putative environmental quality and 0+ snapper density gradients

3. RESULTS

3.1 Beam trawl

3.1.1 Hauraki Gulf

One hundred and two stations were successfully completed in Phase I across the 30 Hauraki Gulf strata. From these, 562 0+ snapper (under 100 mm FL) were sampled, along with 14 older snapper (over 99 mm). The overall 2019-year class strength was 10 685 839 individuals (CV 15.9%), with juveniles found in all strata except for the Waitemata Harbour (n=3 stations) (Table 5). No Phase II sampling was undertaken. Calculations of the likely gain in CV precision that Phase II stations would have produced were around 1%, and a reasonably precise estimate of the 2019 snapper year class strength (i.e., less than 20%) had already been obtained.

Juvenile snapper were concentrated in higher density areas considered to be ‘key nurseries’ (Morrison et al., in prep., 2017 and 2018 survey data), including Kawau Bay and the coast south of it (KAWA, KETE); the eastern end of Tamaki Strait and the Ponui/Chamberlains Island area (SCUL, PAKI); Ponui Channel and the associated islands (WAIW, WAIC, WAIE); Te Kouma Harbour, Coromandel Harbour, and Waimate Bay (KOUM, CORO, WMTE); and the small pocket areas of Port Charles and northern Kennedy Bay on the east Coromandel (CHAR, KEN1) (Figure 7). Lower juvenile density, larger spatial scale nurseries occurred along East Coast Bays (ECBY), Rangitoto Channel through Tamaki Strait proper (TAMA), the large outer Firth of Thames area and the deeper zone off West Coromandel (MIDD, JACK), the Firth of Thames proper (THAM), and Mercury Bay proper (WHIT). At a coarse scale resolution, the western Gulf contributed 17% of numbers, the middle Gulf 36%, the Firth of Thames 23%, the eastern Coromandel Coast 4%, and Great Barrier Island less than 0.5% (Table 5).

Table 5: Hauraki Gulf 2019 snapper 0+ year class population and stratum estimates, CVs, density per km², and proportional strata contributions. Pop. Prop, the contribution of a stratum to the overall Hauraki Gulf year-class estimate; Pop. the summed population size for geographic areas composed of several individual strata; Prop., the summed contribution for a geographic area to the overall Hauraki Gulf 0+ snapper population.

Area	Stratum	Area (km²)	Stations	Number of fish	CV	Density (km)	Pop. Prop.	Pop.	Prop.
West Gulf	FAIR	5.22	3	3 132	85	600	0.00		
	KAWA	32.16	3	115 767	79	3 600	0.01		
	KETE	68.15	3	966 414	49	14 181	0.09		
	OREW	144.33	5	275 332	45	1 908	0.03		
	MAHU	6.54	5	5 136	97	785	0.00		
	ECBY	69.69	3	456 116	87	6 545	0.04		
	WHBR	18.51	3	0		0	0.00	1 821 897	0.17
Mid Gulf	NOIS	155.83	3	651 557	20	4 181	0.06		
	TAMA	206.65	3	1 916 056	47	9 272	0.18		
	OWAI	90.87	3	54 518	83	600	0.01		
	PAKI	56.82	3	706 578	23	12 435	0.07		
	SCUL	24.48	3	288 396	57	11 781	0.03		
	WAIW	4.5	3	130 915	39	29 092	0.01		
	WAIC	11.72	3	53 695	50	4 581	0.01		
	WAIE	9.64	3	82 021	45	8 508	0.01	3 883 735	0.36
East Gulf	MIDD	268.85	3	806 485	82	3 000	0.08		
	JACK	129.99	4	676 921	65	5 207	0.06		
	KOUM	3.45	3	44 596	23	12 926	0.00		
	CORO	15.34	3	138 096	65	8 999	0.01		
	WMTE	21.45	3	330 916	30	15 427	0.03		
	COLV	14.45	3	37 548	30	2 598	0.00		
	WARO	14.9	3	13 528	41	908	0.00	2 048 044	0.19
Firth of Thames	THAM	392.25	10	2 412 650	40	6 151	0.23	2 412 650	0.23
Port Charlies	CHAR	0.27	3	4 753	19	17 605	0.00	4 753	0.00
Off Kennedy Bay	TUAT	10.6	3	13 875	83	1 309	0.00	13 875	0.00
Kennedy Bay	KEN1	1.86	3	97 929	41	36 521	0.01		
	KEN2	1.87	3	12 248	33	6 550	0.00	80 177	0.01
Mercury Bay	WHIT	18.92	3	380 866	43	20 130	0.04	380 866	0.04
	TRYA	5.41	3	17 704	84	3 272	0.00		
Great Barrier Island	BARR	7.59	3	22 138	29	2 917	0.00	39 842	0.00
	Totals	1 812.31	102	10 685 839					
	CV				16				

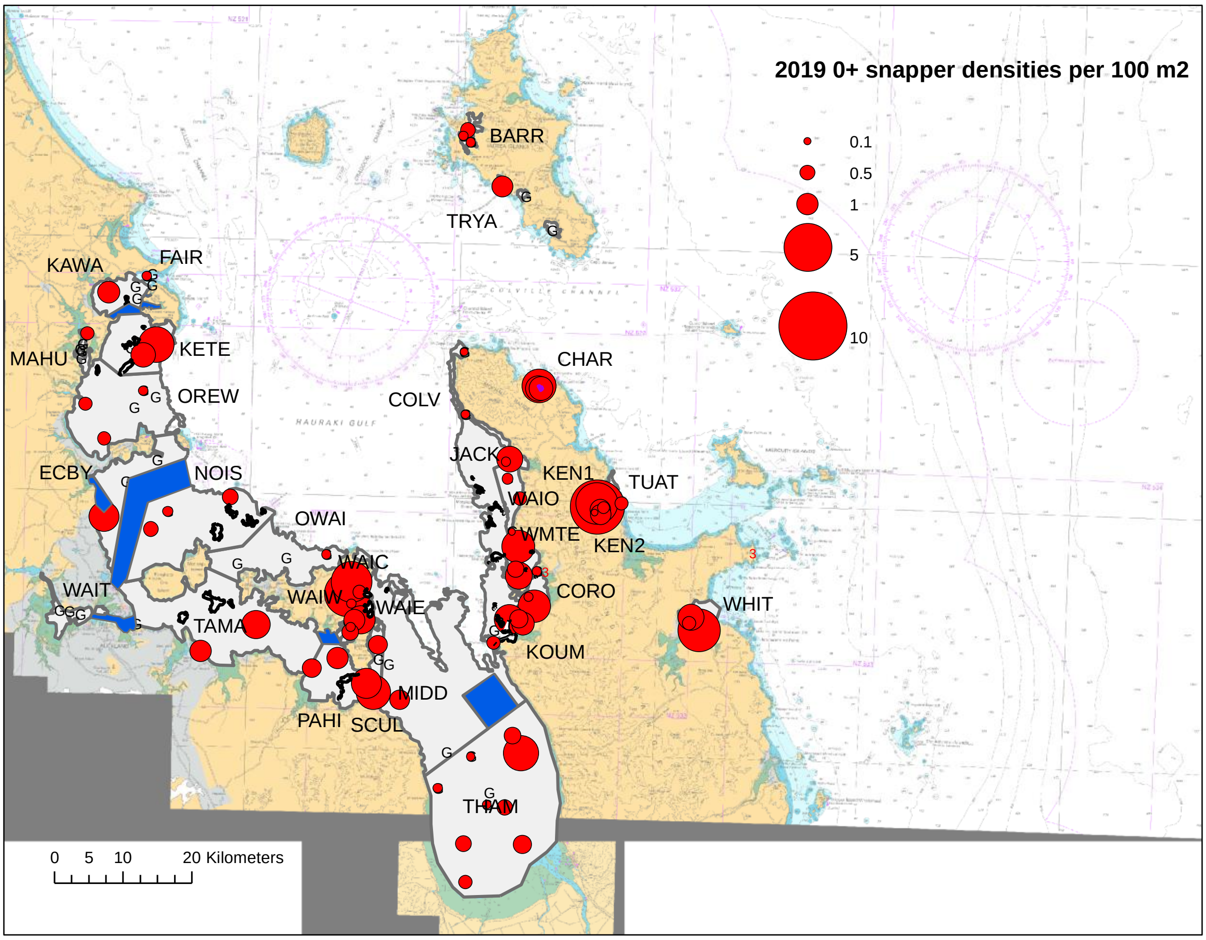


Figure 7: Catch rates of 2019 year-class (0+) snapper, expressed as fish per 100 m^2. Thick square crosses denote zero catch. Blue polygons denote exclusion areas. Sourced from LINZ charts NZ 532, NZ533

At the finer spatial scale of individual strata, density estimates unsurprisingly returned much larger CVs, and the vagaries of random station placement sometimes missed large areas of the stratum (e.g., the three MIDD stratum station placements.

The overall 2019 snapper year class length frequency distribution for the Gulf appeared unimodal, with a mode of fish around 4 cm in length, and a right skewed tail out to 9 cm (Figure 8). However, examination of length frequencies at the stratum scale revealed a more multimodal distribution, with multiple recruitment events (or alternatively but unlikely, very strong spatial variation in growth rates) within a year class (Figure 9, see also Figure 20 later in this report for one mm resolution length bins, note that Figure 20 is unscaled length data to match with earlier surveys). For example, bimodal distributions were apparent in the KETE stratum (the coast south of Kawau Bay) (Figure 9). Differences between spatial groups of strata were also present. For instance, the eastern Coromandel strata from Port Charlies to Kennedy Bay (CHAR, KEN1) held smaller fish with a mode around 2 cm, while the Firth of Thames, Tamaki Strait, Orewa, and the coast south of Kawau Bay (THAM, TAMA, OREWA, KETE) held fish predominantly larger than 4 cm (Figure 9).

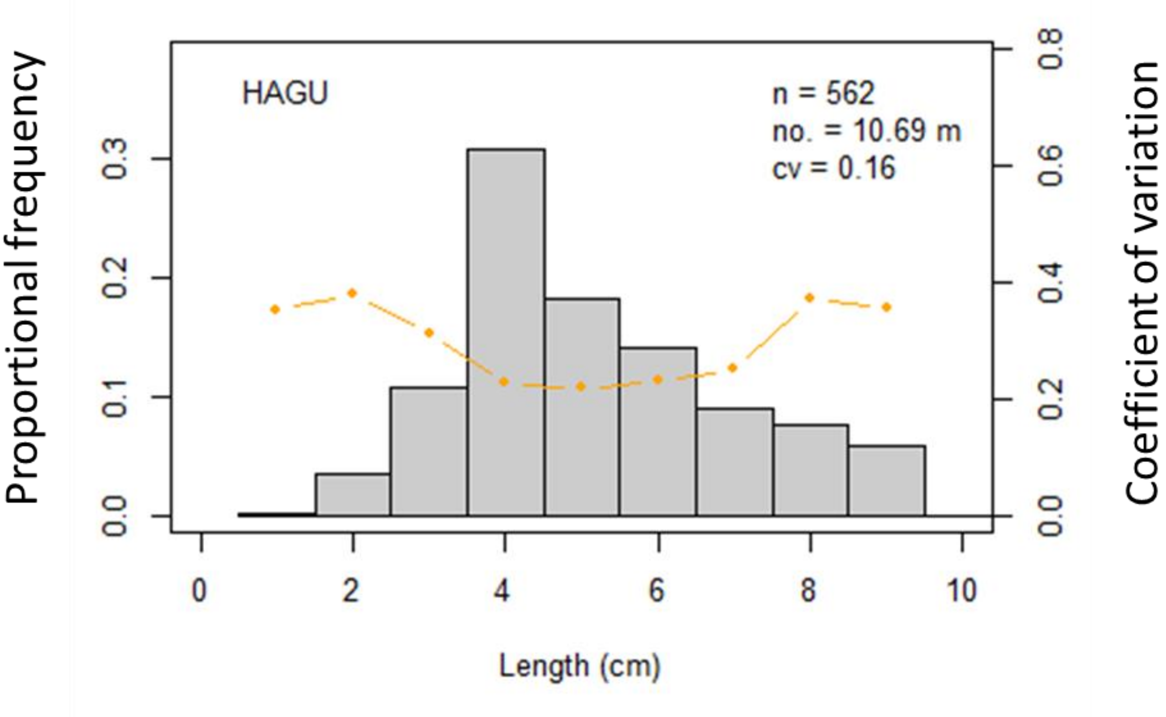


Figure 8: Overall length frequency distribution (1 cm size bins, to the nearest centimetre below the millimetre length measured) for the Hauraki Gulf (HAGU) beam trawl survey. CVs by size class are shown as the orange line.

