Fisheries New Zealand
Tini a Tangaroa

Survey of scallops in Kaipara Harbour, 2017

New Zealand Fisheries Assessment Report 2018/20

J.R. Williams,
R. Bian,
C.L. Roberts.

ISSN 1179-5352 (online)
ISBN 978-1-77665-909-8 (online)

June 2018

New Zealand Government

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-and-resources/publications
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Williams, J.R.; Bian, R.; Roberts, C.L. (2018). Survey of scallops in Kaipara Harbour, 2017.

***New Zealand Fisheries Assessment Report 2018/20.* 29 p.**

A dredge survey of scallops (*Pecten novaezelandiae*) in Kaipara Harbour was conducted in 2017 to inform management of the harbour's non-commercial (recreational and customary) scallop fishery. The objectives of the survey were to 1) estimate the distribution, size structure and relative abundance of scallops in the harbour; and 2) compare data from this survey with data collected in the August 2007 and November 2009 surveys to establish if changes have occurred in the scallop population.

The 2017 survey used a single-phase stratified random survey design. The overall sample extent (189.5 km^2) was divided into two areas, 'previously surveyed' (29.5 km^2) and 'unsurveyed' (160 km^2); this enabled direct comparisons to be made among the 2007, 2009, and 2017 surveys, and investigated whether scallop beds existed elsewhere in the harbour. Stratification was based on the previous survey data, and on depth, geographical area, and local knowledge of possible scallop habitat. Sampling was conducted using a similar vessel and the same recreational scallop dredge as that used previously. Previous surveys towed two bag dredges simultaneously at each station, but, in the present study, analysis of the previous survey data suggested that there was no difference in the population estimates generated in terms of using the data from just one or from both dredges. On this basis, the 2017 survey sampling was conducted by towing a single bag dredge at each station.

The survey was carried out during nine days between 4 September and 13 October 2017. A total of 189 valid stations were sampled within the 30 strata. Scallops were caught in only a few strata, the vast majority in the Shelly Beach bed, with no scallops caught at the previously important bed at Tinopai, only limited numbers in the Tauhoa bed, and only one scallop was caught in the entire northern area of the harbour. There was limited evidence of scallop beds in the previously unsurveyed area of the harbour, despite the comprehensive sampling effort. Additional dredging was conducted in November 2017 to collect scallops for biological studies of length-weight, condition, and disease.

Analysis of the data from all three surveys showed that the status of the Kaipara Harbour scallop population was very low in 2017 compared with 2007 and 2009, with a marked reduction in the distribution and abundance of scallops between 2007/2009 and 2017. In the 'previously surveyed' area consistently surveyed in all three surveys, the estimated population of harvestable sized scallops (100 mm or larger) was 0.40 million (18% CV) in 2017, compared with 0.68 million (14% CV) in 2009 and 0.62 million (14% CV) in 2007. The population size structure was dominated by large scallops in all three survey years, but there were comparatively very few scallops smaller than 80 mm caught in 2017, indicative of low juvenile recruitment. Histopathology and bacteriology investigations by MPI detected that several diseases were present in the scallops collected in November 2017.

The 2017 survey provides evidence that the Kaipara Harbour scallop population has declined, but research has not been conducted to investigate the cause(s) of this decline. Low recruitment may be a factor, and it is likely that the Shelly Beach scallop bed contains the only spawning stock remaining in the harbour; conserving this population should be prioritised. Anthropogenic (e.g. overfishing, effects of fishing, and land-based effects such as increased turbidity and sedimentation) and natural sources (e.g. disease) both contribute to scallop mortality and can result in population declines. The absence of scallops in areas of the harbour which previously supported dense beds suggests that the suitability of the habitat has degraded. New research is required to improve our understanding of the link between scallop biology and habitat, and inform restoration.

1. INTRODUCTION

1.1 Overview

Kaipara Harbour is a large enclosed harbour estuary complex located on the west coast of New Zealand's North Island (Figure 1). The harbour is nationally significant for its intrinsic and amenity value, natural resources, and cultural and historical importance (Haggitt et al. 2008), and contains habitats of particular significance for species that support key fisheries, including scallops (*Pecten novaezelandiae*).

Scallops in Kaipara Harbour support an important non-commercial (recreational and customary) fishery, which is managed as part of the SCA 9A scallop stock, a Group 4 stock in the draft National Fisheries Plan for Inshore Shellfish (Ministry for Primary Industries 2011). The two management objectives for Group 4 stocks in this Plan are 1) "Use Objective – Enable utilisation of each stock"; and 2) "Environment (Stock sustainability) Objective – Ensure catch is at a level that is sustainable".

Local ecological knowledge indicates that scallops were distributed extensively within Kaipara Harbour historically, but that relative scallop abundance declined substantially between the 1950s and 1980s (Morrison et al. 2014). Due to the apparent low availability of scallops to fishers, the harbour's scallop fishery was subject to temporary closures in 2005–07 and 2007–09. Towards the end of these closure periods, dredge surveys were conducted in August 2007 (Walshe & Holdsworth 2007) and November 2009 (Kelly 2009) to assess scallop population status. These were the first quantitative surveys of the scallop beds within the harbour. The 2007 and 2009 surveys showed that scallops were patchily distributed within the harbour, with large high-density beds on the eastern side of the Kaipara River channel, north of Shelly Beach, and on the southern side of the Otamatea Channel, south of Tinopai. Smaller low-density beds were located in the Oruawharo River, Arapaoa River, and Tauhoa Channel areas.

Concerns remain about the state of the Kaipara Harbour scallop fishery, and surveys are required to monitor scallop population status and inform management of the fishery. This report documents the findings of a 2017 dredge survey of scallops in the Kaipara Harbour, carried out under contract to the Ministry for Primary Industries (project SCA2015-02).

1.2 Objectives

The overall research objective was to assess scallop abundance in the Kaipara Harbour. The specific research objectives were to 1) estimate the distribution, size structure and relative abundance of scallops in the Kaipara Harbour; and 2) compare data from this survey with data collected in the August 2007 and November 2009 surveys to establish if changes have occurred in the scallop population. Conducting a 2017 survey enabled a third assessment of the scallop population in Kaipara Harbour, and analysing the data from all three surveys allowed examination of whether there have been changes in scallop population status among years.

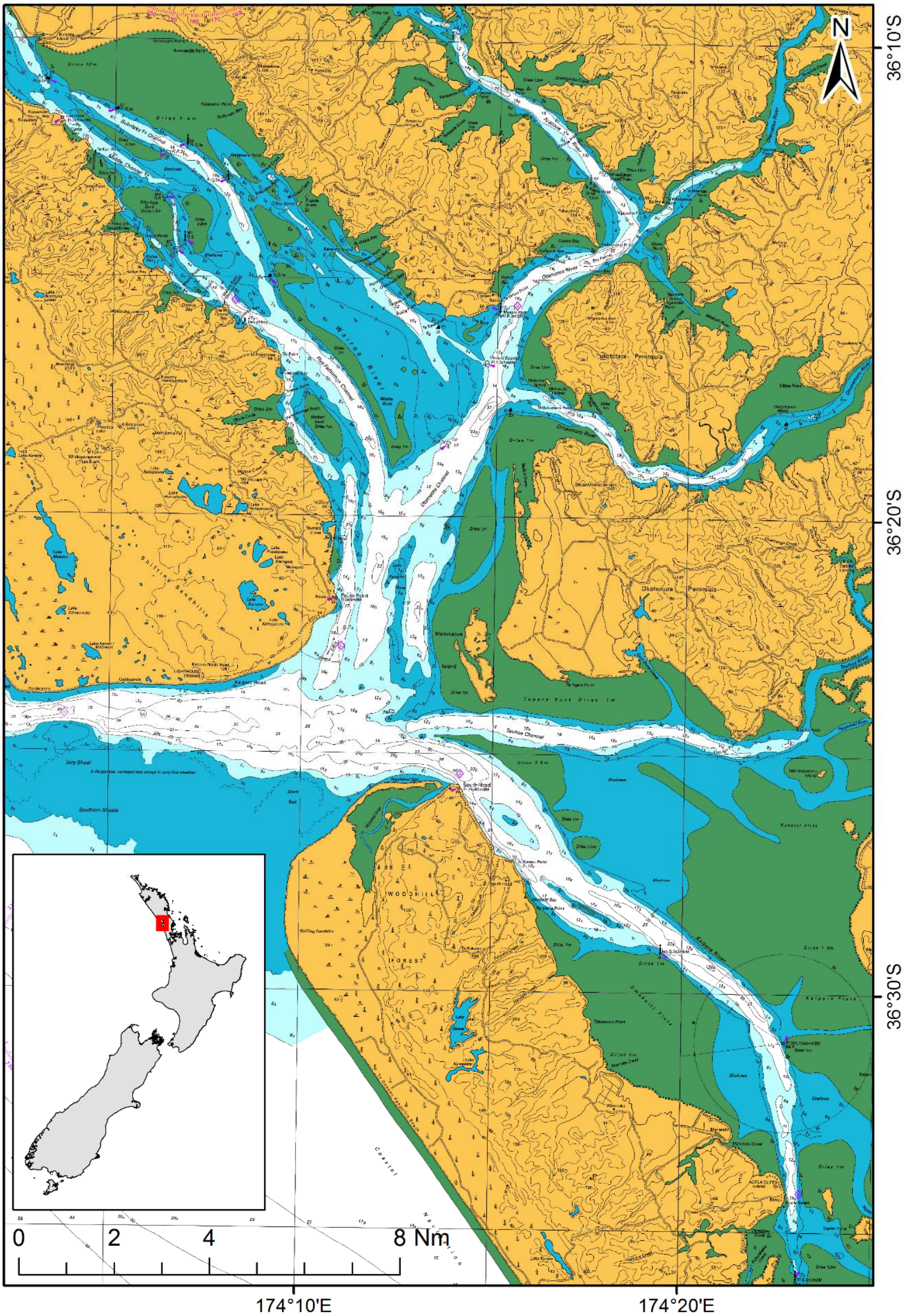

Figure 1: Location of Kaipara Harbour on the west coast of North Island, New Zealand. Chart source: Land Information New Zealand (LINZ).

2. METHODS

2.1 Survey design

The survey was conducted in September–October 2017 using a single-phase stratified random survey design. The survey timing was in between that used in the two previous surveys in 2007 (August) and 2009 (November) surveys.

The sample extent (i.e. overall survey area) used in the previous surveys was restricted to areas encompassing the known scallop beds identified in the initial survey in 2007. Examination of a nautical chart of Kaipara Harbour (LINZ chart NZ4265), published local ecological knowledge (Morrison et al. 2014) and discussions with local fishers suggested that potential scallop beds could exist in other areas of the harbour outside of the areas previously surveyed. In 2017, therefore, we increased the sample extent to cover all areas of potential scallop habitat that could be sampled by dredge in Kaipara Harbour, with survey boundaries delineated by the channel edges marked on the chart (minimum of 2 m chart datum), the outer harbour survey boundary marked by a straight line drawn between Pouto Point and South Head, and inner limits based on bottom type.

The overall sample extent (189.5 km^2) was divided into two areas, 'previously surveyed' (29.5 km^2) and 'unsurveyed' (160 km^2), to enable direct comparisons to be made among surveys (areas calculated using ArcGIS®).

The previously surveyed area was divided into 15 strata (labelled 1–15) representing areas of high and low scallop abundance based on the 2007 and 2009 survey data, which suggested that scallop densities have generally been highest on the banks and bottom of the harbour channels. The previously unsurveyed area was divided into 15 strata (labelled 16–30) on the basis of a combination of depth, geographical area, and local knowledge of possible scallop habitat. One stratum (stratum 19, 2.7 km^2) could not be sampled during the survey because it was too shallow to permit dredging.

