AFMA Project 2016/0806

Australian Government
Australian Fisheries Management Authority

Bass Strait and Central Zone Scallop Fishery — 2017 Survey

Ian Knuckey, Matt Koopman,
Russell Hudson, Michael Davis and Andrew Sullivan

2017

fishwell
CONSULTING

Bass Strait and Central Zone Scallop Fishery
2017 Survey

Ian Knuckey, Matt Koopman,
Russell Hudson, Michael Davis and Andrew Sullivan

AFMA Project 2016/0806

2017

ISBN 978-0-9954122-3-1

Title: Bass Strait and Central Zone Scallop Fishery - 2017 Survey

AFMA Project 2016/0806

2017

Ownership of Intellectual Property Rights

This publication (and any information sourced from it) should be attributed to:

Knuckey, I., Koopman, M., Hudson, R., Davis, M., and A. Sullivan (2017). Bass Strait and Central Zone Scallop Fishery - 2017 Survey. AFMA Project 2016/0806. Fishwell Consulting. 42pp.

Creative Commons Licence

Disclaimer

Researcher Contact Details

Name:	Ian Knuckey
Address:	Fishwell Consulting
	27A Hesse St Queenscliff, VIC 3225
Phone:	+61 3 5258 4399
Mobile:	+61 4 0858 1599
Email:	ian@fishwell.com.au
Web:	www.fishwell.com.au

In submitting this report, the researcher has agreed to AFMA publishing this material in its edited form.

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 research catch allowance and / or a 150 t total allowable catch (TAC) 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 arrangement. 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 2017 research surveys.

Two commercial fishing vessels were selected by an independent panel to conduct the 2017 scallop surveys: the Dell Richey II and the Northern Star. During May and June 2017, stratified random surveys were conducted using these vessels on four beds off each of Flinders Island, King Island and Apollo Bay. Choice of these beds was made by the Scallop Resource Assessment Group (ScallopRAG) and the BSCZSF Co-Management Committee. Boundaries of two of the Flinders Island beds and the four King Island beds were predefined based on the 2016 scallop survey and management spatial closures implemented during the 2016 season. The two additional Flinders Island beds were defined based on exploration around existing beds, while the four Apollo Bay beds were initially based on marks provided by industry, and then mapped out during the survey. 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 combined estimated biomass of scallops at the four Flinders Island beds was above 1463 t (1090 t > 85 mm length). Densities at the Flinders Island beds ranged 0.095–0.167 individuals per m^2. The estimated biomass at the KI-BDE bed was 11,809 t (10,760 t > 85 mm). Estimated biomass was greater than 2,000 t for two other King Island Beds (KI-5S and KI-New), and only 92 t at KI-Mid. Scallops at the Apollo Bay beds were very densely aggregated (up to 2.331 individuals per m^2), and the total biomass estimated from the four adjacent Apollo beds was 5484 t (5464 t > 85 mm)

Meat weights of scallops >85 mm were 89–94 meats to the kg at the Flinders Island beds compared to 44–69 meats per kg at the King Island beds other than KI-BDE which had 92 meats to the kg. Scallops from the Apollo Bay beds were smaller with meat weights of 99–134 meats to the kg. Time series of size frequency, biomass and composition of dead shell indicated significant mortality at the Flinders Island Beds since 2015, and since 2016 at the KI-Mid bed.

Catch composition varied greatly between beds. In general, there was high proportions of old (dead) single shell at the Flinders Island and KI-Mid beds, while other beds were dominated by live Commercial Scallops. The introduced New Zealand Screwshell comprised a large proportion of the catch at FI-3.

Survey results were presented to ScallopRAG on 14/6/2017 and the Scallop Management Advisory Committee (ScallopMAC) on 15/6/2017.

Table of Contents

List of Tables

List of Figures

Acknowledgements

We would like to thank Stuart Richey, John Richey and the crew of the Dell Richey II together with Andy Watts, Ian Rule and the crew of the Northern Star for all of their assistance and hard work in undertaking the 2017 survey. Sally Weekes and Anthony Harding (AFMA), ScallopRAG, ScallopMAC and the BSCZSF Co-Management Committee provided valuable input into the survey logistics and design.

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 research catch allowance and / or a 150 t total allowable catch (TAC) 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 TAC 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 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 2017 stratified random surveys.

Objectives

1. Estimate the scallop biomass and potential commercial catch rates in six different areas of the BSCZSF.
2. Conduct exploratory tows on 10 marks provided by industry, and if potentially viable beds are observed, define bed and survey half of them.
3. Measure the size frequency distribution of scallops in each area and calculate discard rates (% weight of shell <85 mm length).
4. Report results to AFMA, ScallopRAG and ScallopMAC.

Methods

Survey Design

Survey methods follow those of Knuckey *et al.* (2015), modified from those described in Harrington *et al.* (2008). Two commercial scallop 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 of King Island and one off 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 2). 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 to be surveyed during 2017 were based on advice from the Scallop Research Workshop held in Melbourne on 30 March 2017, with input from ScallopRAG and the BSCZSF Co-Management Committee. Again in an effort to provide greater flexibility in management arrangements regarding closures and access to commercially viable beds, it was decided to have a range of previously surveyed beds, modified beds and new exploratory beds. These are outlined in Table 1.