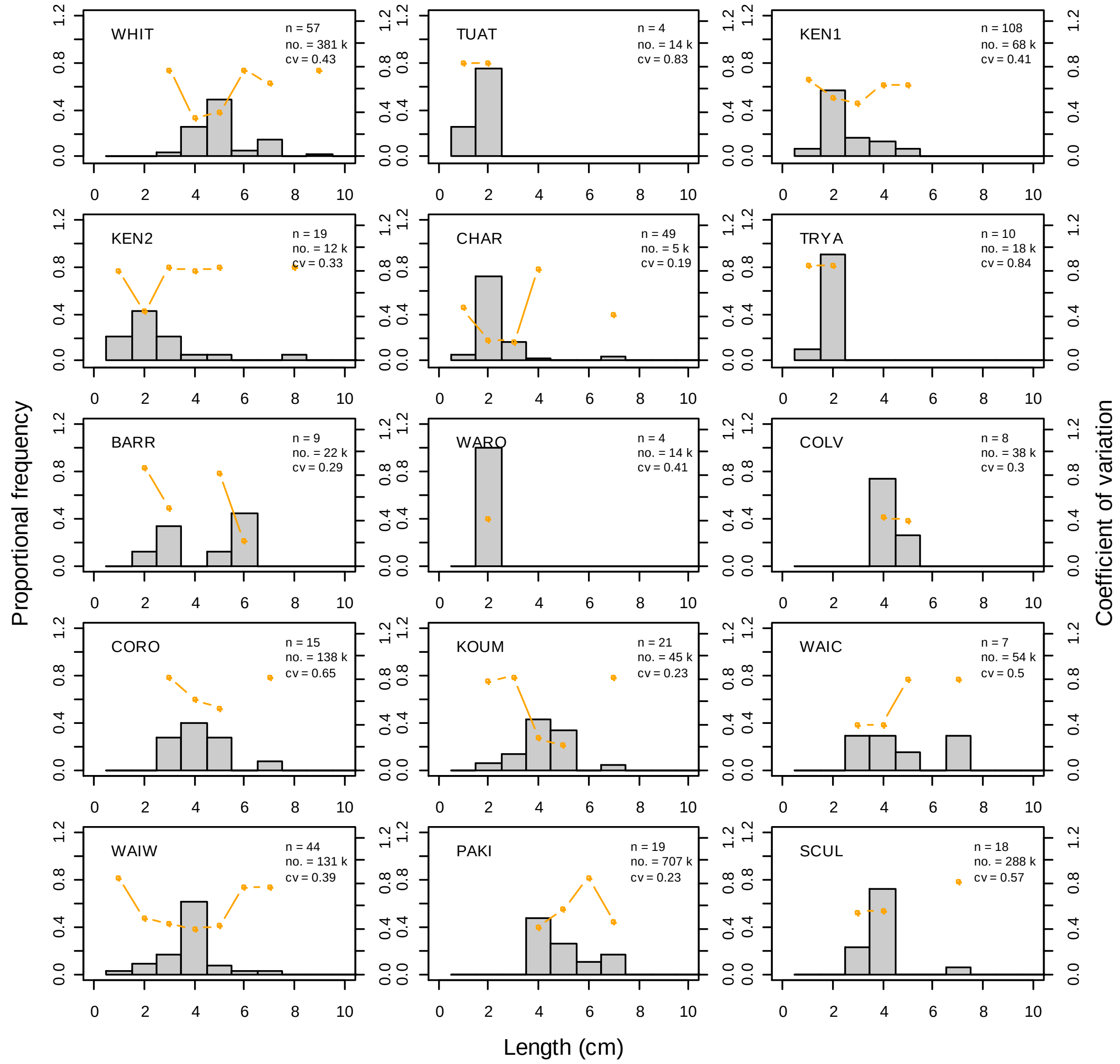


Figure 9: Length frequency distributions (1 cm size bins) by strata for the Hauraki Gulf beam trawl survey. CVs by size class are shown as the orange line.

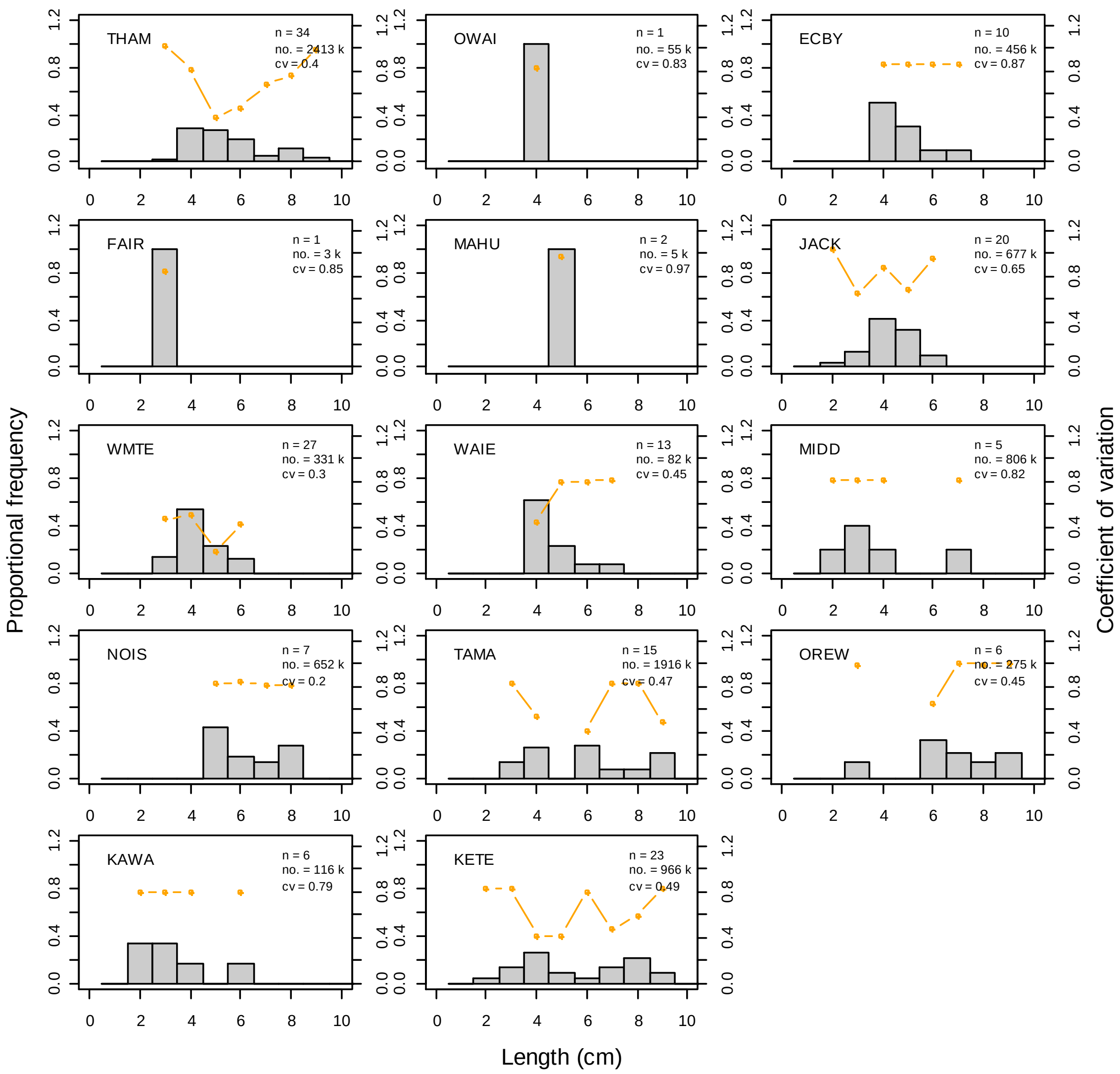


Figure 9 continued.

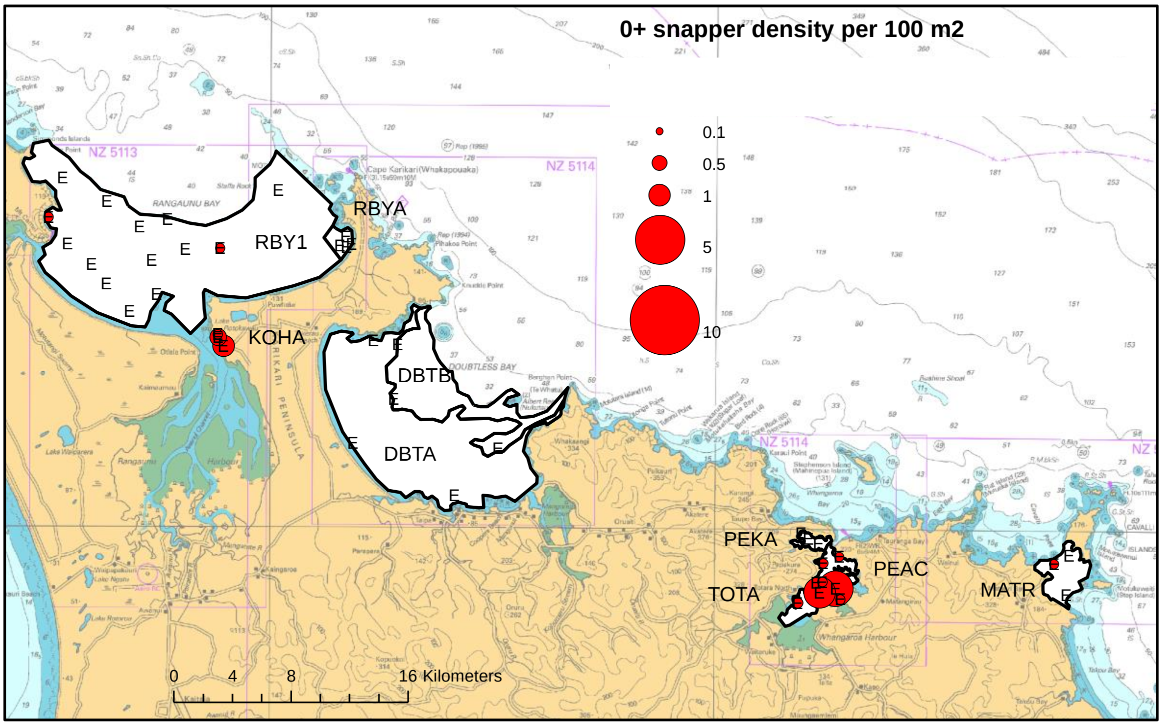
3.1.2 East Northland

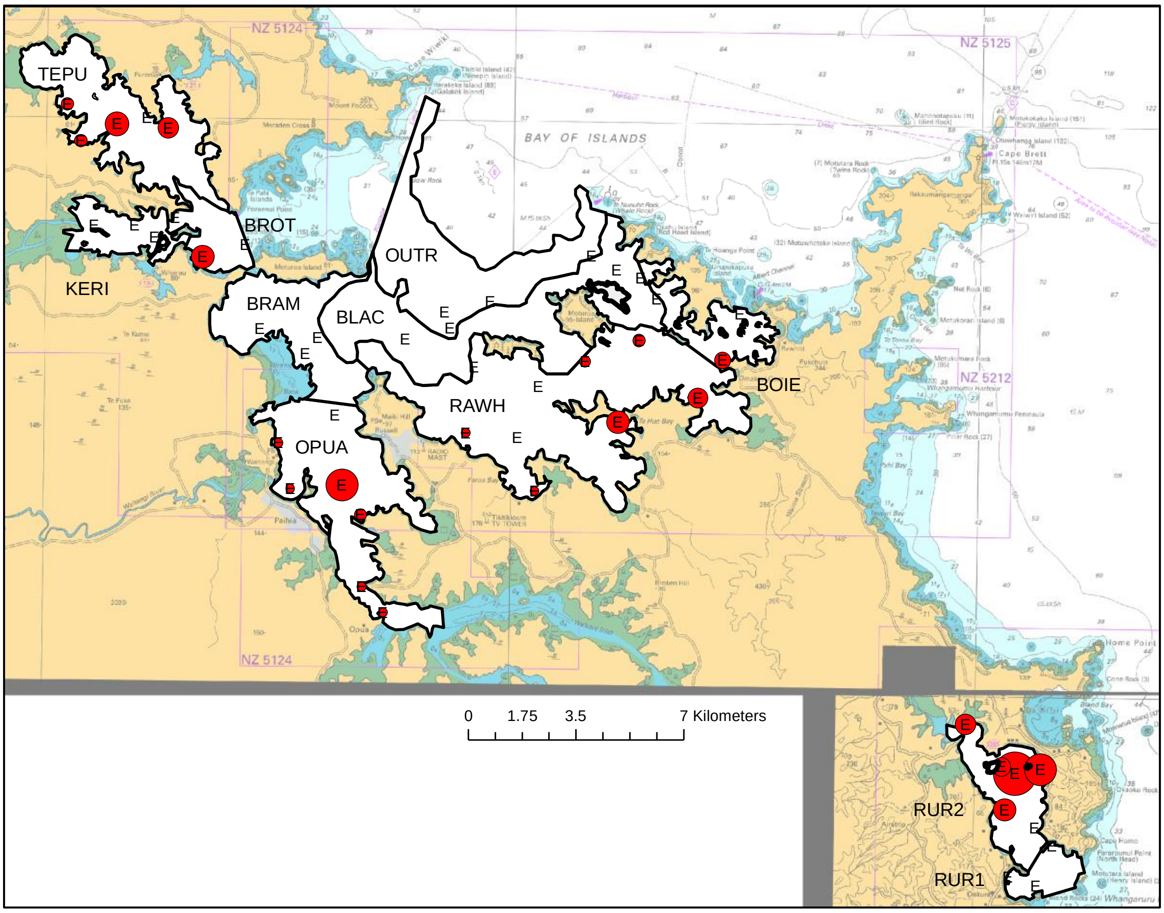
One hundred and two beam trawl stations were successfully completed (88 Phase I, 14 Phase II stations) across the 24 sampling strata. Phase II stations were assigned to RBAY (11), PEAC (1), and TEPU (2). Overall, 167 0+ snapper (under 100 mm) were sampled, along with 3 older snapper (over 99 mm). The 2019-year class strength was 643 187 individuals (CV 18.7%), with juveniles found in 17 of the 24 strata (Table 6). No fish were caught in Doubtless Bay (6 stations), Pekapeka Bay (in Whangaroa Harbour, 3 stations), and several north-eastern Bay of Islands strata (KERI, BRAM; 6 stations) (Figure 10). Deeper strata (30–50 m), sampled to confirm that 0+ snapper did not occur deeper than 30 metres at the time of sampling, also returned no fish (Bay of Islands, BLAC, OUTR; 7 stations). This survey returned a reasonably precise estimate of the 2019 snapper year class recruitment strength and achieved the project's objective.