Stratum details are provided in Table 1, and a map of the stratification is shown in Figure 2.

Table 1: Stratum details for the Kaipara Harbour dredge survey, 2017. N.B. Stratum 19 was too shallow to be sampled; the total survey area was 189.5 km^2 excluding stratum 19.

Area type	Location	Stratum	Area (km^2)	Description
Surveyed_prev	Arapaoa	1	3.6	Arapaoa Low
		2	1.1	Arapaoa High
	Tinopai	3	0.4	Tinopai Low
		4	0.7	Tinopai High
	Outer Oruawharo	5	3.3	Outer Port Albert Low
		6	1.7	Outer Port Albert High
	Inner Oruawharo	7	1.0	Inner Port Albert Low
		8	0.7	Inner Port Albert High
	Tauhoa	9	1.7	Tauhoa Channel Low
		10	1.2	Tauhoa Channel High
	Outer Kaipara River	11	1.2	Outer Channel Low
	Inner Kaipara River	12	4.2	Channel South Low
		13	3.1	Channel South High
	Shelly Beach	14	4.7	Shelly Beach Low
		15	1.0	Shelly Beach High
Unsurveyed_prev	Local Ecological Knowledge (LEK)	16	0.5	Tinopai Bank LEK
		17	0.4	Tinopai Mussel Rock LEK
		18	1.8	Te Kauri Pt LEK
		19	2.7	Oruawharo Heads LEK
		20	1.0	Inner Port Albert LEK
		21	5.5	South Head Bank Deep
		22	1.9	South Head Bank Shallow
		23	2.5	Tauhoa Channel LEK
		24	2.6	Otamatea Channel LEK
		25	0.2	Te Whakarapa Pt LEK
	Unknown_prev	26	52.2	Wairoa River
		27	6.2	Otamatea River
		28	7.4	Tauhoa Channel outer
		29	17.0	Kaipara River outer
		30	60.9	Otamatea Channel outer
		Total area	192.2	

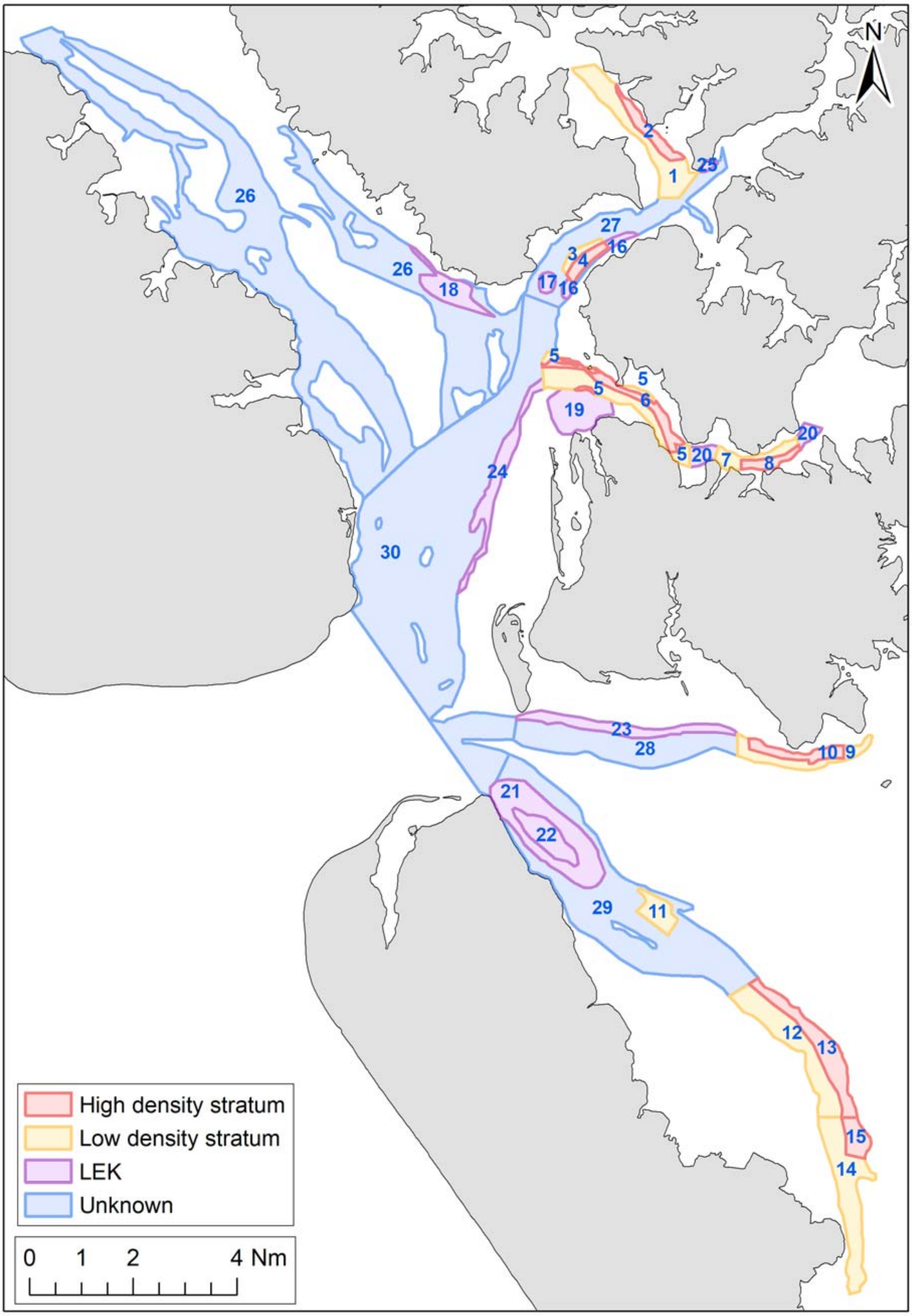

Figure 2: Stratification for the Kaipara Harbour scallop survey, September–October 2017. LEK, Local Ecological Knowledge. Previously surveyed areas (high and low density strata) were sampled separately to previously unsurveyed areas ('LEK' and 'Unknown'), enabling direct comparison of the 2017 survey results with those of the previous 2007 and 2009 surveys.

2.2 Station allocation

Station allocation was conducted using the R function *allocate* (Francis 2006), which allocates stations to strata so as to achieve a specified coefficient of variation (CV), or to minimise the CV with a fixed number of stations. The CV is calculated from historical survey data and the estimated areas of the strata. A minimum allocation of three stations per stratum is used.

The previous surveys each sampled 139 stations in total, requiring 9 days sampling in 2007 (mean of 15 stations per day) and 5 days sampling in 2009 (mean of 28 stations per day). We proposed to sample the same or more stations than that, with the aim of meeting a CV target of 20% for each of the scallop beds (stratum or groups of strata) that comprise the core areas in Kaipara Harbour.

The strata for the 2017 survey were intersected with station data from the 2007 and 2009 surveys, assigning historic catch densities (scallops 100 mm or larger per square metre swept area) to the 2017 survey strata. Boxplots of scallop density by stratum show that the 2017 stratification satisfactorily partitioned the high and low densities observed in 2007 and 2009, and that the two main scallop bed locations of Tinopai (strata 3 and 4) and Shelly Beach (strata 12 to 15) contained the highest densities of scallops (Figure 3).

Analyses in *allocate* were run to investigate how many stations would be needed to meet the target CV of 20% at the level of the overall survey area, at the level of all areas previously surveyed, and at the location level for the two main scallop beds at Tinopai and Shelly Beach. A total allocation of 186 stations was planned for the survey.

Station positions within strata were randomised using GIS software (ArcGIS®), constrained to keep stations a minimum distance apart to prevent dredge tows from overlapping.

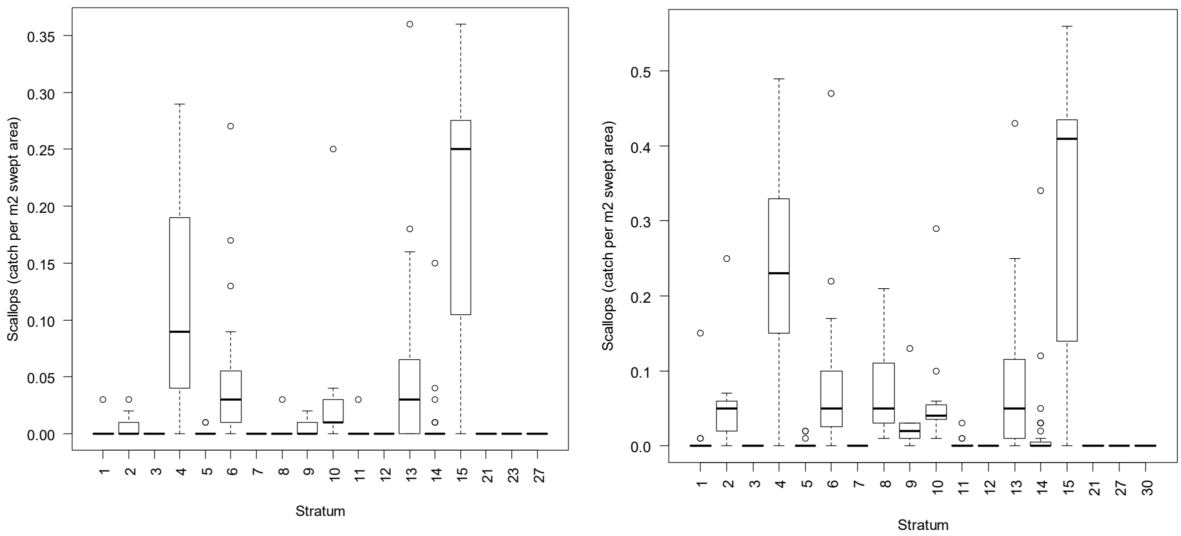

Figure 3: Boxplots of historic (2007 and 2009) survey catch density by 2017 survey strata. Left panel, scallops of recruited size (100 mm or larger); right panel, scallops of any size.

2.3 Vessel and gear

The 2017 survey was conducted using the chartered fishing vessel *Lady Frances* (Figure 4), a very similar vessel to those used in previous surveys (Table 2). The vessel skipper and bag dredge used were the same as those used previously (Walshe & Holdsworth 2007, Kelly 2009). The bag dredge was a lightweight galvanised steel dredge (0.6 m wide × 230 mm high) lined with a catch bag of 65–70 mm mesh (diagonal measurement made knot centre to knot centre with mesh pulled taut). The dredge was attached to the tow warp rope by 5 m of 10-mm diameter steel chain.

Previous surveys towed two bag dredges simultaneously at each station. In the present study, analysis of the previous survey data suggested that there was no difference in the population estimates generated in terms of using the data from just one or from both dredges (Appendix A). On this basis, we conducted the 2017 survey by towing a single bag dredge at each station, reducing the time spent processing catches, and increasing the time available for sampling additional stations.

Figure 4: Fishing vessel *Lady Frances* used in the Kaipara Harbour survey, 2017.

Table 2: Fishing vessels used in Kaipara Harbour scallop surveys.

