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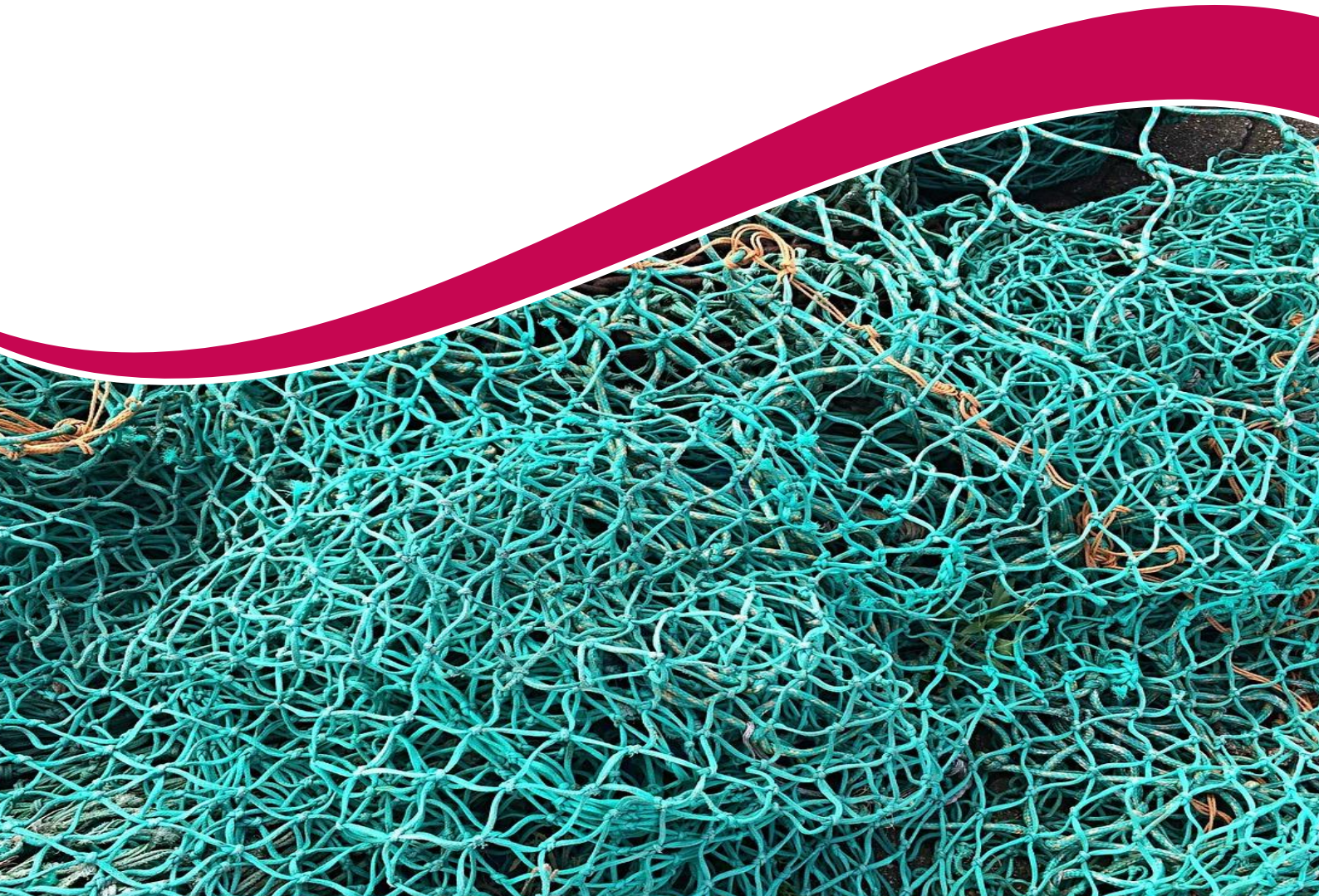
Bass Strait Central Zone Scallop Fishery — 2019 Survey

AFMA Project 2019/0812



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Executive Summary

At the start of each Bass Strait and Central Zone Scallop Fishery (BSCZSF) fishing season, the Australian Fisheries Management Authority (AFMA) provides a 150 t research catch allowance to enable fishers to search for commercially viable scallop (*Pecten fumatus*) beds. Industry members must then undertake research surveys to determine if the fishery can remain open under a Tier 1 (catches ≤ 2000 t) or Tier 2 (catches > 2000 t) management arrangements. Research surveys must carry an independent observer or electronic monitoring that is able to verify catch quantity, shell size and any other scientific data required to determine biomass estimates. This report provides the results of the 2019 research surveys.

Four commercial fishing vessels were selected by an independent panel to conduct the 2019 scallop surveys: the Dell Richey II, Shandara, Odete C and the Rachel Maree, however the Dell Richey II was eventually unable to participate. During May 2019, stratified random surveys were conducted using these vessels on one bed off Flinders Island, nine beds off King Island and two beds off Apollo Bay. Choice and prioritisation of these beds was made based on previous surveys and commercial catches from 2018, and with input from the Scallop Resource Assessment Group (ScallopRAG). Most beds were predefined and remained unchanged from the 2018 survey, while three additional King Island Beds were defined based on commercial catches from previous years and exploratory fishing. One other bed of juvenile scallops was defined based on previous exploratory fishing by an industry member. One mark off Flinders Island provided by industry yielded no beds considered worthwhile surveying. The number of random survey points allocated to each bed was determined from a combination of the size of each bed and practical considerations.

The estimated biomass of scallops at the Flinders Island bed was 1,961 t (1,607 t > 85 mm length), with a density of 0.211 individuals per m^2. The estimated biomass at the KI-BDE bed was 8,353 t (7,135 t > 85 mm), and 19,592 t (18,714 t > 85 mm) at KI-BDSE. A very large biomass of 9,616 t (9,398 t > 85 mm) was also estimated for KI-9. Estimated biomass was greater than 1,000 t for three other King Island beds (KI-5S, KI-New and KI-6). Total biomass estimated from the two adjacent Apollo beds was 1,517 t (1,517 t > 85 mm). Scallop density off King Island was as high as 3.088 individuals per m^2 at KI-BDSE, and 0.563 individuals per m^2 at Apollo Bay beds.

Scallop meats of shells greater than 85 mm length were smallest from KI-7 with most meats less than 10 g, and averaging 157 meats per kg. Flinders Island beds averaged 68 meats per kg, with most around 14 g per meat. There was a wide variety of meat weights amongst the other KI sites. Meats were largest at KI-New, AB2 and KI-5S averaging 54, 60 and 62 meats per kg respectively.

Time series of size frequency, biomass and composition of dead shell indicated significant mortality at the Flinders Island Beds since 2015, and since 2018 at the KI-7 bed. There is evidence of significant recruitment at KI-BDE, and less so at KI-BDSE and KI-7.

Catch composition varied greatly between beds. In general, there was high proportions of old (dead) single shell at the Flinders Island and KI-New beds, while other beds were dominated by live Commercial Scallops.

Survey results were presented to ScallopRAG on 6/6/2019 and the Scallop Management Advisory Committee (ScallopMAC) on 7/6/2019.

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Acknowledgements

We would like to thank Jono Hammond and the crew of the Shandara, Glen Wisby and the crew of the Odete C and John and Graham Cull and the sdkipper and crew of the Rachel Maree for all of their assistance and hard work in undertaking the 2019 survey. We appreciate the owner of the Dell Richey II making that vessel available, despite it not being used. The observers Jessica Kube and Tiffany Sih worked very had to collect all data required to a high quality standard. Sally Weekes and Heather Johnston (AFMA), ScallopRAG, ScallopMAC and the BSCZSF Co-Management Committee provided valuable input into the survey logistics and design. We also thank John Garvey for providing commercial catch and effort data from which the survey design was based.

Introduction

The main target species in the Bass Strait Central Zone Scallop Fishery (BSCZSF) is the Commercial Scallop, *Pecten fumatus*. Commercial Scallops in wild populations live for between five and nine years, but have been observed to die-off rapidly after only three to five years in some situations (Haddon *et al.,* 2006). The species is generally subject to high spatial and temporal variability in recruitment and abundance, variable growth and mortality, and rapidly changing meat yield and reproductive condition. This variability means that management of Commercial Scallops has to be adaptable to sometimes rapidly changing circumstances, yet still ensure protection of the resource in line with the *Commonwealth Fisheries Harvest Strategy Policy 2007* (HSP).

Under the HSP, the initial harvest strategy for the BSCZSF was developed during 2007. It was revised during the 2012 season and in response to industry concerns about the cost-effectiveness and flexibility, was further reviewed during 2014. The BSCZSF Harvest Strategy has two primary objectives. To:

1. keep stocks within the BSCZSF at ecologically sustainable levels and, within that context, maximise the economic returns to the Australian community; and,

2. pursue efficient and cost-effective management in attaining (1) above.

The Harvest Strategy uses a tiered approach designed to apply different levels of management and research services depending on the state of the resource. Underpinning the tiered approach is the need to balance the risk of over exploitation with obtaining initial knowledge on the status of the stock at the commencement of the season through pre-season surveys.

At the start of each fishing season, the Australian Fisheries Management Authority (AFMA) provides a 150 t research catch allowance to enable fishers to search for commercially viable scallop beds, defined as "…*an area or scallop bed containing no greater than 20 per cent of scallops of a size less than 85 mm"*. To increase the catch allowance above 150 t, industry members must undertake research surveys to determine if the fishery can remain open under Tier 1 or Tier 2 level management arrangements.

- **Tier 1 management arrangements** require initial closure of an area/s (not more than 2 scallop beds) that contain ≥1500 tonnes in total of high density scallops of a minimum size of 85 mm. The season begins with a 1000 t total allowable catch (TAC) that can be increased to 2000 t if good catches are achieved.

- **Tier 2 management arrangements** require initial closure of an area/s (not more than 2 scallop beds) that contain ≥3000 tonnes in total of scallops of a minimum size limit of 85 mm of high density. The season begins with a 2000 t TAC that can be increased if good catches are achieved.

Research surveys must carry an independent observer or electronic monitoring that is able to verify catch quantity, shell size and any other scientific data required to determine biomass estimates. This report provides the results of the 2019 stratified random surveys.

1.1 Objectives

1. Estimate the scallop biomass and potential commercial catch rates in three different areas of the BSCZSF.

2. Measure the size frequency distribution of scallops in each area to calculate discard rates.

3. Report results to AFMA, ScallopRAG and ScallopMAC.

Methods

1.2 Survey Design

Survey methods follow those of Knuckey *et al.* (2015), modified from those described in Harrington *et al.* (2008). Three vessels were used to undertake a stratified random survey of scallop beds with independent observers onboard to collect all of the necessary survey data.

The 2015 survey covered three beds off King Island and one off of Flinders Island (Figure 1). To provide greater flexibility in management arrangements regarding closures, this was expanded in 2016 with the addition of an extra four sites off King Island and another site off Flinders Island (Figure 1). In addition to the extra sites, the boundaries of some of the 2015 sites were modified (for example northern and southern boundaries of the bed known as KIMain in Knuckey *et al.* (2015) were brought in slightly, and the eastern and western boundaries moved east slightly to form a bed titled KI-2 in Knuckey *et al.* (2016). The beds surveyed during 2017 were based on advice from the Scallop Research Workshop and input from ScallopRAG and the BSCZSF Co-Management Committee. They comprised previously surveyed beds, modified beds and new exploratory beds. In 2018 two beds were added off King Island, while AB-3, AB-4, FI-3 and FI-4 were not surveyed.

The beds surveyed in 2019 were based on previous surveys and advice from the ScallopRAG and the BSCZSF Co-Management Committee. Changes to the beds surveyed since 2015 are outlined in Table 1.

Figure 1. History of beds surveyed off Flinders Island (top left panel), King Island (top right panel) and Apollo Bay (lower panel) since 2015.

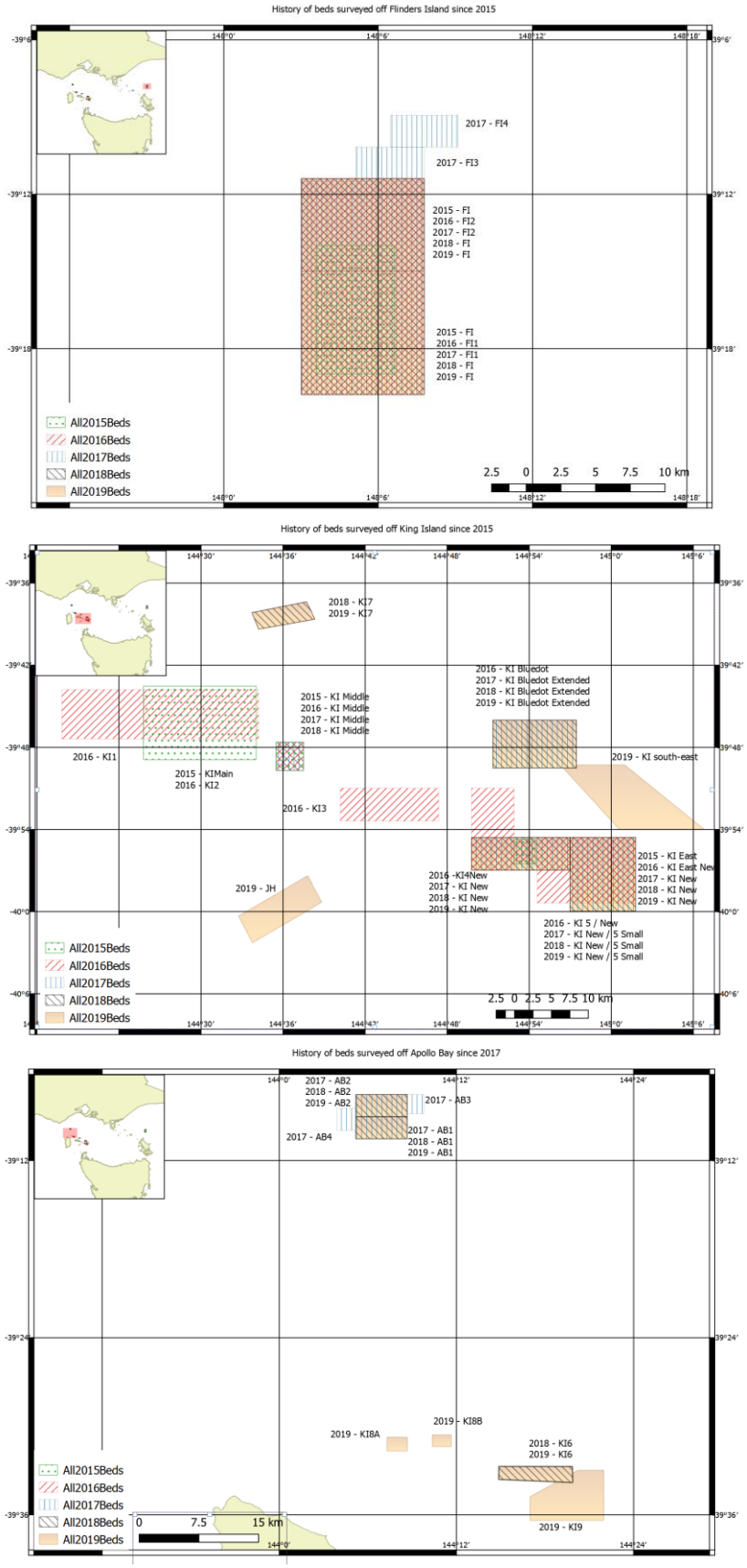


Table 1. Description of changed to beds surveyed since 2015.

Bed Type	Name	Description
Previously surveyed	KI-5S	Originally a larger area that was surveyed in 2016, KI-5S was formed by extending the eastern boundary of KI-New south to -40˚S, and including the area of KI-5 to the east of that. This bed remained unchanged from the 2018 survey.
	KI-New	KI-New was a bed that was defined for management proposes (it formed the initial closure) after the 2016 survey, covering at least parts of three different beds surveyed in 2016. It is bound by the latitudes and longitudes shown in Table 4. It comprised parts of a bed called KIEast which was surveyed during 2015, and again in 2016, along with two new adjacent beds, KI-4 and KI-5. KI-New has remained unchanged from the 2018 survey.
	KI-BSE	During the TAC setting by the MAC for the 2016 season, industry provided information regarding a dense bed of small scallops that would be more suitable for closure than the KI-New bed. This bed titled King Island Blue Dot was mapped out and then surveyed during August of 2016. The area was expanded north and west to form an area closure that replaced the closure of KI-New. The boundaries of this expanded area are shown in Table 4. This bed remained unchanged from the 2018 survey.
	AB-1 and AB-2	Seven exploratory marks off King Island were provided by industry in 2017 to be explored and considered for additional survey beds. Only one of those showed enough promise to survey, and the skippers mapped out area, splitting it into two beds. During 2017, two additional smaller beds were added to each of the western and eastern boundaries, however these contained low densities of scallops and were dropped from the 2018 survey. The Apollo 1 and 2 bed boundaries remained unchanged from the 2018 survey. The borders of those beds are in Table 4.
	KI6	Examination of 2018 commercial catch and effort data revealed significant catches in a large area at approximately longitude 144˚ 17’, latitude 39˚ 32’. The vessels mapped out this area to provide a smaller area with high density scallops with the boundaries shown in in Table 4. The bed boundaries remained unchanged from the 2018 survey.
	KI7	Examination of 2018 commercial catch and effort data revealed significant catches in a large area at approximately longitude 144˚ 36’, latitude 39˚ 38’. The vessels mapped out this area to provide a smaller area with high density scallops with the boundaries shown in in Table 4. The bed boundaries remained unchanged from the 2018 survey.
	FI	FI-1 was called the “Flinders Island” bed during the 2015 survey. For the 2016 and 2017 surveys, the area was expanded and spilt into the two beds (FI-1 and FI-2). Two additional smaller beds were added to the northern boundary of FI2 in 2017, however because of low densities, these were dropped for the 2018 survey. For the

		2018 survey, FI-1 and FI-2 were combined into a single large bed bound by the latitudes and longitudes shown in Table 4. The bed boundaries remained unchanged from the 2018 survey.
Exploratory / New Beds	KI8a and KI8b	Examination of 2019 commercial catch and effort data revealed significant catches in a large area at approximately longitude 144˚ 10', latitude 39˚ 31'. Within the general area of this effort, there were three main patches of densely populated scallop beds separated by areas of low density and an underwater cable. The two largest of these small areas were selected to survey and their boundaries shown in Table 5Table 4.
	KI9	Examination of 2019 commercial catch and effort data revealed significant catches in a large area at approximately longitude 144˚ 21', latitude 39˚ 35'. The final boundaries were set based on a combination of fishing effort by the survey vessel in the previous year and exploratory fishing. The boundaries shown in Table 5.
	JH	An industry member provided two marks that bound a line of exploratory shots that contained relatively high densities of juvenile scallops (~50 mm). Being the most recent sign of significant recruitment there was interest in tracking the growth of this bed, however there was some sensitivity around the potential to disturb the bed by surveying it. As a compromise, a relatively small survey area was set with only 20 sampling sites. The boundaries shown in Table 5.
	KI-BDSE	Examination of 2019 commercial catch and effort data revealed significant catches in a large area at approximately longitude 145˚ 00, latitude 39˚ 49. The final boundaries were set based on a combination of fishing effort by the survey vessel in the previous year and exploratory fishing. The final boundaries are shown in Table 5.
	AW2	One exploratory mark was provided from industry observations off Flinders Island. Exploratory fishing did not yield appreciable densities of scallops and no bed was defined there.
Not surveyed in 2019	KI-Mid	This bed remained unchanged from 2015, 2016, 2017 and 2018.