As with the Hauraki Gulf, juveniles were concentrated in higher density areas considered to be 'key nurseries' (Morrison et al., in prep., 2018 survey), including Whangaroa Harbour, the Bay of Islands, and Whangaruru Harbour (Figure 10). Unlike the Hauraki Gulf, lower density but larger spatial scale nurseries were absent; aside from Rangaunu Bay, which contributed 6.3% of the overall 2019 recruitment numbers. This was due to its large area (33% of the survey region), even though it only held 230 fish per km^2. It also attracted 11 of the 14 Phase II stations sampled (Figure 10).

Table 6: East Northland 2019 snapper 0+ year class population and stratum estimates, CV's, density per km^2, and stratum proportional contributions. Pop. Prop, the contribution of a stratum to the overall East Northland year-class estimate; Pop. the summed population size for geographic areas composed of several individual strata; Prop., the summed contribution for a geographic area to the overall East Northland 0+ snapper population.

Area	Stratum	Area (km^2)	Stations	Number of fish	CV	Density (km)	Pop. Prop.	Pop.	Prop.
Rangaunu Bay	RBYI	145.3	14	40 753	69	280 497	0.06		
	RBYA	2.7	4	0		0	0.00		
	KOHA	0.4	3	2 533	33	5 890	0.00	43 286	0.07
Doubtless Bay	DBTA	87.2	3	0		0	0.00		
	DBTB	32.8	3	0		0	0.00	0	0
Whangaroa	PEKA	2.2	3	0		0	0.00		
Harbour	PEAC	5.7	5	39 382	71	6 970	0.06		
	TOTA	4.0	3	31 837	68	7 999	0.05	72 219	0.11
Cavalli Passage	MATR	8.9	3	5 831	83	654	0.01		0.01
Bay of Islands	TEPU	15.2	5	100 676	39	6 610	0.16		
	KERI	4.7	3	0		0	0.00		
	BROT	4.2	3	19 287	82	4 581	0.03		
	OUTR	16.7	4	0		0	0.00		
	BLAC	10.6	3	0		0	0.00		
	BRAM	11.1	3	0		0	0.00		
	OPUA	18.1	7	95 616	67	5 282	0.15		
	RAWH	33.2	9	123 156	40	3 706	0.19		
	BOIE	5.6	3	12 160	81	2 159	0.02	350 897	0.55
Whangaruru	RUR2	7.6	6	132 399	41	17 513	0.21		
Harbour	RUR1	2.8	3	0		0	0.00	132 399	0.21
Whangarei	WREW	18.1	3	35 460	83	1 963	0.06		
Harbour	WREE	11.7	3	0		0	0.00		
	WRS1	1.4	3	1 819	79	1 308	0.00		
	WRS2	1.1	3	2 272	3	2 028	0.00	39 552	0.06
	Totals	451.19	102	643 187					
	CV				19				


0+ snapper density per 100 m2
0.1
0.5
1
5
10
RBY1
RBYA
KOHA
DBTB
DBTA
PEKA
PEAC
TOTA
MATR
0
4
8
16 Kilometers


TEPU
BROT
KERI
OUTR
BRAM
BLAC
RAWH
BOIE
OPUA
RUR2
RUR1
0
1.75
3.5
7 Kilometers

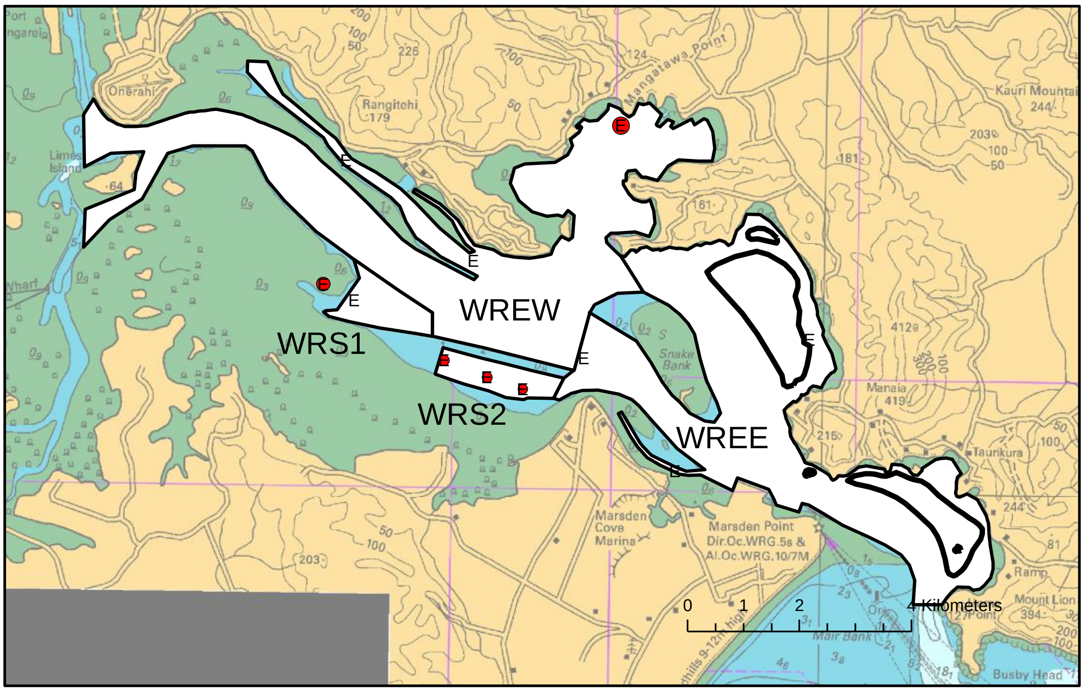


Figure 10: East Northland catch rates of 2019 0+ juvenile snapper, expressed as fish per 100 m^2. Square crosses denote zero catch. Scale varies across the images. Sourced from LINZ charts NZ512, NZ521

The overall 2019 snapper year class length frequency of the East Northland appeared bimodal, with modes at 4 and 8 cm (Figure 11). Examination of length frequencies at the stratum scale was limited by the small numbers of fish sampled in most strata (Figure 12). Whangaroa Harbour had a dominant length mode at 3–4 cm (TOTA, PEAC) and Whangaruru Harbour at 4–5 cm (RUR2), while Bay of Islands strata supported a broader range of modes at 4, 5, and 7 cm (OPUA, TEPU, BROT respectively) (Figure 12).

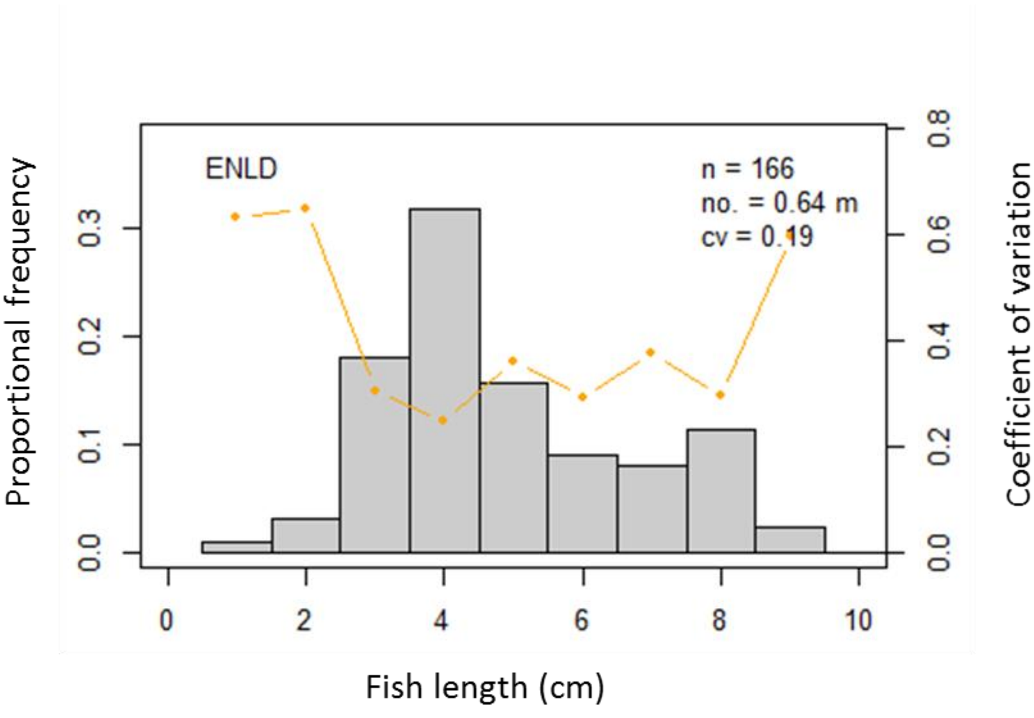


Figure 11: Overall length frequencies (1 cm size bins) for the Hauraki Gulf (HAGU) beam trawl survey. CVs by size class are shown as the orange line.

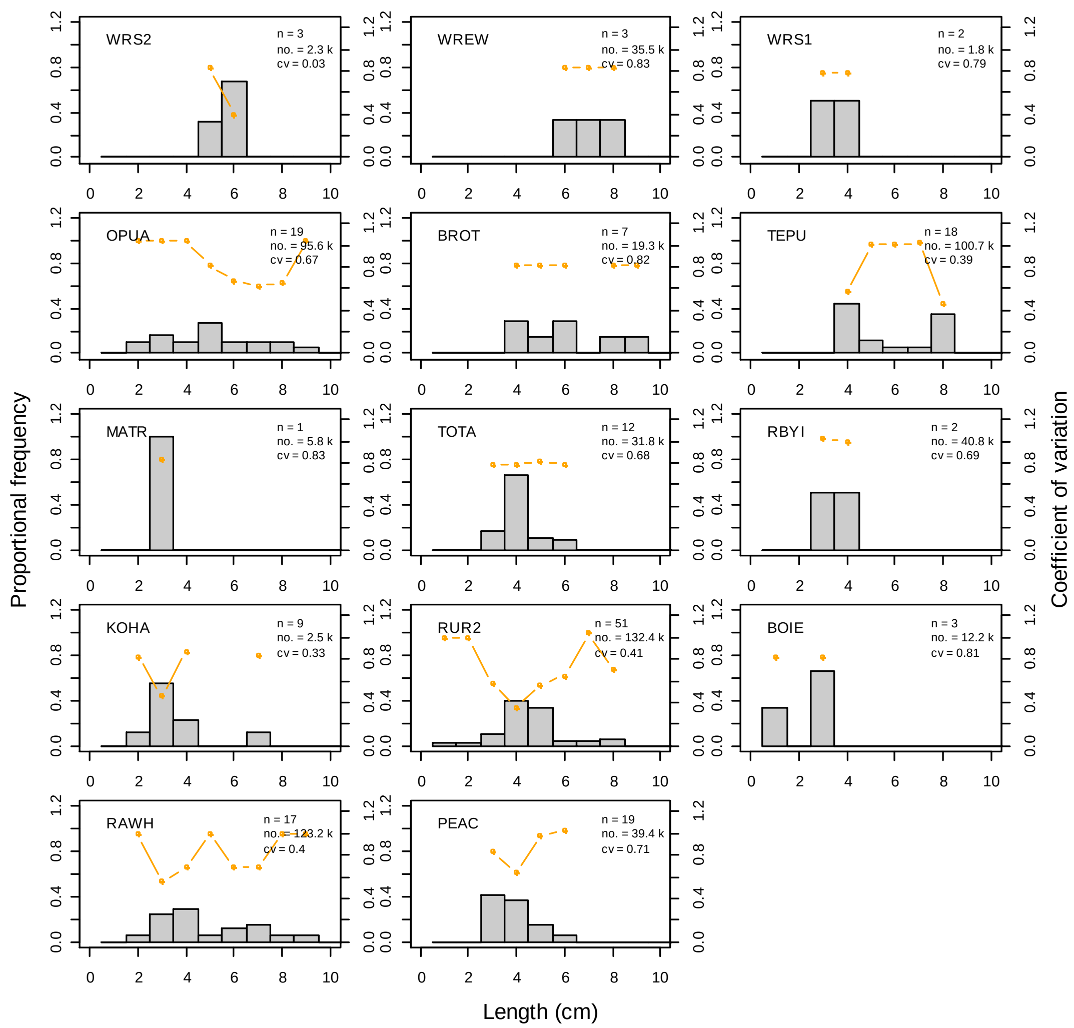


Figure 12: Length frequencies (1 cm size bins) by strata for the East Northland beam trawl survey. Only strata that held fish are shown. CVs by size class are shown as the orange line.

3.2 Beach seine

3.2.1 Parengarenga Harbour

Sixteen stations were successfully completed in this single-phase survey. Only 26 0+ snapper were sampled from this harbour, and the corresponding population estimate was low, at 4359 fish, with a CV of 46% (Table 7). The highest densities were associated with a small area of subtidal seagrass in the southern harbour (Figure 13) (average of 852 individuals per km). The dominant size mode occurred at 1–2 cm length (due to a few smaller fish falling in large spatial strata, with concurrent scaling up by areas) (Figures 14), while a small number of larger 4 to 6 cm fish were associated with the small southern harbour subtidal seagrass strata (Figure 15).

Table 7: East Northland 2019 snapper 0+ year class population and stratum estimates, CV's, density per km / km^2, and stratum proportional contributions, for the four beach survey harbours of Parengarenga, Houhora, Rangaunu, and Whangarei. Pop. Prop, the contribution of a stratum to a given harbours population.; Prop., the contribution of a given harbour to the overall East Northland four-harbour year-class strength estimate.