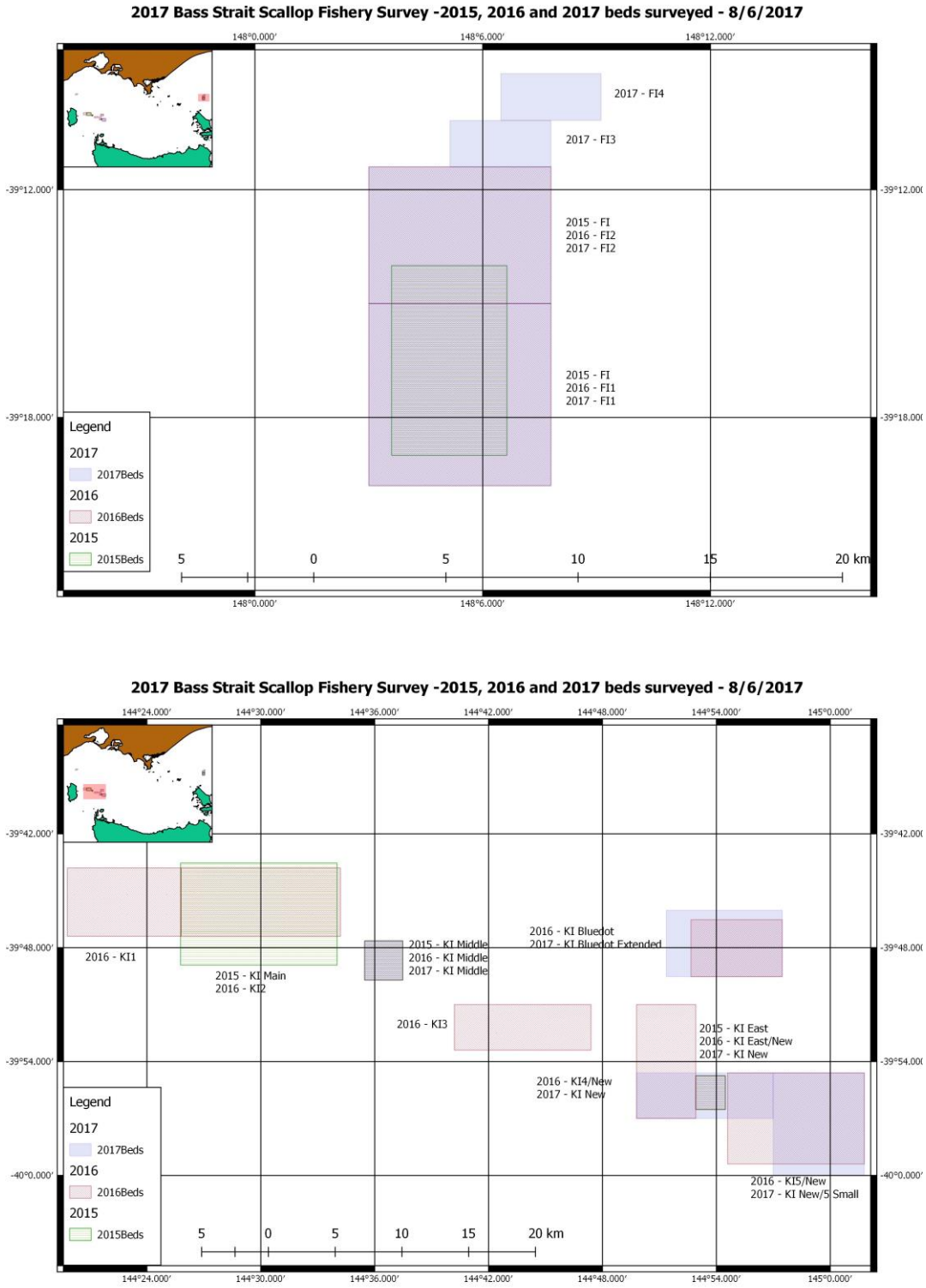

Figure 1. History of beds surveyed off Flinders Island (top panel) and King Island (lower panel) since 2015.

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

Bed Type	Name	Description
Previously surveyed	KI-Mid	Unchanged from the bed surveyed in 2015 and 2016. See Table 4 for bed boundaries.
	FI-1 and FI-2	FI-1 was called the "Flinders Island" bed during the 2015 survey. For the 2016 survey, the area was expanded and spilt into the two beds (FI-1 and FI-2), bound by the latitudes and longitudes shown in Table 4.
	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 survey in 2016. It is bound by the latitudes and longitudes shown in Table 4. A bed called KIEast was surveyed during 2015, and again in 2016, along with two new adjacent beds, KI-4 andKI-5.
	KI-Bluedot Extended	During the TAC setting 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.
Modified Beds	KI-5S	Originally a larger area that was surveyed in 2016 (see the boundaries above), KI-5S was formed by extending the eastern boundary of KI-New south to S -40˚, and including the area of KI-5 to the east of that.
Exploratory Beds	FI-3 and FI-4	Four exploratory marks off Flinders Island were provided by industry to be explored and considered for additional survey beds. Three of the marks were to the east of FI-1 and FI-2, and very few scallops were caught around those marks. The forth mark was within FI-2. Rather than survey very sparse areas around the exploratory marks, the skipper extended the Flinders Island beds to the north east, to two small beds titled FI-3 and FI-4. The borders of those beds are in Table 4.
	AB-1 and AB-2	Seven exploratory marks off King Island were provided by industry to be explored and considered for additional survey beds. Only one of those showed enough promise to survey, and the skippers mapped out beds. The borders of those beds are in Table 4.
	AB-3 and AB-4	After additional exploratory fishing around AB-1 and AB-2, the skipper put in two smaller beds, one to the west and one to the east. They are titled AB-3 and AB-4 and the borders of those beds are in Table 4.

It was decided to re-survey the following 2016 beds (as described in Knuckey *et al.* 2016): KI-Mid, FI-1 and FI-2. It was also decided to survey: the expanded area around the 2016 BlueDot bed reflecting the closure imposed during 2016 to form the "KI BlueDot Extended" bed (KI-BDE); the southern parts of KI-4, all of KIEast and the north-west corner of KI-5 formed KI-New; and the eastern part of KI-5 with the western boundary with the same longitude as the eastern boundary of KI-New to form KI-5S. A call was made to industry for additional potential survey sites. Seven locations were provided off King Island, and four off Flinders Island, although one of those off Flinders Island fell within FI-2 and was omitted from the survey. The cost of surveying all exploratory sites was prohibitive, and so it was resolved to undertake surveying of exploratory sites as follows:

- At most, only half of exploratory sites will be fully surveyed
- At least five exploratory tows[1] will be undertaken around each of the exploratory sites to assess their potential as a viable bed based on the guideline of catch rates of greater than 50 kg / shot, but also allowing for the skippers discretion (based on experience)

[1] Observers are not required to monitor exploratory tows, however they are recorded on the Olrac DDL and skippers logsheet.

- Skippers (if possible in consultation with the observer) will decide which exploratory sites to survey
- Beds will be defined at the exploratory sites to be surveyed by making exploratory tows north-south and east-west to find where catch rates drop below 50 kg / shot
- Once beds are defined, random tows will be allocated, and the bed surveyed

Exploratory tow around marks provided off Flinders Island conducted by each vessel revealed very little promise, with catches generally ranging 0–10 kg per shot. The skippers considered that there was no point surveying any of those marks, and instead provided boundaries to an extension of the existing Flinders Island beds that we titled FI-3 and FI-4 (Figure 2 and Figure 3). Likewise, only one of the exploratory beds off King Island showed promise (KI80(a) in Figure 2). Vessels mapped the extent of the bed and initially provided the boundaries of two beds we titled AB-1 and AB-2. After additional exploratory tows, the boundaries of two additional beds were provided that we titled AB-3 and AB-4 (Figure 2 and Figure 3).

The number of survey points allocated was largely guided by sampling effort during 2016, with consideration given to the maximum number of tows that can be achieved in a 12 hour sampling block[2] and the area of the bed. Primary sampling sites within each bed were randomly allocated using the QGIS Random Points Tool (Figure 3). Additional survey points were allocated to each bed as "backup sites", to be used where "primary sites" were unfishable.

During 2017, surveys were conducted onboard the fishing vessels Dell Richey II (Scientific Permit# 1003402) and the Northern Star (Scientific Permit# 1003403) as 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 three minutes.