Details			Survey
	2007	2009	2017
Trip code	SER0701	SHM0901	LAD1701
Vessel name	*Serene*	*Shamrock Too*	*Lady Frances*
MNZ number	101034	–	135188
Construction	steel	plywood	fibreglass
Length overall (m)	14.76	*14.30*	14.30
Beam (m)	*4.2*	*4.2*	4.55
Engine(s)	twin motors	single motor	single motor
	Detroit diesel	Scania V8 diesel	Man 450 diesel
Total engine power (hp)	*220–240 (110–120 ea)*	*425*	–
Total engine power (kW)	*164–179*	*317*	478

2.4 Dredging procedure

At each station, the vessel conducted a standardised 0.13 n.mile dredge tow using the same protocol as used in the previous surveys (Walshe & Holdsworth 2007, Kelly 2009). The GPS coordinates of the vessel position were recorded at the start and end of the tow, and the actual tow distance was monitored using the vessel's plotter, and an independent vessel tracking system (Voyage Tracker, Lennard Electronics Ltd.). The tow started when the winch brake was set, and ended when hauling with the winch commenced. The skipper was instructed to tow the gear (tow along the depth contour, select tow speed and warp length) so as to maximise the total catch at that station while avoiding crossing stratum boundaries, foul ground, and obstructions. The length of warp used for each tow was estimated by the skipper and recorded. At the end of the tow, the dredge was retrieved, the percentage fullness of the dredge visually estimated, the dredge contents were emptied into fish bins, and the catch volume was visually estimated. Each dredge catch was photographed.

2.5 Catch sampling

A standard dredge catch sampling procedure was used as follows. All live scallops were sorted from the catch and placed into fish cases. Dead scallops termed 'cluckers' (articulated scallops shells, shell hinge still intact) were also sorted from the catch to provide information on levels of recent mortality. All scallops (live scallops and dead 'cluckers') were measured for shell length (along the anterior–posterior axis, using digital callipers mounted on a measuring board). The entire catch (sorted live and dead clucker scallops, and the remaining unsorted bycatch) was characterised by estimating its volume and the percentage composition by species (or the lowest practicable taxonomic grouping). To aid this, common species were listed on the catch form in a number of predetermined categories (i.e. scallops; other bivalves; gastropods and cephalopods; starfish and echinoderms; polychaetes; bryozoans and hydroids; algae; sponges, ascidians and anemones; crustaceans; fish; substrate).

Sand dollars (*Fellaster zelandiae*, species code FZE, also commonly known as sea biscuits or snapper biscuits) were abundant at many stations, particularly in the outer harbour. At 22 stations, the catch of FZE was also measured (urchin test diameter). The vessel skipper commented that the size of FZE appeared to be smaller than in the past.

Several invasive (non-native) species were caught and quantified during the survey, including Asian date mussels (*Musculista senhousia*), clubbed tunicates (*Styela clava*), and Asian paddle crabs (*Charybdis japonica*). Dredge catches often contained a lot of mud/silt, except for in the outer areas of the harbour. Seawater clarity was generally very poor.

The tow data (date, station number, recorder, tow start and finish times and positions, wind force, water depth, warp length, dredge fullness, bottom type) and catch data (volume and percentage composition in scallop and bycatch categories) were recorded on pre-printed waterproof forms; the scallop length data were captured electronically. The bycatch data collected were stored in the *scallop* database but not analysed within this project.

2.6 Population estimation

A non-parametric resampling with replacement (bootstrapping) method was used to estimate the density, abundance and biomass of scallops from the Kaipara Harbour dredge surveys. This population estimation approach was originally described by Cryer & Parkinson (2006); an updated, and more detailed, description of the method can be found in Williams et al. (2013). The estimation method uses bootstrapping (1000 bootstrap iterations) to produce 1000 estimates of the metrics of interest (scallop density, abundance, greenweight biomass, and meatweight biomass).

In the analysis within this project, each of the 1000 bootstrap iterations involved the following three steps:

1. Sampling fraction. The "raw" length frequency distribution for each tow is "scaled" by the inverse of the sampling fraction, if required (no. of scallops measured / total no. of scallops counted).
2. Swept area. The "scaled" length frequency distribution for each tow is converted to "uncorrected" density at length per unit area of seabed swept by the dredge (assuming the dredge to be 100% efficient for all size classes and assuming the calculated area swept by the dredge is without error).
3. Weight at length. The "real" density at length for each tow is converted to a weight at length distribution, using a length-weight relationship to predict individual scallop weight from length. The length-weight model parameters a and b are randomly selected from 2000 sets of these parameters, applying them in the length-weight equation to convert density to weight.

Summary statistics (mean, CV, median and 95% confidence intervals) for the metrics of interest are calculated from the 1000 bootstrapped estimates at different levels of grouping (stratum, location, population).

Stratum length frequency distributions were calculated as the mean tow length frequency distribution for that stratum scaled by the stratum area. Length frequency distributions at higher levels of grouping (e.g. locations) were calculated as the sum of the stratum length frequency distributions for the strata within each location. The stratum areas were considered to be without error.

2.7 Comparative analysis

The dredge survey provided data to estimate the distribution, abundance/biomass and size structure of the Kaipara Harbour scallop population in 2017. Estimates produced were relative estimates only, because there is no information on the efficiency of the recreational bag dredge used in the surveys.

To enable comparisons among surveys, data from the previous 2007 and 2009 surveys were also reanalysed as follows. All data from the 2007 and 2009 survey data were extracted from the *scallop* database. Survey stations were intersected with the 2017 survey stratification using GIS software, and the data were reanalysed using the same resampling with replacement (bootstrapping) approach to scallop estimation described above.
Through this analysis, outputs from each survey year included:

1. maps showing scallop distribution and abundance (spatial density)
2. estimates of abundance (numbers and biomass)
3. population length frequency plots

These outputs were used to describe and interpret the status of the Kaipara Harbour scallop population in each survey year, and establish if changes have occurred in the population.

3. RESULTS

3.1 Survey sampling

The survey was carried out during nine days at sea between 4 September and 13 October 2017. A total of 189 valid stations (bag dredge tows) were sampled within the 30 strata (Figure 5). In stratum 15 (Shelly Beach bed), 10 of these stations were sampled by towing the bag dredge and a box dredge simultaneously, which suggested that the bag dredge was the better sampling gear for conducting the survey (Appendix B). A summary of the sampling conducted resulting in valid data for analysis is shown in Table 3.

Table 3: Sampling details, Kaipara Harbour scallop survey, 2017. Depths are those shown by the vessel's plotter, uncorrected for transducer depth or tidal height.

Trip code	Stations	Depth	Dredge	Species	Life status	Catch	Measured
LAD1701	189	range = 1–38 m	bag	SCA	live	797	791
		mean = 10 m			cluckers	28	28
	10	range =1–15 m	box	SCA	live	398	372
		mean = 9 m			cluckers	15	15

3.2 Biological sampling

After the completion of the survey, some additional dredge tows were conducted by the survey skipper on 6 November 2017 to collect scallops for biological studies. A total of 210 scallops were collected from tows in the scallop bed locations of Shelly Beach (5 tows, n = 198 scallops) and Tauhoa (2 tows, n = 12 scallops). These were processed in the laboratory by measuring individual length and green weight (n = 207 scallops), and by conducting dissections and weighing individual body components (muscle, gonad, viscera, shell) on a subset of these scallops (n = 24), and couriering another subset of scallops (n = 12 from each location) to the MPI Animal Health Laboratory in Wallaceville for disease investigations.

Length and green weight data for the Kaipara Harbour scallops collected fall within the range of observations of length weight measured in scallops collected from the Coromandel scallop stock SCA CS in previous research (Figure 6). The Kaipara length weight regression was used in the population estimation procedure of the present study to predict relative biomass.

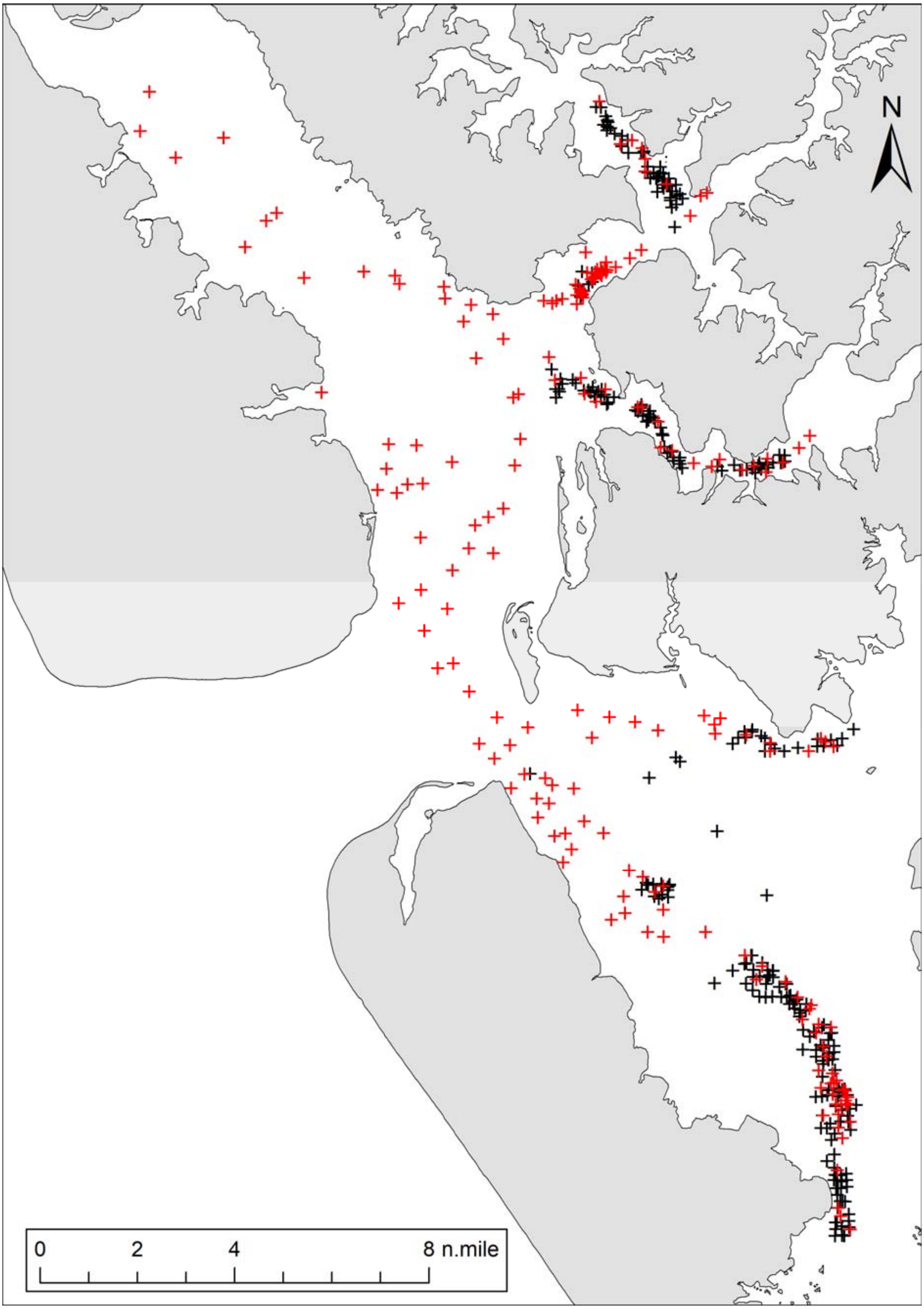

Figure 5: Station positions sampled (red crosses), Kaipara Harbour dredge survey, September–October 2017. Black crosses denote station positions sampled in the previous surveys in 2007 and 2009.