Area	Stratum	Length (m)	Area (km^2)	Stations	Number of fish	CV	Density (km)	Density (km^2)	Pop. Prop.	Prop.
Parengarenga Harbour	PBAN	53 107		4	1 475	100	28		0.34	
	PBAS	55 762		4	2 478	60	44		0.57	
	PSEN	5 682		5	0		0		0.00	
	PSES	476		3	405	76	852		0.09	
	Totals	115 027		16	4 359	46				0.06
Houhora Harbour	HBAR	27 440		4	0		0		0.00	
	HSEA	3 726		4	1 449	100	389		1.00	
	Totals	31 166		16	1 449	100				0.02
Rangaunu Harbour	RBAR	49 289		2	0		0		0.00	
	RSEA	55 490		10	0		0		0.00	
	RLAG		2.95	4	16 459	100		5 579	1.00	
	Totals	104 779		16	16 459	100				0.24
Whangarei Harbour	WBAR	81 757		4	2 271	97	28		0.05	
	WSEA	8 312		4	1 385	78	167		0.03	
	WDPA		1.3	4	0			0	0.00	
	WDPB		1.68	4	41 948	85		24 969	0.92	0.67
	Totals	90 069		16	45 604	78				
All four harbours	**Totals**	**341 041**	**5.93**	**56**	**67 871**	**58**				

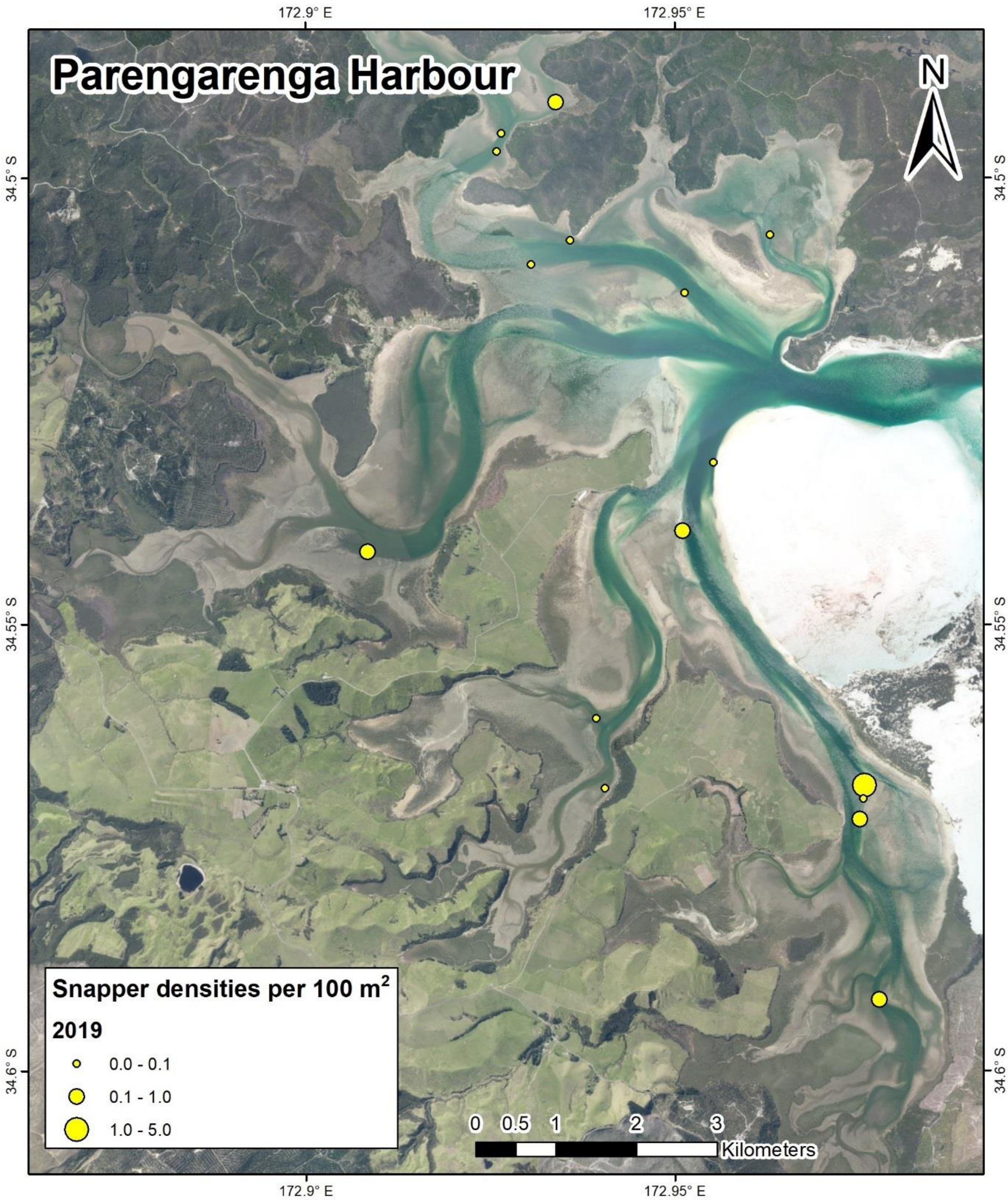


Figure 13: Catch rates of 2019 0+ year class snapper in Parengarenga Harbour, expressed as fish per 100 m^2. Image from Google Earth; Image ©2019 CNES /Airbus © Google. Data SIO, NOAA, US Navy, NGA GEBCO. Image © Terrametrics.

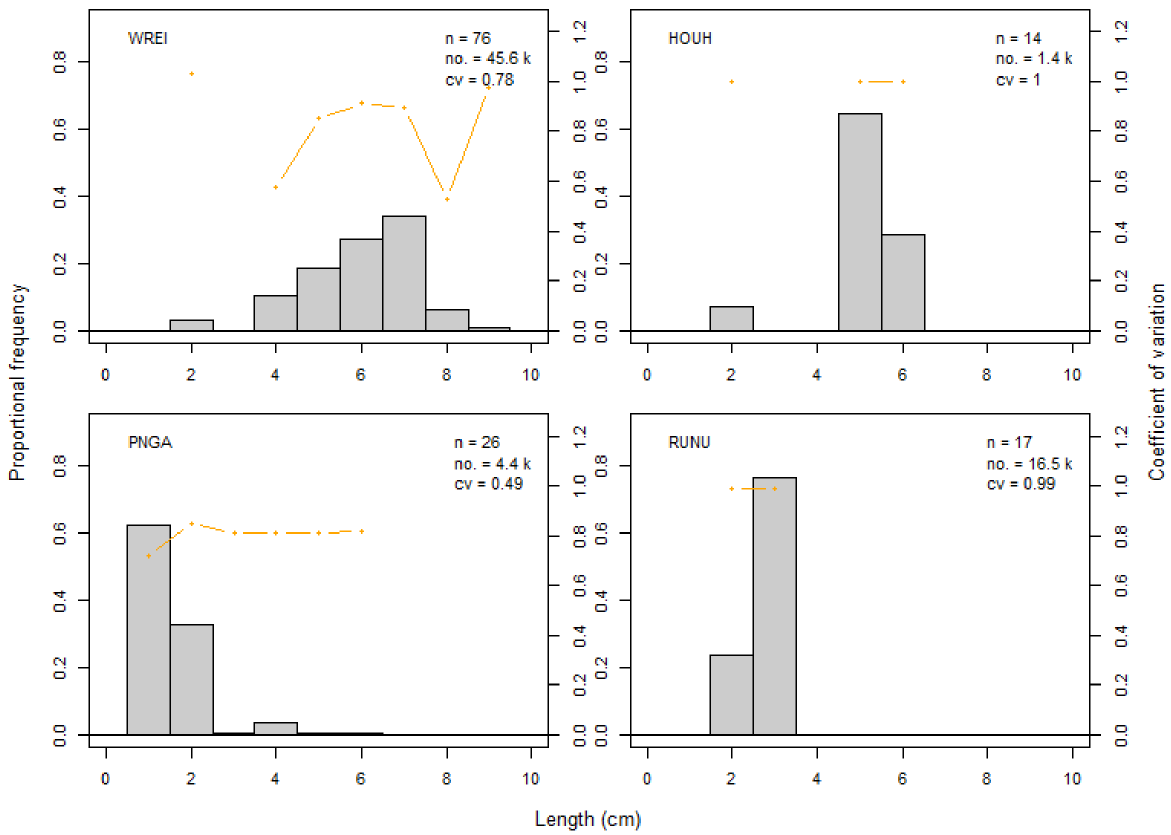


Figure 14: Length frequencies (1 cm size bins) at the harbour scale for Whangarei (WREI), Houhora (HOUH), Parengarenga (WREI), and Rangaunu (RUNU) harbour beach seine surveys. Only strata that held fish are shown. CVs by size class are shown as the orange line.

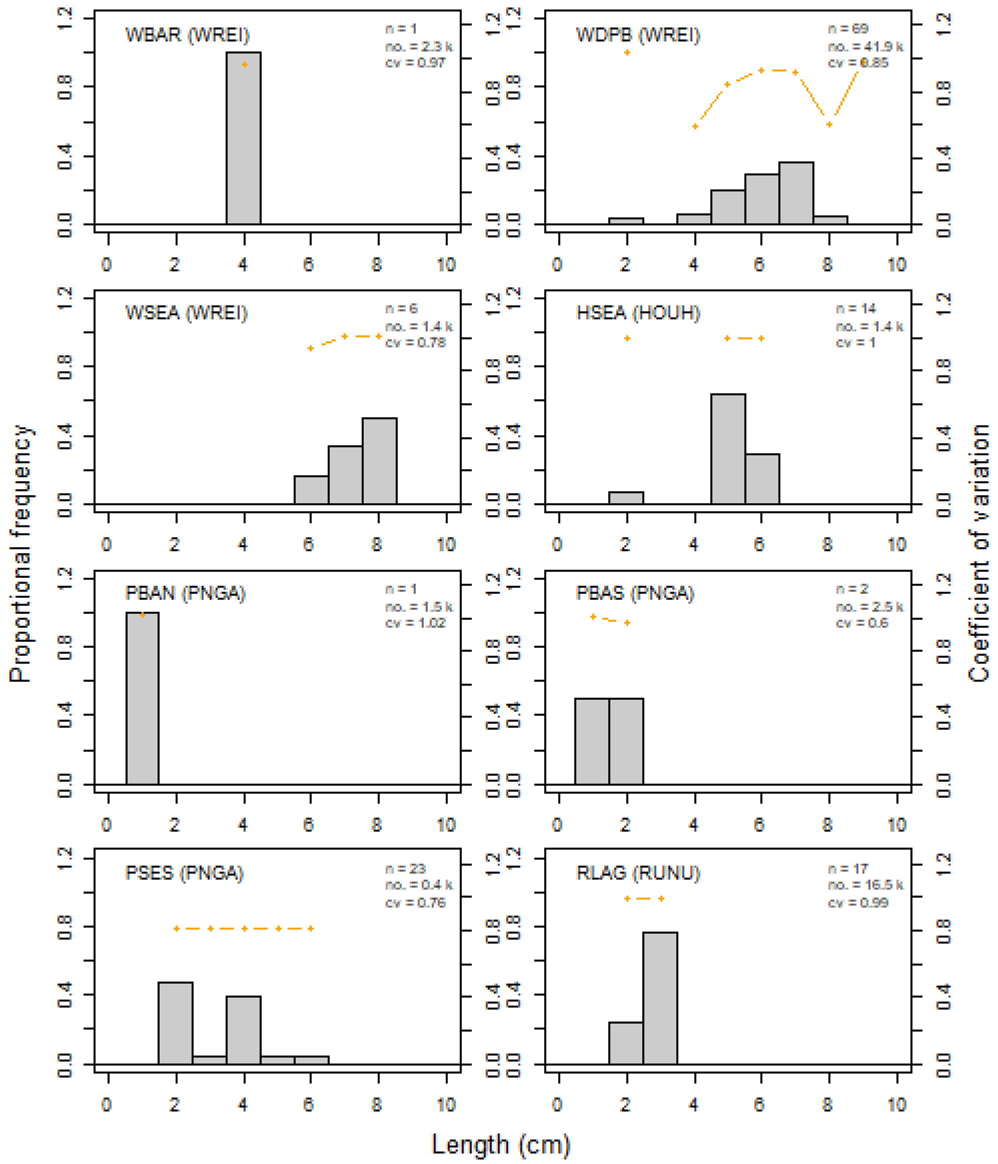


Figure 15: Length frequencies (1 cm size bins) at the individual stratum level for Whangarei (WREI), Houhora (HOUH), Parengarenga (PNGA) and Rangaunu (RUNU) harbours. Only strata that held fish are shown. CVs by size class are shown as the orange line.

3.2.2 Houhora Harbour

Eight stations were successfully completed in this single-phase survey. Only 14 0+ snapper were sampled from this harbour, all from a single subtidal seagrass station (Figure 16). The corresponding population estimate was low, at 1448, with a CV of 100% (Table 7). The dominant size mode occurred at 5–6 cm length (Figures 14, 15).