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

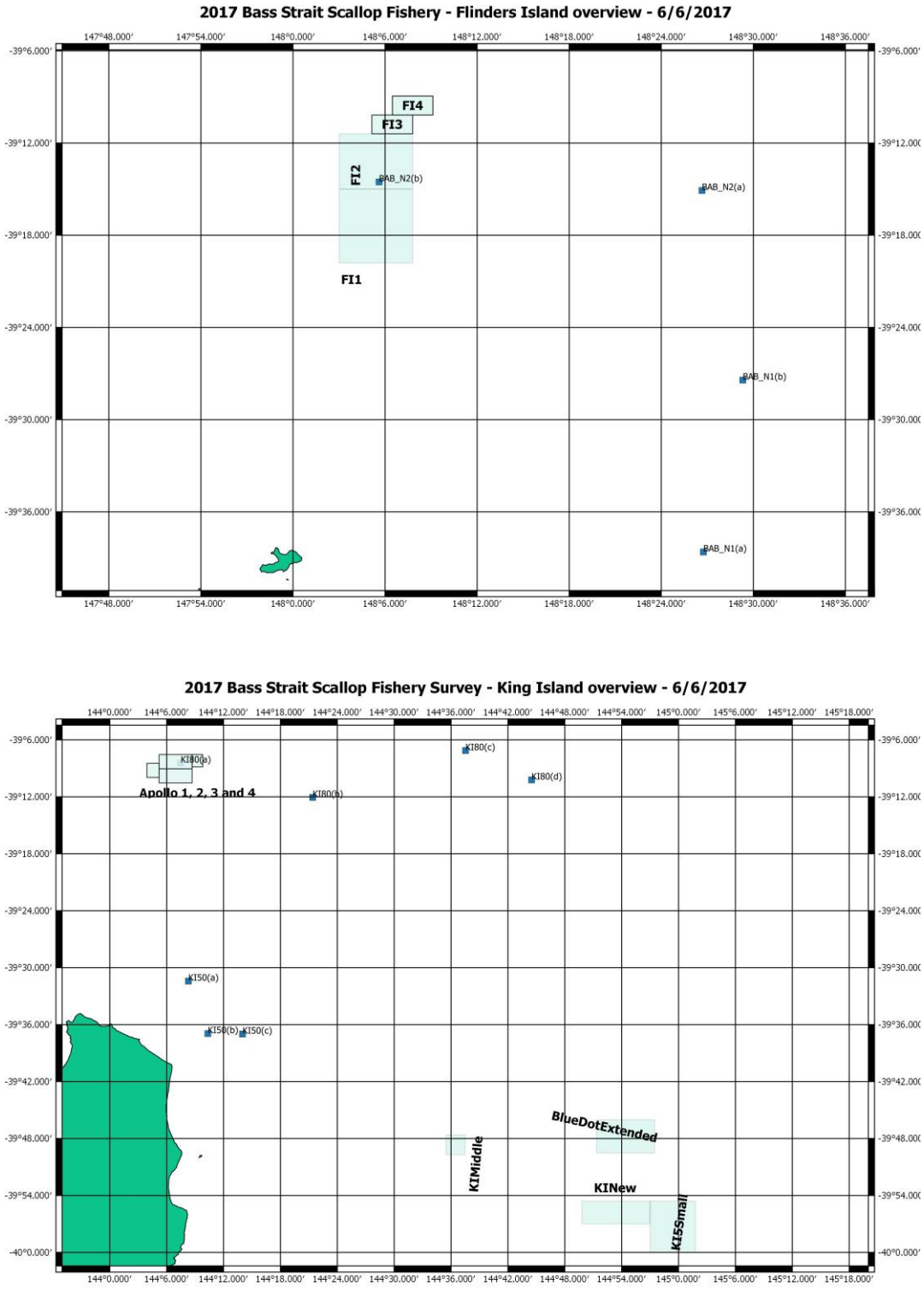

Figure 2. Location of beds surveyed (light blue boxes) off Flinders Island (top panel) and King Island (lower panel) during 2017 and exploratory marks (small dark blue marks).

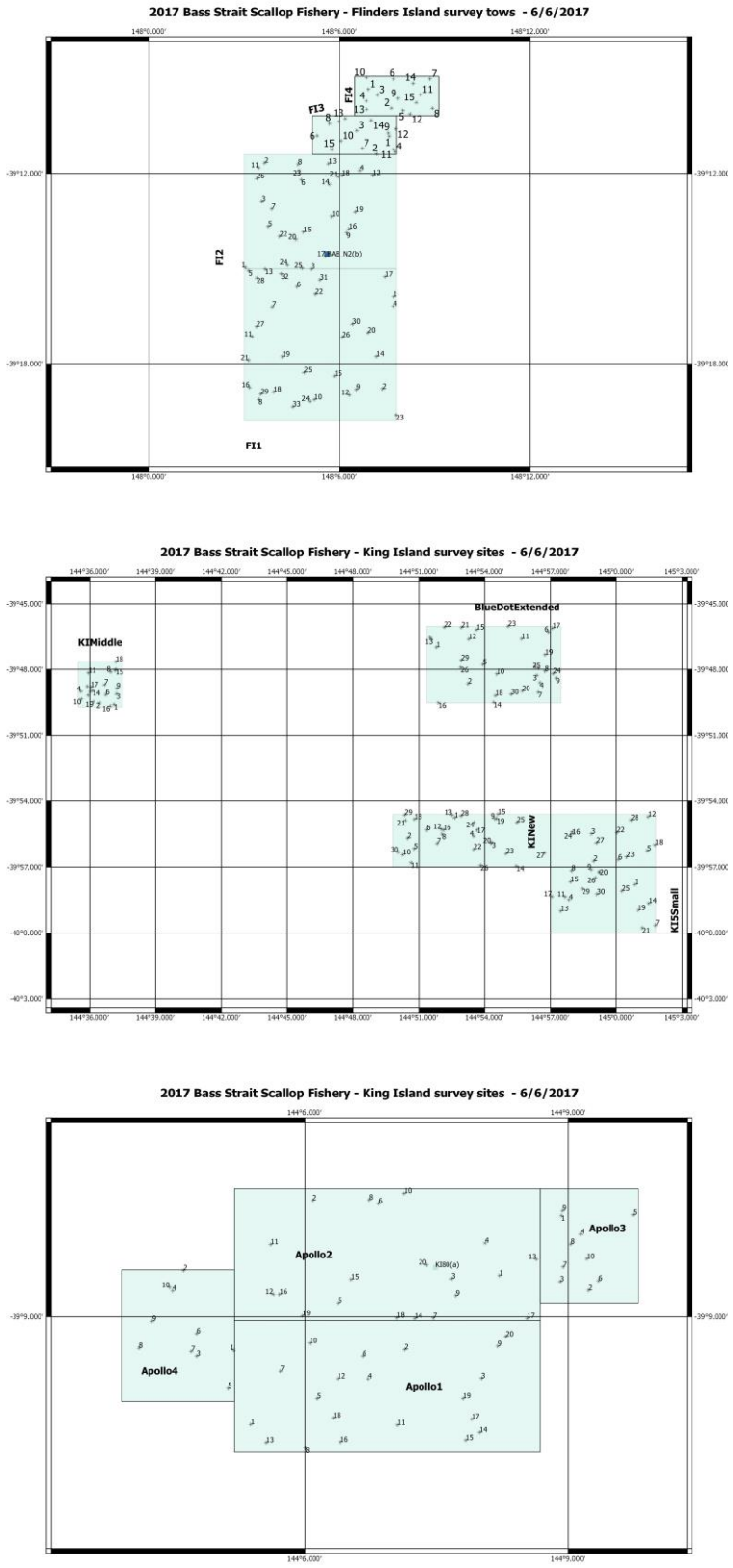

Figure 3. Location of survey marks in beds surveyed off Flinders Island (top panel) and King Island (middle and lower panels) during 2017.

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 either 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 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 11 and Table 12 based on Harrington *et al.,* (2010) (see Appendix 1). Adductor meat and 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.

Data analysis

All data processing and analysis was undertaken in R (R Core Team, 2016), 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 Dell Richey 2 and Northern Star were 4.1 m and 4.02 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:

$$B = meanD * A * 3.03 / 1000$$

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

Lower 95% CL= ((meanD - (t_{n-1} x SE_{meanD})) x 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% 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.

Potential commercial catch rates

Following Semmens and Jones (2014), potential commercial catch rates were estimated by calculating the weight of scallops that would be caught per hour given the mean density, and assumptions around a "typical scallop tow".