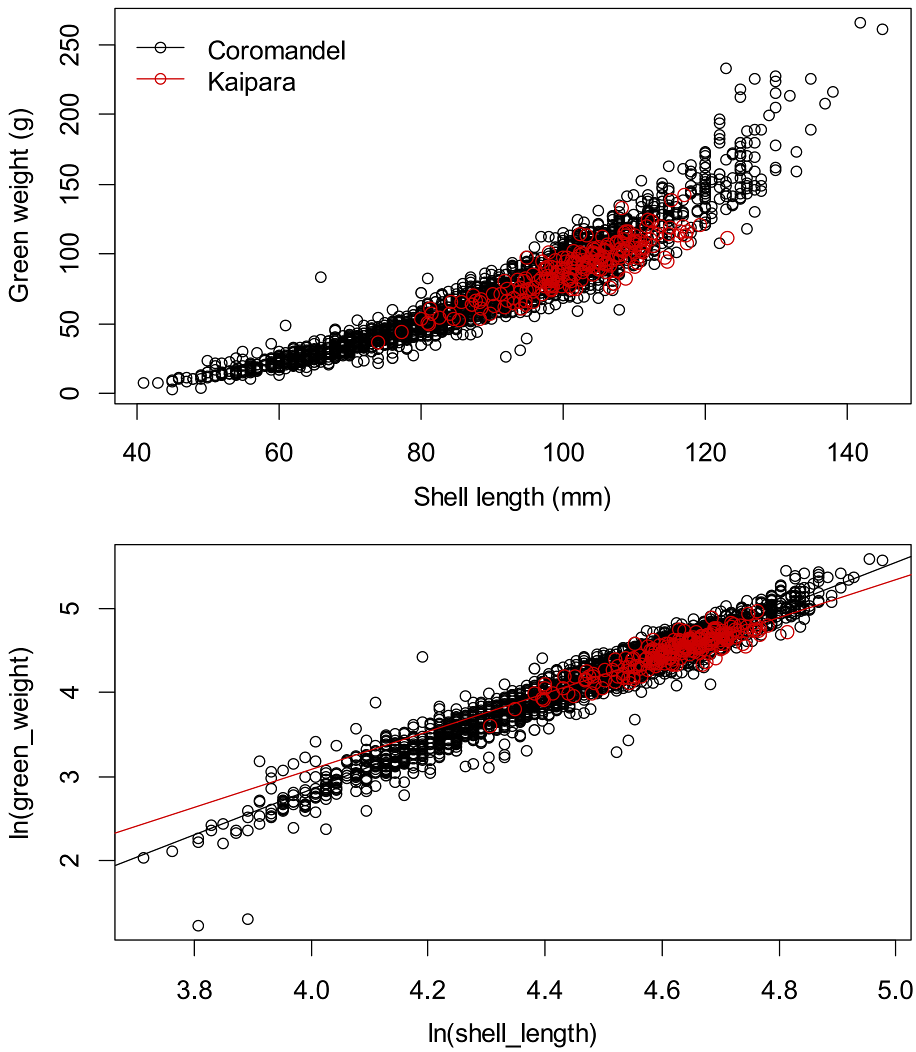

Figure 6: Length – weight data and least squares regression for scallops collected from Kaipara Harbour (red symbols, present study; *n* = 207) and the Coromandel scallop stock SCA CS (black symbols, unpublished data held by NIWA; *n* = 2504).

3.3 Spatial distribution

The distribution of relative spatial density (catch of scallops per standard 0.13 n.mile (250 m) dredge tow, expressed as scallops.m^{-2} for the area swept) in the 2007, 2009 and 2017 surveys is shown in Figure 7. Values are uncorrected for dredge efficiency, which is unknown for the bag dredge gear used in the surveys. These spatial density plots illustrate the marked reduction in the distribution of scallops between 2007/2009 and 2017. In 2017, scallops were caught in only a few strata, the vast majority in the Shelly Beach bed, with no scallops caught at the previously important bed at Tinopai, only limited numbers in the Tauhoa bed, and only one scallop was caught in the entire northern area of Kaipara Harbour (1 scallop, Arapoa stratum). There was limited evidence of scallop beds in the previously unsurveyed areas of Kaipara Harbour, despite the comprehensive sampling effort.

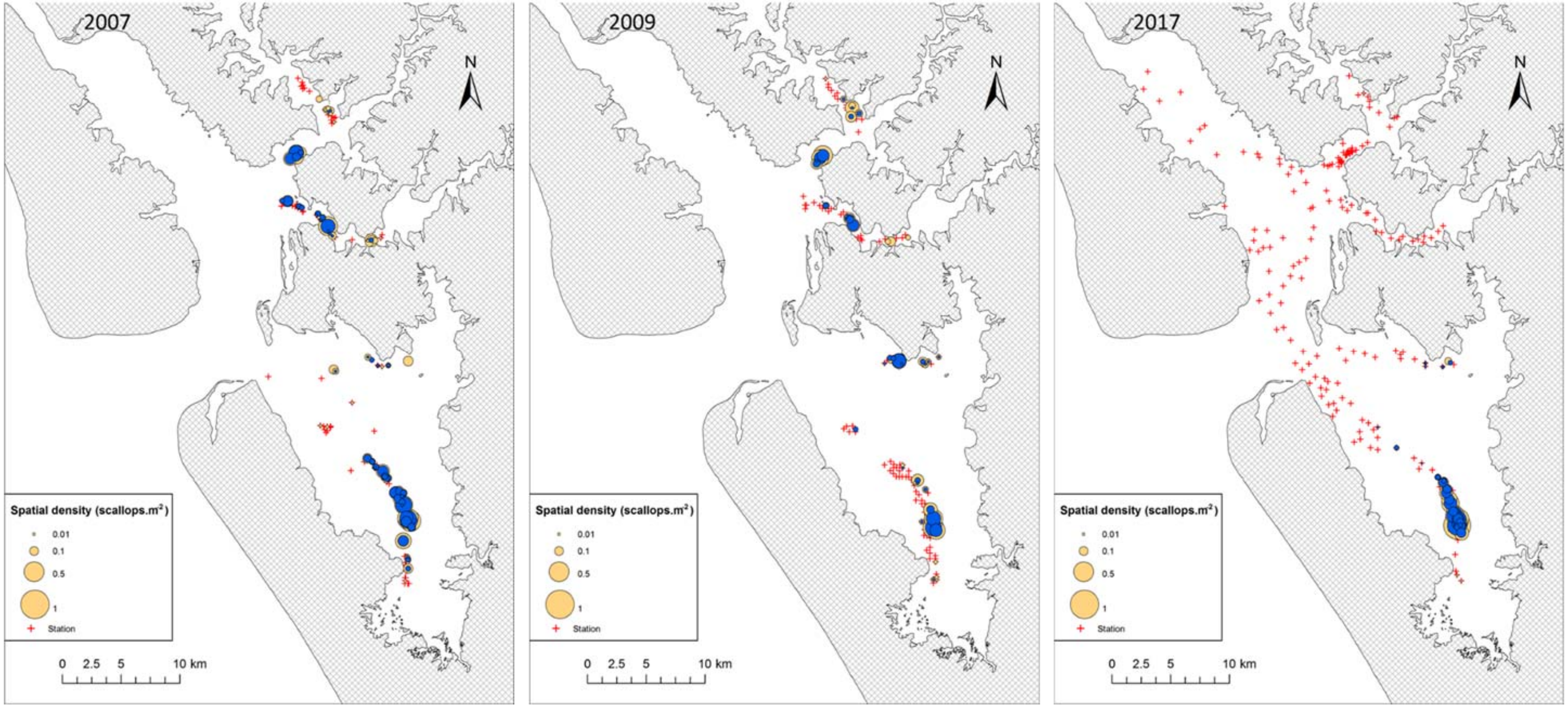

Figure 7: Scallop spatial density per standard tow, Kaipara Harbour, by survey year (left to right: 2007, 2009 and 2017). Circle area is proportional to density (scallops.m^{-2}). Dark blue shaded circles denote scallops of harvestable size (100 mm or larger), brown shaded circles denote scallops of any size. Values are uncorrected for dredge efficiency.

3.4 Abundance and biomass

Our estimation approach used non-parametric re-sampling with replacement (1000 bootstraps) to produce a sample of 1000 estimates of scallop biomass (or other metric of interest). A frequency distribution plot of those estimates provides the most complete description of the nature of the variation in our sample and can be viewed as an approximation of the uncertainty in our knowledge of the biomass. The CV (standard deviation divided by the mean) is a good measure of the dispersion of that sample. The median (as opposed to the mean) is the best measure of central tendency for our sample, and the 95% confidence interval (CI) is used to express the uncertainty in our estimate.

In 2017, the estimated population abundance of scallops of harvestable size (100 mm or larger) in the entire survey area was 0.43 million (95% CI = 0.28–0.61; mean = 0.44, CV = 19%); which equates to an estimated biomass of 44 t green weight (median value, 95% CI = 29–62 t; mean = 44 t, CV = 0.19; Figure 8). Population estimates by different spatial groupings are tabulated in Table 4.

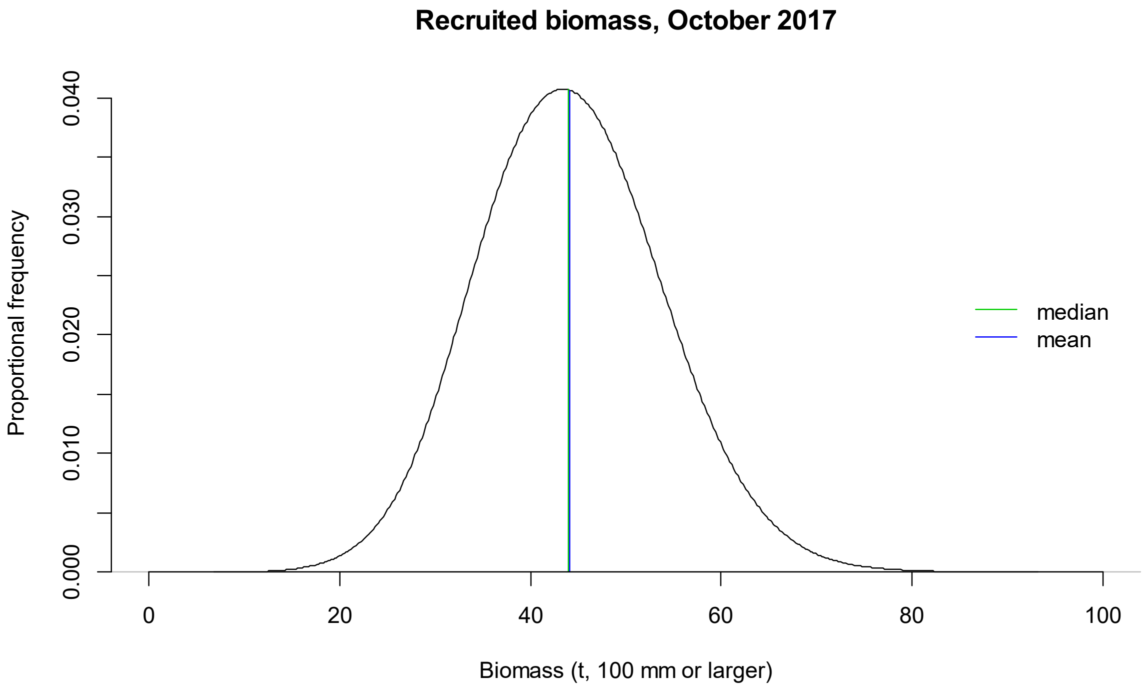

Figure 8: Proportional frequency distribution of the relative biomass (t green weight, uncorrected for dredge efficiency) of harvestable (‘recruited’) scallops (100 mm or larger) in Kaipara Harbour, 2017. The distribution was derived using a non-parametric resampling with replacement approach to estimating biomass (1000 bootstraps).

In the ‘previously surveyed’ area consistently surveyed in all three surveys, the estimated population of harvestable sized scallops was substantially lower in 2017 than in 2007 and 2009:

- 2007: 0.62 million scallops (14% CV), 63 t green weight (14% CV)
- 2009: 0.68 million scallops (14% CV), 71 t green weight (15% CV)
- 2017: 0.40 million scallops (18% CV), 40 t green weight (18% CV)

Changes in population density within the previously surveyed area are plotted at the finer spatial scales of location (Figure 9) and stratum (Figure 10), and tabulated for the four locations that have held key scallop beds since the 2007 survey (Table 5). In 2017, densities were lower than in 2009 at all locations except for Inner Kaipara River (containing stratum 13), which (together with stratum 15) held the one main scallop bed remaining in Kaipara Harbour in 2017.