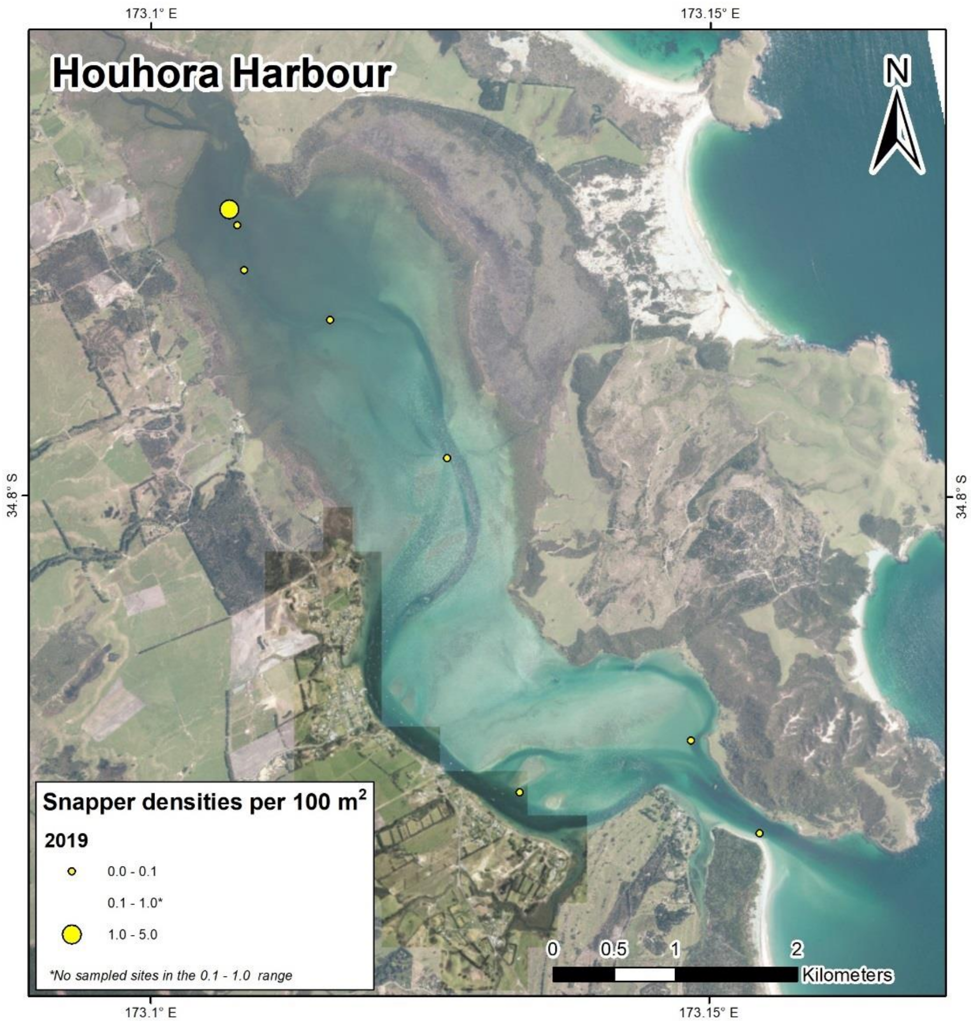


Figure 16: Catch rates of 2019 0+ year class snapper in Houhora Harbour, expressed as fish per 100 m^2. Image from Google Earth; Image ©2019 CNES /Airbus © Google. Data SIO, NOAA, US Navy, NGA GEBCO. Image © Maxar Technologies.

3.2.3 Rangaunu Harbour

Sixteen stations were successfully completed in this single-phase survey. Only 17 0+ snapper were sampled from this harbour from a single station, with a corresponding low population estimate of 16 459 individuals (CV 100%) (Table 7). All the 0+ snapper were caught at one subtidal seagrass station in the lagoon strata (RLAG). The dominant size mode occurred at 3 cm length (Figures 14, 15).

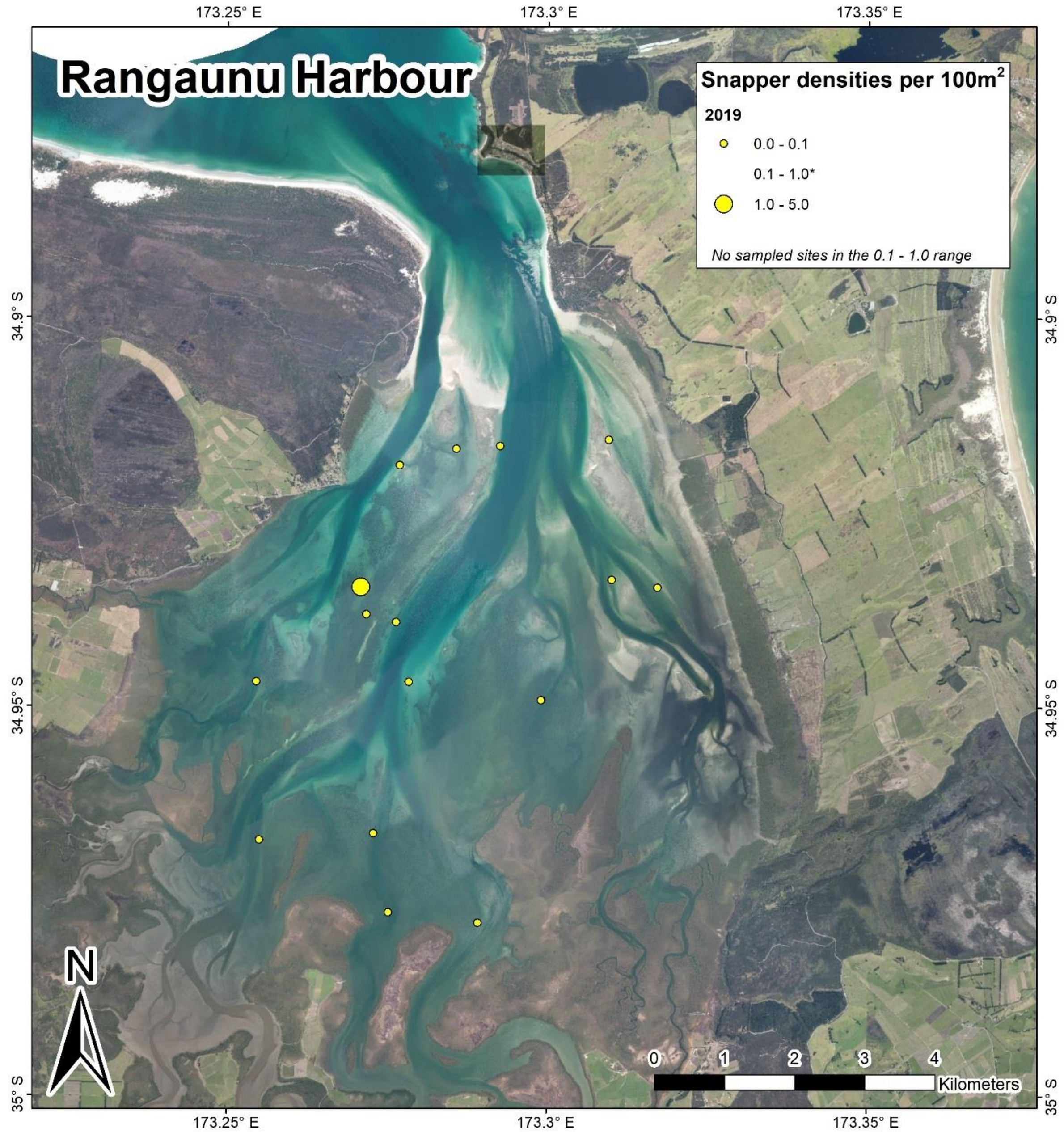


Figure 17: Catch rates of 2019 0+ year class snapper in Rangaunu Harbour, expressed as fish per 100 m^2. Image from Google Earth: Image © 2019 Terrametrics, Image © 2019 CNES / Airbus, © 2018 Google; Image © 2019 Maxar Technologies.

3.2.4 Whangarei Harbour

Sixteen stations were successfully completed in this single-phase survey. Only 76 0+ snapper were sampled from this harbour with a corresponding low population estimate of 67 871 individuals (CV of 58%) (Table 7). Most 0+ snapper were caught in the two-dimensional subtidal seagrass strata along the eastern side of Takahiwai Reach (WDPB) (Figure 18). The dominant size mode occurred at 4–8 cm length (Figures 14, 15).

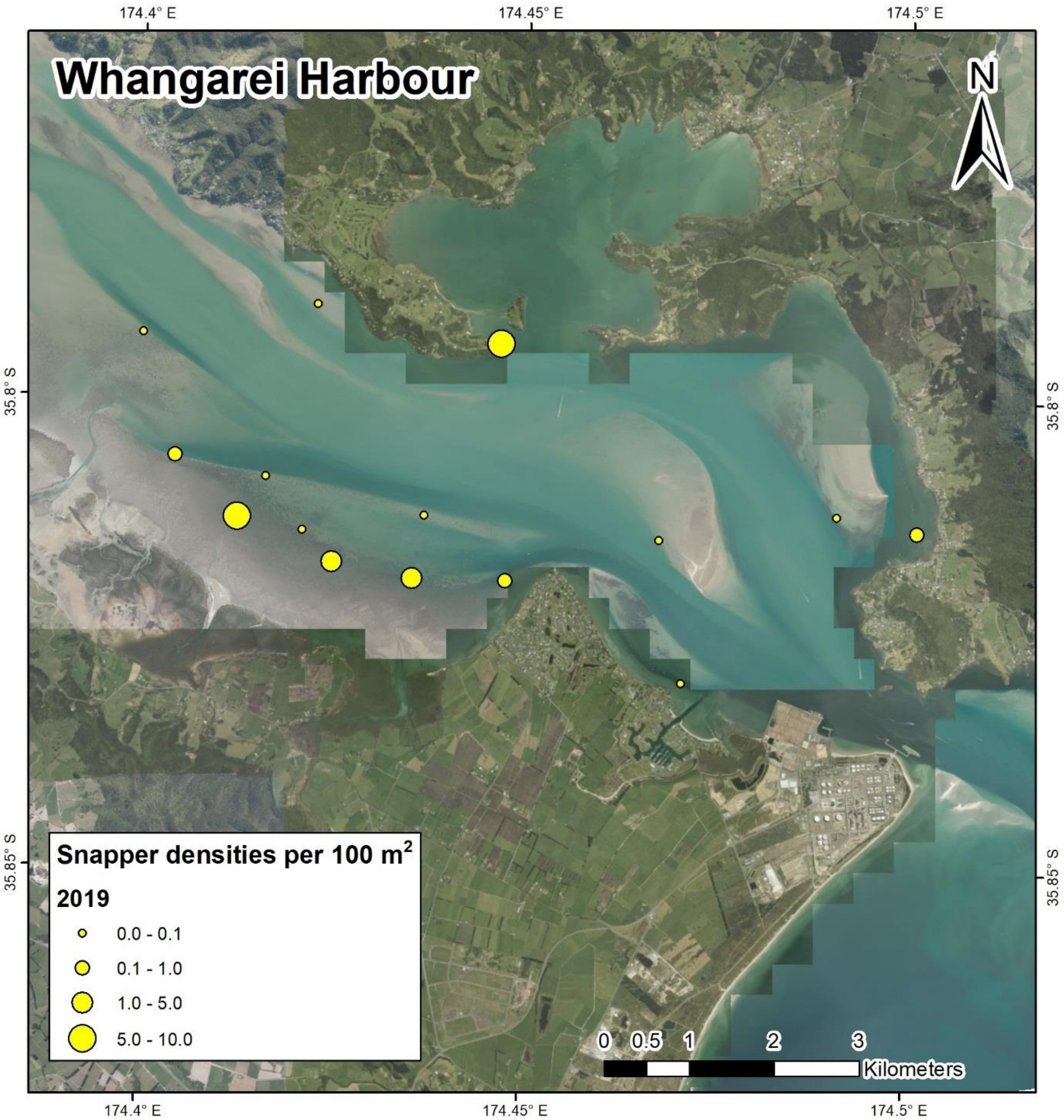


Figure 18: Catch rates of 2019 0+ year class snapper in Whangarei Harbour, expressed as fish per 100 m^2. Image from Google Earth: Image © 2019 Maxar Technologies, data SIO, NOAA, US Navy, NGA, GEBCO, © 2018 Google, image © 2019 CNES / Airbus

An overall combined scaled length frequency for the four beach seine survey harbours is given in Figure 19, and shows a bimodal distribution, with modes at 3 and 7 cm fish length.