Semmens and Jones (2014) reported that commercial fishers generally conduct four 10-minute tows per hour, with each going approximately 750 m. A scallop density reported in kg/1000 m^2, equates to a distance covered of 250 m (assuming dredge width of 4 m). An estimate of catch of a 10 minute commercial tow (C^{tow}) was calculated as:

$C^{tow} = D_{1000}$ x 3

Where D_{1000} is the mean kg of scallops per 1000 m^2.

To estimate potential catch per hour, C^{tow} is multiplied by 4 (i.e. four 10 minute tows per hour).

$C^{hour} = C^{tow}$ x 4

Because no commercial fishing was conducted during the survey, potential commercial catch rates were calculated only from random survey tows, and so could be considered very conservative.

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 includes quality assurance protocols including automatic data capture (time, date and position), field restrictions, range checks, mandatory fields and lookup tables. All data were manually error checked against data sheets. This database is regularly backed up, and used to extract data for analyses. Data analyses were undertaken using R (R Core Team, 2016), and a subset of outputs were reproduced and compared using an alternative software package. Scallops were measured using the electronic measuring board. 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

Survey shots

A total of 89 valid, random, non-targeted tows were undertaken during 16–18 May 2017 inside the four Flinders Island beds (Table 5). The total area of the Flinders Inland beds — FI-1, FI-2, FI-3 and FI-4 — were 61.30 km^2, 46.02 km^2, 8.68 km^2 and 8.70 km^2 respectively (Figure 3, Table 4). Depth of survey tows ranged 50–60 m and bottom temperatures ranged 15.3–16.8°C[3]. Mean distances towed were 522 m (range 405 m–671 m) at FI-1, 578 m (546 m–618 m) at FI-2, 572 m (546 m–657 m) at FI-3 and 520 m (446 m–633 m) at FI-4.

The 170 valid, random, non-targeted tows inside the eight beds off King Island Beds were surveyed over two trips by each vessel during 20–22 May 2017 and 1–2 June 2017. The total areas of the beds labelled KI-5S, KI-New, KI-Mid, KI-BDE, AB-1, AB-2, AB-3 and AB-4 are 68.31 km^2, 45.56 km^2, 10.99 km^2, 56.53 km^2, 13.93 km^2, 13.95 km^2, 3.88 km^2 and 5.14 km^2 respectively. Depths fished at the four most southern King Island beds ranged 44–53 m and bottom temperatures ranged 15.3–15.8°C, while depths at the Apollo beds ranged 80–89 m and bottom temperatures ranged 14.5–15.0°C[3]. Mean distances towed at beds KI-5S, KI-New, KI-Mid, KI-BDE, AB-1, AB-2, AB-3 and AB-4 were 577 m (535 m–626 m), 534 m (460 m–701 m),

[3] Only temperature and depth data were available from the Northern Star at the time the report was written.

536 m (449 m–604 m), 567 m (529 m–593 m), 562 m (522 m–605 m), 519 m (461 m–605 m), 559 m (525 m–605 m) and 495 m (454 m–552 m).

Biomass, size and potential commercial catch rates

Estimated mean biomasses within FI-1, FI-2, FI-3 and FI-4 were 737.3 t (95%CI 424.4 t – 1050.2 t), 585.1 t (95%CI 472.8 t – 697.4 t), 56.5 t (95%CI 16.9 t – 96.2 t) and 84.0 t (95%CI 53.3 t – 114.7 t) (Table 5). Using discard rates of 19.2% (80.8% > 85 mm), 34.0% (66.0% > 85 mm), 22.4% (77.6% > 85 mm) and 21.9% (78.1% > 85 mm), mean biomasses for scallops > 85 mm were 595.4 t, 385.9 t, 43.9 t and 65.6 t respectively (Table 6).

At the Flinders Island beds, densities were highest (up to about 40 kg/1000m^2) in the northern half of FI-1, and lowest in the southern half of that be where there were four zero catches in the south-west corner (Figure 4). Densities of up to 26 kg/1000m^2 were found across the other three Flinders Island beds (Figure 5, Figure 6, Figure 7), appearing most dense in a line running north-east through FI-3 and FI-4. Density in individuals per square metre range 0.095 individuals per m^2 at FI-3 to 0.167 individuals per m^2 at FI-2.

Estimated mean biomasses from the most southern four King Island Beds ranged from 92.0 t (95%CI 35.0 t – 149.0 t) at the smallest bed (KI-New), to 11,809.2 t (95%CI 8,307.1 t – 15,311.31 t) in the second largest bed (KI-BDE (Table 4, Table 5). Mean biomass estimates for AB-1 was 2,856.1 t (95%CI 2,104.0 t – 3,608.3 t), 2,182.0 t (95%CI 1,568.7 t – 2,795.3 t) at AB-2, 301.3 t (95%CI 125.8 t – 476.7 t) at AB-3 and 144.1 t (95%CI 85.8 t – 202.4 t) at AB-4. The percentage of scallops <85mm was ranged 0% to 8.9% at the King Island Beds, and 0.1% to 0.8% at the Apollo Bay beds (Table 7and 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 what the estimated mean biomass above 85 mm was 10,760.4 t.

Densities at within each King Island bed are shown in Figure 8 –Figure 15. Scallops were caught at medium densities throughout KI-5S and KI-New, with some lower densities in the south of both beds and in the north east of KI-5S. Densities were particularly low in the south of KI-Mid, with three zero catches, but increased towards the north. Very high densities were observed throughout KI-BDE apart from on the south-eastern and eastern edges. The highest density (462 kg/1000m^2) was recorded along the northern boundary of the KI-BDE. At the Apollo beds, the area of highest density ran in a south-west to north-east direction through AB-1 and AB-2, Estimated densities in numbers at the King Island Beds ranged from 0.070 individuals per m^2 at KI Middle to 2.400 individuals per m^2 at KI-BDE (Table 5). High densities were also observed at the Apollo Bay beds, with AB-1 being 2.331 individuals per m^2 and AB-2 being 1.604 individuals per m^2 (Table 5).

Comparisons of biomass estimate, percent 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 has changed considerable. Care should be taken when interpreting those results, and consideration of changes in bed areas over time should be made.

Biologicals

Scallops measured from the from the Flinders Island beds were smaller form other areas ranging 86 to 90 mm length (Table 7). The distribution of lengths from scallops at the Flinders Island

beds were broadly spread from 80–100 mm with long tails extending below 60 mm (Figure 19). Mean length at KI-BDE was the smallest of the King Island beds with a mean length of 91 mm, while KI Middle had the largest averaging 111 mm. KI Middle had the narrowest size range of all beds, and no scallops less than 85 mm. Scallops at KI-BDE were mostly 86–102 mm, and had more scallops below 85 mm than any other King Island bed Size distribution of the Apollo Bay beds were very similar to each other, averaging 98–101 mm, with the bulk of the scallops 90–105 mm.

Comparison of length-weight regressions revealed that the interaction terms was not significant ($p=0.09$), and so there was not enough evidence to conclude that there is a difference in slopes in the length -weight relationship between beds. However the p-value for the indicator variable ($p<0.0001$) suggests that there is a difference in intercepts, and it appears that there are differences in length-weight relationships between areas (Flinders Island, King Island and Apollo beds). A similar result was obtained when beds were grouped into the areas Flinders Island, King Island and Apollo ($p=0.19$). However the differences in the length-weight relationship between areas appeared large enough for us to calculate separate length-weight relationships for each area for calculations of density in individuals per square metre (Figure 17, Table 8). For example, the predicted weight of a 100 mm scallop using parameters from King Island is 15% heavier that when using parameters from Apollo Bay scallops.