It was decided to re-survey the following 2018 beds (as described in Knuckey *et al.* 2018): KI-5S, KI-New, KI-BDE, KI-6, KI-7, FI, AB-1, and AB-2. KI-Mid had a lower priority than the other sites due to significant die-off of the Commercial Scallops there. Three areas of high commercial catches in 2018 were added to the sites to be surveyed: KI-BDSE, KI-8 (which was eventually split into two small beds: KI-8a and KI-8b) and KI-9. The south-west and north-east extent of a bed with a dense population of small scallops was also provided. There was no information on the width of this bed, and rather than disturbing it with exploratory fishing, a 1 nm buffer was placed on either side of a line connecting the south-west and north-east marks. This formed the JH bed.

Exploratory tows around two marks provided off Flinders Island (AW2) conducted by one of the vessels revealed very little promise, with the skipper and observer agreeing that there was no value in putting in a survey bed.

The number of survey points allocated to each bed was largely guided by sampling effort during 2016, 2017 and 2018, with consideration given to the maximum number of tows that can be achieved in a 12-hour sampling block[1] and the area of the bed. Primary sampling sites within each bed were randomly allocated using the QGIS Random Points Tool. Additional survey points were allocated to each bed as "backup sites", to be used where "primary sites" were unfishable.

During 2019, surveys were conducted onboard the fishing vessels Shandara (Scientific Permit# 1004223), Rachel Maree (Scientific Permit# 1004222) and Odete C (Scientific Permit# 1004225), which were selected by an independent panel. To be considered a valid tow, the vessel must dredge within 100 m of the tow location provided (Appendix 1, Figure 24). Lotek LAT1400-64kb temperature-depth loggers were attached to the dredge at the start of the first tow, and set to record an observation every 90 seconds.

1.3 Sampling methods

For each shot, estimates were made of weight of: total live scallop catch, dead shell and all bycatch by species / species group. Dead shell were separated into:

- Clappers (both valves still connected at the hinge)
- Old single (single valve – inside appears old and overgrown with epiphytes / epifauna)
- New single (single valve – inside appears new without any epiphytes / epifauna)

A random sample of at least 35 scallops (where available) was collected from each shot before they went through the tumbler. The observer measured the length of those scallops using an electronic measuring board. Either the first or last (or both) scallop from each shot measured using the measuring board was also measured by hand using digital callipers or a metal ruler. This was done to ensure accuracy and consistency of the measuring board throughout the survey. The sample weight of scallops measured was also recorded.

From every fifth shot, an additional 10 random scallops were taken before passing through the tumbler to collect biological information. First, the whole scallop was weighed, then split and the gonad condition staged according to the scale in Table 12 and Table 13 based on Harrington *et al.* (2010) (see Appendix 1). Adductor meat and

[1] For OHS reasons, observers are restricted to a maximum of 12 hour sampling in a 24 hour period.

gonad were removed from the shell and weighed together to calculate number of meats per kg. Shell height and width were also measured for morphometric analyses. No samples were taken for biologicals from the JH site as there is little interest in meat weights, gonad stage and discard rates from there, and because of the additional time constraints on the observer by having to sample two sperate catches per tow.

1.4 Data analysis

All data processing and analysis was undertaken in R (R Core Team, 2019), and density plot created using the package "mapplots" (Gerritsen, 2014). Estimates of biomass and potential commercial catch rates followed the methods of Semmens and Jones (2014).

Biomass

The internal widths of the dredges used during the survey were measured in accordance with Semmens and Jones (2014). Dredge widths used by the Shandara, Odete C and Racheal Maree were 3.900 m, 3.905 m and 3.875 m (Table 2). A dredge efficiency of 33% was assumed.

Swept area (S) of each tow was calculated as follows:

$S=LxW$

Where L is the tow distance (m) and W is the width of the dredge (m). Tow distance was calculated from the straight-line distance between start and end tow positions.

Scallop catch in each tow ($C^{standardised}$ in kg/1000 m^2) was calculated as follows:

$C^{standardised} = (C/S)x1000$

Where C is the estimated catch in a shot (kg).

Assuming a 33% dredge efficiency, biomass (B) in tonnes and 95% confidence limits (CL) were estimated for each stratum (bed) as follows:

$B = meanD * A * 3.03 / 1000$

$\text{Upper 95\% CL} = ((meanD + (t_{n-1} \times SE_{meanD})) \times A)*3.03 / 1000$

$\text{Lower 95\% CL} = ((meanD - (t_{n-1} \times SE_{meanD})) \times A)*3.03 / 1000$

Were meanD is the mean density (kg) of scallops per m^2 swept, t_{n-1} is the t –value for the number of shots (n) -1, SE_{meanD} is the standard error of meanD and A is the total stratum area (m^2). The area of each bed was calculated using the R package "geosphere" (Hijmans et al., 2015).

Biomass and upper and lower 95% confidence limits (CL) of scallops greater than 85 mm were calculated as follows:

$B_{>85mm}$ = B * (1-discard rate)

Upper 95% $CL_{>85mm}$ = Upper 95% CL * (1-discard rate)

Lower 95% $CL_{>85mm}$ = Lower 95% CL * (1-discard rate)

where the discard rate was calculated using catch weighted length frequencies converted to weight.

An estimate of density in individuals per square metre (*I*) was obtained as follows

$$I = \sum_{len} WLf / S$$

Were *WLf* is the weighted length frequency for each length class *len*, and *S* is the swept area (m^2).

All densities (kg / m^2 and individuals per m^2) reported have been adjusted for the 33% assumed dredge efficiency.

Selectivity study

The JH site contained a high density of juvenile scallops of which a high proportion would pass through the dredge's meshes. There was some interest in investigating the selectivity of the scallop dredge, as well as estimating the biomass of Commercial Scallops at this site. Small mesh (25 mm x 25 mm) panels were used to cover half of the dredge, with the dredge separated internally so that the catch on each side of the dredge was kept separate. The catch was recorded separately for each side of the dredge, and where available, at least 35 scallops from each side measured.

Biologicals

The length-weight relationship was calculated for each area separately, and the parameters of the relationship are provided in the results. The length-weight relationship was applied to catch-weighted size frequencies to calculate the discard rate at 85 mm. The discard rate was used in calculations of biomass of scallops greater than 85 mm. Number of meats per kg was calculated separately for each bed by dividing 1000 by the mean meat and gonad weight in grams.

Quality Assurance

The survey was undertaken following Standard Operating Procedures. All tow and scallop catch data were recorded in ORLAC Dynamic Data Logger (DDL), which

contains quality assurance protocols including automatic data capture (time, date and position), field restrictions, range checks, mandatory fields and lookup tables. This database is hosted on a cloud-based server and data are extracted for analyses. Data were manually error checked against data sheets. Data analyses were undertaken using R (R Core Team, 2019), and a subset of outputs were reproduced and compared using an alternative software package. Scallops were measured using electronic measuring boards. The first or last (or both) scallop from each shot was measured by both the measuring board and by hand using either digital callipers or a metal ruler. This was done to ensure accuracy and consistency of the measuring board throughout the survey.

Results and their interpretations and conclusions were discussed amongst the research team, and draft reports were reviewed by co-authors and AFMA managers. Where required, comments were addressed in preparation of the final report.

Results

1.5 Survey shots

The 2019 BSCZSF survey was undertaken over two legs during May. During the first leg, the Rachel Maree surveyed Apollo Bay and King Island beds between 30th April 2019 and 4th May 2019, while the Shandara surveyed King Island beds between 29th April and 3rd May 2019 The second leg of the survey was undertaken from 14th May 2019 to 18th May 2019 by the Shandara which surveyed King Island beds, and the Odete C which surveyed Flinders Island and King Island beds between 12th May 2019 to 17th May 2019.

From 12 to 25 valid, random, non-targeted tows were undertaken in each of the survey beds (Table 6). Mean distances towed were: 557 m at Flinders Island (FI), 595 m at KI Bluedot Extended (KI-BDE), 552 m at KI Bluedot SouthEast (KI-BDSE), 555 m at KI5 Small (KI-5S), 546 m at KI-6, 524 m at KI-7, 544 m at KI-8a, 532 m at KI-8b, 505 m at KI-9, 523 m at JH, 537 m at AB-1, and 542 m at AB-2. Depth of survey tows ranged 50–89 m and bottom temperatures ranged 14.5–16.6°C[2]. Total area of each stratum is shown in Table 4 and Table 5.

[2] Only temperature and depth data were available from the Rachel Maree and Odete C at the time the report was written.

1.6 Biomass, size and potential commercial catch rates

Estimated mean biomass within FI was 1,961 t (95%CI 946 t – 2,977 t) (Table 6). Using a discard rate of 18.1% (81.9% > 85 mm), mean biomass for scallops > 85 mm was 1,607 t (Table 7). Densities were highest through the middle of FI and towards the south-east, and generally lowest in the north and south-west corner (Figure 2). Density in individuals per square metre was 0.211 individuals per m^2 (Table 6).

Estimated mean biomasses from the nine King Island Beds surveyed with the full grid were; 1,612 t (95%CI 1,096 t – 2,128 t) at KI-5S, 8,353 t (95%CI 6,602 t – 10,104 t) at KI-BDE, 19,592 t (95%CI 12,669 t – 26,514 t) at KI-BDSE, 1,182 t (95%CI 756 t – 1,608 t) at KI-New, 1,960 t (95%CI 1,332 t – 2,588 t) at KI-6, 837 t (95%CI 343 t – 1,332 t) at KI-7, 795 t (95%CI 576 t – 1,015 t) at KI-8a, 363 t (95%CI 254 t – 472 t) at KI-8b and 9,616 t (95%CI 6,756 t – 12,476 t) at KI9 (Table 6). Mean biomass estimates for AB-1 was 631 t (95%CI 483 t – 779 t) and 886 t (95%CI 629 t – 1,143 t) at AB-2 (Table 6). The percentage of scallops <85mm was mostly less than 5% at the King Island Beds, and less than 0.2% at the Apollo Bay beds (Table 8 and Figure 19). Consequently, mean biomasses of scallops > 85 mm were either the same, or only slightly lower than total biomass estimates except for at KI-BDE and KI-BDSE where the estimated mean biomasses above 85 mm were 7,135 t and 18,714 t respectively (Table 7).

Densities from each shot within each King Island and Apollo Bay bed are shown in Figure 3 –Figure 15. Scallops were caught at medium to low densities throughout KI-5S and KI-New, with some lower densities in the south-east of KI-5S and south-west of KI-New. Scallop densities were very high throughout most of KI-BDE, and extended south-east into KI-BDSE. At the Apollo Bay beds, highest densities were in the centre and east of centre and were lowest in the north and south-east. Densities were medium to very high at KI-6 and the adjoining KI-9. At KI-7, densities were highest through the centre of the bed and in the north-west corner. KI-8a and KI-8b both contained very high densities throughout, apart from the medium to high catches in the south-west corner of KI-8b. Estimated densities in numbers at the King Island beds ranged from 0.170 individuals per m^2 at KI-5S to 3.088 individuals per m^2 at KI-BDSE (Table 6). High densities were also observed at the KI-BDE (1.597 individuals per m^2), KI-6 (1.458 individuals per m^2), KI-8a (2.156 individuals per m^2), KI-8b (1.230 individuals per m^2) and KI-9 (2.867 individuals per m^2).

Mean biomass at the JH bed using the uncovered half of the dredge was 956 t, and 4,615 t with the covered half, however there is a high degree of uncertainty around those estimates (Table 6). Densities were five times higher within the covered half, while density in individuals per square metre was more than 8 times higher. Nearly 0% of Commercial Scallops caught in the covered half of the dredge were greater than 85 mm, resulting in a biomass > 85 mm of 0.4 t, while in the uncovered half, 2.6% of the catch was greater than 85 mm and the estimated biomass over that size was 119 t. Densities in the uncovered half were greatest in the south of the bed (Figure 14).

Conversely, very high densities were recorded in the covered half in the north-east quarter of the bed.

Comparisons of biomass estimates, percent catch composition and size distributions of beds that have been repeatedly surveyed are shown in Appendix 2. While the sampling methods have been consistent, the areas of the beds have changed considerably. Care should be taken when interpreting those results, and consideration of changes in bed areas over time should be made.

1.7 Biologicals

Scallops measured from the from the Flinders Island beds were smaller from other areas (apart from the JH bed) (Table 8). The distribution of lengths there were broadly spread from 80–100 mm with long tails extending below 65 mm, and a mean length of 91 mm (Figure 19). Mean lengths at KI-BDE (91 mm) and KI_BDSE (93 mm) were the smallest of the King Island beds (apart from the JH bed), while KI-New had the largest averaging 111 mm. There was a clear sign of recruitment at KI-BDE and to a lesser extent at KI-BDSE and KI-7, which is the next bed to the north-west of KI-BDE. Size distributions at KI-8a and KI-8b were similar to each other with the bulk of the scallops 95–110 mm. Likewise, size distributions of KI-6 and KI-9 were similar to each other, but smaller than the KI-8 beds, mostly sized 90–100 mm. Size distribution of the Apollo Bay beds were very similar to each other, averaging 104 and 105 mm, with the bulk of the scallops 100–110 mm. Size distributions between covered and uncovered grids at the JH site were very different. From the uncovered half of the grid they averaged 61 mm compared to 58 mm in the covered half, however median length were very similar at 58 mm and 57 mm respectively. Percent frequency was highest around 48–55 mm in the covered side, and 68–76 in the uncovered half.

Comparison of length-weight regressions revealed that the interaction term was significant ($p<0.0001$), suggesting that there is a difference in slopes in the length-weight relationship between beds . The p-value for the indicator variable was also significant ($p<0.0001$) suggesting that there is also a difference in intercepts, and it appears that there are differences in length-weight relationships between beds. A similar result was obtained when beds were grouped into the areas Flinders Island, King Island and Apollo ($p<0.0001$). Separate length-weight relationships were calculate for each area for calculations of discard rates by weights (Figure 17, Table 9).

Scallop meats of shells greater than 85 mm length were smallest from KI-7 despite the size frequency being similar to other KI sites. Most meats were less than 10 g, and they averaged 157 meats per kg (Table 8, Figure 20). Mean length and weight from that site were both lower than those from the other KI sites, and the observer noted that meats were particularly small at that site. Flinders Island beds averaged 68 meats per kg, with most around 14 g per meat. There was a wide variety of meat weights

amongst the other KI sites. Meats were largest at KI-New, AB2 and KI-5S averaging 54, 60 and 62 meats per kg respectively.

Two of the beds that show signs of recruitment, KI-BDE and KI-7 had relatively large proportion of gonads at stage 1 (Figure 21). KI-7 had particularly less developed gonad with nearly 90% of gonads at stage 1 or 2. Commercial Scallops were most often assessed as being in stages 2-4 with stage 5.3 only recorded at AB-2 and stage 5.2 from FI, KI-BDE, KI-8a, KI-8b, AB-1 and AB-2.

Scatterplots of each combination of size measurements (including total weight) shown in Figure 16 reveal a linear relationship between measurements (except for those with total weight). Shell height for a given width and length for a given width appear greater at the FI bed than KI and AB beds (Figure 17). ANCOVA results implied that the gradients are not significantly different ($F=0.30$, $p=0.7$ and $F=0.62$, $p=0.5$ respectively), but summaries of the reduced models revealed significant (both $p<0.0001$) differences in the intercepts between areas. The slopes of height against length appear different between beds, and the slopes ($F=0.9.75$, $p=0.<0.0001$) and intercepts (both $p<0.0001$) were significantly different. Principle Component Analysis reveals that ratios between different measurements of scallops reveals a high degree of overlap between beds, but high variability within the KI bed.(Figure 18). A closer look shows that KI-New and KI-5S are different in morphology to other KI beds, with the main differenced being elongation and compacity, both of those ratios include width.

1.8 Bycatch

A total of 77 different bycatch species / groups were identified during the survey (Table 10), and catch composition varied greatly between beds. The total catch was mostly old single shell at FI (87%), while live Commercial Scallops comprised only 8% of the catch (Figure 22). The catches at most KI and AB sites were dominated by Commercial Scallop, comprising 41–76% of the total catch, however they comprised only 6% of the catch at KI-7 which was dominated by old single, broken shell and Spider Crabs. In the uncovered half of the dredge at the JH bed, Eleven-arm Seastars (41%), Commercial Scallop (31%) and old singe shell (6%) comprised most of the catch.

Considering only the four different scallop “groups” (Commercial Scallops, old single, new single, and clappers), FI had a much higher percentage of old single shell (more than 80%) than other beds, while about 37% of the scallop catch from KI-7 and KI-BDE was old single shell (Figure 23). KI-7 also had the highest percentage of new single and clappers

Table 2. Inputs used in biomass calculations that are not derived from the surveys.

Inputs	Shandara	Odete C	Rachel Maree
Dredge width	3.900 m	3.905	3.875
Dredge efficiency	33%	33%	33%

Table 3. Estimated total commercial catch (t) and the number of vessels that fished within each survey bed during 2018 based on logbook data.* This was in the area initially used in the survey design, but these areas were refined for the 2019 survey.

Bed	Values	Number of vessels
FI	0 t	0
KI-5S	Confidential – included in "other areas" catch	1
KI-New	0	0
KI-BDE*	575 t	10
KI-BDSE	366 t	5
KI-6	217t	7
KI-7	99 t	7
KI-8*	679 t	9
KI-9*	157 t	9
AB-1	Confidential – included in "other areas" catch	1
AB-2	183 t – Note: This site was closed to fishing for the 2018 season, however the course resolution of recording effort places it in AB2 rather than AB1.	5
All other areas	960 t	11
Total	3250 t	12

Table 4. Boundaries (decimal degrees) of each scallop bed other than KI6 and KI7 surveyed in 2018 and area of polygons (km^2).