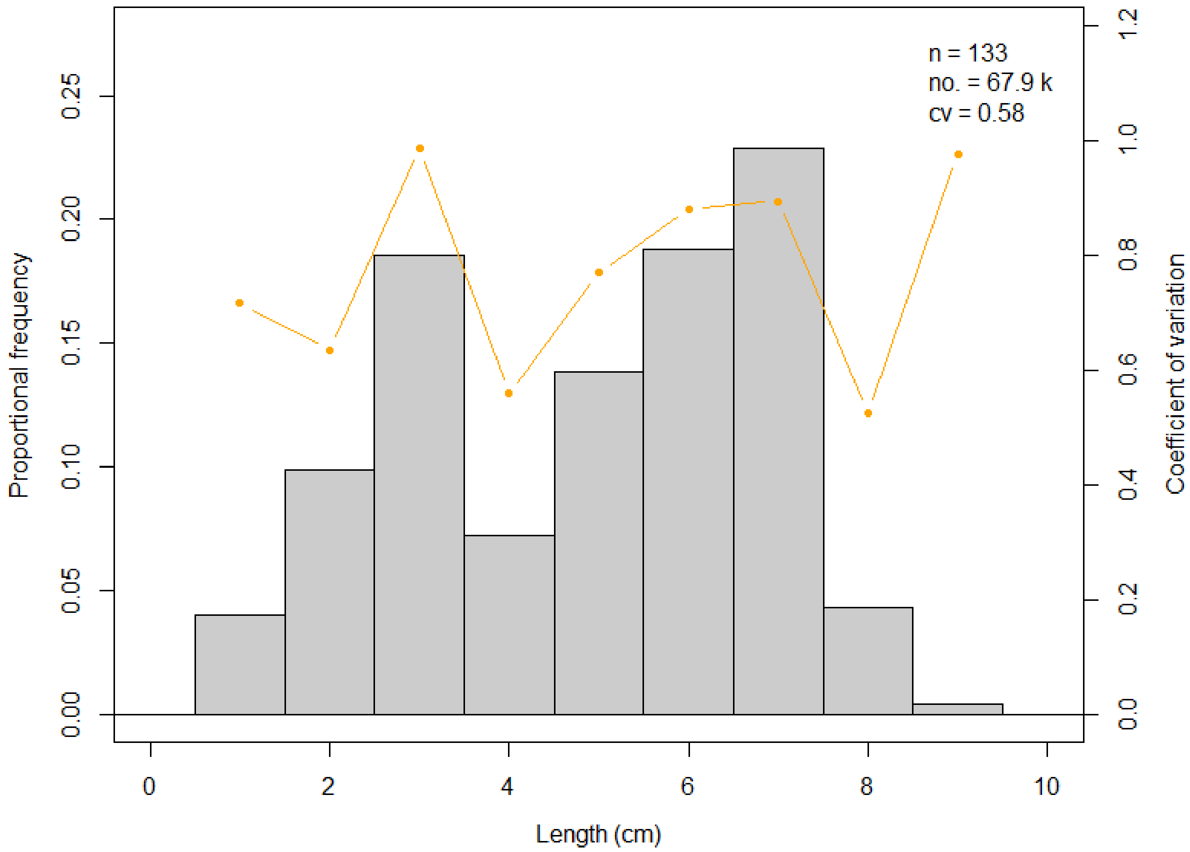


Figure 19: Scaled length frequency distribution (1 cm size bins) for the combined four East Northland beach seine surveys. CVs by size class are shown as the orange line.

3.3 Previous years beach seine and beam trawl survey data

Some data from previous surveys is given in this section, to provide a temporal context to the 2019 survey results. For beam trawl, this is limited to overall size frequency distributions, to provide an overview of their stability across years. For beach seine, catch rates are given as well as overall size frequency distributions, to help explore (in the discussion) why the 2019 beach seine survey population estimates are so low.

3.3.1 Beam trawl

Earlier beam trawl survey unscaled length frequency distributions are given in Figure 20. The Hauraki Gulf surveys (2017, 2018) were dominated by fish in the 20–60 mm size range. The 2017 survey had much higher intensity sampling (more stations) than the 2018 survey. Fish ranged from around 17 to 88 mm in size, with potentially five or more size modes being present, presumably representing different spawning events (not all necessarily in the same area/s). The 2018 survey was of lower sampling intensity and largely returned fish in the 20 to 80 mm size range, with no clear modes, probably due to the much lower number of fish measured.

The East Northland surveys (2013, 2018) were dominated by fish in the 20 to 70 mm, and 20 to 80 mm size ranges respectively. Most of the 2013 fish were from 30 to 60 mm in length, formed of one or more overlapping modes. In 2018, two or more discrete modes were present; a less dominant one centred around 30 mm, and a more dominant one around 50 to 70 mm.

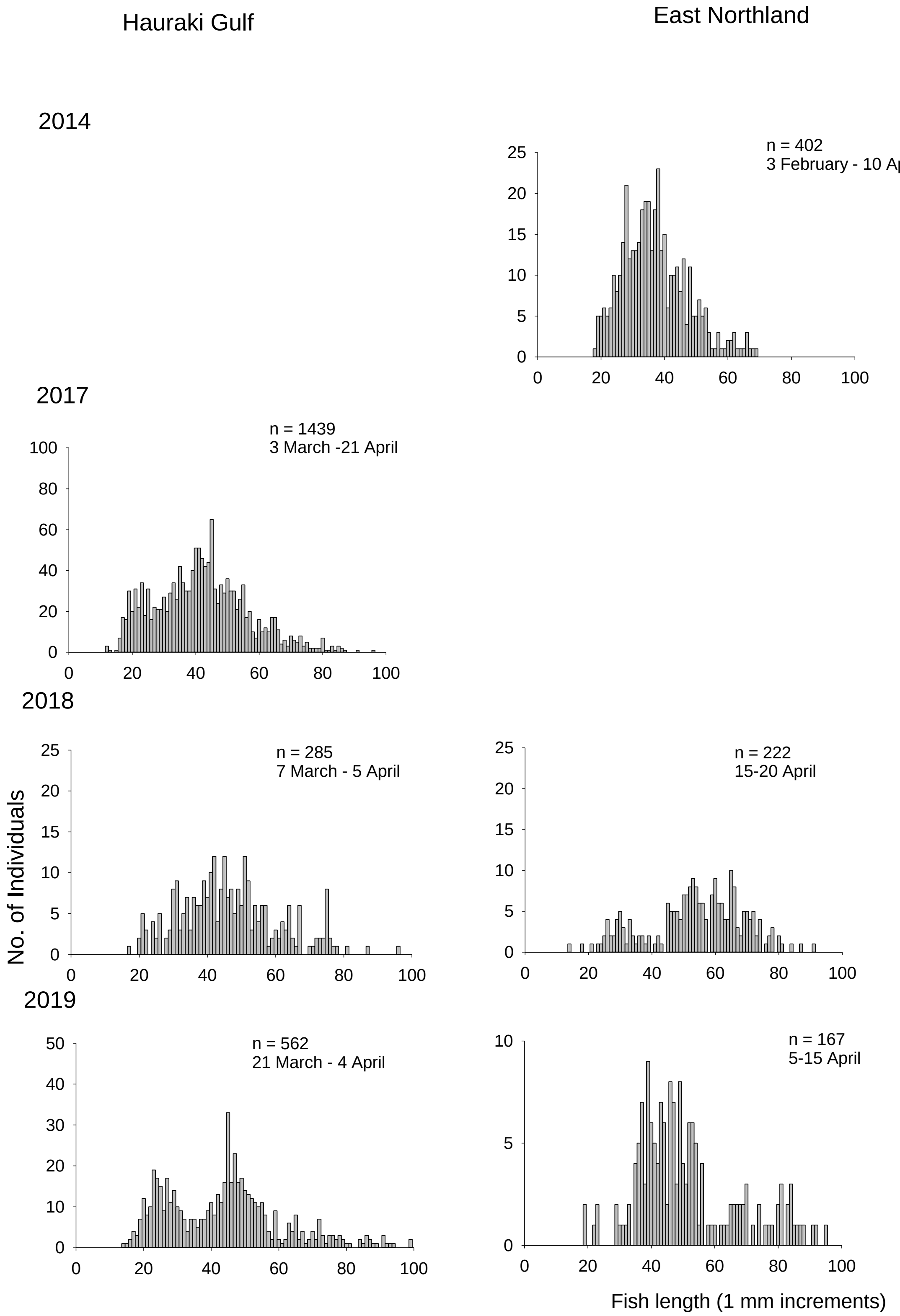


Figure 20: Snapper length frequencies from different beam trawl surveys of East Northland and the Hauraki Gulf (raw data, no scaling by strata). Note that the y-axis scaling varies across graphs. n, total number of snapper measured; and date of sampling given. Sampling intensity and design varies between years (see Table 4). Some additional snapper lengths from 2019 East Northland stations not included in the population estimates have been included (poor performance tows).

3.3.2 Beach seine

Parengarenga Harbour

A quasi-random 2013 beach seine survey of the harbour (33 stations) (Figures 21, 22) returned a population size estimate of 1.081 million fish (CV 17%) (versus 4359 fish in 2019, a 99.6% reduction), and average densities of 9400 individuals per km (versus 38 in 2019). Similarly, 8 beach seine tows in 2018, designed to cover a gradient of high to low quality subtidal seagrass sites from the 2013 survey, returned an average 73 000 individuals per km (versus 44 and 852 in 2019). The 2013 and 2018 surveys were dominated by juveniles in the 40–60 mm length range, along with a smaller additional mode at 21 mm in 2013, presumably representing late-spawned fish (Figure 22).

Rangaunu Harbour

A quasi-random 2013 beach seine survey of the harbour (57 stations) (Figures 21, 22) returned a population size estimate of 1.886 million fish (CV 30%) (versus no fish at all in the equivalent area in 2019), and average densities of 18 004 individuals per km (versus 0 in 2019). Similarly, 8 beach seine tows in 2018, designed to cover a gradient of high to low quality subtidal seagrass sites from the 2013 survey, returned an average 107 222 individuals per km (versus 0 in 2019). An earlier limited survey in 2004 returned a dominant fish length mode at 60–80 mm, along with a smaller mode at 30–50 mm (Figure 22). The 2013 survey returned two or more overlapping modes; a less dominant mode around 30 mm, and a dominant mode around 50 mm. The 2018 survey returned a unimodal length distribution, centred around 40 mm, with a left skewed main distribution of 30 to 60 mm long fish.

Whangarei Harbour

No survey was carried out in 2013 in Whangarei Harbour. However, eight beach seine tows were made in 2018, selected to cover a gradient of high to low density sites (Figures 21, 22). These returned an average 17 056 individuals per km of subtidal seagrass (versus 167 in 2019). Snapper lengths ranged from 20 to 96 mm, with a less dominant mode at 30 mm, and a dominant mode at 70 mm (Figure 22).

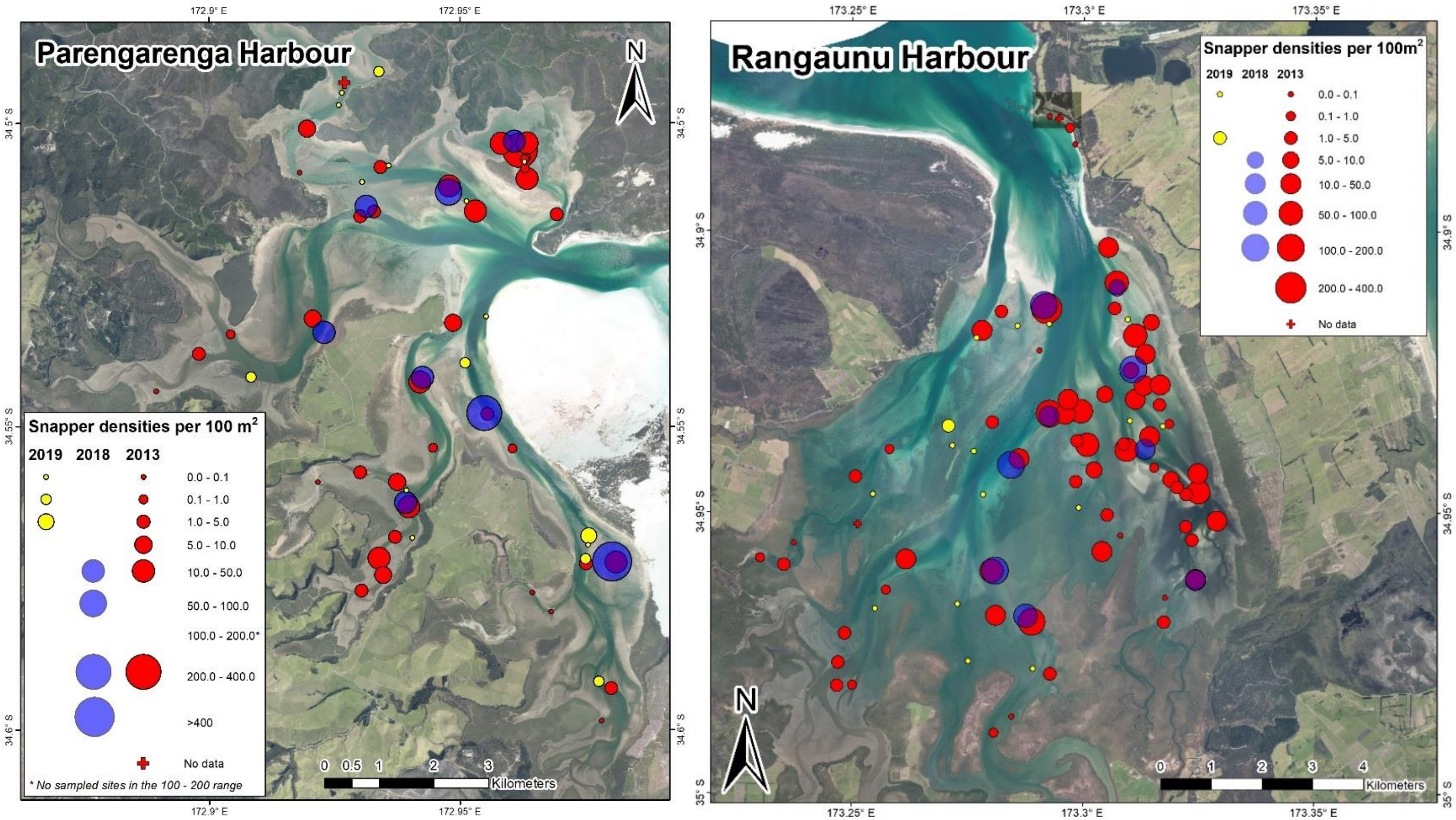


Figure 21. Juvenile 0+ snapper catch rates from previous surveys of Parengarenga, Rangaunu and Whangarei harbours, contrasted with to 2019 survey catch rates. Note that the symbols are not proportional in scale, to avoid small or nil catches being displayed at scales too small to visualise. Images from Google Earth; Left) Image ©2019 CNES /Airbus © Google. Data SIO, NOAA, US Navy, NGA GEBCO. Image © Terrametrics, Right) Image © 2019 Terrametrics, Image © 2019 CNES / Airbus, © 2018 Google; Image © 2019 Maxar Technologies.