Reflecting the smaller size of scallops measures there, scallop meats of shells greater than 85 mm length from the Flinders Island beds averaged 89 to 94 meats per kg, compared with 44–69 meats per kg from the King Island beds other than KI-BDE (Table 7, Figure 20). KI-BDE, with the long tails of small fish in the size frequency distribution had 92 meats per kg. Of the King Island beds, meat weights were by far the smallest at KI-3, and largest at KI-1. Meat weights were smallest at Apollo Bay beds ranging 99–134 meats per kg.

Different from the 2016 survey, gonads from Flinders Island were more developed than those from the King Island beds, particularly at FI-2 and FI-3 (Figure 21). Up to 75% of scallops at Flinders Island were at stage 5.1 or 5.2 (Figure 21). No scallops were above stage 4 at KI-5S or KI-Mid, while at KI-BDE and KI-New, about 10 to 12% of scallops were staged 5.1. More than 90% of scallops from the Apollo Bay beds were staged 3 or lower.

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). The relationship between length and width was similar between beds (Figure 17) and ANCOVA results imply that the gradients are not significantly different ($F=0.216$, $p=0.806$). Shell width at a given length appeared smaller at the Flinders Island beds than the Apollo Bay and King Island beds (Figure 17), and while there is no difference in slopes ($F=0.884$, $p=0.414$), a summary of the reduced model revealed significant (both $p<0.0001$) differences in the intercepts between areas. The width for a given height was higher for King Island and Apollo Bay samples than those from Flinders Island, and as for the width -length relationship, there is no difference in slopes ($F=0.495$, $p=0.610$), but there were significant (both $p<0.0001$) differences in the intercepts between areas. Principle Component Analysis reveals that ratios between different measurements of scallops from King Island are very similar to those from Apollo Bay, but somewhat different to those from Apollo Bay (Figure 18). This is partly because of their smaller size, but also because of their convexity and compacity, which are both reflective of PC2.

Bycatch

A total of 83 different bycatch species / groups were identified during the main surveys (Table 9). Catch composition varied greatly between beds. At the Flinders Island beds about half of the total catch was old single shell, 8% was new single shell, and live Commercial Scallops comprised only 2% and 6% of the catch (Figure 22). The introduced New Zealand Screw Shell comprised 32% of the catch at FI-3 and 8% at FI-4. The catches at KI-5S, KI-New and to a lesser extent KI-BDE were dominated by Commercial Scallop 18–21% of the catch was live Commercial Scallops at each bed. 46% of the catch at KI-Mid was new single shell. Apart from AB-4, the Apollo Bay beds were largely dominated by Commercial Scallop (78–96%.). AB-4 comprised 22% sponge, 19% old single shell and 34% Commercial Scallops.

Considering only the four different scallop "groups" (Commercial Scallops, old single, new single, and clappers), Flinders Island had a much higher percentage of old single shell (greater than 60% and as high as 90%) than other beds, and less than 10% from other beds (Figure 23). The Flinders Island Beds also had higher catches of new single shell than most other beds, as well as some clappers. KI-Mid had the highest percent of new single shells (about 60%), while AB-4 had about 45% new single and old single shell.

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

Inputs	Dell Richey 2	Northern Star
Dredge width	4.1 m	4.02 m
Dredge efficiency	33%	33%

Table 3. Estimated total commercial catch (t) and the number of vessels that fished within each survey bed during 2016 (excluding surveys) based on logbook data.

Bed	Values	Number of vessels
FI-1	0 t	
FI-2	0 t	
FI-3	0 t	
FI-4	0 t	
KI-5S	298.2 t	10
KI-New	198.4 t	7
KI-Mid	0 t	
KI-BDE	0 t	
All other areas	2246.5 t	12
Not assigned		2
Total	2761.5 t	

Table 4. Boundaries (decimal degrees) of each scallop bed surveyed in 2017 and area of each polygon (km^2).

Bed	Nickname	Latitude		Longitude		Total
		Northern	Southern	Western	Eastern	Area (km^2)
Flinders Island 1	FI-1	-39.250	-39.33	148.050	148.130	61.30
Flinders Island 2	FI-2	-39.190	-39.25	148.050	148.130	46.02
Flinders Island 3	FI-3	-39.1696	-39.190	148.0857	148.130	8.68
Flinders Island 4	FI-4	-39.149	-39.1696	148.108	148.152	8.70
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 Middle	KI-Mid	-39.794	-39.8285	144.5912	144.6247	10.99
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
Apollo Bay 3	AB-3	-39.1257	-39.1474	144.1447	144.1633	3.88
Apollo Bay 4	AB-4	-39.1411	-39.1661	144.0652	144.0866	5.14
	Total					342.99

°

Table 5. 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.

Area	Bed	Number of tows	Mean density (kg / 1000m^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-1	33	12.0	14.4	424.4	737.3	1050.2	48	0.153
FI	FI-2	26	12.7	6.0	472.8	585.1	697.4	50	0.167
FI	FI-3	15	6.5	8.3	16.9	56.5	96.2	26	0.095
FI	FI-4	15	9.7	6.4	53.3	84.0	114.7	38	0.114
Sub-total		**89**				**1,462.9**			
KI	KI-5S	30	44.8	33.5	2203.8	3059.2	3914.7	177	0.327
KI	KI-BDE	30	208.9	165.9	8307.1	11809.2	15311.3	827	2.400
KI	KI-Mid	20	8.4	11.1	35.0	92.0	149.0	33	0.070
KI	KI-New	30	51.2	21.8	1962.1	2332.5	2702.9	203	0.405
Sub-total		**110**				**17,292.9**			
AB	AB-1	20	205.1	115.4	2104.0	2856.1	3608.3	812	2.331
AB	AB-2	20	156.4	93.9	1568.7	2182.0	2795.3	619	1.604
AB	AB-3	10	77.7	63.3	125.8	301.3	476.7	308	0.987
AB	AB-4	10	28.0	15.9	85.8	144.1	202.4	111	0.279
Sub-total		**60**				**5,483.5**			
Total		**259**				**24,239.3**			

Table 6. 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.

Bed	% weight > 85 mm	Lower 95% CL (t)	Estimated Biomass (t)	Upper 95% CL (t)
FI-1	80.8	342.7	595.4	848.0
FI-2	66.0	311.8	385.9	460.0
FI-3	77.6	13.1	43.9	74.7
FI-4	78.1	41.6	65.6	89.6
Sub-total			**1090.8**	
KI-5S	100.0	2202.9	3058.0	3913.1
KI-BD	91.1	7569.3	10760.4	13951.4
KI-Mid	100.0	35.0	92.0	149.0
KI-New	99.5	1952.1	2320.7	2689.2
Sub-total			**16231.1**	
AB-1	99.5	2093.6	2842.0	3590.5
AB-2	99.8	1566.0	2178.2	2790.4
AB-3	99.9	125.7	300.9	476.2
AB-4	99.2	85.0	142.9	200.7
Sub-total			**5464.0**	
Total			**22785.9**	

Table 7. 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-1	840	90	90	0.32	19.2	80.8	89
FI-2	963	86	86	0.24	34.0	66.0	94
FI-3	346	90	90	0.41	22.4	77.6	90
FI-4	506	89	90	0.37	21.9	78.1	93
KI-5S	1426	108	108	0.18	0.0	100.0	69
KI-BD	1273	93	91	0.27	8.9	91.1	92
KI-Mid	482	112	111	0.26	0.0	100.0	44
KI-New	1864	108	107	0.22	0.5	99.5	53
AB-1	1000	100	100	0.20	0.5	99.5	134
AB-2	1088	102	101	0.19	0.2	99.8	99
AB-3	500	99	99	0.28	0.1	99.9	117
AB-4	453	98	98	0.30	0.8	99.2	106

Table 8. Number of scallops retained for biological sampling, and parameter estimates for length weight relationships.