Bed	Nickname	Latitude		Longitude		Total
		Northern	Southern	Western	Eastern	Area (km^2)
Flinders Island	FI	-39.190	-39.33	148.050	148.130	107.32
King Island 5 Small	KI-5S	-39.910	-40.000	144.950	145.030	68.31
King Island New	KI-New	-39.910	-39.950	144.830	144.950	45.56
King Island Bluedot Ext	KI-BDE	-39.7671	-39.8255	144.8561	144.958	56.53
Apollo Bay 1	AB-1	-39.1507	-39.1757	144.0866	144.1447	13.93
Apollo Bay 2	AB-2	-39.1257	-39.1507	144.0866	144.1447	13.95

°

Table 5. Boundaries (decimal degrees) of KI6 and KI7 surveyed in 2018 and area of polygons (km^2). * The north-west corner of BDSE overlapped with KI-BDE, and so that overlapping area was removed from the polygon. This can be seen in Figure 6. # The north-west corner of KI-9 overlapped with KI-6, and so that overlapping area was removed from the polygon. This can be seen in Figure 10.

Bed	Nickname	Position (latitude / longitude)				Total
		North-west	North-east	South-east	South-west	Area (km^2)
King Island 6	KI-6	-39.5457/ 144.2482	-39.5458/ 144.3313	-39.5639/ 144.3317	-39.5604/ 144.248	13.08
King Island 7	KI-7	-39.6362/ 144.5618	-39.623/ 144.6282	-39.6442/ 144.6391	-39.6564/ 144.57	14.53
King Island 8a	KI-8a	-39.5125/ 144.1220	-39.5129/ 144.1448	-39.5283/ 144.1449	-39.5283/ 144.1219	3.42
King Island 8b	KI-8b	-39.5100/ 144.1730	- 39.5100/144. 1943	-39.5233/ 144.1943	-39.5233/ 144.1730	2.72
King Island 9#	KI-9	-39.58/ 144.2833; -39.55/ 144.3375	-39.55/ 144.3667	-39.6067/ 144.3667	-39.6067/ 144.2833	36.39
JH	JH	-40.0059/ 144.5454	-39.9566/ 144.6297	-39.9888/ 144.6475	-40.0382/ 144.5624	34.08
King Island Bluedot SE*	KI-BDSE	-39.82167/ 144.93833	-39.82167/ 145.01667	-39.9/ 145.11333	-39.9/ 145.01	66.95

Table 6. Biomass estimates, 95% confidence limits and number of tows included in analyses using the straight-line method. Note that both densities have been adjusted for a 33% assumed dredge efficiency. *These figure use data from the unmeshed half of the dredge – half dredge width was used in swept area calculations. # These figure use data from the meshed half of the dredge – half dredge width was used in swept area calculations. Number of shots and estimated biomass is not added to sub-totals or totals.

Area	Bed	Number of tows	Mean density (kg/1000 m^2)	Standard deviation (kg/1000 m^2)	Lower 95% CL (t)	Estimated biomass (t)	Upper 95% CL (t)	Potential catch rate (kg/hr)	Density (ind/m^2)
FI	FI	25	18.3	22.9	945.6	1,961.3	2,976.9	72.4	0.211
Sub-total		**25**				**1,961.3**			
KI	KI-5S	25	23.6	18.3	1,096.1	1,612.1	2,128.1	93.5	0.170
KI	KI-BDE	25	147.8	75	6,602.3	8,353.4	10,104.4	585.2	1.597
KI	KI-BDSE	25	292.6	250.5	12,668.6	19,591.5	26,514.3	1159	3.088
KI	KI-New	25	25.9	22.7	755.6	1,181.9	1,608.2	102.7	0.173
KI	KI-6	25	149.8	116.3	1,332.3	1,960.1	2,588	593.4	1.458
KI	KI-7	25	57.6	82.4	342.9	837.2	1,331.5	228.1	0.599
KI	KI-8a	15	232.5	115.7	576.1	795.4	1,014.6	920.8	2.156
KI	KI-8b	12	133.6	63.1	253.9	362.7	471.6	529	1.230
KI	KI-9	25	264.2	190.4	6,756.4	9,616.2	12,476	1046.5	2.867
KI	JHUnCover*	20	28.1	58.2	27.6	956.2	1,884.7	111.1	0.842
KI	JHCover#	20#	135.4	195.1	1,502.1	4,614.6	7,727	536.2	7.069
Sub-total		**222**				**45,266.7**			
AB	AB-1	25	45.3	25.7	483.3	631.3	779.3	179.5	0.390
AB	AB-2	25	63.5	44.7	628.9	886.1	1,143.4	251.5	0.563
Sub-total		**50**				**1,517.4**			
Total		**297**				**48,745.4**			

Table 7. Percent weight of scallops > 85 mm (catch weighted by weight), and biomass estimates 95% confidence limits for scallops greater than 85 mm calculated using the straight-line method. *These figure use data from the unmeshed half of the dredge – half dredge width was used in swept area calculations. # These figure use data from the meshed half of the dredge – half dredge width was used in swept area calculations. Number of shots and estimated biomass is not added to sub-totals or totals.

Bed	% weight > 85 mm	Lower 95% CL (t)	Estimated Biomass (t)	Upper 95% CL (t)
FI	81.9	774.9	1,607.2	2,439.4
Sub-total			**1,607.2**	
KI-5S	99.8	1,093.7	1,608.6	2,123.5
KI-BDE	85.4	5,639.5	7,135.3	8,631.0
KI-BDSE	95.5	12,101.0	18,713.8	25,326.4
KI-New	100.0	755.6	1,181.8	1,608.1
KI-6	98.6	1,313.5	1,932.4	2,551.5
KI-7	97.5	334.2	816.0	1,297.7
KI-8a	98.3	566.4	782.1	997.6
KI-8b	98.5	250.0	357.1	464.4
KI-9	97.7	6,603.4	9,398.4	12,193.4
JH-Uncover#	2.6	38.9	119.4	199.9
JH-Cover*	0.0	0.0	0.4	0.9
Sub-total			**42,044.9**	
AB-1	99.9	483.0	630.9	778.8
AB-2	100.0	628.7	885.9	1143.1
Sub-total			**1,516.8**	
Total			**45,168.9**	

Table 8. Number of length measurements (N), median, mean and standard error (SE) of scallops measured, and % of scallops measured (catch weighted by weight) less than and greater than 85 mm and mean number of meats per kg of scallops greater than 85 mm from each bed.

		Length (mm)			85 mm		Meats / kg
Bed	N	Median	Mean	SE	%<	%>	Mean
FI	815	90	90.5	0.2	15.2	84.8	68
KI-5S	1047	109	107.8	0.3	0.3	99.7	62
KI-BDE	925	94	90.6	0.4	13.5	86.5	80
KI-BDSE	945	93	92.8	0.2	5.8	94.2	88
KI-New	1050	111	110.6	0.2	0.0	100.0	54
KI-6	1251	101	100.5	0.2	1.0	99.0	71
KI-7	1136	99	97.4	0.3	5.1	94.9	157
KI-8a	609	102	101.8	0.3	1.7	98.3	72
KI-8b	450	101.5	101.0	0.4	2.1	97.9	66
KI-9	1252	95	95.7	0.2	3.4	96.6	84
JH – Uncovered	585	58	61.0	0.5	91.3	8.7	*
JH – Covered	648	57	58.4	0.4	99.6	0.4	*
AB-1	883	105	104.5	0.2	0.1	99.9	*
AB-2	927	105	104.4	0.2	0.1	99.9	60

Table 9. Number of scallops retained for biological sampling, and parameter estimates for length weight relationships.

Area	N	a	b	Adjusted R^2
Flinders Island	50	-6.1441	2.3356	0.69
King Island	433	-8.0034	2.7115	0.88
Apollo Bay	100	-3.7750	1.8198	0.58

Table 10. Catch of each species in each bed. (u) refers to undifferentiated species recorded at a higher taxonomic level.

	Catch (kg)												
Species	FI	BDE	BDSE	JH	KI5S	KI6	KI7	KI8a	KI8b	KI9	KINEW	AB1	AB2
Commercial Scallop	298.6	2812.15	4942.45	180.8	420	2620	966.8	2411.5	1093	4180	455.5	781	1097.2
Clappers		10		0.1	0.3	55	2620	2	1	7.5			
New Single	4	820	290	32.5	60.4	950	2860	325	98	1147	89.6	90.5	123.36
Old Single	3144	2245	1395	31.5	100.7	547	3755	555	143	465	87.2	113.6	293.3
Algae - Phyllospora						1	5			0.4	0.3		
Armour Gurnard (Undifferentiated)	0.3	0.48	0.25										
Ascidian (U)					35.4		3.4			40.7	62		
Australian Angelshark													3.6
Australian Burrfish				0.25									
Australian Tulip Shell	6.75	26.45	17.15					2.16	0.6				0.3
Banded Stingaree		0.3	2.85				1.2	0.5	0.63			1.2	0.93
Bassina Spp.	0.01											0.1	0.05
Brittlestars (U)	0.01			0.01			0.21						
Bug (U)	0.5			0.3		0.3	0.3	0.75	0.2	0.1	0.1	0.7	0.6
Butterfly Gurnard			0.13		0.2				0.1		0.4		0.05
Cassidae (U)											0.3		
Catshark (U)					0.2								
Cocky Gurnard		1	0.56	0.2		0.8	0.8			1.9	0.6		
Common Gurnard Perch			1.5	0.2				1.6	0.7		0.2		
Common Stargazer									0.4				1.55
Conger & Short-Tail Conger Eel (U)													0.01
Cowrie (U)	0.1							1.8	1			0.3	0.1
Crab (U)		0.2	0.02			0.1	0.11	0.05			0.01	0.01	0.04
Crested Flounder								0.07					
Doughboy Scallop	18.5	423.4	40	10.7	8.2	131	384	109.3	4.81	1392			
Draughtboard Shark				0.3			2						4.4
Eleven-Arm Seastar		6.03	0.15	223.5	2.2		13.5	4.65	0.05		0.7		0.83
False Bailer Shell													1.8
Fan-Like Dog-Cockle	12.02												

	Catch (kg)												
Species	FI	BDE	BDSE	JH	KI5S	KI6	KI7	KI8a	KI8b	KI9	KINEW	AB1	AB2
Flounder (U)		0.05											
Gastropod (U)	0.35	0.75	1.43					1.9				0.4	0.1
Greenback Stingaree	0.06		1.2			1		0.75	1.4		0.95	2.6	
Gunn Leatherjacket							0.1						
Hard Coral	0.4			0.5				0.3	0.01			0.7	
Hermit Crab (U)	2.32	5.55	3.5	2.5	7.9	16.2	40.2	7.2	3.71	3	1.9	1.25	0.37
Holothurian (U)		60.5		2.6	1.1	2.4		0.8	1.7		3.2	8.65	0.8
Jellyfish (U)					0.1								
King Island Thickshell-Clam	2.2												
Latchet						0.1							
Maori Octopus								2.9	1.3				
Mollusc (U)	0	0	0.75	10.7	33.4	20.5	59.6	2.82	5.8	43.2	24.5	0.3	1
Nautilus (U)					0.2								
New Zealand Screw Shell				1							0.42		
Octopus (U)	0.76	7	1.23		1.3	9.1	15.8	1.66	1.85	6.2		1.95	2.05
Oysters				12	0.9						0.4		0.95
Pale Octopus								0.42					0.2
Pen Shell	0.1							0.5	1.5			1.7	9.48
Polychaete Worm (U)							0.2		0.1		0.02		0.05
Polymastia Spp.												0.7	
Razor Clams								1				0.8	0.6
Red Cod							0.3		0				
Red Gurnard									0.1				
Roundsnout Gurnard								0.4					
Sea Urchin (U)	0.11						9.5	0.51	0.01		0.1	0.77	0.55
Seapen (U)	0.6						0.2	0.4	0.1	0.1		0.6	4.55
Searobin & Armour Gurnard (U)													0.15
Seastar (U)			0.05		0.26	1.3	0.7	1.56	0.67	0.9	0.02	18.75	20.73
Sergeant Baker							0.2			0.3			
Shark Egg (U)		0.3				0.1	0.2	0.1	0		0.4		
Shaw Cowfish				1			0.1						
Shell	0	0	1478.5	17	4	1532	3121	150	0.1	2460	1.7	1.78	14.46

	Catch (kg)											
Species	FI	BDE	BDSE	JH	KI5S	KI6	KI7	KI8a	KI8b	KI9	KINEW	AB1	AB2
Skate (U)		1			0.5						0.3		
Soft Coral (U)							1					0.15	0.05
Southern Sand Flathead				0.2			0.2			0.4	0.5		
Sparsely-Spotted Stingaree				1	1.3	0.3	0.4				1.6		1.8
Speckled Stargazer												0.3	
Spider Crab (U)	4.15	77.25	35.35	6	4.2	3	3.1	4.55	0.35	7.7	8.8		
Spiny Pipehorse						0.4	0.2						
Sponge (U)	81	30.2	30	2.9	4	53	1347.3	56.4	35	159	6.3	29.4	30.3
Sponges (Coral)				1			1	6.8					
Stargazer (U)	6.5	3			1.1	0.4	0.2				0.3		0.3
Stingray (U)	8	1						0.8			5		1.7
Stony Coral								0.02					
Substrate - Rock				20		55	1137	21	27	142		41.4	1.7
Tasmanian Numbfish		0.15								0.3			
Tiger Flathead				1						0.2	1	0.2	1.2
Triggerfish & Leatherjacket (U)	1												
Venus Shells	2.36							0.5				2	1.07
Volute (U)	0.55	1.05	1.45		0.3	4.3	1	0.7	2	15.1	0.5	3.4	3.4
Whitespotted Skate	0.5		2.55			0.5	0.6		3.1	1.2			

Figure 2. Scallop density (kg / 1000 m^2) within the defined stratum of the FI bed near Flinders Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

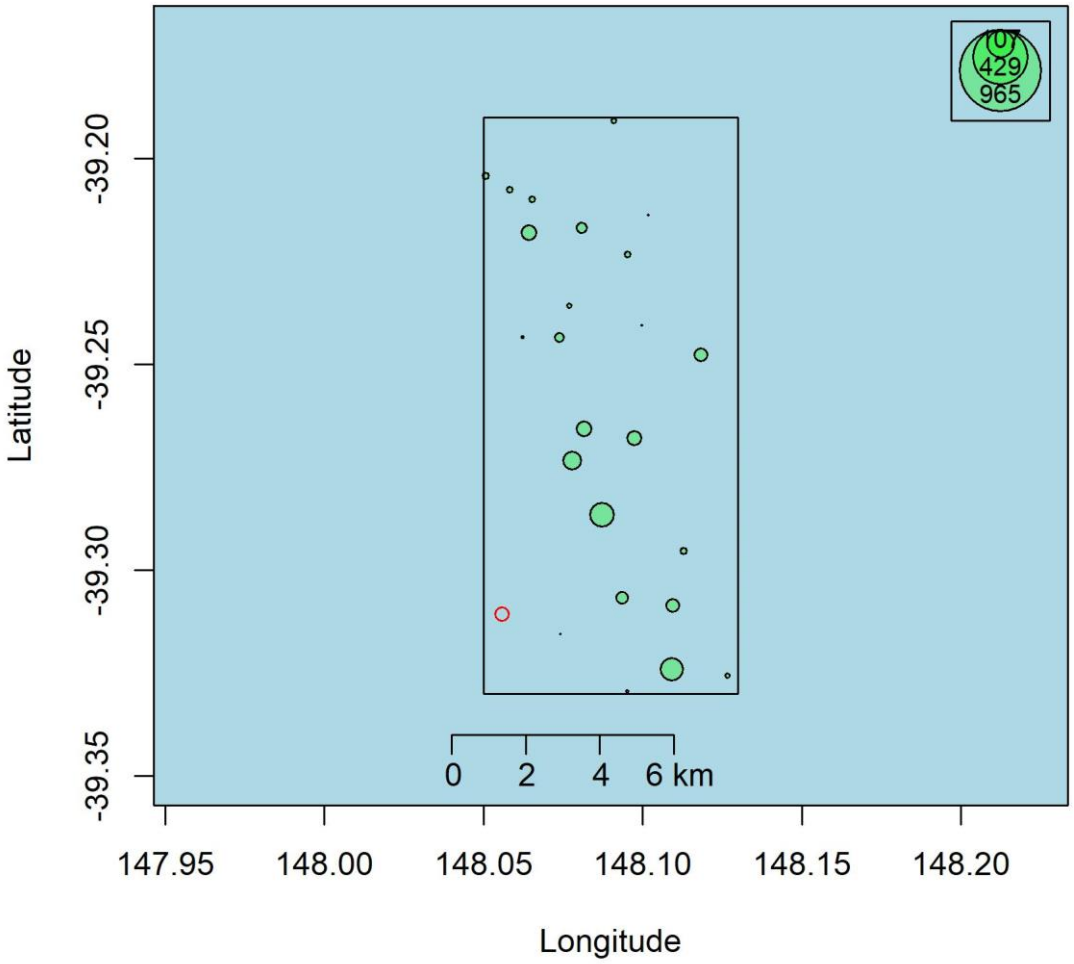


Figure 3. Scallop density (kg / 1000 m^2) within the defined stratum of the KI-5S bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