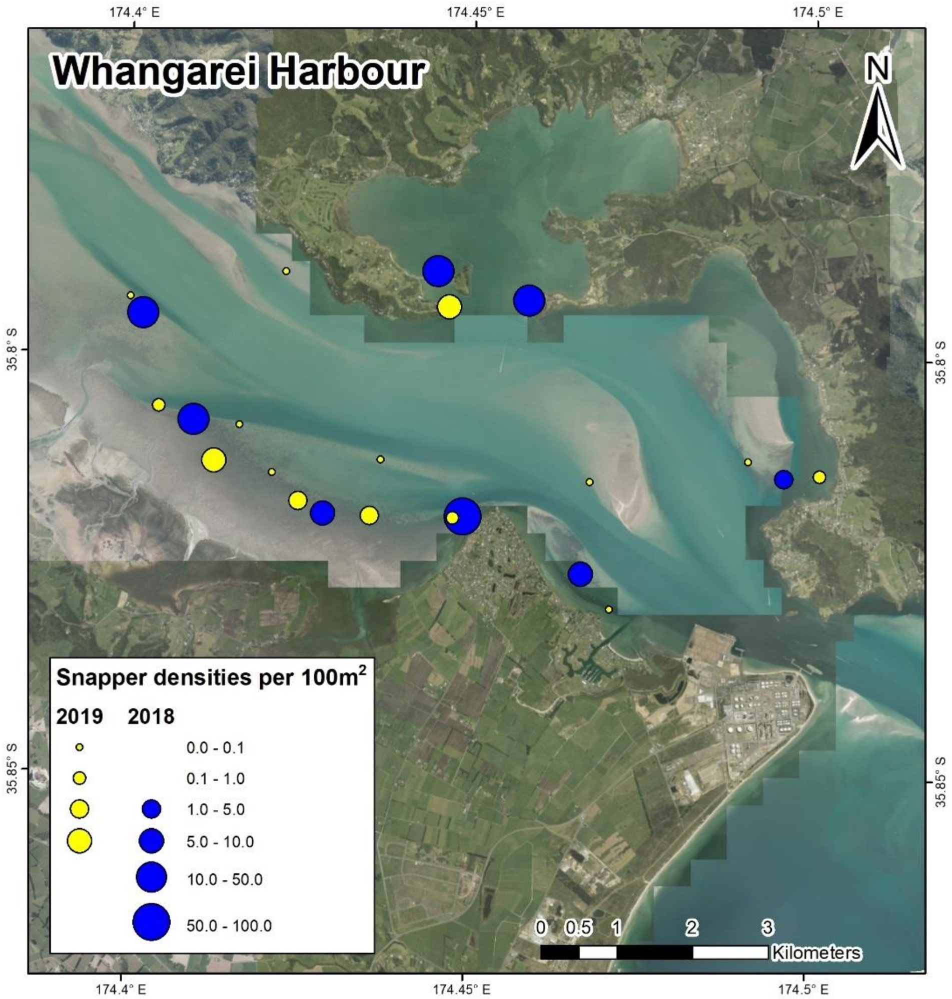


Figure 21 continued. Image from Google Earth: Image © 2019 Maxar Technologies, data SIO, NOAA, US Navy, NGA, GEBCO, © 2018 Google, image © 2019 CNES / Airbus

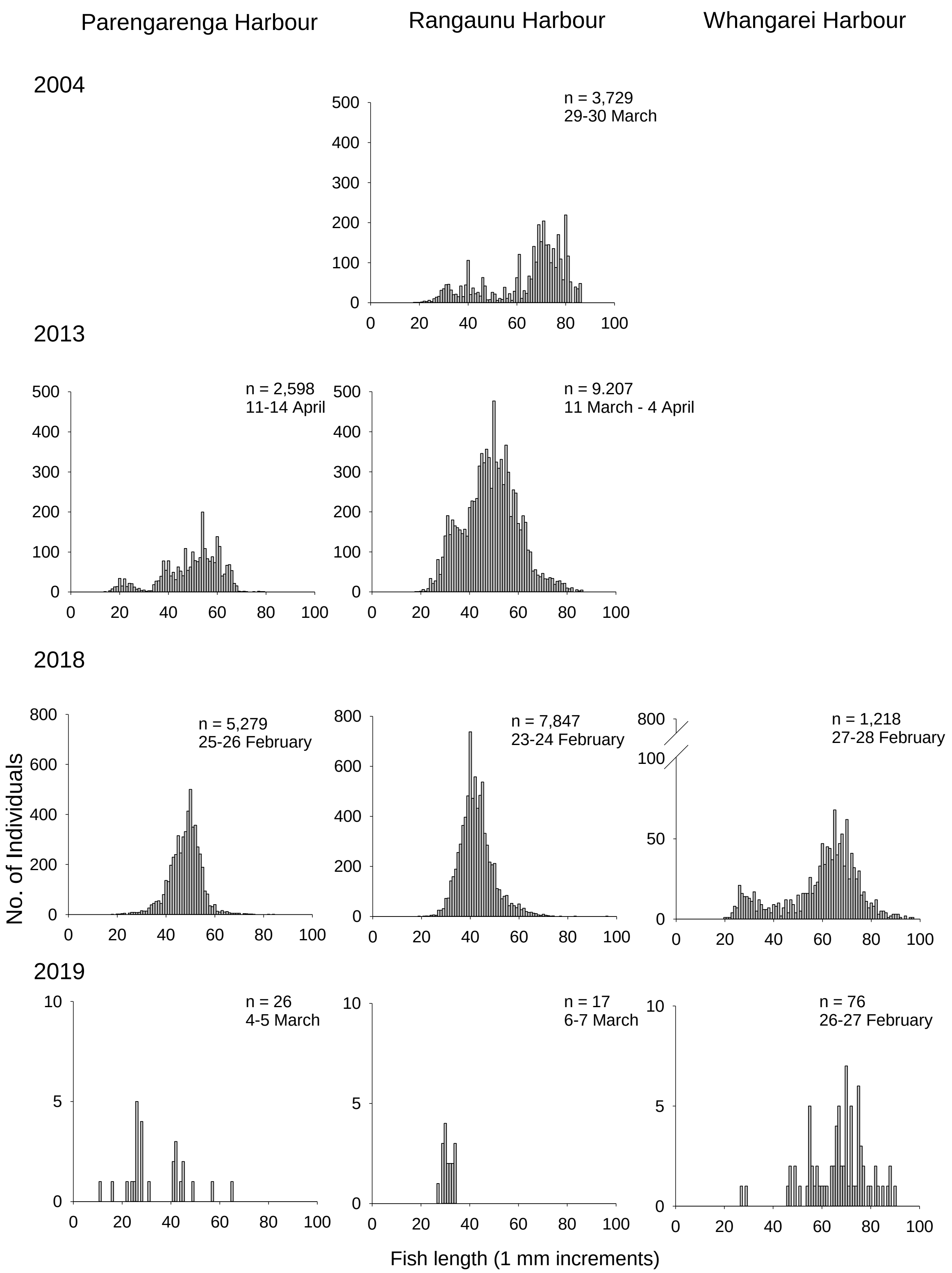


Figure 22: Snapper length frequencies from different beach seine surveys of Parengarenga, Rangaunu, and Whangarei harbours (raw data, no scaling by strata). Note that the y-axis scaling varies across graphs. n, total number of snapper measured; and date of sampling given. Sampling intensity and design varies between times and harbours (see Table 4).

4. DISCUSSION

Two pilot beam trawl surveys were successfully completed, with the East Northland survey returning a population estimate of 643 000 individuals (CV 19%), and the Hauraki Gulf survey an estimate of 10 686 000 individuals (CV 16%). While no target CVs were set in the project's objectives, these CVs are less than 20%; often the target set for Fisheries New Zealand finfish and shellfish abundance/biomass surveys. They demonstrate that 0+ snapper beam trawl surveys can return acceptable CVs and potentially provide a statistically robust way of estimating year class strengths. The stratification developed from previous surveys in 2017 (Hauraki Gulf) and 2018 (East Northland) worked well, suggesting that these strata are temporally stable with regards to spatial variation in abundance.

These findings reinforce the seasonal presence of high 0+ snapper densities in particular estuarine and coastal areas, including Whangaroa Harbour, the Bay of Islands, and Whangaruru Harbour in East Northland; and Kawau Bay to Whangaparoa, eastern Tamaki Strait and Ponui Channel, and the mid-western Coromandel coast (Te Houma Harbour and Coromandel Harbours, Waimate embayment), as well as including the Firth of Thames given its large size, for the Hauraki Gulf proper. On the eastern Coromandel, smaller pockets of high density nurseries occurred at Port Charles, northern Kennedy Bay, and in Mercury Bay proper. Port Fitzroy on Great Barrier Island also holds snapper nursery value, but this may be more variable across different years (in 2019, only 22 000 fish, CV 30%, but in 2017, 200 000 fish, CV 29%, Morrison et al., unpubl. data). Also of note was Mahurangi Harbour which was identified as a 0+ (and older juvenile year classes) snapper nursery by Morrison & Carbines (2006). In this 2019 survey it held only 5 000 fish (CV 97%, five stations) and in 2004 (March–April) it held 105 000 0+ snapper (CV 17%, 62 stations). Subsequent work by Usmar (2009) returned year-class population estimates of 115 000 in 2006, and 321 000 in 2007. One potential explanation is that Mahurangi Harbour fish-habitats may have been degraded ecologically from catchment sediment run-off (Morrison et al. 2009, Usmar 2009), and this low 2019 estimate may be indicative of a loss of fish nursery function (as fish densities in adjacent coastal Gulf strata were much higher).

In East Northland, the 2019 beach seine surveys returned very low population sizes and much higher CV's, relative to the 2019 beam trawl surveys, which from the viewpoint of a single year (2019) would suggest limited value in these beach seine surveys. With a combined four-harbour 2019-year class estimate of only 68 000 individuals (CV 58%), of which 62% was contributed by Whangarei, these subtidal seagrass habitat areas were largely devoid of 0+ snapper. This high CV (and the individual harbour's CV) was unsurprising, given the very low fish densities, that most stations did not have any snapper with catches clustered in only one or two stations per strata, and the relatively low level of sampling replication.

However, these results are in stark contrast to all previous beach seine surveys (and informal visits in some non-survey years for fish collection), where 0+ snapper catches were consistently in the thousands (even with low sampling effort), e.g., 8 beach seine tows per harbour in 2018 captured 5270 individuals from Parengarenga, 7847 individuals from Rangaunu, and 1218 individuals from Whangarei; contrasted with the present 2019 survey's catches of 26, 17, and 76 respectively.

A 2013 fish-habitat survey (quasi-random) of Parengarenga and Rangaunu harbours returned population sizes of 1.081 million (CV 17%) and 1.886 million (CV 34%) respectively. With a combined population size of 2.967 million, this is in strong contrast to the 2019 combined estimate for these two harbours of 21 000 fish (0.007% of the 2013 population size). The 2013-year class for East Northland (and the Hauraki Gulf) has not yet fully recruited into the commercial fishery (most recent available data 2017–18) and will need several more years to do so, before relative year-class strength can be assessed

No previous quantitative information exists for Houhora Harbour. Informal beach seine collection of 0+ snapper for otolith chemistry in 2018 in an area with limited and poor-quality seagrass still returned around 200 small snapper (around 2 cm), along with a dozen larger juveniles (30–50 mm), suggesting much higher recruitment than in 2019 (14 fish from one station; four subtidal seagrass stations sampled). Whangarei Harbour also has little older survey data. The limited previous data available shows a strong decrease in recruitment numbers between the 2018 and 2019-year classes for the one-dimensional subtidal seagrass habitat stratum, from 17 056 0+ snapper per km of subtidal seagrass habitat in 2018, down to 167 per km) in 2019.

While snapper recruitment is known to vary widely from year to year (which is why recruitment surveys are needed), this almost complete absence of 0+ snapper from very high-quality subtidal seagrass habitats is unprecedented (c.f. all previous surveys/collections, and other northern areas with subtidal seagrass (e.g. Kaipara Harbour, Bay of Islands; Morrison et al. 2014c). Additional searching of the best quality seagrass habitats seen in Rangaunu Harbour by the very experienced 2019 survey team caught no snapper at all. Our speculative suggestion is that a recruitment failure has occurred for these Far North systems in 2019. The only alternative explanation is that the surveys were conducted either after the juvenile fish had left the subtidal seagrass habitats, or before they had recruited in from the plankton. Both possibilities are highly unlikely. The surveys were conducted between 28th February and March 6th; within the time window of previous surveys (26th February to April 4th). Those previous surveys (Parengarenga, Rangaunu) returned fish modes mainly in the 40 to 60 mm range (up to 80 mm in 2004), representing fish ages of 35 to 65 days post-settlement (Stewart 2018). The net mesh can retain snapper as small as 9 mm long (immediately post-settlement fish) when caught up with by-catch debris (e.g. seagrass blades, cockle and larger dead shells, woody debris), although most fish of such small size will pass straight through the meshes. The size selectively of the beach seine nets has not been quantified, but is thought to approach 100% around 17–18 mm. Even very late-spawned fish were likely to have been encountered if present.