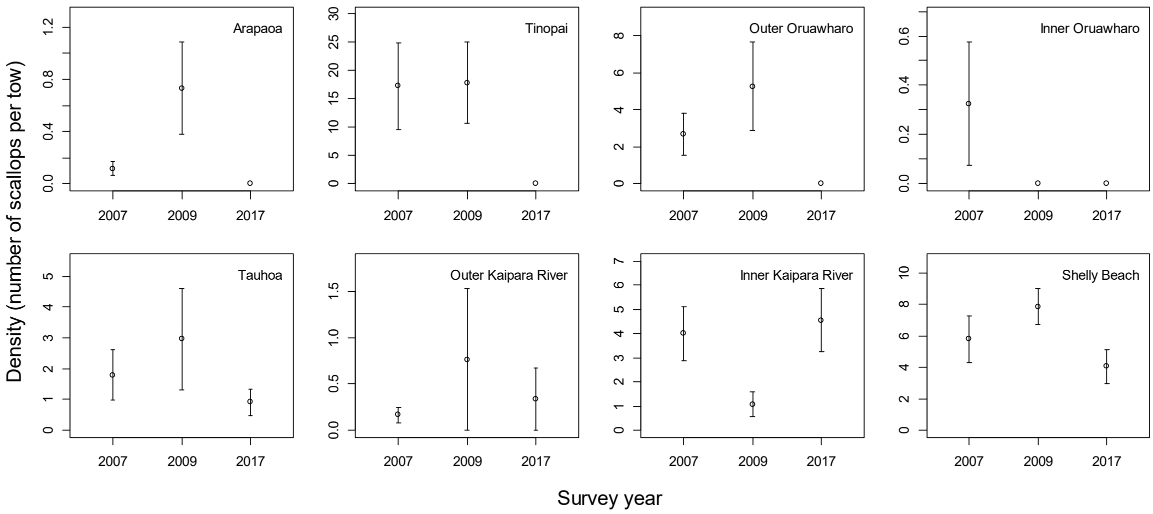

Figure 9: Estimated population density of scallops (100 mm or larger) by survey location in Kaipara Harbour in 2007, 2009, and 2017.

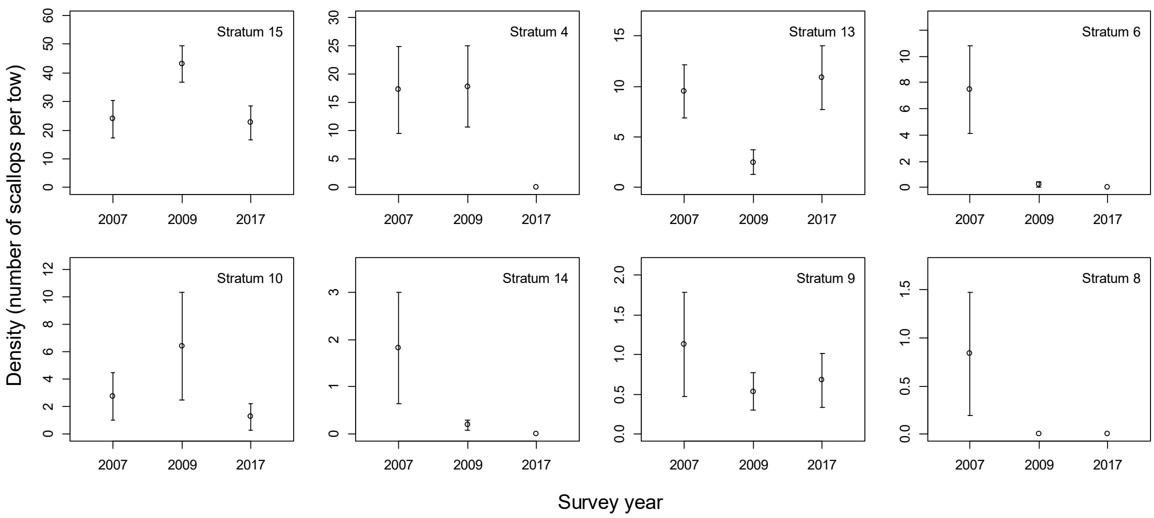

Figure 10: Estimated population density of scallops (100 mm or larger) by key survey strata in Kaipara Harbour in 2007, 2009, and 2017.

Table 4: Population estimates of scallops in Kaipara Harbour in September–October 2017 (full survey extent) at different spatial scales (location, surveyed/unsurveyed, total). Estimates were produced for harvestable size scallops (100 mm or larger), predicting green weight from length. Estimates are not corrected for dredge efficiency because this is unknown for the bag dredge used in the survey. The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps).

Location	Area (km^2)	n	Density (scallops m^{-2})					Abundance (millions)					Scallop weight(g)		Biomass (t green weight)				
			mean	CV	median	2.5%CI	97.5%CI	mean	CV	median	2.5%CI	97.5%CI	mean	median	mean	CV	median	2.5%CI	97.5%CI
Arapaoa	4.66	7	0.00	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00	NA	NA	0.00	NA	0.00	0.00	0.00
Tinopai	1.11	21	0.00	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00	NA	NA	0.00	NA	0.00	0.00	0.00
Outer Oruawharo	4.98	10	0.00	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00	NA	NA	0.00	NA	0.00	0.00	0.00
Inner Oruawharo	1.69	6	0.00	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00	NA	NA	0.00	NA	0.00	0.00	0.00
Tauhoa	2.84	7	0.01	0.41	0.01	0.00	0.01	0.02	0.41	0.02	0.01	0.03	107.38	106.73	1.85	0.39	1.84	0.55	3.30
Outer Kaipara River	1.20	3	0.00	0.83	0.00	0.00	0.01	0.00	0.83	0.00	0.00	0.01	167.08	166.58	0.44	0.83	0.45	0.00	1.33
Inner Kaipara River	7.32	15	0.03	0.27	0.03	0.01	0.05	0.22	0.27	0.22	0.11	0.35	100.37	100.70	22.37	0.27	22.27	11.09	34.30
Shelly Beach	5.68	21	0.03	0.25	0.03	0.01	0.04	0.15	0.25	0.15	0.09	0.23	100.11	100.66	15.34	0.26	15.21	8.51	23.39
LEK	16.34	36	0.00	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00	NA	NA	0.00	NA	0.00	0.00	0.00
Unknown_prev	143.74	63	0.00	0.96	0.00	0.00	0.00	0.04	0.96	0.04	0.00	0.12	105.38	105.19	4.25	0.96	4.32	0.00	13.09
Surveyed_prev	29.46	90	0.01	0.18	0.01	0.01	0.02	0.40	0.18	0.40	0.26	0.55	101.02	101.00	39.99	0.18	40.04	26.83	54.63
Unsurveyed_prev	160.08	99	0.00	0.96	0.00	0.00	0.00	0.04	0.96	0.04	0.00	0.12	105.38	105.19	4.25	0.96	4.32	0.00	13.09
Total	189.54	189	0.00	0.19	0.00	0.00	0.00	0.44	0.19	0.43	0.28	0.61	101.42	101.65	44.24	0.19	44.01	29.03	61.87

Table 5: Population estimates of scallops in Kaipara Harbour in 2007, 2009, and 2017 in the 'previously surveyed' area consistently surveyed in all surveys. Estimates are presented for each of 4 key locations that have held scallop beds during this period, and for the total 'previously surveyed area'. Estimates were produced for harvestable size scallops (100 mm or larger), predicting green weight from length. Estimates are not corrected for dredge efficiency because this is unknown for the bag dredge used in the survey. The analysis used a non-parametric resampling with replacement approach to estimation (1000 bootstraps).

Year	Grouping	Area	n	Density (scallops m^{-2})					Abundance (millions)					Scallop weight (g)		Biomass (t green)				
		(km^2)		mean	CV	median	2.5%CI	97.5%CI	mean	CV	median	2.5%CI	97.5%CI	mean	median	mean	CV	median	2.5%CI	97.5%CI
2007	Tinopai	0.67	5	0.11	0.39	0.11	0.04	0.21	0.08	0.39	0.08	0.03	0.14	101.75	100.92	7.81	0.41	7.73	2.45	14.67
	Tauhoa	2.84	6	0.01	0.34	0.01	0.00	0.02	0.03	0.34	0.03	0.01	0.06	110.38	111.36	3.79	0.36	3.79	1.30	6.36
	Inner Kaipara River	7.32	28	0.03	0.27	0.03	0.02	0.04	0.20	0.27	0.19	0.11	0.31	103.66	103.55	20.41	0.27	19.90	11.44	32.33
	Shelly Beach	5.68	28	0.04	0.25	0.04	0.02	0.06	0.22	0.25	0.21	0.11	0.32	97.06	97.24	21.09	0.25	20.90	10.88	31.20
	Surveyed_prev	**29.03**	**132**	**0.02**	**0.14**	**0.02**	**0.02**	**0.03**	**0.62**	**0.14**	**0.62**	**0.45**	**0.80**	**101.18**	**101.20**	**63.08**	**0.14**	**62.66**	**46.08**	**80.90**
2009	Tinopai	0.67	4	0.12	0.36	0.12	0.04	0.20	0.08	0.36	0.08	0.03	0.13	103.08	101.76	7.96	0.37	8.08	2.62	13.90
	Tauhoa	2.84	14	0.02	0.53	0.02	0.01	0.04	0.06	0.53	0.05	0.02	0.12	109.00	109.28	6.03	0.56	5.94	1.69	13.41
	Inner Kaipara River	7.32	33	0.01	0.44	0.01	0.00	0.01	0.05	0.44	0.05	0.01	0.11	105.18	105.66	5.59	0.42	5.38	1.67	10.84
	Shelly Beach	5.68	27	0.05	0.12	0.05	0.04	0.07	0.30	0.12	0.30	0.22	0.37	104.13	104.01	31.00	0.13	30.97	22.96	39.26
	Surveyed_prev	**29.03**	**138**	**0.02**	**0.14**	**0.02**	**0.02**	**0.03**	**0.69**	**0.14**	**0.68**	**0.51**	**0.91**	**105.22**	**105.22**	**72.26**	**0.15**	**71.37**	**53.54**	**96.48**
2017	Tinopai	1.11	21	0.00	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00	NA	NA	0.00	NA	0.00	0.00	0.00
	Tauhoa	2.84	7	0.01	0.41	0.01	0.00	0.01	0.02	0.41	0.02	0.01	0.03	107.38	106.73	1.85	0.39	1.84	0.55	3.30
	Inner Kaipara River	7.32	15	0.03	0.27	0.03	0.01	0.05	0.22	0.27	0.22	0.11	0.35	100.37	100.70	22.37	0.27	22.27	11.09	34.30
	Shelly Beach	5.68	21	0.03	0.25	0.03	0.01	0.04	0.15	0.25	0.15	0.09	0.23	100.11	100.66	15.34	0.26	15.21	8.51	23.39
	Surveyed_prev	**29.46**	**90**	**0.01**	**0.18**	**0.01**	**0.01**	**0.02**	**0.40**	**0.18**	**0.40**	**0.26**	**0.55**	**101.02**	**101.00**	**39.99**	**0.18**	**40.04**	**26.83**	**54.63**

3.5 Length frequency

The scaled length frequency distribution of the scallop population within the area surveyed was dominated by large scallops in all three survey years, but there were very few scallops smaller than 80 mm caught in 2017, compared with the much higher numbers of small scallops caught in 2007 and particularly 2009 (Figure 11). Length frequencies are also shown separately for locations in the southern (Figure 12) and northern (Figure 13) parts of the harbour.