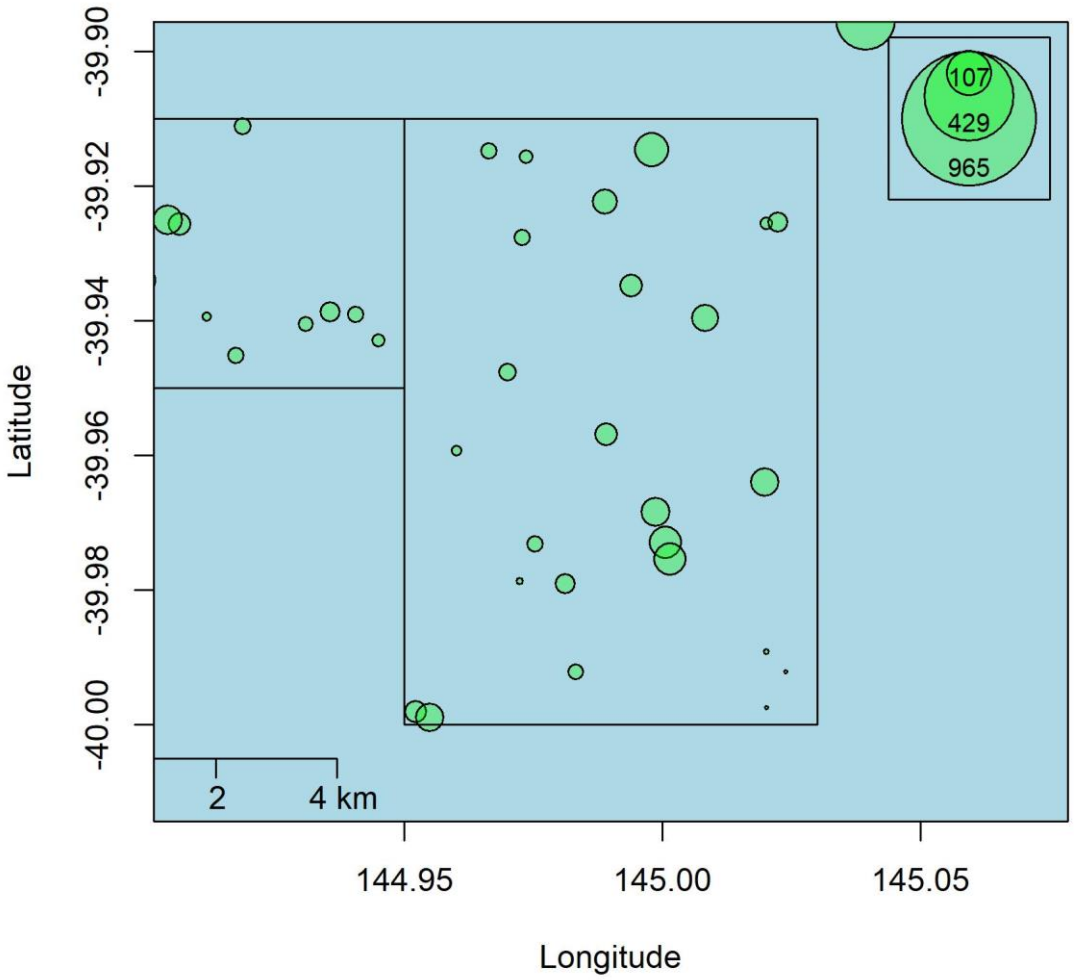


Figure 4. Scallop density (kg / 1000 m^2) within the defined stratum of the KI-New bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

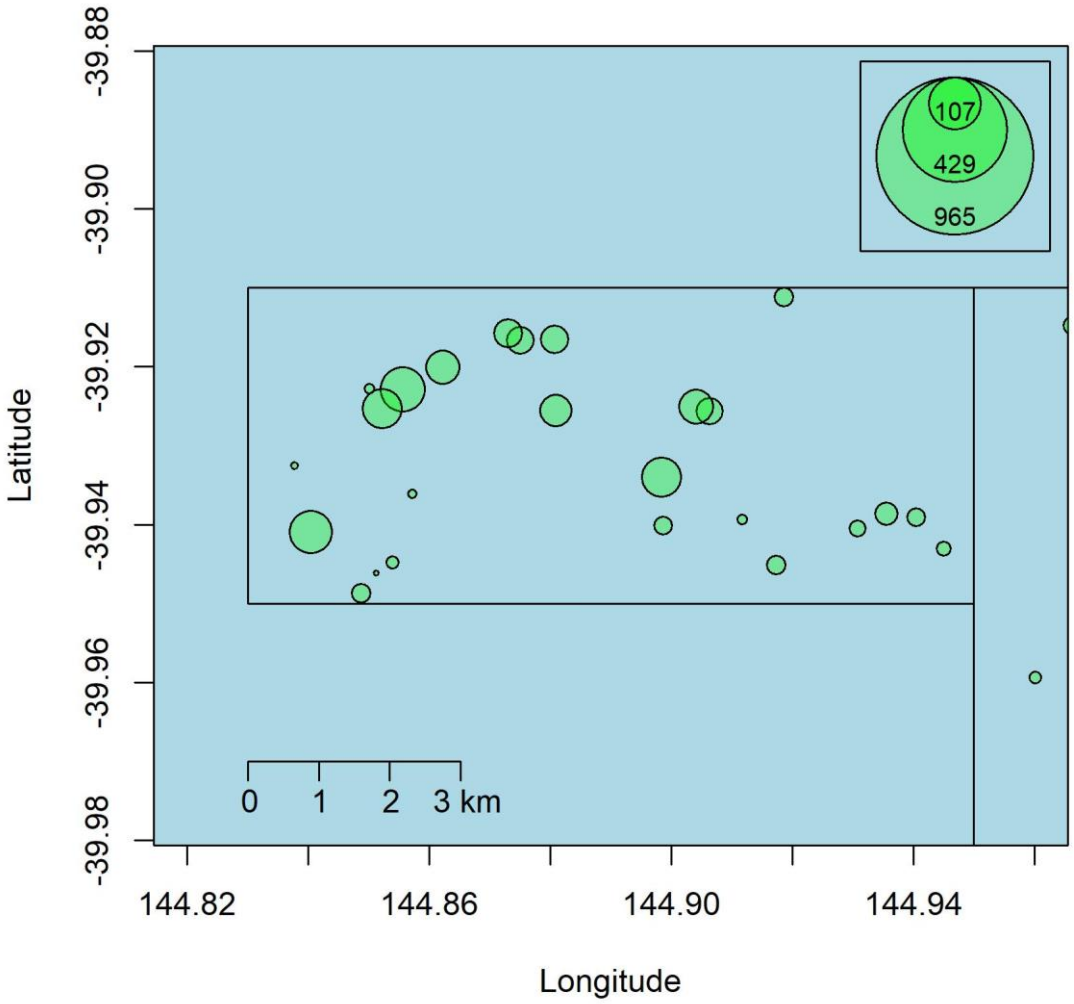


Figure 5. Scallop density (kg / 1000 m^2) within the defined stratum of the KI-Bluedot Extended bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

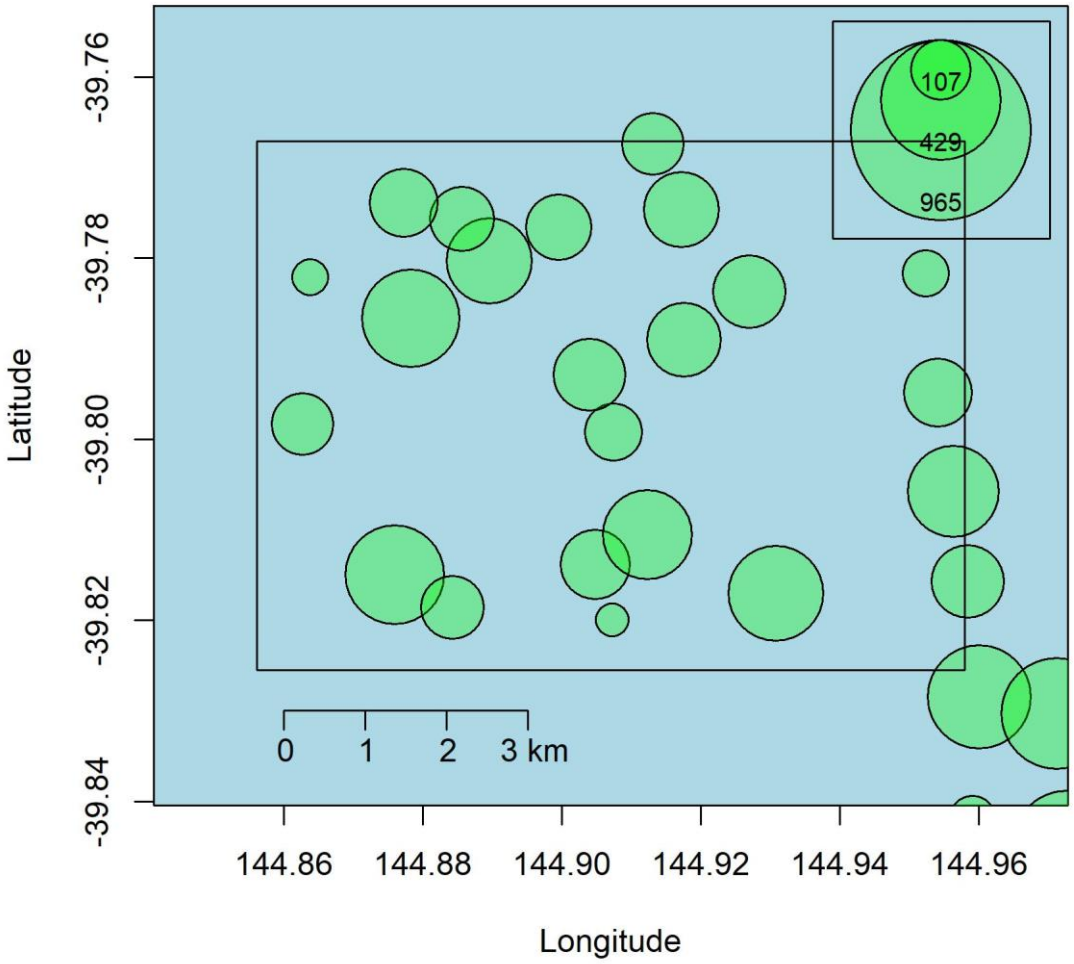


Figure 6. Scallop density (kg / 1000 m^2) within the defined stratum of the KI- Bluedot South-East bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

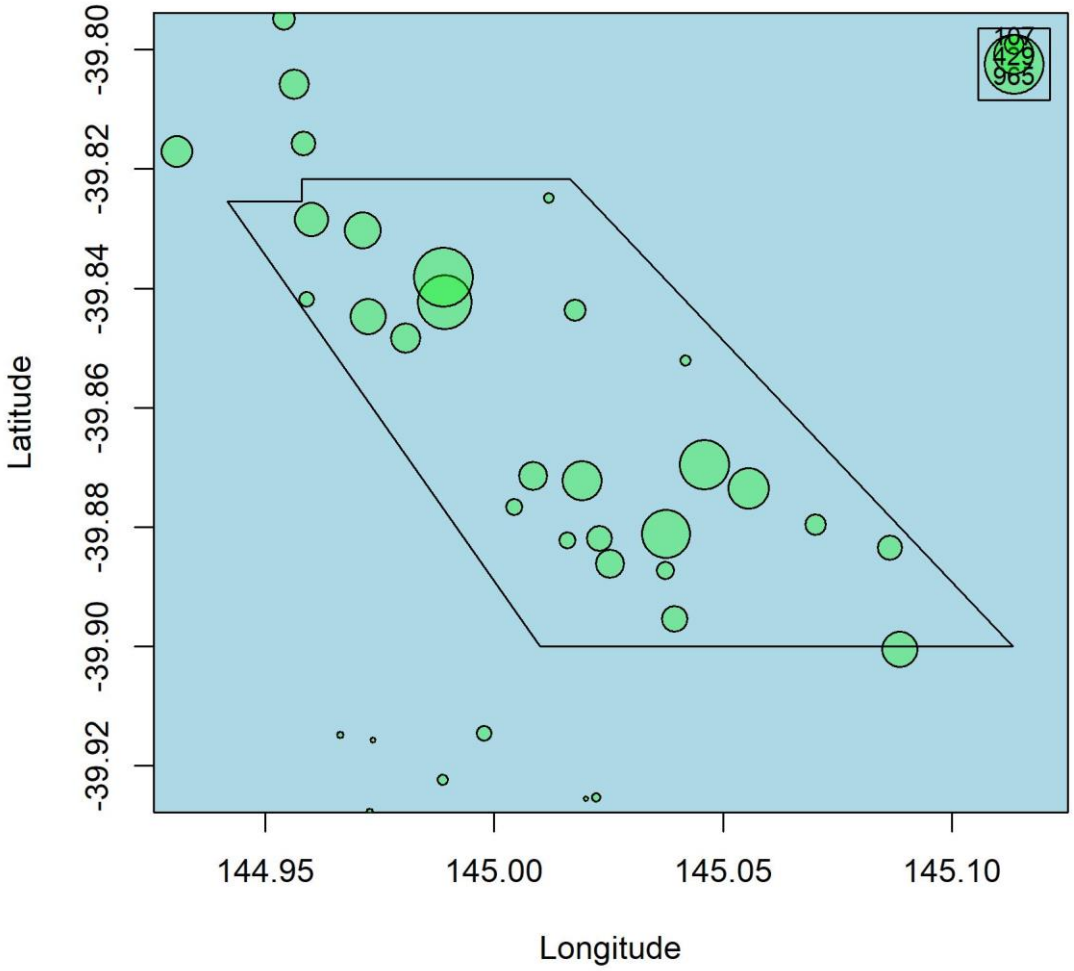


Figure 7. Scallop density (kg / 1000 m^2) within the defined stratum of the AB-1 bed near Apollo Bay. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

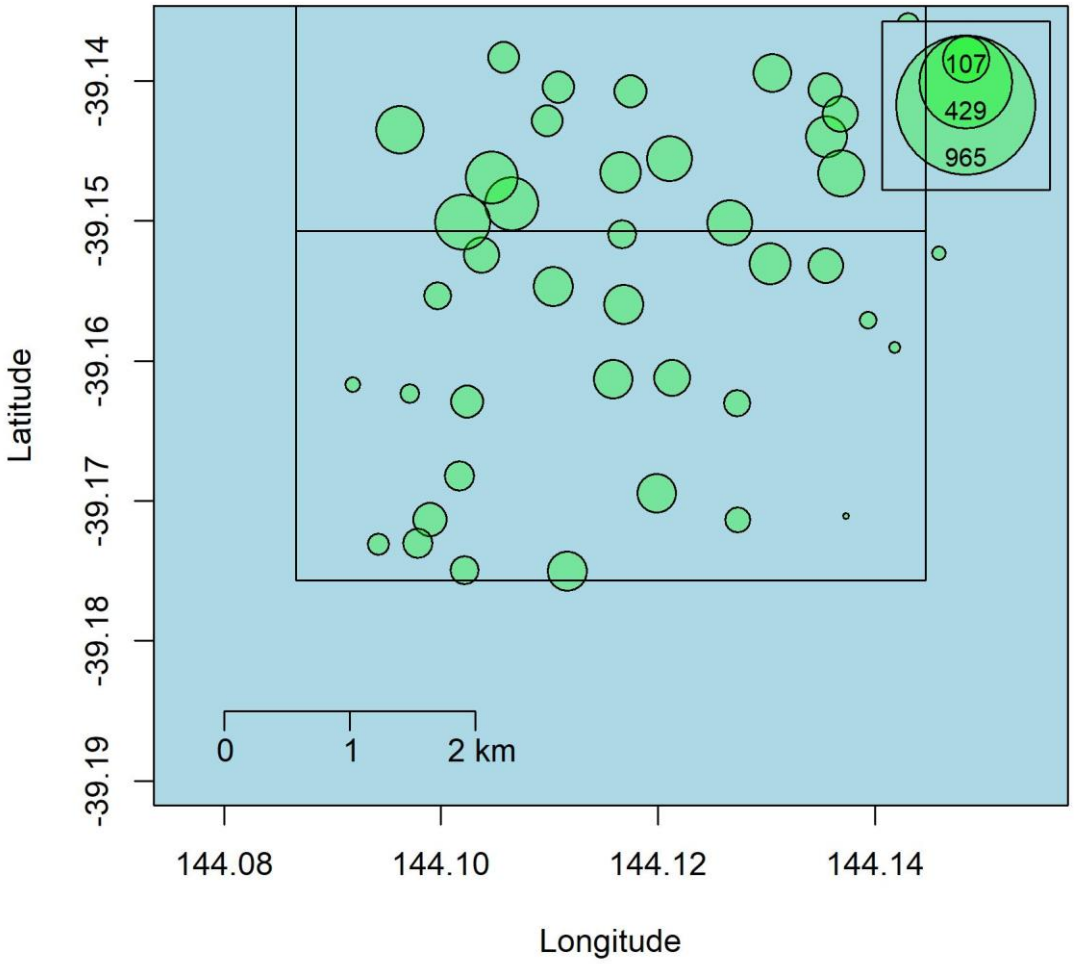


Figure 8. Scallop density (kg / 1000 m^2) within the defined stratum of the AB-2 bed near Apollo Bay. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

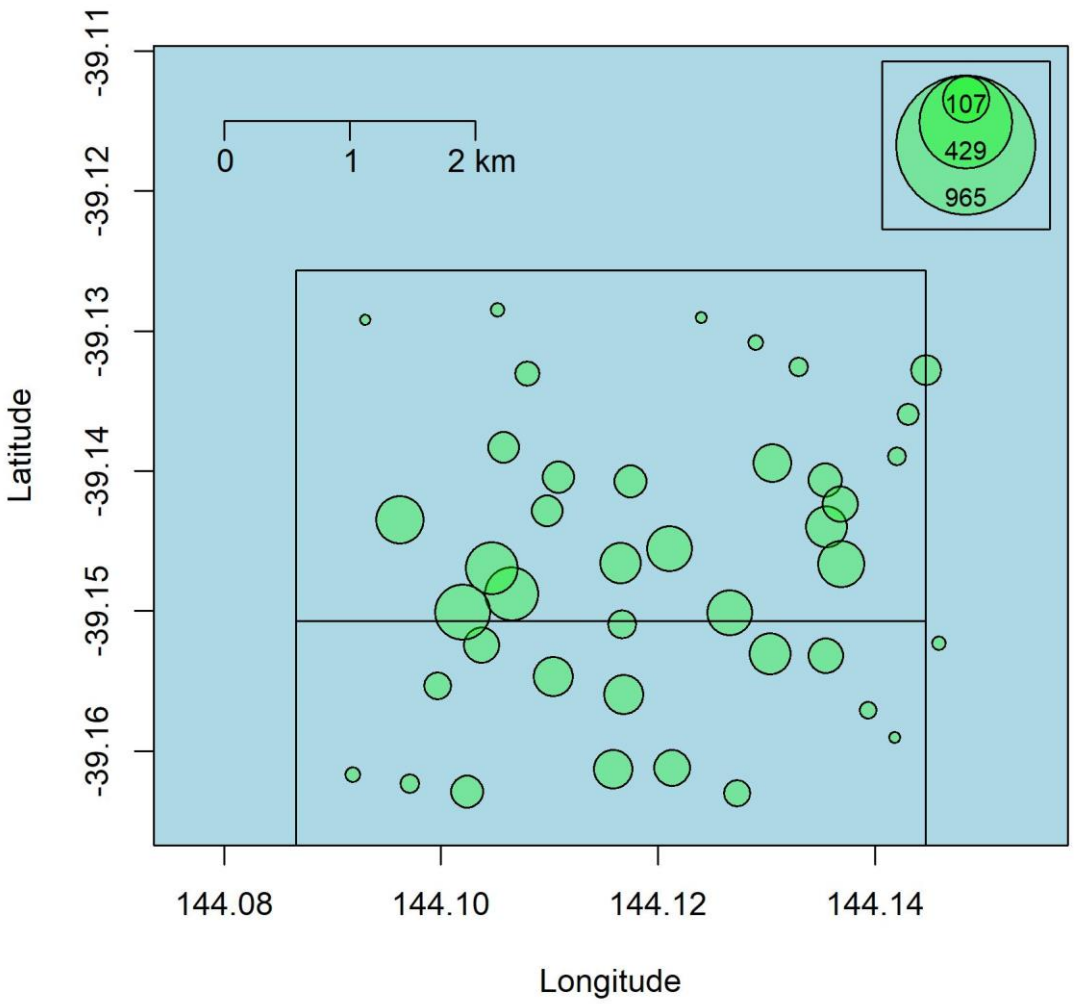


Figure 9. Scallop density (kg / 1000 m^2) within the defined stratum of the KI-6 bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