Area	N	a	b	Adjusted R^2
Flinders Island	109	-7.1124	2.5037	0.80
King Island	170	-6.1395	2.3064	0.88
Apollo Bay	118	-5.9269	2.2291	0.69

Table 9. Catch of each species in each bed. (u) refers to undifferentiated species recorded at a higher taxonomic level.

	Catch (kg)											
	Flinders Island				King Island							
Common name	FI-1	FI-2	FI-3	FI-4	KI-5S	KI-BD	KI-Mid	KI-New	AB-1	AB-2	AB-3	AB-4
Commercial scallop	282.3	259	75.12	99.5	1048.5	4813.17	115.4	1088	3107.9	2181	581.6	187.5
Clappers	11	21.1	0	2.8	0.5	2.05	0.8	2	0	1.5	0	0
New single	764	267	22	217	59.05	78	175.2	117	5.7	443	1	107
Old single	3110	3935	1730	615	12.35	564.8	8	33.3	95.6	100	31	45
Algae - Phyllospora												2
Ascidian (u)		2.5	6		8	392.5		58				
Bailer Shell									0.7		1	
Banded stingaree	1.4	0.6	1.5	1.3	0.2	0.55	0.7			0.4	0.1	1.4
Bassina spp.								0.7				
Bighead gurnard perch	2											
Brittlestars			0.1									
Brown Algae		0.4										
Bug	4	0.5	0.5	7.3		0.1		0.7	0.1	1.4		0.6
Bulldog stargazer		0.5										
Cocky gurnard	0.1	0.6	0.2	0.2				0.7		0.1		0.1
Common gurnard perch		0.1				0.2		0.5				
Common stargazer	4			15			3	0.6		0.6		
Common stinkfish			0.1									
Conger eel			0.1									
Cowrie (u)	0.2	0.1							0.1			
Crab (u)					0.15							
Crassatellidae (u)	56.3			0.5								
Cuttlefish (u)	1.2			1.5			2					
Dog cockles		14.9									0.05	
Doughboy scallop	6.6	570	552	6.5	12.15	1556.5		1.5	0.05	4	0.2	
Draughtboard shark				3		6.6	3.5					
Eleven armed seastar						18.9						
False bailer shell						2.3						
Flathead (u)	0.1											
Flounder (u)	0.2		0.1				0.3	0.4				
Gastropod (u)					2							
Greenback stingaree	1.7	0.1	0.1	81.8								
Hard Coral	15							0.5		3.7		23.5
Hermit crab (u)	55	25.4	17.5	46	0.1	6	0.4	6.1		1.8	0.4	0.5
Holothurian (u)										1		0.8
Jack mackerel								0.2				
Longnose skate							0.2					
Mollusc (u)	85.5	11.9	14.1	39.9			2.4	30.4		1.2		3.9
Moreton Bay bug (u)	3.5											
Mosaic leatherjacket	0.6											
New Zealand Screw Shell	16	129	1382	124.5				5.5				
Octopus (u)	65.8	9.4	6.2	9.1		0.1	0.2	3.3	0.401	1.1		0.7
Oysters	5.1	35.5	25		28.5	2061		0.2	2.8	1	2.2	
Pale octopus					2	1.1			0.2		0.35	
Peacock skate				0.5		6.8	0.8					
Polychaete worm (u)	0.1		0.1									
Pufferfish (u)							0.8					
Razorfish (u)		20.5	7			0.6			3.2		0.3	

	Catch (kg)											
	Flinders Island				King Island							
Common name	FI-1	FI-2	FI-3	FI-4	KI-5S	KI-BD	KI-Mid	KI-New	AB-1	AB-2	AB-3	AB-4
Round-snouted gurnard	1											
Roundsnout gurnard					0.1	0.38	0.1	0.6		0.2		
Sandyback stingaree				0.5				0.6				
Sea cucumber							1.6	1.5				
Sea urchin (u)	5.1	9.6	0.1	0.5				0.4	0.15	0.5	0.75	0.6
Seapen (u)	1.7	0.2	0.2	1.4			0.4		0.9	2.3	4	2.8
Seastar (u)	2.7	1.3	0.2	2.3			12.9	0.5	4.7	10.1	2.9	7.5
Shaw cowfish							0.1					
Silver cobbler				0.1								
Silver dory					0.05							
Skate (u)						0.3						
Soft coral (u)								0.3				
Sole (u)		0.3										
Southern blue-ringed octopus	0.8			0.2								
Southern sand flathead			1.2		1.5	1.3			0.6			
Sparsely-spotted stingaree	2	0.3	0.4	1.1			5.7	0.3				
Speckled stargazer		4	10									
Spider crab (u)	3.8	1.4	41		242.5	188.6	6.3	35.4	0.5	2.3		
Sponge (u)	594	11	2	4	11.2	285.5	3.1	85	19.1	22.5	8.7	120
Sponges (Coral)		4	4									
Starfish											0.7	
Stargazer (u)			0.5		0.2	0.3					5	
Stingaree & giant stingaree (u)	6.5											
Stingray (u)					3.3	10.6			0.2		1.8	
Substrate	780	1147	395	275		1368	32.5	42.4		32		48.5
Substrate - Rock									2			
Swimmer crab		0.1	0.1			0.4						
Tasmanian numbfish							0.3	0.4				
Tiger flathead		1.2			0.4					1.8		
Toadfish (u)						0.5						
Triggerfish & leatherjacket (u)	0.8			0.1		0.3						
Triton shells		35.1	53		5.2	36.5			0.1		0.1	
Velvet leatherjacket			0.2									
Venus shells	30	7		7			0.1	0.1				0.1
Volute (u)	3	17.5	0.2	3	0.8			0.2	0.2	0.1		2

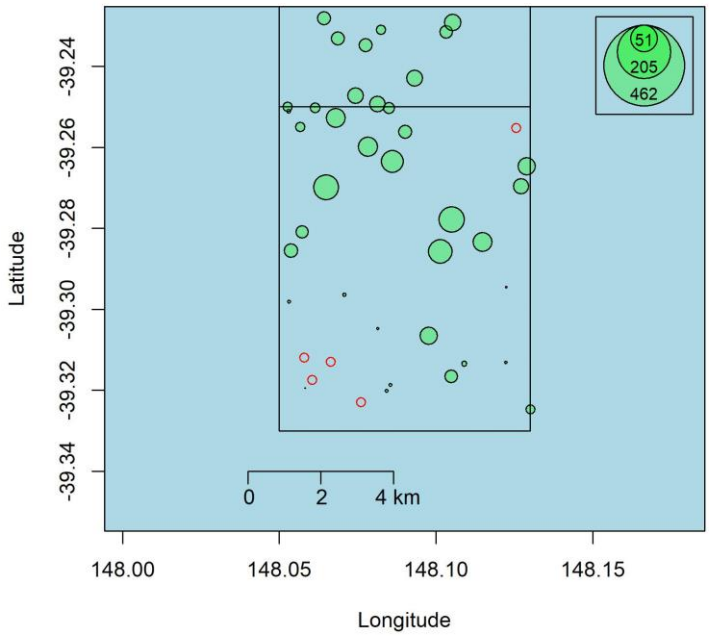

Figure 4. Scallop density (kg / 1000 m^2) within the defined stratum of the FI-1 bed near Flinders Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