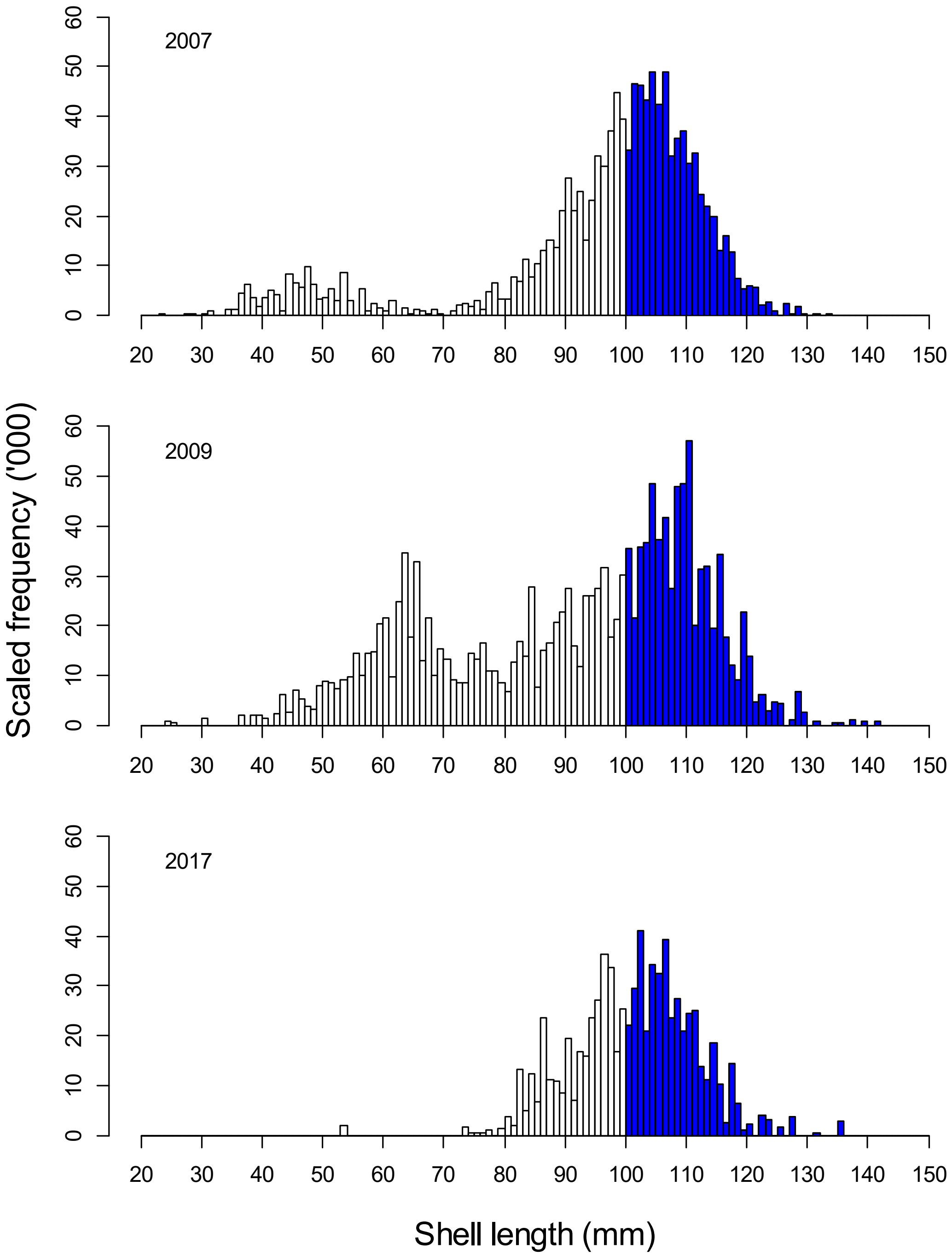

Figure 11: Length frequency distribution for scallops in Kaipara Harbour in 2007, 2009 and 2017. Data uncorrected for bag dredge efficiency, which is unknown. Dark shaded bars show scallops of harvestable size (100 mm shell length or larger).

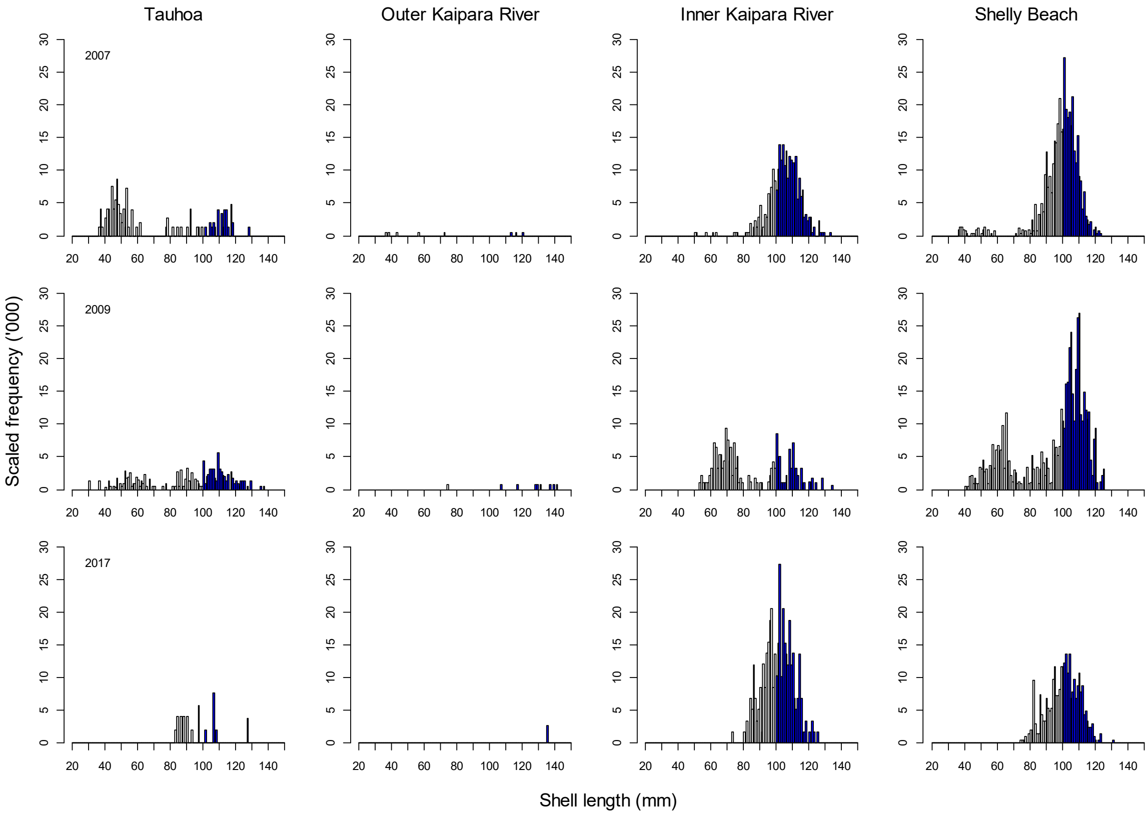

Figure 12: Length frequency distribution for scallops in four locations within the southern half of Kaipara Harbour, 2007, 2009 and 2017. Data uncorrected for bag dredge efficiency, which is unknown. Dark shaded bars show scallops of harvestable size (100 mm shell length or larger).

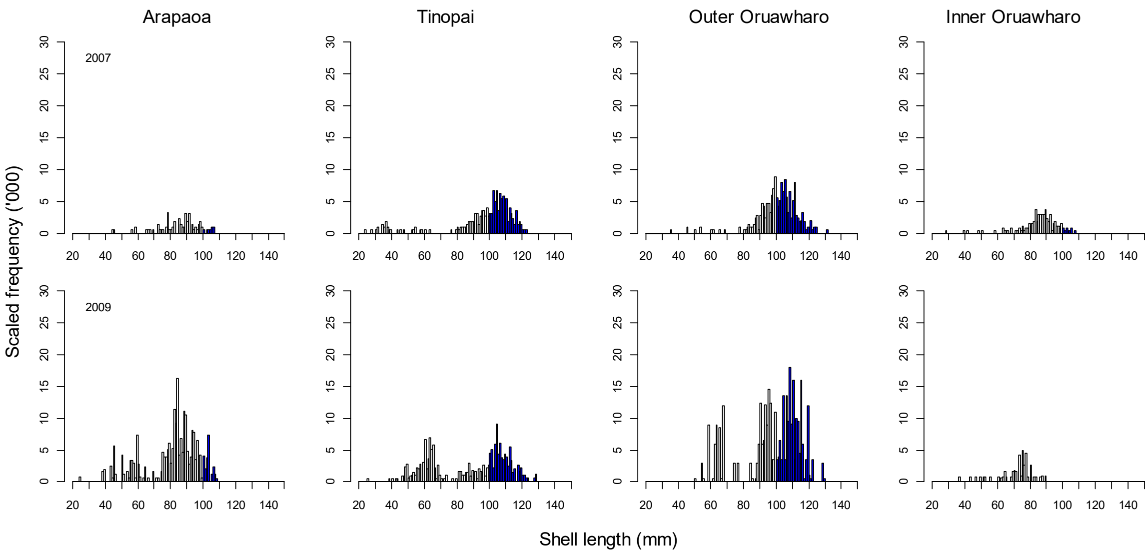

Figure 13: Length frequency distribution for scallops in four locations within the northern half of Kaipara Harbour, 2007 and 2009; length frequencies for 2017 are not shown here because only 1 scallop (from the Arapoa location) was caught in the entire northern half of the harbour surveyed.

3.6 Disease investigation

Scallops collected from the Shelly Beach and Tauhoa locations on 6 November 2017 appeared to be in poor condition, and specimens were sent to MPI for analysis, under disease investigation accession number W1701850. The summary findings of that investigation are copied below.

FISH PATHOLOGY

All histopathology slides exhibited focal destruction of the digestive gland tubules. In many cases, complete destruction of the digestive epithelium cells exposed the underlying basement membrane. Within these empty compartments was amorphous green/brown material of unknown identity: possibly cellular debris or another origin. These signs are consistent with that of the virus-like particle (VLP) reported from New Zealand scallops by Hine and Wesney (1997). The contribution of these VLPs to the ill thrift and mortality events of the scallops is uncertain and further investigation is necessary to elucidate this host-pathogen relationship. In addition to the VLPs, bacterial infiltrate of the labial palps was observed, the presence of RLOs, and Perkinsus cells. In this investigation, not one causal factor or disease could be identified and, therefore, the poor condition and mortality of these animals is likely to be a combination of many factors

BACTERIOLOGY

Light to medium mixed growth was observed across the majority of samples. By DNA sequencing the Vibrio atpA gene (Thompson et al. 2007), Vibrio alginolyticus was idenified (ID 99%), and by sequencing th 16S rRNA gene Pseudomanas sp. was identified (ID 99%). These isolates are likely incidental findings are unlikely to be primary pathogens in this case.

4. DISCUSSION

The results of the survey show that the status of the Kaipara Harbour scallop population was very low in 2017 compared with 2007 (Walshe & Holdsworth 2007) and 2009 (Kelly 2009). The key findings of the 2017 survey are that scallop distribution was limited, adult abundance was low (in all but one scallop bed), juvenile abundance was very low, and histopathology and bacteriology studies detected that several diseases were present.

The number of scallop beds in Kaipara Harbour has markedly declined since 2009, with essentially only one main scallop bed (Shelly Beach) remaining in the harbour in 2017 in which catch rates of recruited scallops (i.e. harvestable size, 100 mm or larger) were relatively high. Survey catches in previously important beds, such as the one to the south of Tinopai, did not contain any live scallops in 2017. Additional comprehensive sampling in previously unsurveyed areas found no evidence of significant scallop beds outside of the areas previously surveyed. In future monitoring, surveying only the core areas identified in the three surveys is warranted.