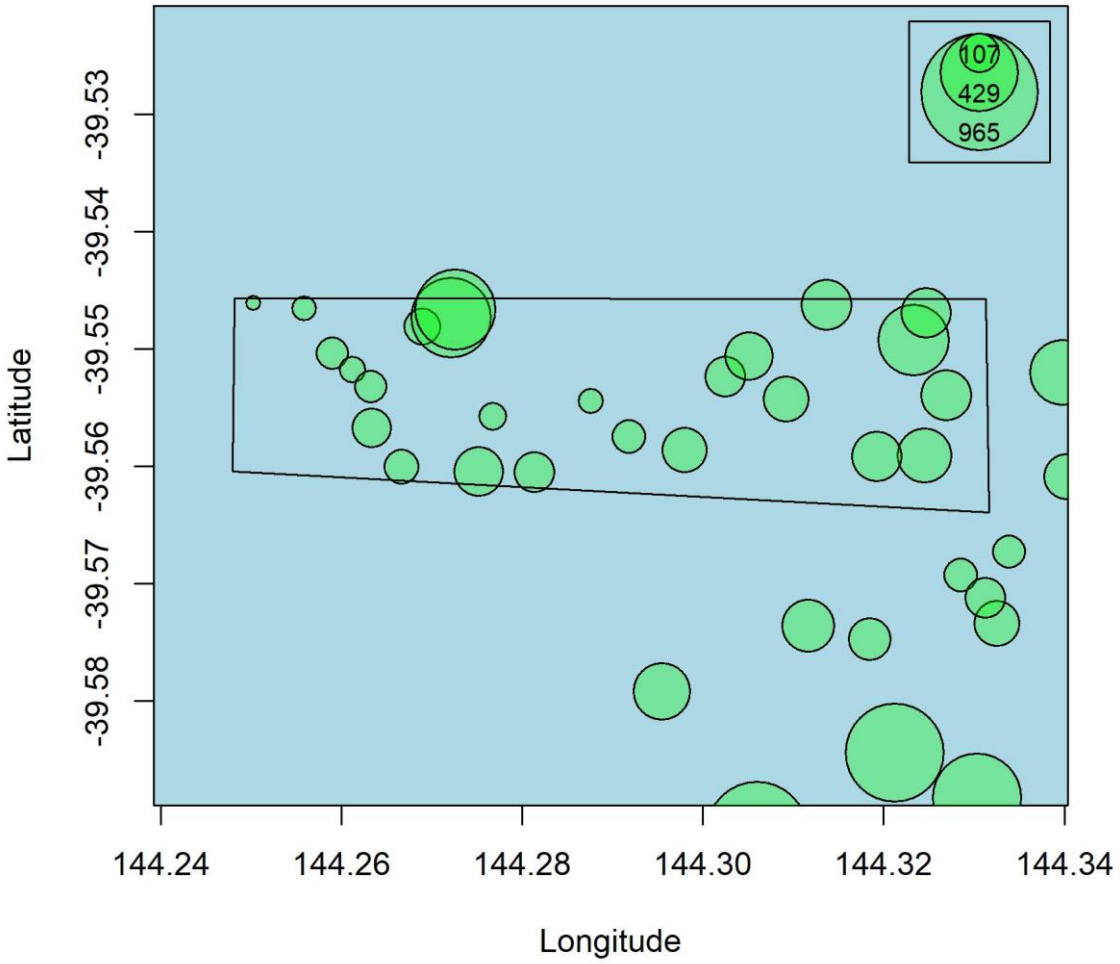


Figure 10. Scallop density (kg / 1000 m^2) within the defined stratum of the KI-9 bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

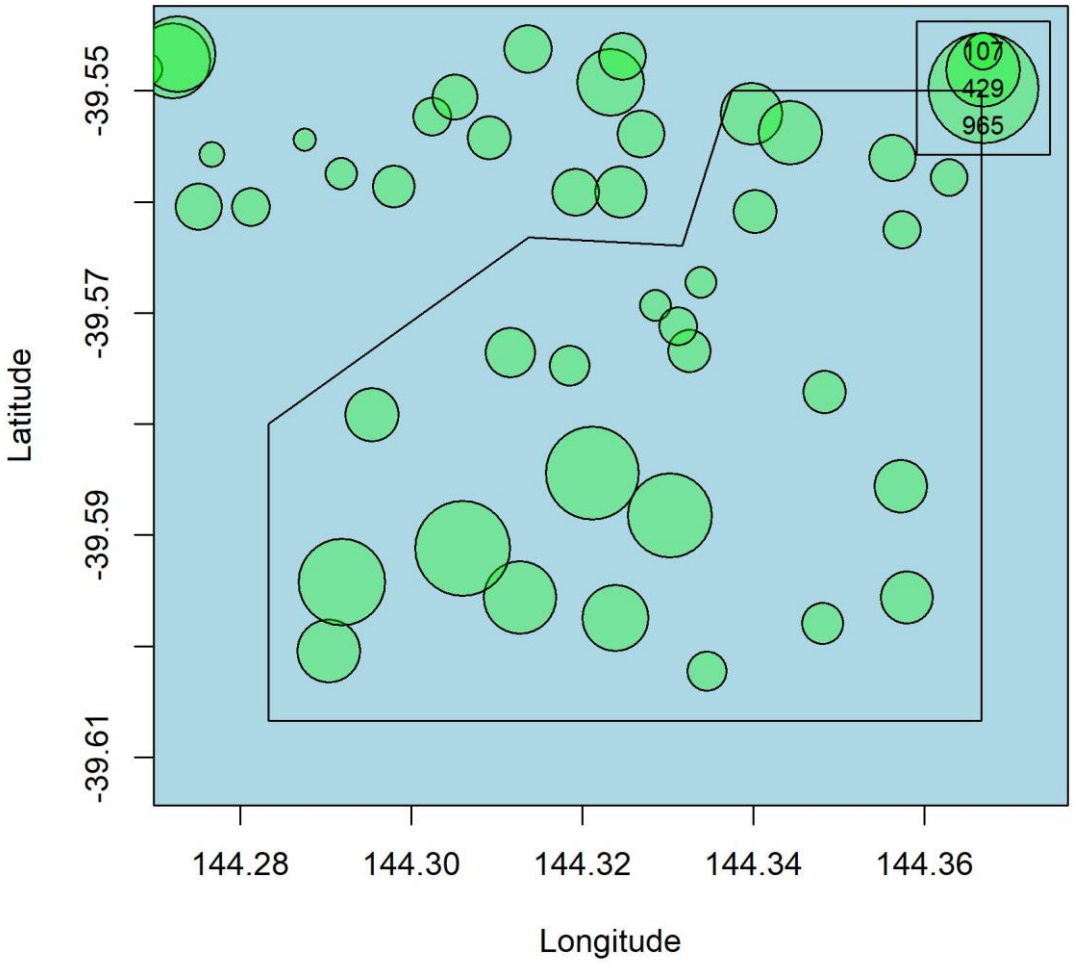


Figure 11. Scallop density (kg / 1000 m^2) within the defined stratum of the KI-7 bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

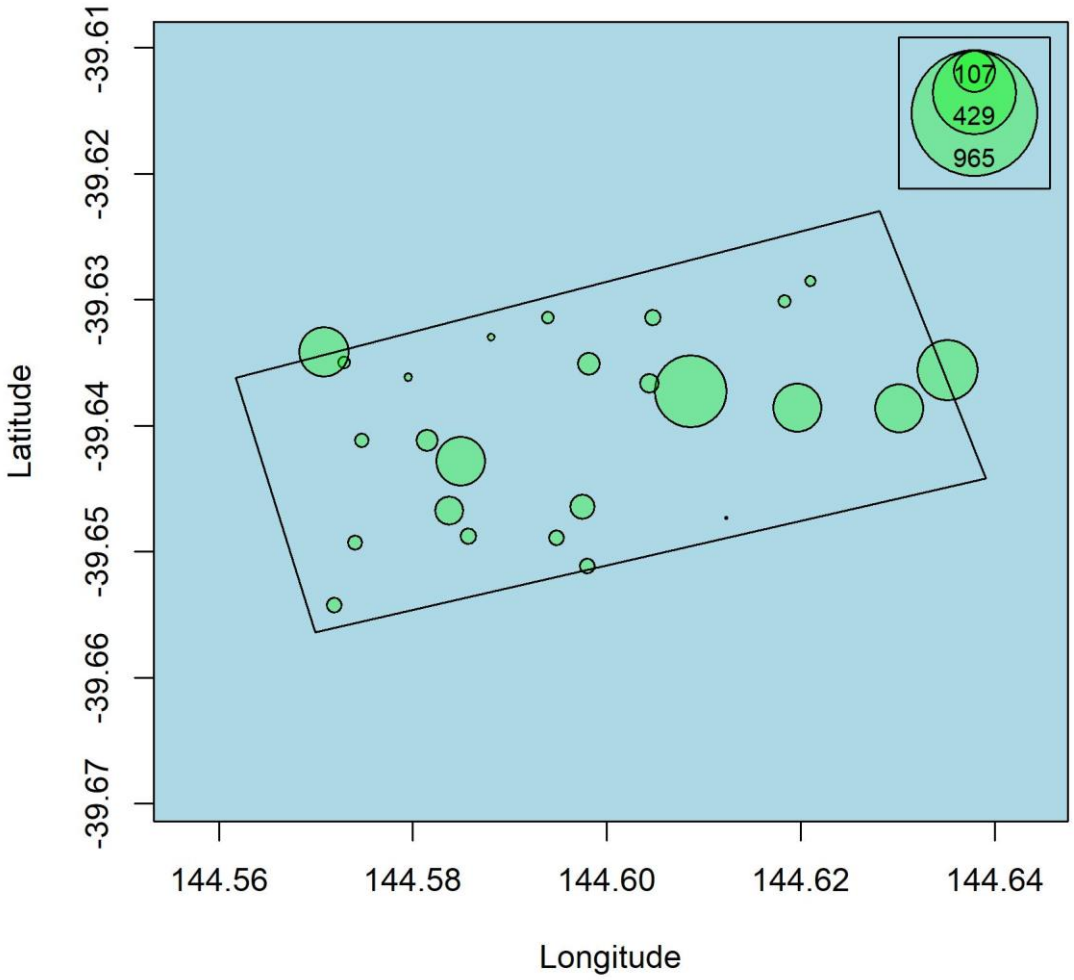


Figure 12. Scallop density (kg / 1000 m^2) within the defined stratum of the KI-8a bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

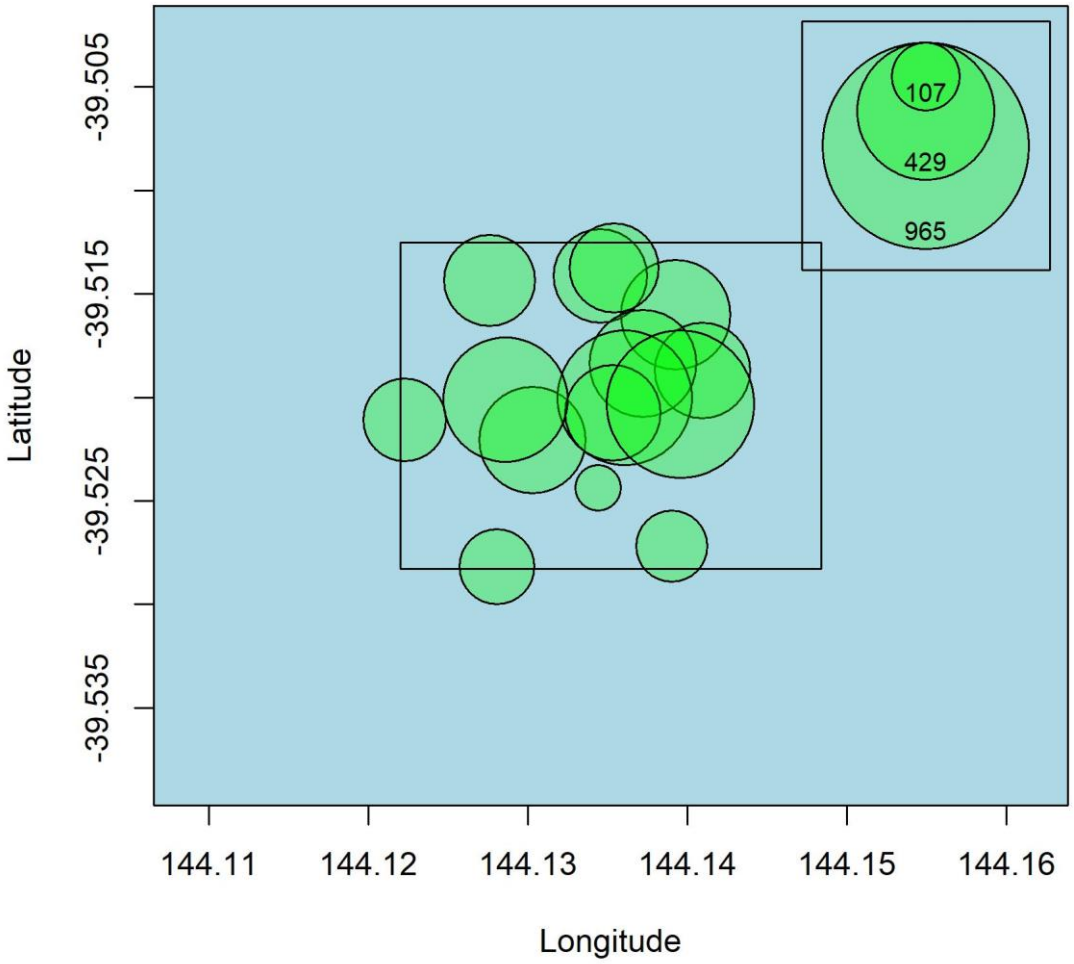


Figure 13. Scallop density (kg / 1000 m^2) within the defined stratum of the KI-8b bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

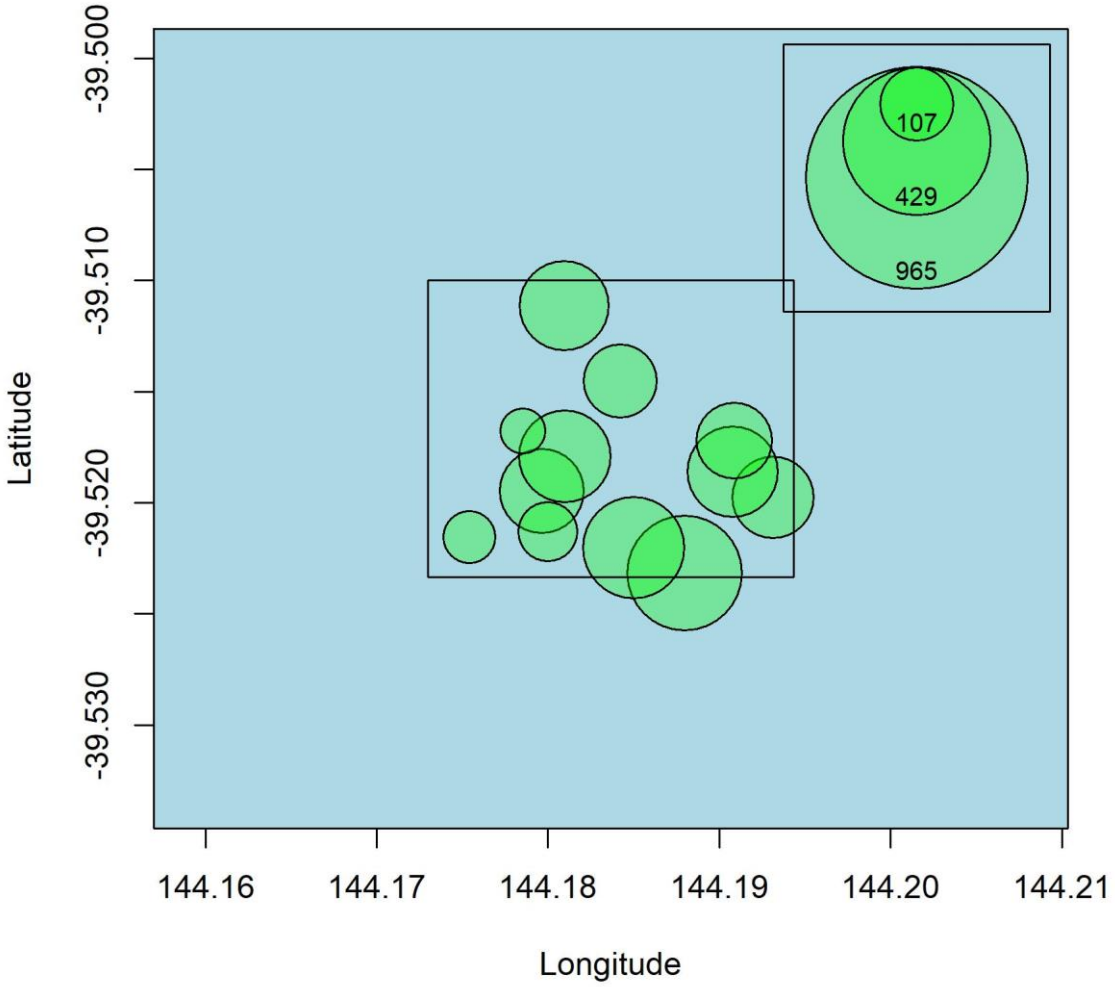


Figure 14. Scallop density (kg / 1000 m^2) within the defined stratum of the JH bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches. Note : these data only comprise catches from the uncovered half of the dredge. Half dredge width was used to calculate swept area.