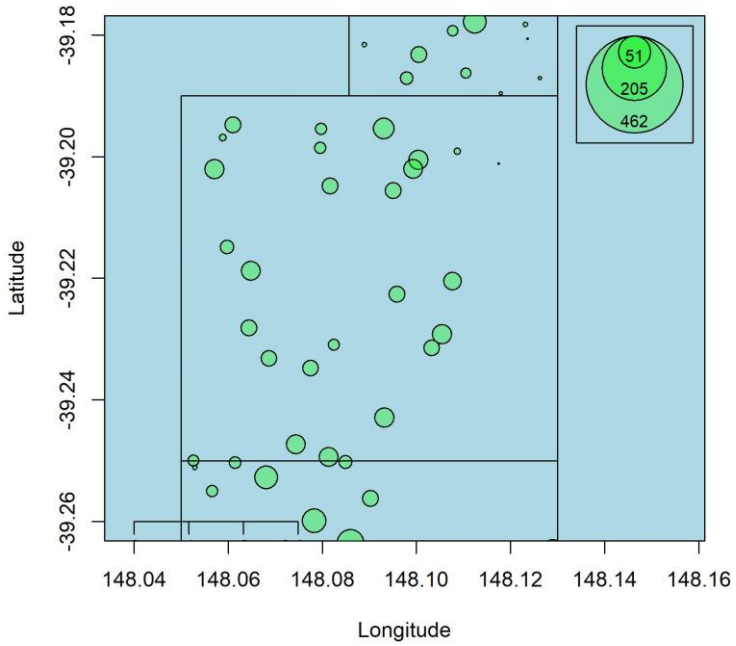

Figure 5. Scallop density (kg / 1000 m^2) within the defined stratum of the FI-2 bed near Flinders Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

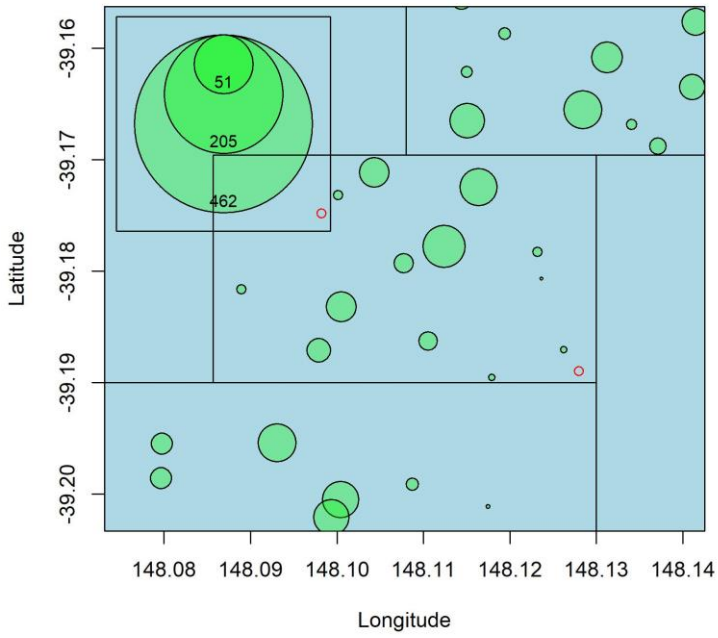

Figure 6. Scallop density (kg / 1000 m^2) within the defined stratum of the FI-3 bed near Flinders Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

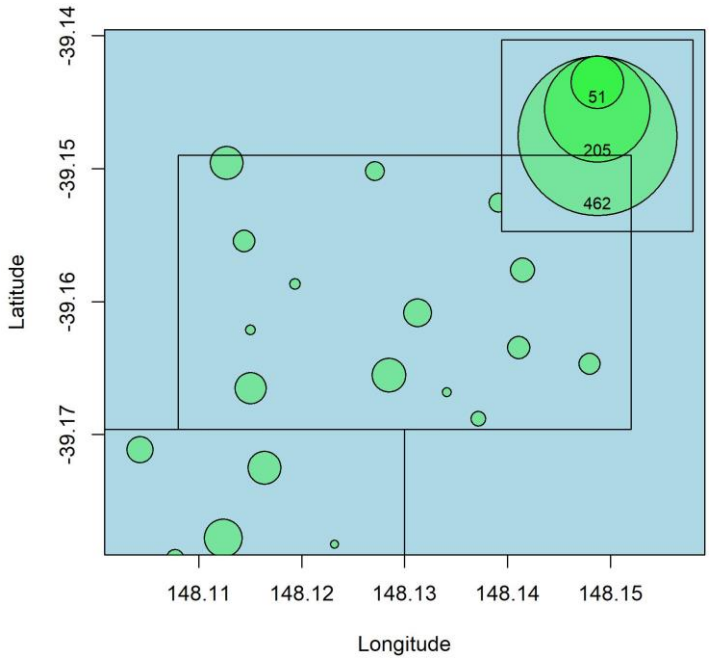

Figure 7. Scallop density (kg / 1000 m^2) within the defined stratum of the FI-4 bed near Flinders Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

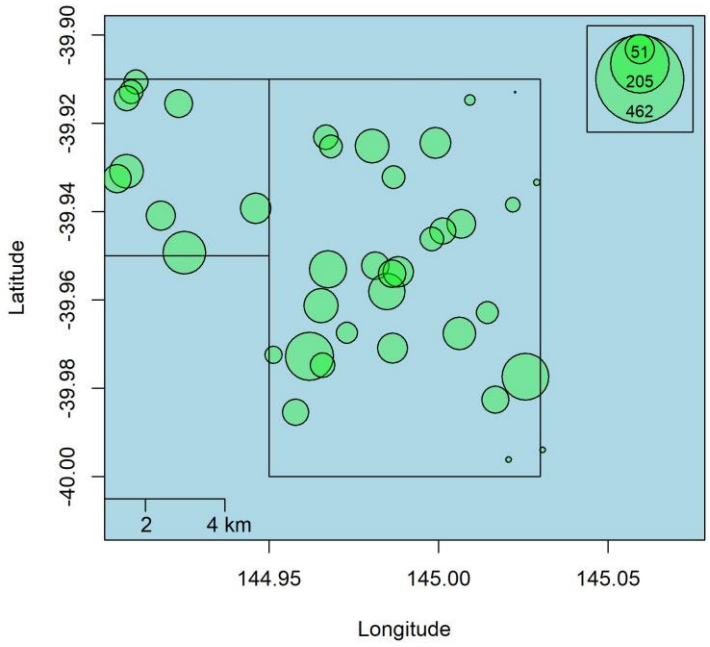

Figure 8. Scallop density (kg / 1000 m^2) within the defined stratum of the KI-5S bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