In the areas covered by all three surveys (2007, 2009, and 2017), recruited abundance in 2017 was only about 60% of the 2009 estimated abundance. This large decrease in abundance is attributed to the reduction in the number of scallop beds in the harbour. Interestingly, abundance in the remaining Shelly Beach bed (strata 13 and 15) was similar in 2017 to that in 2007.

Very few small scallops were caught in 2017, interpreted here as evidence that recruitment to the population earlier in 2017 had been low. It is assumed that the survey bag dredge has low selectivity for scallops smaller than the mesh size, but despite this the surveys in 2007 and 2009 caught considerably more small scallops than in the 2017 survey. Differences in the survey timing are unlikely to explain this difference.

The disease investigation by MPI showed that the Kaipara Harbour scallops collected in November 2017 were in poor health. Histopathology showed extreme damage to the digestive glands consistent with virus-like particles (VLPs) of *Pecten novaezelandiae* (Hine & Wesney 1997). Also present was bacterial infiltrate, *Rickettsia*-like organisms, and *Perkinsus olseni* at higher prevalence than found in scallops elsewhere in New Zealand.

Historically in Kaipara Harbour, scallops were usually harvested by hand-gathering at low tide in the extensive fringing intertidal beds, but local people report that the beds in these areas were lost many decades ago (Morrison et al. 2014), and hence these areas were not included in the 2007 to 2017 survey coverage. Since around the 1970s/1980s most fishers have harvested scallops by dredging. Walshe & Holdsworth (2007) reported that "prior to the section 186A closure [in 2005–07] there were reports of over 100 boats dredging the Shelly Beach beds simultaneously" and that, given the relatively small area of the beds, that "this level of fishing pressure could lead to local depletion of beds over peak summer periods".

The 2017 survey provides evidence that the scallop population has declined, but research has not been conducted to investigate the cause(s) of this decline. Population declines can occur from low recruitment and/or high mortality. Low recruitment could be a factor, and this was observed in 2017. It is likely that the Shelly Beach bed contains the only spawning stock remaining in the harbour, and the authors recommend that, based on the available science, conserving this population should be prioritised. Larval supply from this bed could in future provide larvae to repopulate other areas within the harbour. Anthropogenic (e.g. overfishing, effects of fishing, and land-based effects such as increased turbidity and sedimentation) and natural sources (e.g. disease) both contribute to scallop mortality and can result in population declines.

Scallops are sedentary, suspension-feeding bivalves which are patchily distributed in suitable habitat. The absence of scallops in areas which previously supported dense beds suggests that the suitability of the habitat has degraded. Several studies have provided useful information on habitats within Kaipara Harbour, including key work on benthic marine habitats and communities (Hewitt & Funnell 2005), a review of marine environmental information (Haggitt et al. 2008), patterns and rates of sedimentation and intertidal vegetation changes (Swales et al. 2011), and habitats of particular significance for fisheries management (Morrison et al. 2014). New research is required, however, to improve our understanding of the link between scallop biology and habitat, and inform restoration.

5. ACKNOWLEDGMENTS

This work was completed under Objectives 1 and 2 of Ministry for Primary Industries project SCA201502. Special thanks to vessel skipper Rod Bridge (Rono Ventures Ltd) and crew Kim Hilford for their expertise in conducting the dredge sampling aboard *Lady Frances*. Thanks also to NIWA colleagues Matt Smith, Dane Buckthought, and Jim Drury for their assistance with gear trials and the initial survey work. We extend our thanks to the many different people and groups who kindly assisted with this project, including but not limited to: Te Uri O Hau (Tina Latimer and Kaitiaki including Luke Connelly), Ngati Whatua O Kaipara (Brenda Christianson), the Integrated Kaipara Harbour Management Group (Willie Wright), Anjali Pande (MPI Biosecurity Surveillance and Incursion Investigation Group), local fishers Rex and Steph Tredwell (local fishers), David Fisher (NIWA – MPI Research Data Manager), Mark Morrison (NIWA), and Shane Kelly (Coast & Catchment Ltd). We are grateful to members of the Shellfish Fisheries Assessment Working Group for their appraisal of the survey methods and results, and to Ian Tuck for reviewing the report.

6. REFERENCES

Cryer, M.; Parkinson, D.M. (2006). Biomass surveys and stock assessments for the Coromandel and Northland scallop fisheries, 2005. *New Zealand Fisheries Assessment Report 2006/34*: 53 p.

Haggitt, T.; Mead, S.; Bellingham, M. (2008). Review of environmental information on the Kaipara Harbour Marine Environment. ARC Technical Publication TP354. Report prepared for Auckland Regional Council by ASR Ltd and Coastal and Aquatic Systems Ltd. p.

Hewitt, J.E.; Funnell, G.A. (2005). Benthic marine habitats and communities of the southern Kaipara. NIWA Client Report HAM2005-077 prepared for Auckland Regional Council. p.

Hine, P.M.; Wesney, B. (1997). Virus-like particles associated with cytopathology in the digestive gland epithelium of scallops *Pecten novaezelandiae* and toheroa *Paphies ventricosum*. *Diseases of Aquatic Organisms 29*: 197–204.

Kelly, S. (2009). Monitoring scallops in the Kaipara Harbour scallop 186A closure. Final Research Report for Ministry of Fisheries project SCA200901. 21 p. (Unpublished report held by Fisheries New Zealand, Wellington.).

Ministry for Primary Industries (2011). Draft National Fisheries Plan for Inshore Shellfish. 54 p. (Unpublished report held by Fisheries New Zealand, Wellington.). (http://www.fish.govt.nz/en-nz/Fisheries+Planning/default.htm).

Morrison, M.A.; Lowe, M.L.; Jones, E.G.; Makey, L.; Shankar, U.; Usmar, N.; Miller, A.; Smith, M.; Middleton, C. (2014). Habitats of particular significance for fisheries management: the Kaipara Harbour. *New Zealand Aquatic Environment and Biodiversity Report No. 129*: 169 p.

Swales, A.; Gibbs, M.; Ovenden, R.; Costley, K.; Hermanspahn, N.; Budd, R.; Rendle, D.; Hart, C.; Wadhwa, S. (2011). Patterns and rates of recent sedimentation and intertidal vegetation changes in the Kaipara Harbour. 141 p. (NIWA Client Report HAM2011-40. Prepared by NIWA for Auckland Council and Northland Regional Council.).

Walshe, K.; Holdsworth, J. (2007). Monitoring S186A closures: Kaipara Harbour scallop survey. Final Research Report for Ministry of Fisheries project CUS200601. 14 p. (Unpublished report held by Fisheries New Zealand, Wellington.).

Williams, J.R.; Parkinson, D.M.; Bian, R. (2013). Biomass survey and yield calculation for the Coromandel scallop fishery, 2012. *New Zealand Fisheries Assessment Report 2013/18*: 57 p.

APPENDIX A: Examination of 2009 survey data

Distance towed and dredge fullness

In the previous 2007 and 2009 surveys, dredge tow distance was reported as about 250 m. Using data on the tow start and end coordinates (recorded in decimal degrees in t_station), distance towed can be calculated using NIWA's *distance.lat.long* function in R (which uses the simple spherical model). In the 2007 survey, it appears that separate start and end coordinates were not recorded. In the 2009 survey, the overall average calculated distance towed (median = 237 m, mean = 238) was close to the nominal 250 m tow distance reported, although there was variability within strata (range across all tows = 35 to 354 m), although distance towed varied slightly by stratum (Figure 14, left panel). A distance of 237 m equates to 0.13 n.miles, which for consistency became the target tow length for the 2017 survey. Towing for a greater distance could result in the dredge becoming saturated (100% full) and no longer fishing effectively during the latter part of the tow. Plotting the visual estimates of dredge fullness by stratum in the 2009 survey showed that tows were not saturated in most strata, except that this was not the case for stratum TNP where on average tows were 100% full (Figure 14, right panel). Stratum details from the 2009 survey are provided in Table 6.

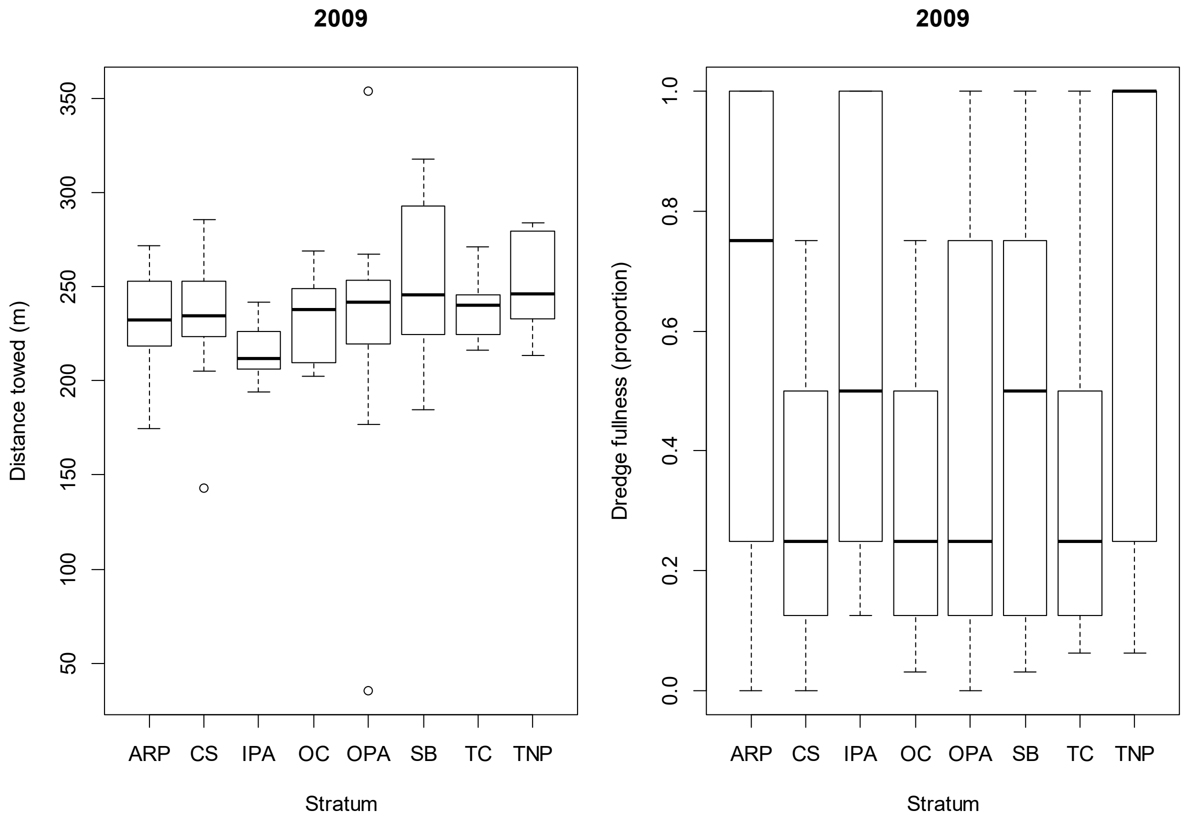

Figure 14: Distance towed (left) and dredge fullness (right) by stratum, 2009 survey.

Table 6: Stratum details from the 2009 survey. Outer Kaipara River and Tauhoa Channel combined into one single large stratum.