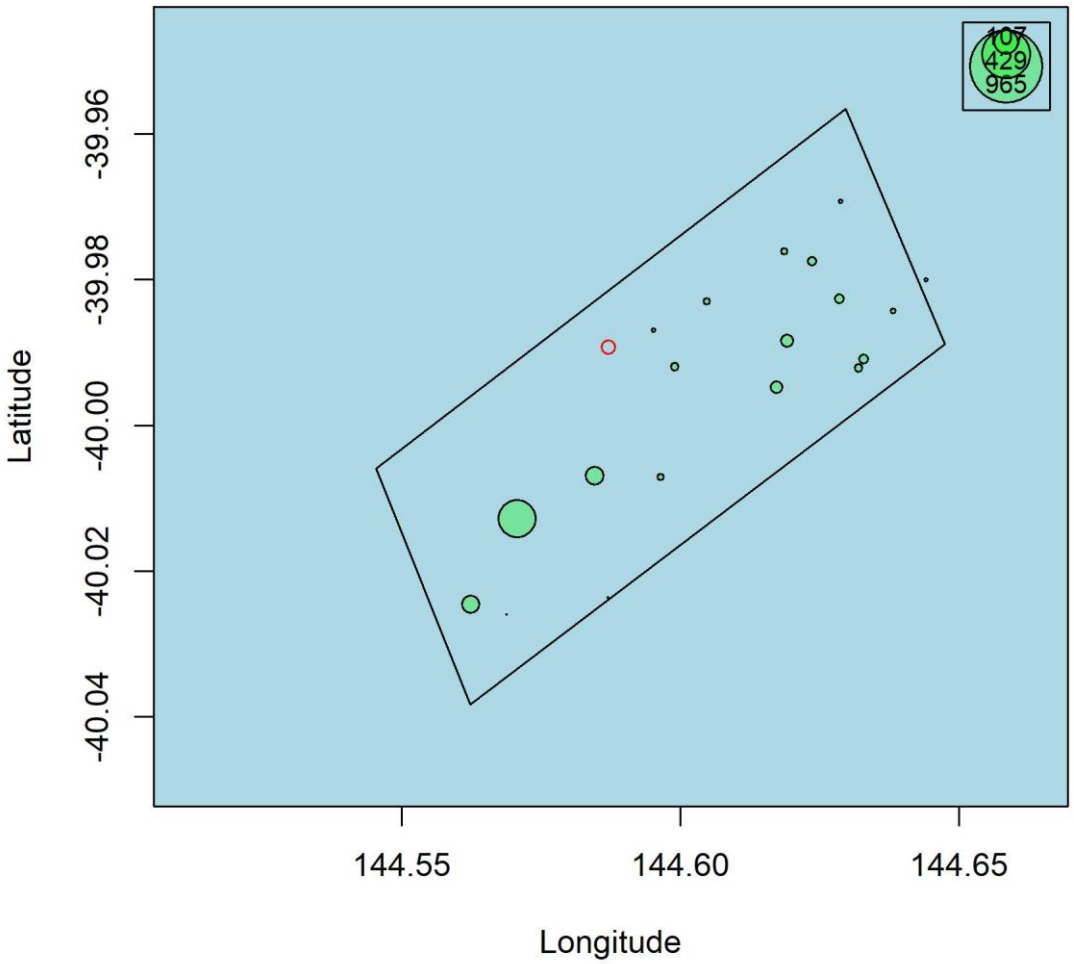


Figure 15. Scallop density (kg / 1000 m^2) within the defined stratum of the JH bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches. Note : these data only comprise catches from the covered half of the dredge. Half dredge width was used to calculate swept area.

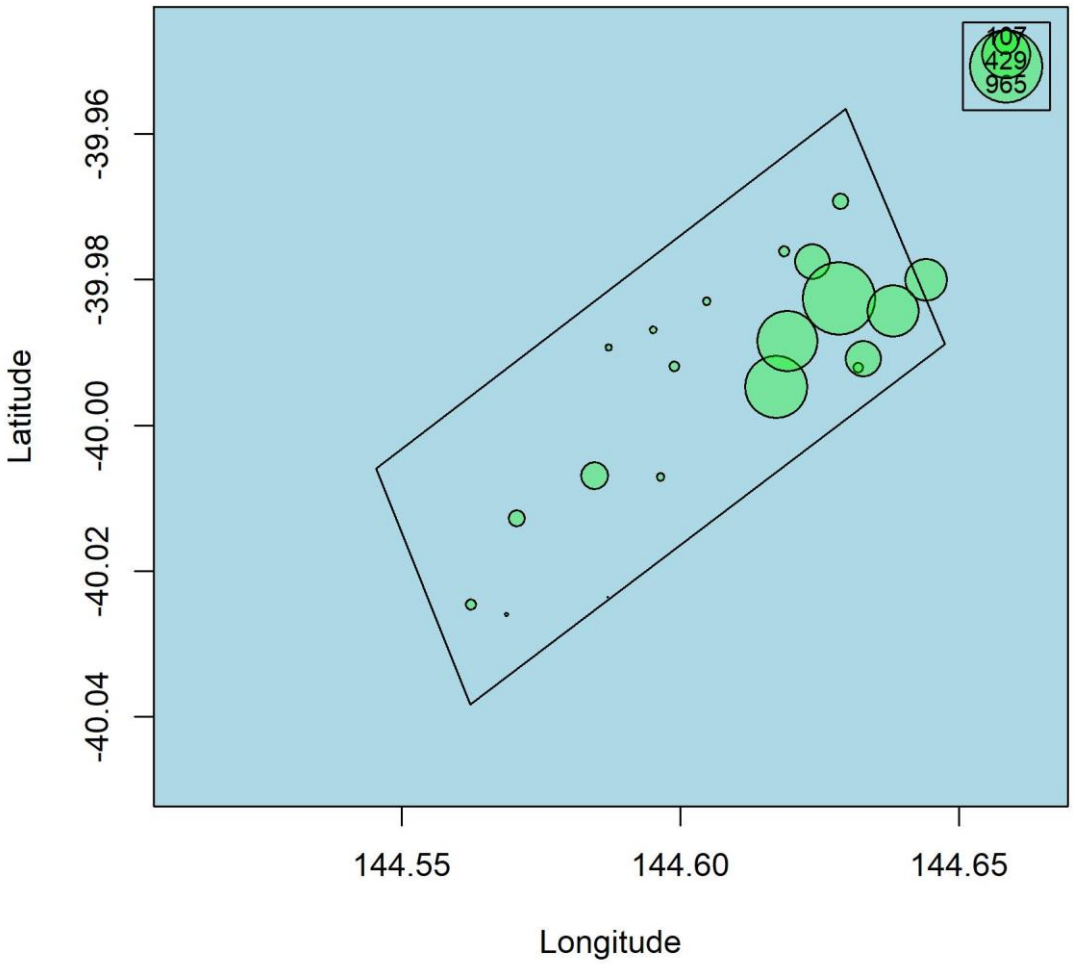


Figure 16. Scatterplot matrix of size measurements and total weight for all samples combined.

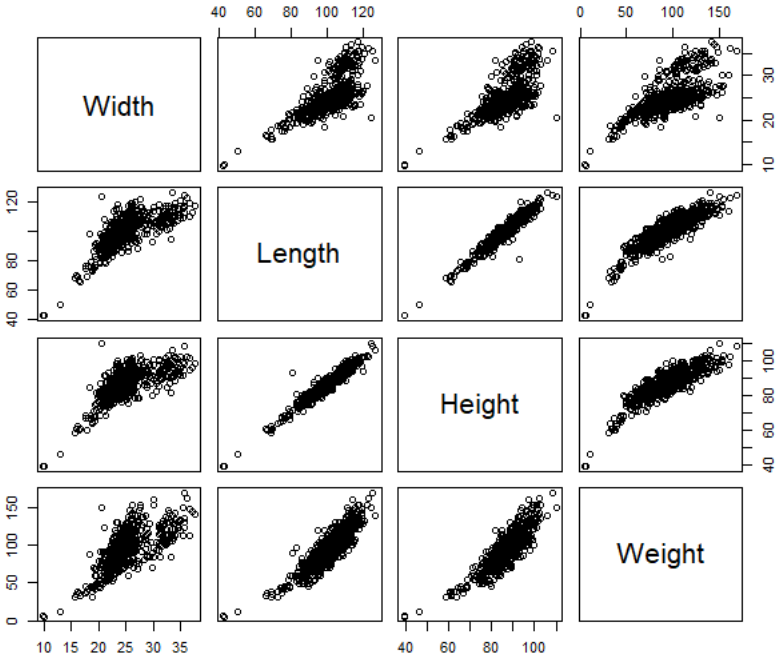


Figure 17. Log transformed A) length and weight, B) length and height, C) length and width and D) height and width from each bed.

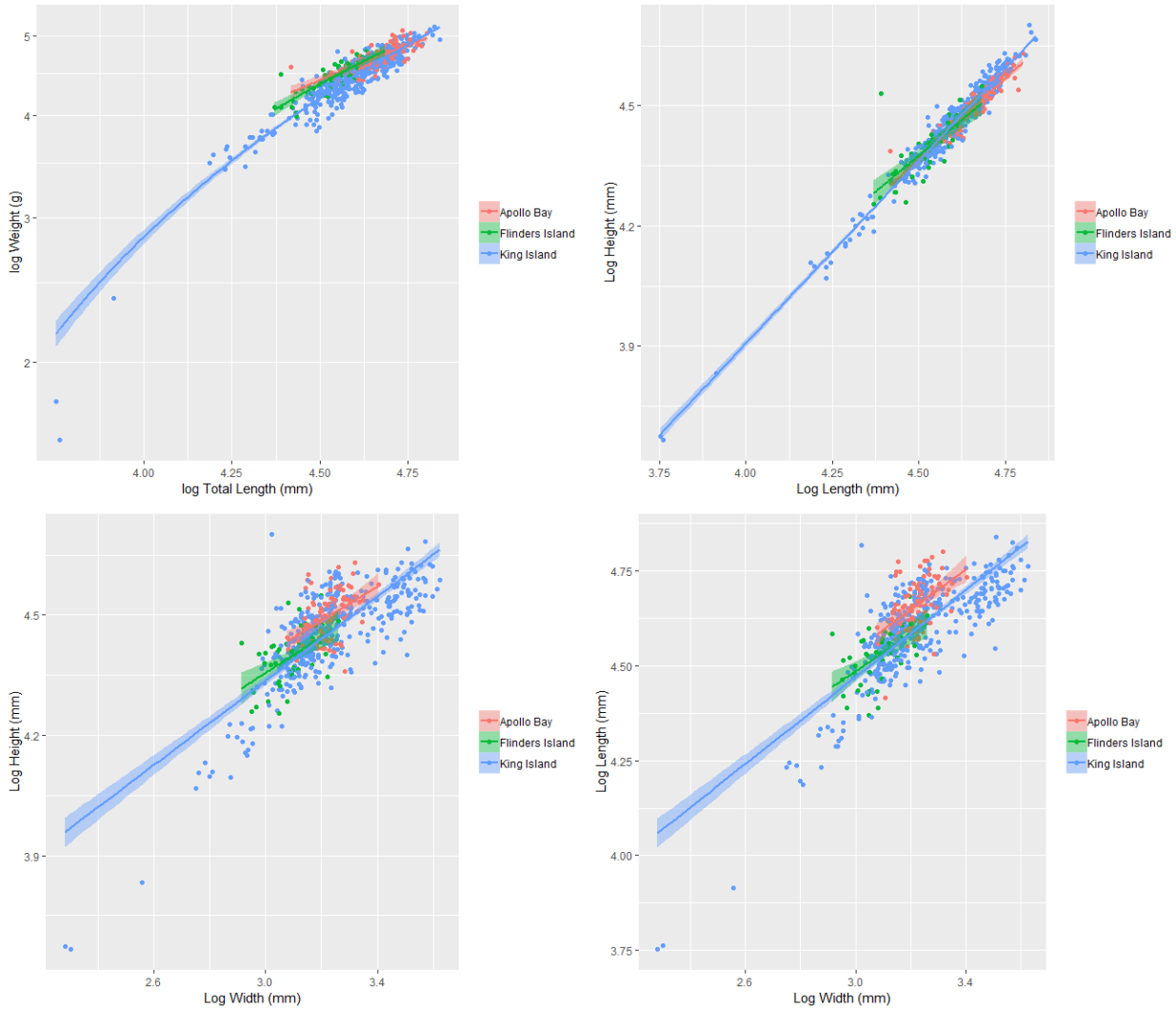


Figure 18. Principle component analysis on ratios of different shell measurements and weight: Elongation – length/width; Convexity – height/ width; Compacity - length / width; Weight1 – weight/ length, Weight2 – weight/ height, Weight1 – weight/ width.

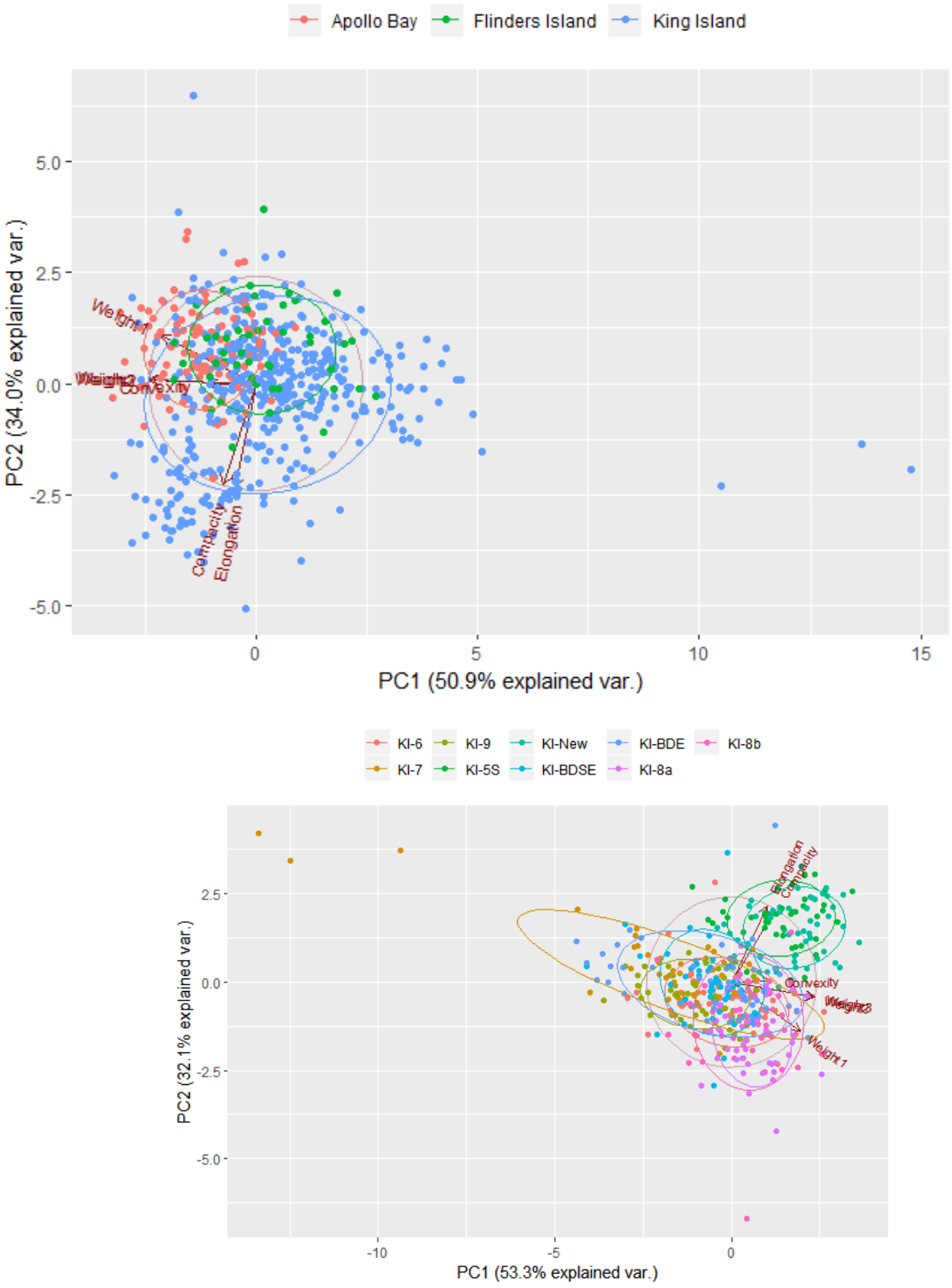


Figure 19. Catch weighted size frequency from shots included in biomass estimates from each bed. The vertical line is at 85 mm.

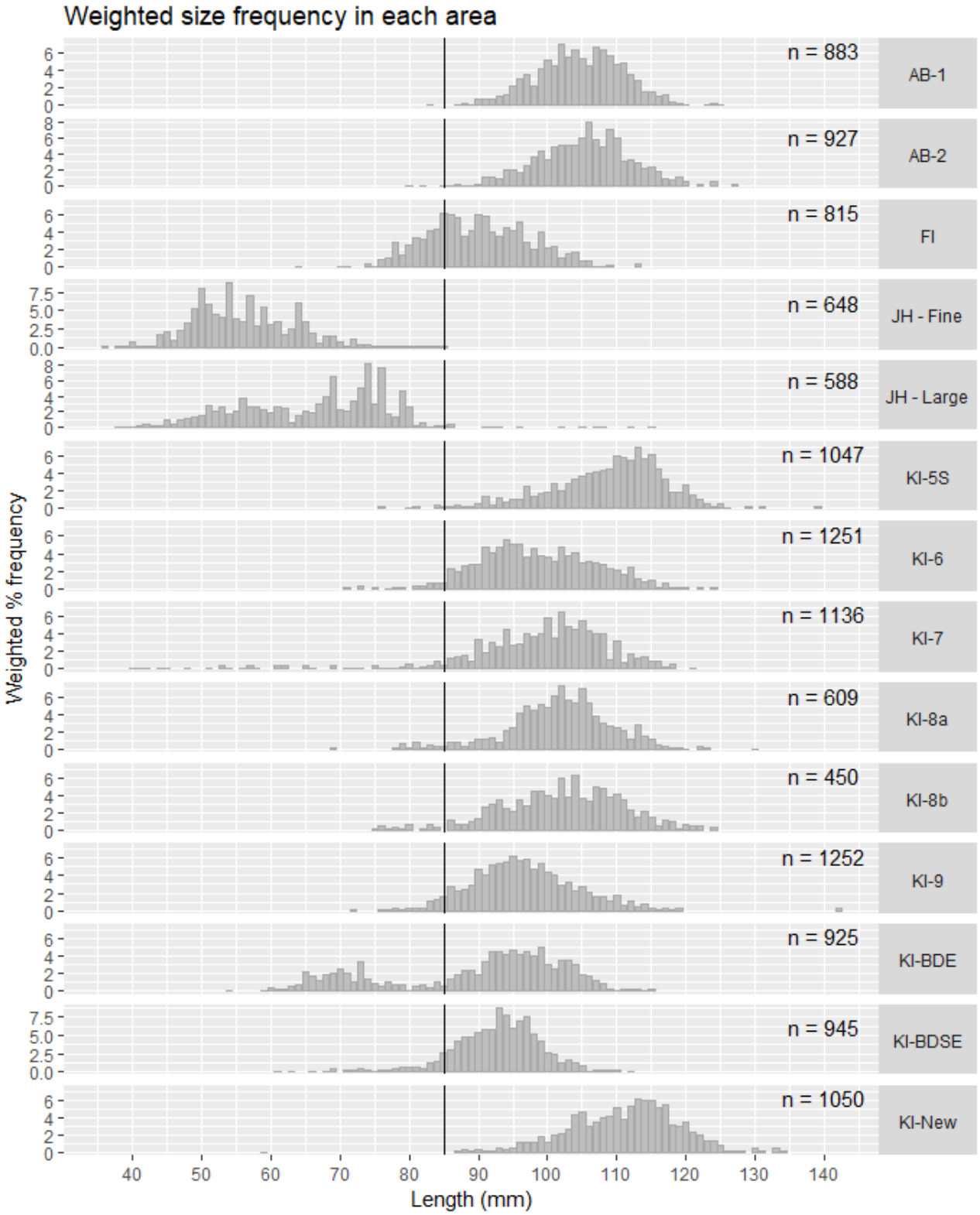


Figure 20. Frequency of combined meat and gonad weights of scallops >85 mm measured from each bed binned into 2 g weight categories.