If juveniles had been spawned very early in the season, they would still have been in the subtidal seagrass systems of the four harbours; and more broadly, the deeper channel system of Whangarei Harbour. Exactly when 0+ snapper leave shallow subtidal seagrass habitats is poorly known, but fish can be present in high densities in early May, and then usually disappear before the end of June; which seems to correlate well with the first cold snap of winter. In harbours with deeper subtidal channel areas with a range of habitats, they can spend their first 18 months in the harbour (e.g., Kaipara Harbour, Francis et al. 2012, Mahurangi Harbour, Morrison et al. unpubl, data), occurring in the deeper areas of the channels, before dispersing out into the coastal system. The beam trawl survey of Whangarei, conducted after the beach seine work, found relatively few juveniles in its deeper subtidal channels (35 000, CV 83%), providing no evidence of early movement of large numbers of recruits off into deeper habitats. Rangaunu Harbour, in contrast to Whangarei Harbour, has only limited subtidal channel areas, which do not hold 0+ snapper once beyond the lower depth boundary limits of subtidal seagrass (Morrison et al., unpubl. data). The first coastal area encountered by 0+ fish leaving the harbour is Rangaunu Bay, which the harbour opens out to. As with Whangarei Harbour, no evidence of significant numbers of 0+ snapper was found in Rangaunu Bay, where 0+ snapper densities were very low, with a total population size of 41 000 fish (CV 69%). Collectively, there was no evidence to suggest that 0+ snapper had recruited into the subtidal seagrass meadows very early, and then left these habitats by late February, before the beach seine surveys commenced. No historical beach seine data are available for Hauraki Gulf subtidal seagrass habitats, as this habitat is now extremely rare and functionally extinct in the Gulf (Schwarz et al. 2006, Morrison et al 2009, 2014a-c).

Other data uses

The 2019 beam trawl survey data will also be very useful for other purposes. The seafloor video generated from the attached Go-Pro cameras, along with the quantified beam trawl by-catch, will be of great utility in contributing to seafloor nursery/non-nursery habitat maps currently being developed in the MBIE Bottlenecks programme. This includes beam trawl stations located over seafloor areas very recently fully mapped with high resolution multibeam echo sounders. In the Hauraki Gulf, this includes Port Fitzroy (BARR), the eastern Ponui Island to Tarakihi Island area (parts of MIDD, SCUL) the Waimate Island embayment (WMTE), and part of Port Charles (CHAR); funded by MBIE Bottlenecks, Foundation North, Auckland Council, Waikato Regional Council, and NIWA Vessel Fund contributions;, as well as Kawau Bay and south (KAWA, KETE), East Coast Bays (ECBY), Tamaki Strait (TAMA) and the Noises Islands (NOIS) areas through Land Information New Zealand (LINZ). In East Northland, Whangaroa Harbour (PEKA, PEAC, TOTA) has been mapped by MBIE Bottlenecks and LINZ (two surveys), as well as the Bay of Islands (deeper than 10 m) by the LINZ Oceans2020 BOI programme in 2008 (deeper than 10 m areas of TEPU, KERI, BROT, OUTR, BLAC, BRAM, OPUA, RAWHH, BOIE). These beam trawl data will be integrated with the multibeam data, to help build the seafloor habitat maps. In turn, those habitat maps are likely to enable more effective beam trawl habitat-based stratification designs in the future; as well as explicitly identifying nursery areas and habitats, and their boundaries, for more proactive directed ecosystem-based fisheries management.

All the 0+ snapper caught in the 2019 beam trawl and beach seine surveys have also been archived (in frozen form). Current MBIE Bottlenecks work is investigating the potential of otolith chemistry to assign fish back to specific nursery areas, using 2017 and 2018 year-class fish collected across East Northland and the Hauraki Gulf. If individual nursery/area elemental signatures can be developed, then it will be possible to track the spatial connectivity of different nursery areas to different regions of the SNA 1 stock, and their relative contributions to overall snapper recruitment. For the 2017 and 2018-year classes, it is planned to collect fish for this purpose (as practical) from the upcoming Hauraki Gulf and Bay of Plenty Kaharoa trawl surveys (2017 year-class as 3+ fish; 2018 year-class as 2+ fish), and then later on in 2024 or later, as adults 5+ years or older, once they have fully recruited to the fished component of the SNA 1 stock. There is potential in the future to also use the 2019-year class samples in the same fashion.

5. CONCLUSIONS

The results from the two pilot beam trawl surveys confirm that beam trawl surveys can be successfully run across East Northland and the Hauraki Gulf, and return acceptable coefficients of variation for juvenile snapper. Whether these estimates provide a means to accurately predict recruitment to the fishery remains to be tested. This will require comparisons of several beam trawl / beach seine 0+ snapper year-class surveys, against the same year classes once they have fully recruited to the adult fishery. Ideally, these will encompass both weak and strong year-classes, to allow for good contrasts.

Depending on survey requirements, future surveys could drop some of the strata that hold a relatively low proportion of a year-class's population, and their stations reallocated to other strata with higher contributions, to improve the CVs. We would suggest caution with this, because in very high year-class recruitment years, those lower value strata may produce higher year-class proportional contributions, and many fish recruits could be 'forced out' into these (putatively less optimal) strata, as the best habitat areas/strata become saturated (the core hypothesis of the current MBIE Bottlenecks programme). Despite lesser fitness outcomes expected for these fish in these lower value habitats/areas (reduced survival and growth rates), they will still contribute to year-class strength.

Multiple large, spatially stable snapper spawning aggregations are also known to occur seasonally across the East Northland and Hauraki Gulf sub-stocks (at least 4 in East Northland, and 5 in the greater Hauraki Gulf; each suspected to be tied to a nursery area). The spatial linkages between these spawning aggregations and nursery habitat areas may change in the future, through shifting oceanographic larval transport mechanisms (including climate change impacts). Continued monitoring of as many 0+ snapper nursery strata as possible will future-proof surveys against any large spatial shifts in recruitment patterns over time.

We would suggest that beach seine surveys are also important, notwithstanding the 2019 survey results, with the subtidal seagrass habitats of East Northland providing a high proportion of overall snapper recruitment (e.g., as in 2013). The likely 2019 year-class recruitment failure in the Far North estuaries (Parengarenga, Rangaunu and Whangarei harbours) and probably (to a lesser extent) in the coastal zone, could be of concern if it persists over multiple years beyond 2019. The MBIE Bottlenecks programme is planning to assess 0+ snapper mortality rates in Rangaunu Harbour subtidal seagrass in 2020, which will provide some information on the 2020-year class. We know of no other planned work in East Northland that will further investigate potential 0+ snapper recruitment failure, before 2024–2025, when the 2019-year class will start to recruit into the adult fisheries and become available to data collection through the ongoing commercial fish shed catch-at-age MPI sampling programme.

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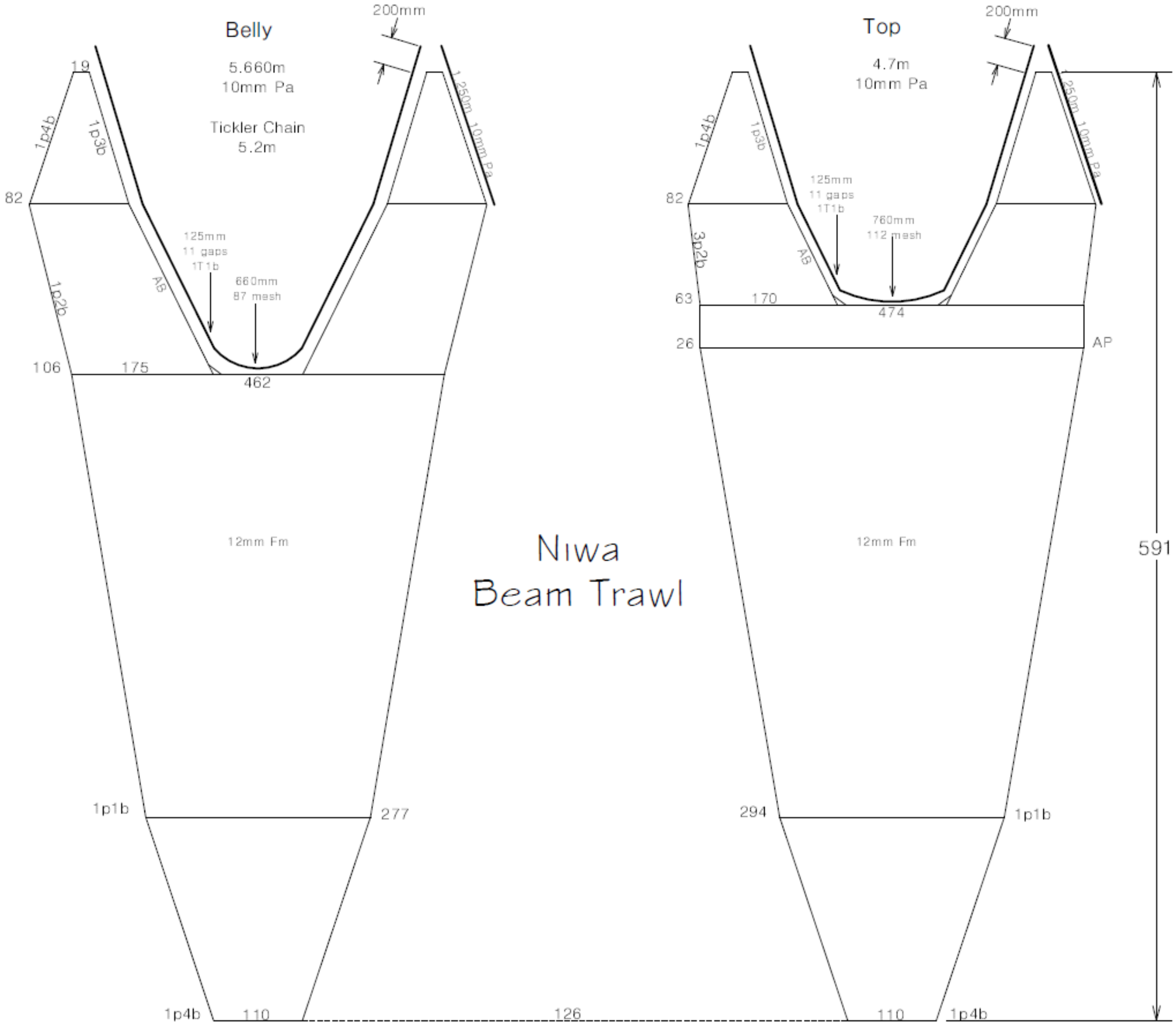
APPENDIX 1: Net plan for beam trawl



APPENDIX 2: Catch summary of all finfish and squid species caught by beam trawl and beach seine

		Beam trawl			Beach seine				
Common name	Scientific name	Hauraki Gulf	East Northland	Total	Parengarenga	Houhora	Rangaunu	Whangarei	Total
Anchovy	*Engraulis australis*	1610	26	1636	-	-	-	-	-
Snapper (< 10 cm / 0+)	*Pagrus auratus*	562	167	729	17	14	26	76	133
Snapper (>9 cm)		14	3	17	-	-	-	-	-
Green greasy-backed prawn	*Metapenaeus bennettae*	168	1	169	-	-	-	-	-
Spotty	*Notolabrus celidotus*	28	137	165	58	1	8	335	402
Triplefin	*Tripterygiidae*	8	150	158	412	77	879	60	1428
Jack mackerel	*Trachurus spp.*	62	1	63	-	-	3	-	3
Red mullet	*Upeneichthys lineatus*	52	2	54	-	-	-	1	1
Sand flounder	*Rhombosolea plebeia*	7	27	34	-	-	-	-	-
Opalfish	*Hemerocoetes sp.*	18	14	32	-	-	-	-	-
Leatherjacket	*Meuschenia scaber*	20	2	22	-	-	1	10	11
Pilchard	*Sardinops sagax*	5	15	20	-	-	-	-	-
Sole	*Peltorhamphus sp.*	11	6	17	-	-	-	-	-
Trevally	*Pseudocaranx georgianus*	17	-	17	-	-	-	1	1
Red gurnard	*Chelidonichthys kumu*	11	-	11	-	-	-	-	-
Witch	*Arnoglossus scapha*	6	3	9	-	-	-	-	-
Clingfish	*Gobiesocidae*	4	3	7	-	-	-	-	-
Red cod	*Pseudophycis bachus*	7	-	7	-	-	-	-	-
Pipefish	*Syngnathidae*	1	5	6	-	-	-	-	-
Bastard red cod	*Pseudophycis breviuscula*	2	3	5	-	-	-	-	-
Broad squid	*Sepioteuthis australis*	-	5	5	-	-	-	-	-
Topknot	*Notoclinus fenestratus*	-	4	4	-	-	-	-	-
Rock cod	*Lotella rhacinus*	3	-	3	-	-	-	-	-
Lizardfish	*Synodontidae*	-	2	2	-	-	-	-	-
Red snapper	*Centroberyx affinis*	-	2	2	-	-	-	-	-
Spotted stargazer	*Genyagnus monopterygius*	1	-	1	-	-	-	-	-
Squid		1	-	1	-	-	-	-	-
Yellowbelly flounder	*Rhombosolea leporina*	1	-	1	-	-	-	-	-
Sand goby	*Favonigobius lentiginosus*				119	210	1176	85	1590
Exquisite goby	*Favonigobius exquisites*				377	355	488	171	1391
Garfish/piper	*Hyporhamphus ihi*				94	770	351	153	1368
Yellow-eyed mullet	*Aldrichetta forsteri*				64	36	76	46	222
Parore	*Girella tricuspidata*				18	1	24	46	89
Grey mullet	*Mugil cephalus*				-	22	-	-	22
Flatfish					-	2	-	-	2
Scorpion Fish	*Scorpaena papillosa*				-	-	1	-	1
Kahawai	*Arripis trutta*				-	1	-	-	1
Total		2619	578	3197	1159	1489	3032	984	6664
Number of speces		24	20	26	8	11	11	11	16