Stratum name	Area (ha)	Code
Tinopai	111	TNP
Arapaoa	466	ARP
Outer Oruawharo	498	OPA
Inner Oruawharo	469	IPA
Tauhoa Channel	284	TC
Inner Kaipara River	694	CS
Shelly Beach	568	SB
Outer Kaipara River	120	TC

Bag dredge position, and population estimation using 1 or 2 dredges, or both dredges combined
Catch data (visual estimate of dredge fullness, scallop catch numbers, and scallop lengths) for the port and starboard bag dredges were recorded separately in the 2009 survey. Analysis of these data suggested that there were no differences between the port and starboard bag dredge positions, in terms of dredge fullness, scallop catch numbers, or scallop shell lengths per tow (Figure 15).

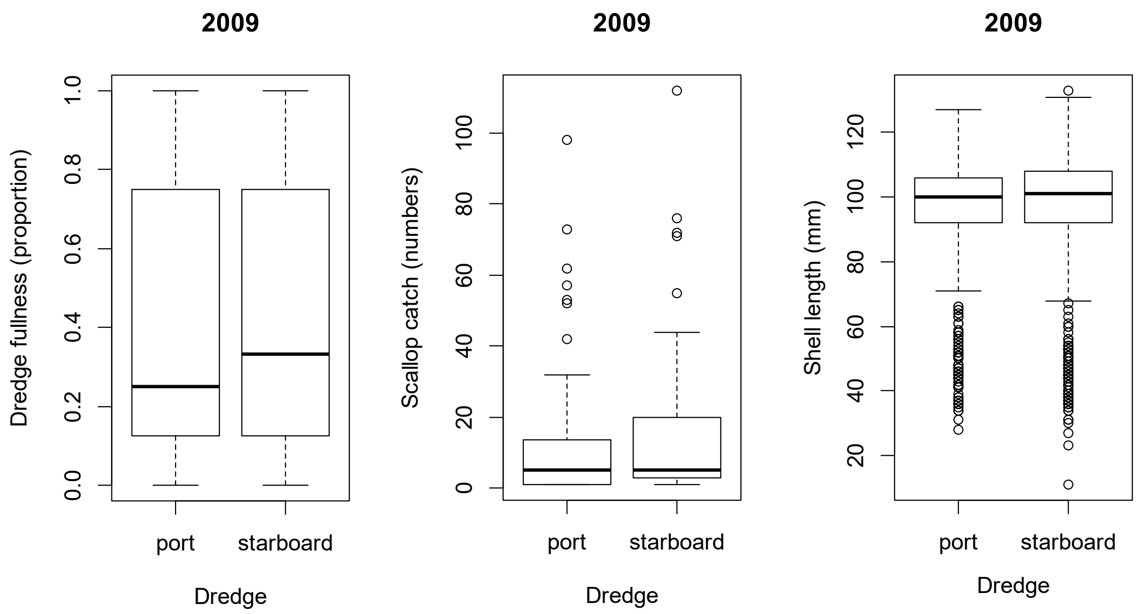

Figure 15: Dredge fullness (left), scallop catch numbers (centre), and scallop shell lengths (right) per tow by bag dredge position (port or starboard side of vessel), 2009 survey. Excludes stations where no scallops were caught.

The 2009 survey data were analysed to assess whether estimates of population abundance were sensitive to using data from only one (port or starboard) or both dredges (port and starboard combined). There was no difference between the two approaches in terms of the estimates generated, for scallops of any size or for scallops 100 mm or larger (Figure **16**). On this basis, it was decided to use only one dredge in the 2017 survey to reduce catch processing time, allowing more stations to be sampled within the fixed survey duration than if two dredges had been used.

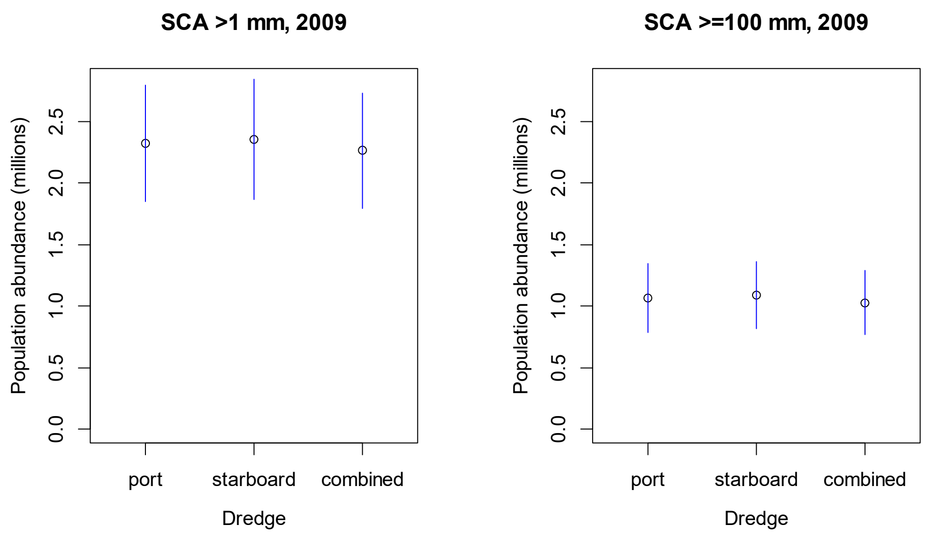

Figure 16**: Estimated scallop abundance (mean and CV) by bag dredge (using data from either the port dredge or the starboard dredge, or using the combined data from both dredges), 2009 survey.**

APPENDIX B: Paired gear sampling

At the initiation of this project, we had some concerns that the efficiency of the bag dredge used in the previous two surveys could be highly variable given its design and light weight, which could result in inaccurate and imprecise estimates of scallop abundance. Discussions with experienced commercial scallop fishers suggested that a robust box dredge with tines would have more consistent contact with the seabed and thus be a more reliable approach for sampling scallops. We therefore conducted some initial gear trials work to sample using the two different types of recreational scallop dredge: 1) bag dredge without tines, of the same design as that used in the 2007 and 2009 surveys; and 2) box dredge with tines. At the start of the survey, paired gear sampling was conducted at a key scallop bed in Kaipara Harbour (Shelly Beach location) using both dredge types to collect data enabling fair comparison of changes in the scallop population among years. The remaining sampling was conducted using the bag dredge only.

Paired bag and box dredge sampling was conducted at 11 stations in stratum 15, on 4 September 2017. At each station, the two different dredge types were simultaneously towed from the single survey vessel (*Lady Frances*). While the central position of the box dredge was fixed and could not be moved (due to the position of the tipping frame), the position of the bag dredge was randomised so that half of the tows were conducted with the bag on the port side, and half on the starboard side. At two stations, the box dredge turned upside down (‘flipped’), which does not happen with the bag dredge given its symmetrical design; tows where the box dredge had ‘flipped’ were deemed invalid, and were repeated. At one of these stations, the box dredge flipped again during the repeat tow.

Analysis of data from the 10 valid stations (tows) completed shows that there were no differences between the two dredge types in terms of the number of scallops caught per tow or the scallop shell lengths observed per tow (Figure 17) despite the greater area swept by the box dredge (width = 0.8 m; bag dredge width = 0.6 m). Also, there was no difference in scallop catch between the port and starboard sides of the vessel from which the bag dredge was towed (Figure 18).

The population abundance of scallops within the total area of stratum 15 was estimated using the data from the 10 valid stations sampled with paired tows. Given that catches were similar between the two dredge types, but that the swept area per tow was larger for the box dredge, mean abundance was higher when estimated from the bag dredge catch data, particularly for larger scallops (100 mm or larger), although given the variance around the mean estimates, the difference at the stratum level may not be significant (Figure 19).

On this basis, it was decided to abandon the use of the box dredge (apparently less efficient, and more damaging to scallops, than the bag dredge) and proceed with using a single bag dredge for the remainder of the survey.

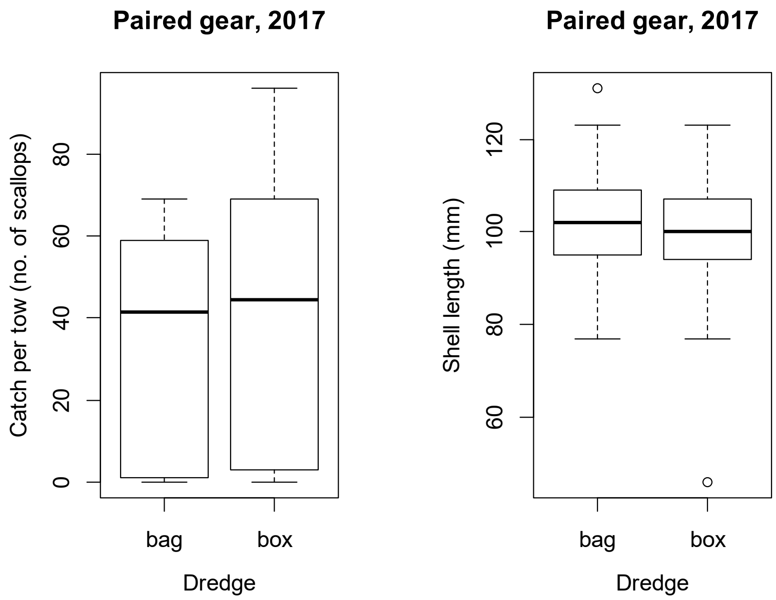

Figure 17: Scallop catch numbers (left) and shell lengths (right) per tow by dredge type, from paired gear sampling in stratum 15, 2017 survey.

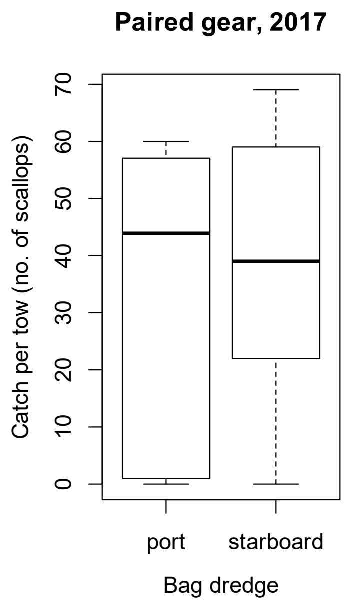

Figure 18: Scallop catch numbers per tow by bag dredge position (port or starboard side of vessel), from paired gear sampling in stratum 15, 2017 survey.

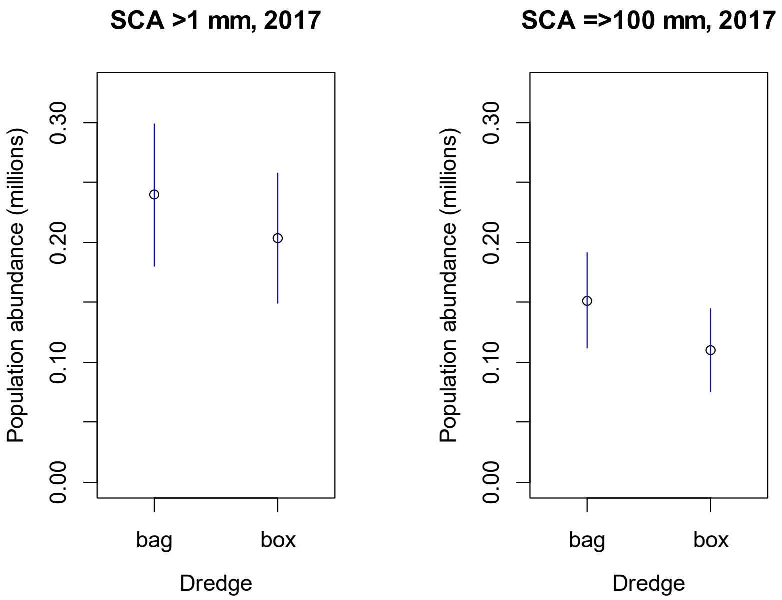

Figure 19: Estimated scallop abundance (mean and CV) by dredge type, from paired gear sampling in stratum 15, 2017 survey.