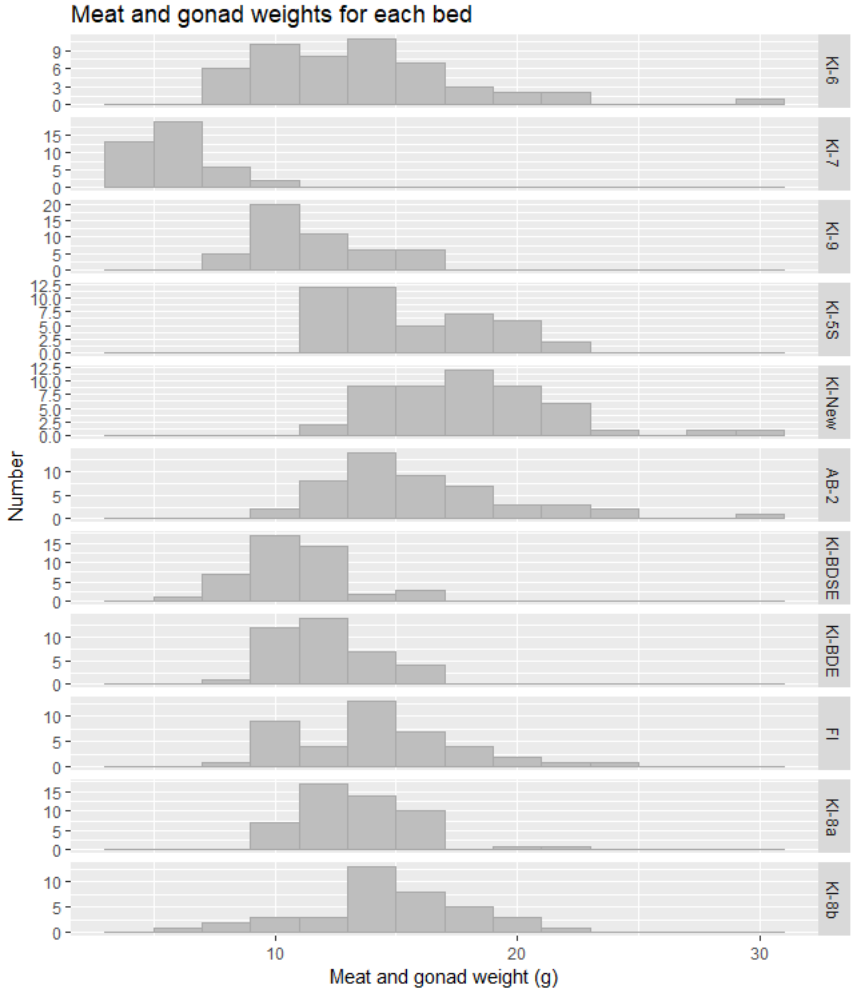


Figure 21. Percent of scallops at each stage from each bed based on macroscopic staging criteria.

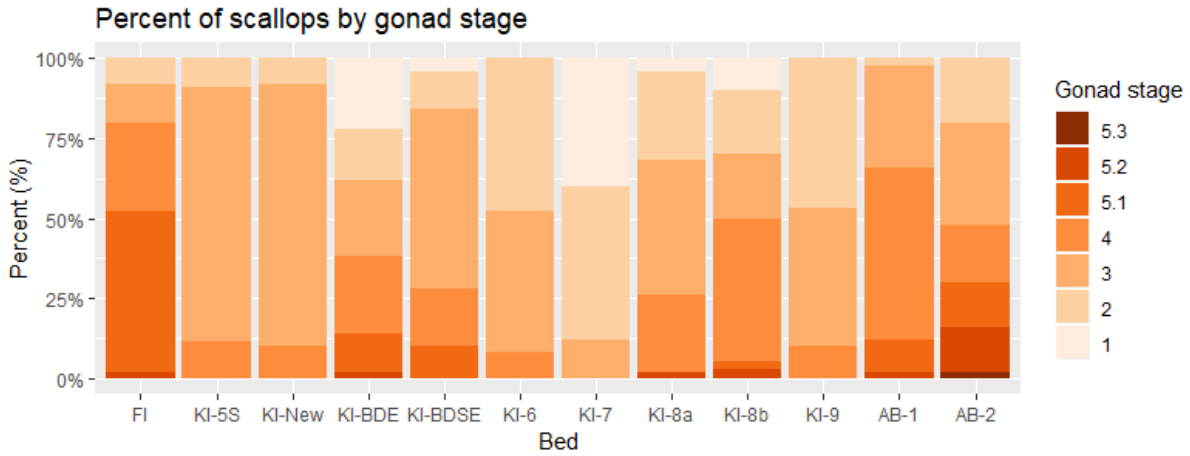


Figure 22. Percent catch composition in each bed sampled by weight from all beds. Note: bycatch was not sufficiently recorded for the first seven shots at the JH site because of the additional sampling time required to process catches from covered and uncovered halves of the dredge. Catch composition in the graph below for that site does not include catch from those shots.

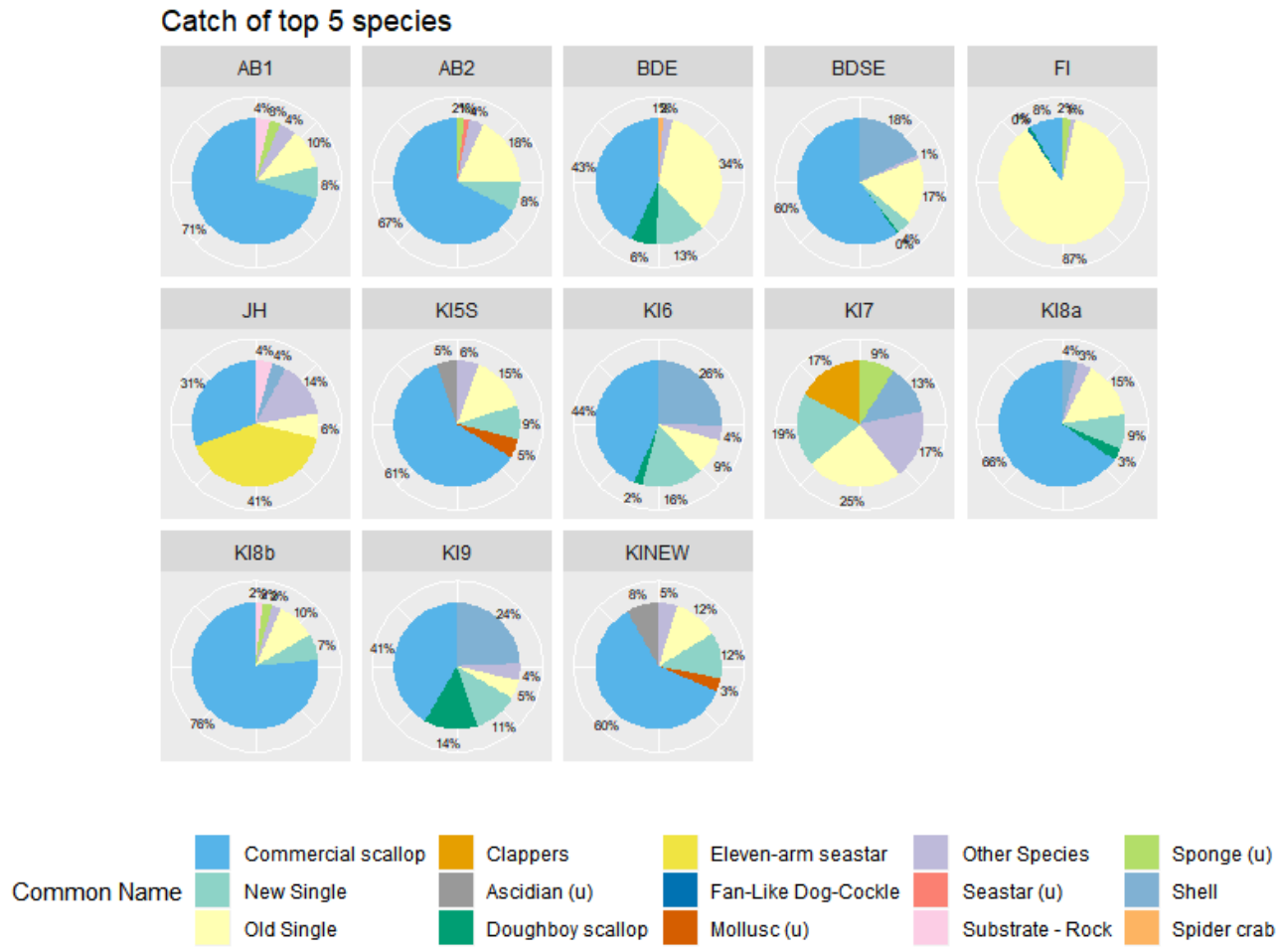
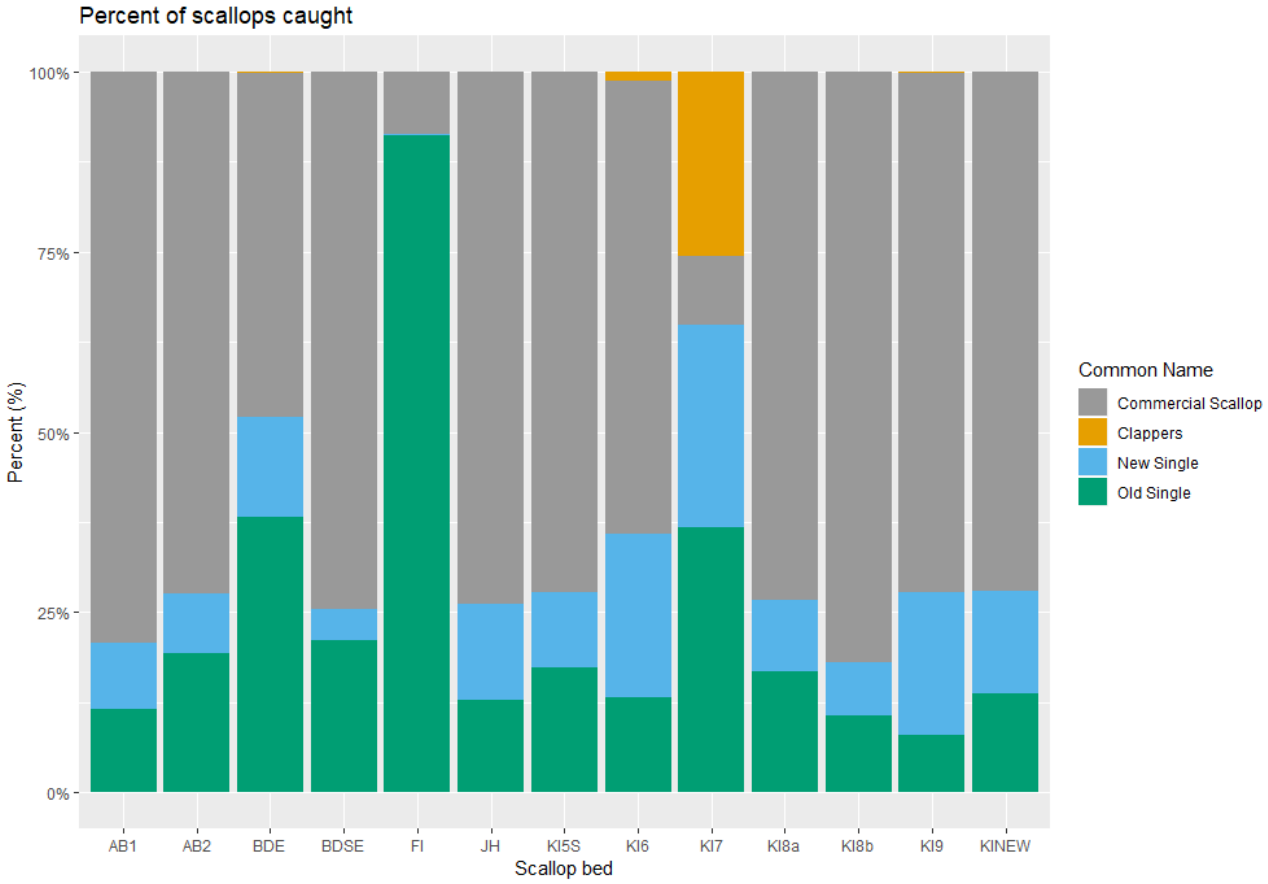


Figure 23. Percent composition of clappers, live scallop, new single and old single shell from each Bed. Note: bycatch was not sufficiently recorded for the first seven shots at the JH site because of the additional sampling time required to process catches from covered and uncovered halves of the dredge. Catch composition in the graph below for that site does not include catch from those shots.



Discussion

1.9 Main survey

Random stratified surveys were successfully undertaken on twelve scallop beds off each of Flinders Island, King Island and Apollo Bay. Beds were selected based on a combination of previous surveys, distribution of catch and effort, advice from ScallopRAG and marks provided by industry. In total, 297 valid, random survey tows were undertaken. Biomass was calculated for each bed using area swept calculated from the straight line distance between the start and end tow points and the measured internal width of the dredges.

Biomass continues to reduce at FI from 2522 t in 2018 to 1961 t in 2019, of which 1,607 t was above 85 mm (Table 11), while the % weight of shell >85mm (determining the discard rate) was 81.9% (Table 11). Densities at Flinders Island were 18.3 kg/1000m^2 and 0.211 individuals per m^2 (Table 11). No commercial catch was recorded from the Flinders

Island bed during 2018 (Table 3). Like previous years, there was a significant amount of dead scallop shell in the catch (Figure 23).

KI-BDE decreased in biomass since the 2018 survey (see Appendix 2) with an estimated 8,353 t biomass (Table 11), of which 7,135 t was greater than 85 mm (Table 11). There is strong evidence of recruitment at this site with a relatively large number of Commercial Scallops in the range of 60–75 mm. There was 575 t of commercial catch reported from within this bed during 2018. Density at this site was 1.597 individuals per m^2 (Table 11). KI-5S had a biomass of scallops >85 mm of 1,609 t, while biomass >85 mm decreased at KI-New to 1,182 t. Very large biomasses >85 mm were estimated at KI-BDSE and KI-9 of 18,714 t and 9,398 t respectively. Densities at these two beds were 3.088 individuals per m^2 and 2.867 individuals per m^2. Significant quantities of commercial catch were reported from these beds 2018 (Table 3). From the area used in the design of the KI-8 beds, 679 t of commercial catch was reported in 2018, and the two small beds within that are held an estimated 782 t and 357 t of dense populations (2.156 individuals per m^2 and1.230 individuals per m^2) and of Commercial Scallops from the current survey.

Biomass estimates for the two Apollo Bay beds are much lower than those from 2018 with 631 t at AB-1 and 886 t at AB-2. Densities were also substantially down at 0.390 and 0.563 individuals per m^2 (Table 11).

Table 11. Summary of data used to inform the ScallopRAG and ScallopMAC recommendation for 2019 harvest strategy requirements and TAC. *These figure use data from the unmeshed half of the dredge – half dredge width was used in swept area calculations.

Area	Bed	Estimated biomass (t)	% weight > 85 mm	Estimated biomass (t)>85 mm	Density (ind/m^2)	Mean size	Meats / kg
FI	FI-1	1,961.3	81.9	1,607.2	0.211	90.5	68
	Sub-total	1,961.3		**1,607.2**			
KI	KI-5S	1,612.1	99.8	1,608.6	0.170	107.8	62
KI	KI-BDE	8,353.4	85.4	7,135.3	1.597	90.6	80
KI	KI-BDSE	19,591.5	95.5	18,713.8	3.088	92.8	88
KI	KI-New	1,181.9	100.0	1,181.8	0.173	110.6	54
KI	KI-6	1,960.1	98.6	1,932.4	1.458	100.5	71
KI	KI-7	837.2	97.5	816.0	0.599	97.4	157
KI	KI-8a	795.4	98.3	782.1	2.156	101.8	72
KI	KI-8b	362.7	98.5	357.1	1.230	101.0	66
KI	KI-9	9,616.2	97.7	9,398.4	2.867	95.7	84
KI	JHUncov*	956.2	2.6	119.4		61.0	
	Sub-total	**45,266.7**		**42,044.9**			
AB	AB-1	631.3	99.9	630.9	0.390	104.5	
AB	AB-2	886.1	100.0	885.9	0.563	104.4	60
	Sub-total	**1,517.4**		**1,516.8**			
	Total	**48,745.4**		**45,168.9**			

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Appendix 1 – Methods

Figure 24. How to conduct a valid survey shot. Green circle is 100 m radius.

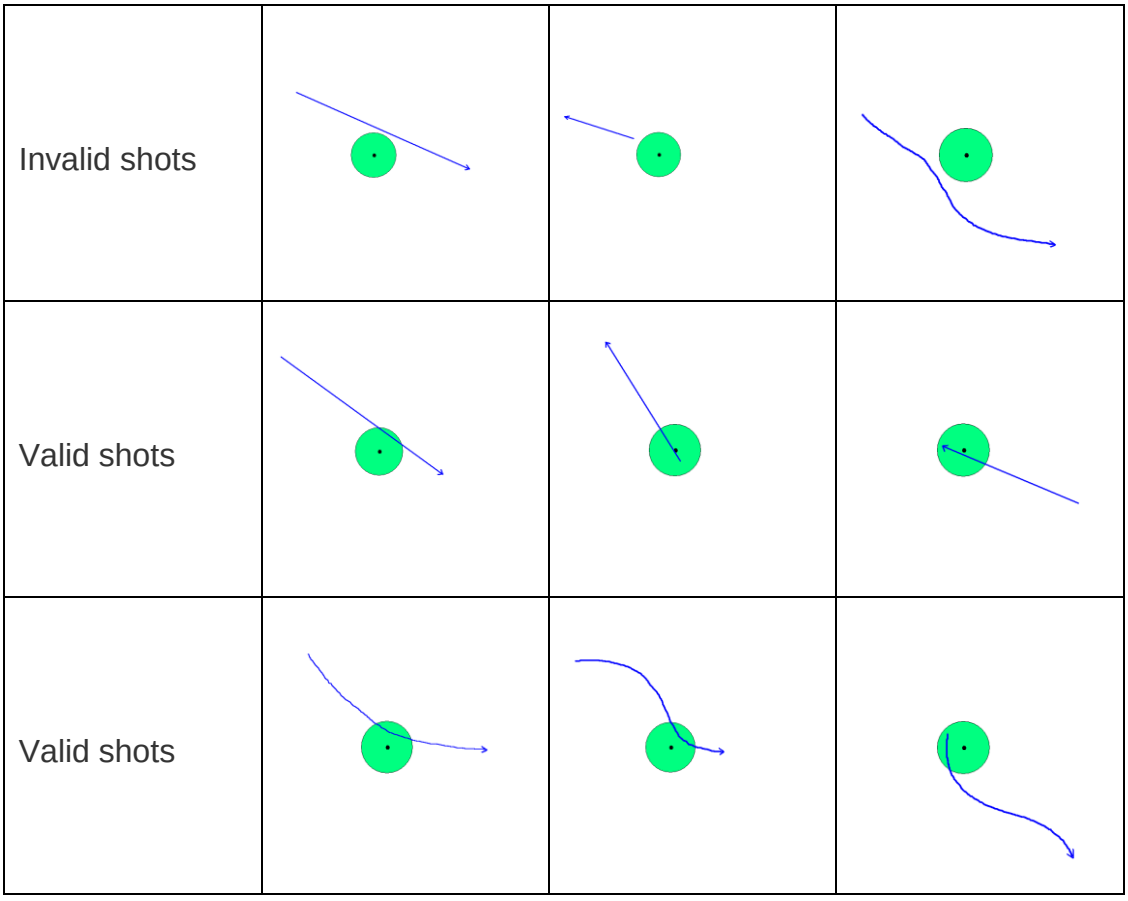


Table 12. Gonad maturation scheme for macroscopic field staging of scallops (taken from Harrington et al., 2010).

Stages	*Description*
1	Immature. Small strap-like organ, transparent and with the intestine seen looping through it.
2	Similar to stage-1, but gonad larger. Completely spawned scallops may revert to this stage.
3	Early developing. Gonad larger with male and female components distinguishable, but with the intestine visible through the wall of the testis and ovary. Ovary becoming orange.
4	Gonad larger than stage-3. Intestine only in the male part of the gonad. Ovary becoming orange.
5	Gonad larger than stage-4, intestine not visible. Ovary orange. Will be sub-categorised as stage 5.1 – 5.3 (see Table 13)
6	Ripe. Gonad very large and full, ovary bright orange. Difficult to differentiate from stage-5.
7	Running ripe. Expresses when light pressure applied.
8	Spent

Table 13. Gonad maturation scheme for macroscopic field staging of scallops (taken from Harrington et al., 2010).

Stages	*Description*
5.1	Ovary orange. Intestine not visible. Gonad smaller than size of meat.
5.2	Ovary orange. Intestine not visible. Gonad approximately equal to size of meat.
5.3	Ovary orange. Intestine not visible. Gonad larger than size of meat.

Appendix 2 – Time series data

Flinders Island

2018 commercial catch	0 t
2019 biomass	1961 t
Change since 2015	-4348 t

Figure 25. Summary of commercial catch, biomass, change in biomass, percent composition of live scallops and dead scallop shell and size frequency distribution from 2015 to 2019 from within the FI bed boundaries used during the 2019 survey. Note that while data included in these results are from tows conducted within the FI bed boundaries used during the 2019 survey, the previous surveys were designed based on different areas (Figure 1, Table 1).

King Island 5 Small (KI-5S)

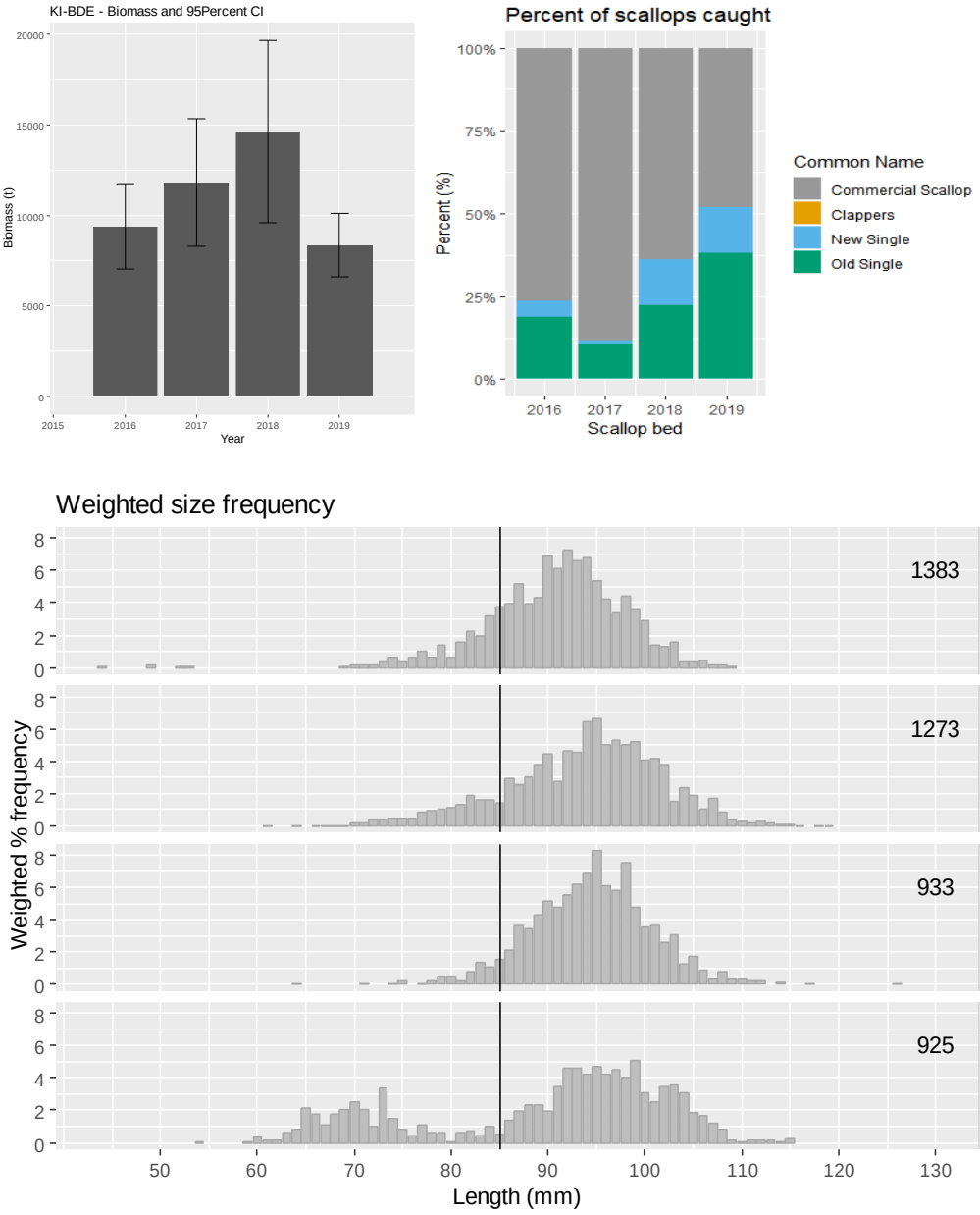
2018 commercial catch	Confidential
2019 biomass	1612 t
Change since 2016	-3206 t

Figure 26. Summary of commercial catch, biomass, change in biomass, percent composition of live scallops and dead scallop shell and size frequency distribution from 2016 to 2019 from within the KI 5 Small bed boundaries used during the 2019 survey. Note that while data included in these results are from tows conducted within the KI-5S bed boundaries used during the 2019 survey, previous surveys were designed based on different areas (Figure 1, Table 1).

King Island Bluedot Extended (KI-BDE)

2018 commercial catch	575 t
2019 biomass	8353 t
Change since 2016	-1034 t

Figure 27. Summary of commercial catch, biomass, change in biomass, percent composition of live scallops and dead scallop shell and size frequency distribution from 2016 to 2019 from within the KI-BDE bed boundaries used during the 2019 survey. Note that while data included in these results are from tows conducted within the KI-BDE bed boundaries used during the 2017 survey, previous surveys were designed based on different areas (Figure 1, Table 1).



King Island New (KI-New)

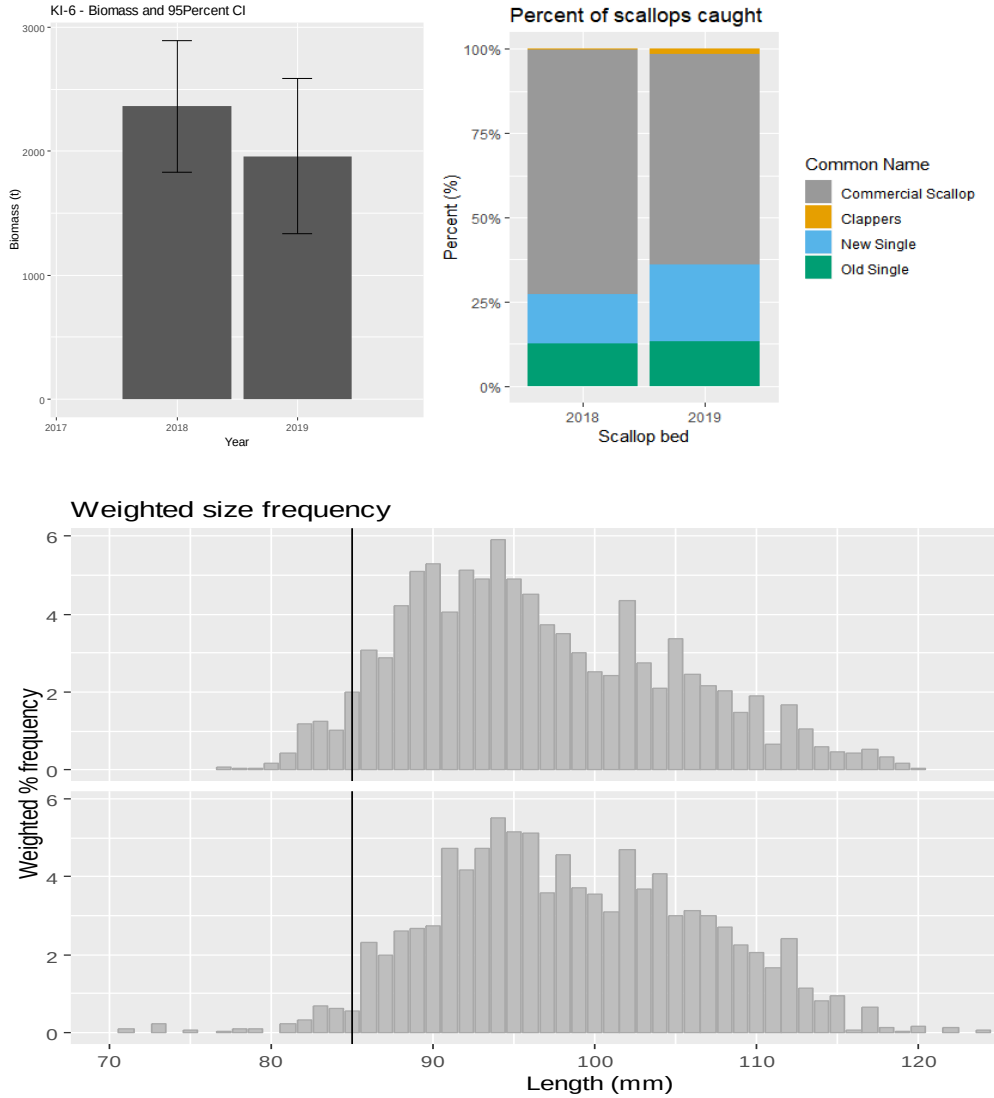
2018 commercial catch	0 t
2019 biomass	1182 t
Change since 2015	-1477 t

Figure 28. Summary of commercial catch, biomass, change in biomass, percent composition of live scallops and dead scallop shell and size frequency distribution from 2015 to 2019 from within the KI New bed boundaries used during the 2019 survey. Note that while data included in these results are from tows conducted within the KI New bed boundaries used during the 2019 survey, previous surveys were designed based on different areas (Figure 1, Table 1).

King Island 6 (KI-6)

2018 commercial catch	217 t
2019 biomass	1960 t
Change since 2018	-400 t

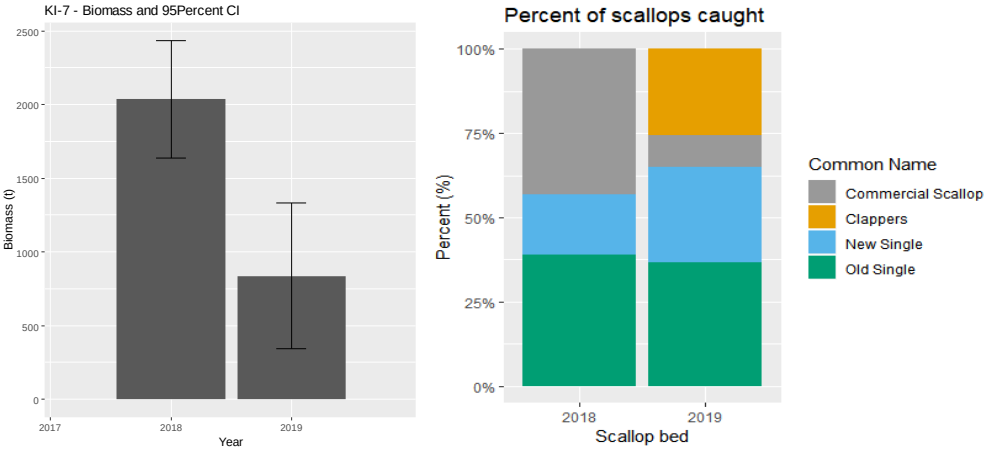
Figure 29. Summary of commercial catch, biomass, change in biomass, percent composition of live scallops and dead scallop shell and size frequency distribution from 2018 to 2019 from within the KI 6.

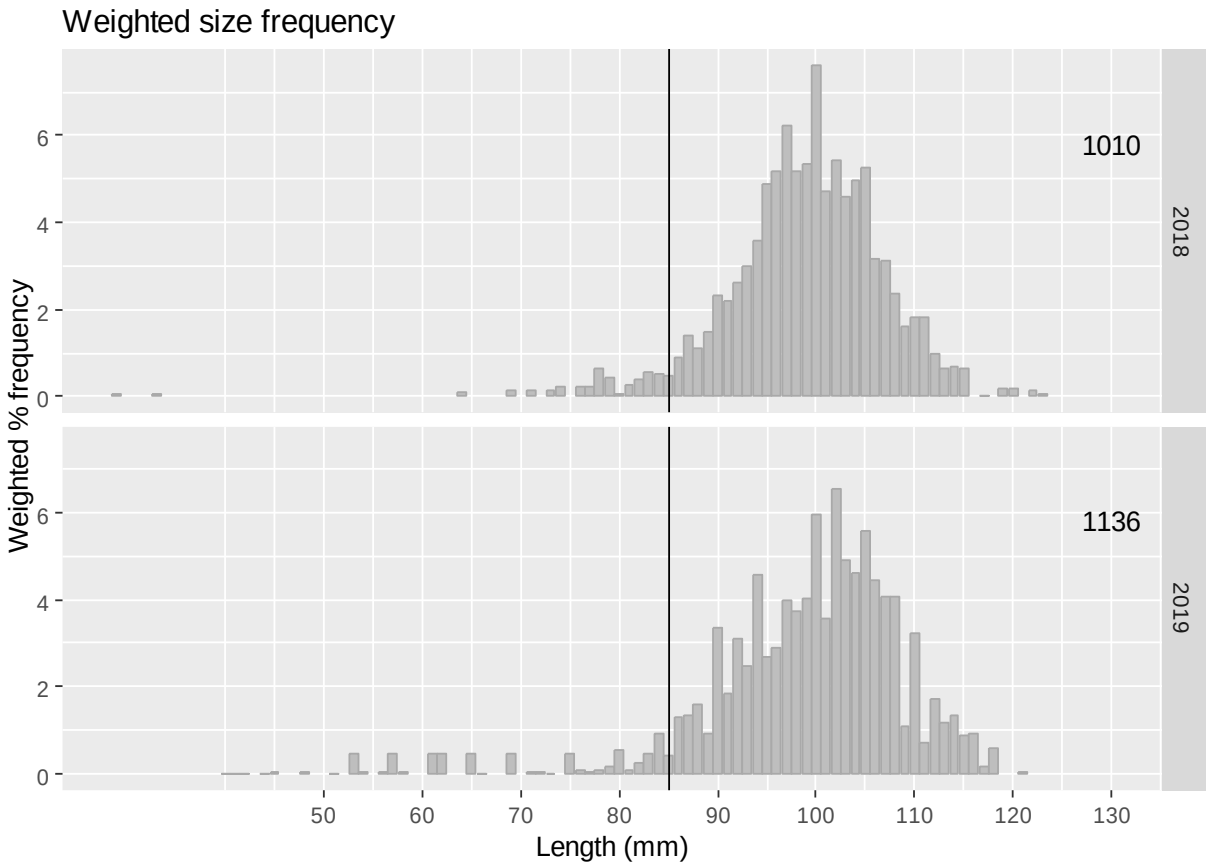


King Island 7 (KI-7)

2018 commercial catch	99 t
2019 biomass	837 t
Change since 2018	-1199 t

Figure 30. Summary of commercial catch, biomass, change in biomass, percent composition of live scallops and dead scallop shell and size frequency distribution from 2018 to 2019 from within KI 7.





Apollo Bay 1 (AB1)

2018 commercial catch	Confidential
2019 biomass	631 t
Change since 2017	-1547 t

Figure 27. Summary of commercial catch, biomass, change in biomass, percent composition of live scallops and dead scallop shell and size frequency distribution from 2017 to 2019 from within the AB1 bed boundaries used during the 2019 survey.

Apollo Bay 2 (AB2)

2018 commercial catch	183 t – Note: This site was closed to fishing for the 2018 season, however the course resolution of recording effort places it in AB2 rather than AB1.
2019 biomass	886 t
Change since 2017	-1975 t

Figure 31. Summary of commercial catch, biomass, change in biomass, percent composition of live scallops and dead scallop shell and size frequency distribution from 2017 to 2019 from within the AB2 bed boundaries used during the 2019 survey.