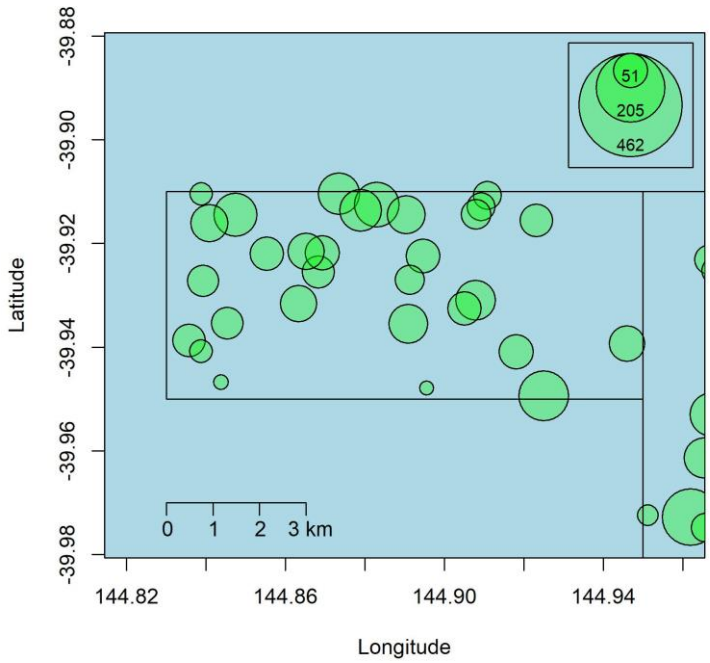

Figure 9. Scallop density (kg / 1000 m^2) within the defined stratum of the KI-New bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

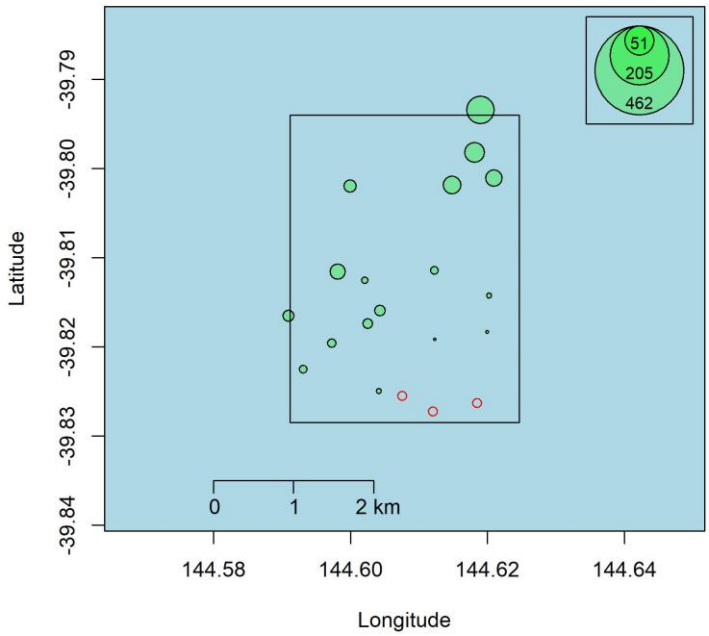

Figure 10. Scallop density (kg / 1000 m^2) within the defined stratum of the KI-Mid bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

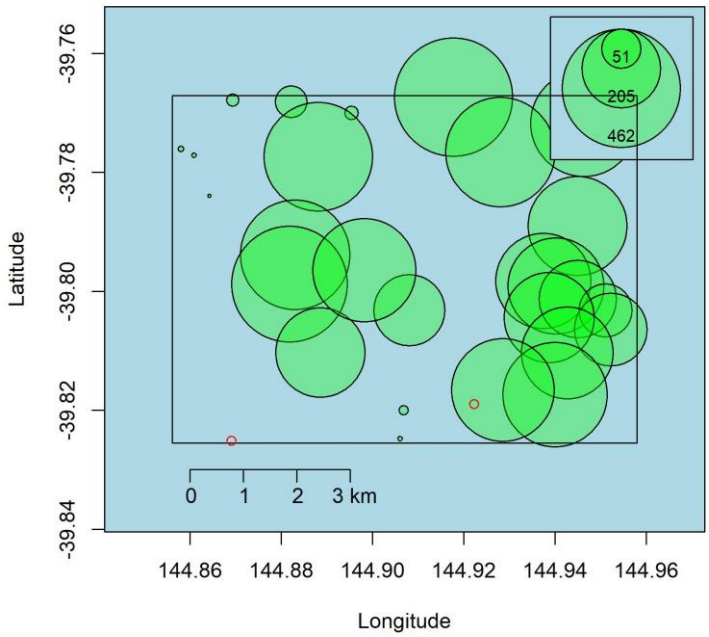

Figure 11. Scallop density (kg / 1000 m^2) within the defined stratum of the King Island Bluedot Extended bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

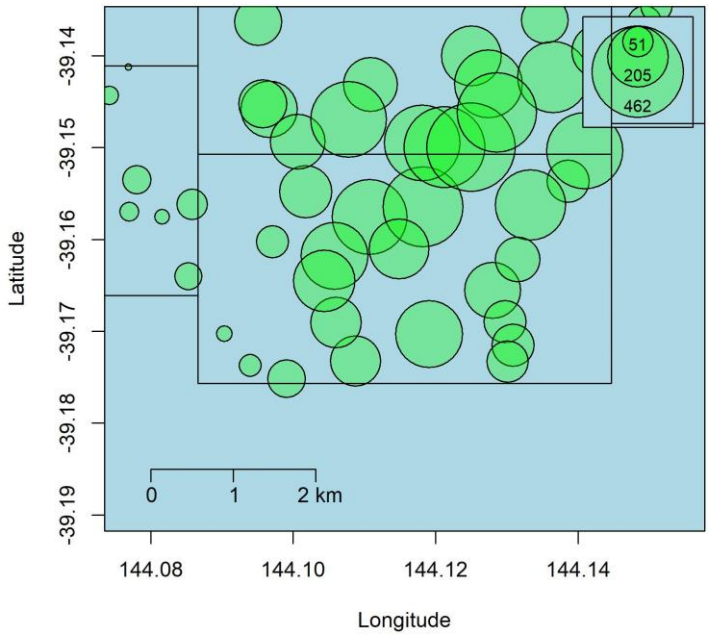

Figure 12. Scallop density (kg / 1000 m^2) within the defined stratum of the AB-1 bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

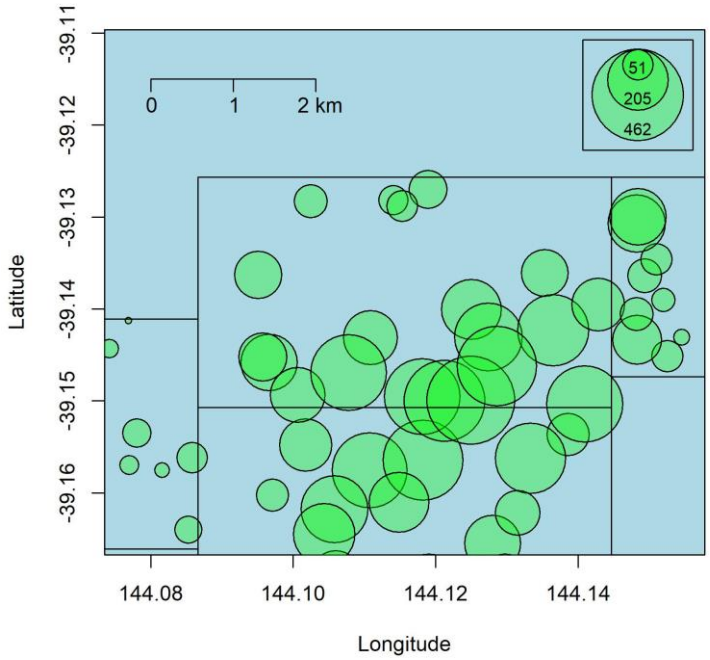

Figure 13. Scallop density (kg / 1000 m^2) within the defined stratum of the AB-2 bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

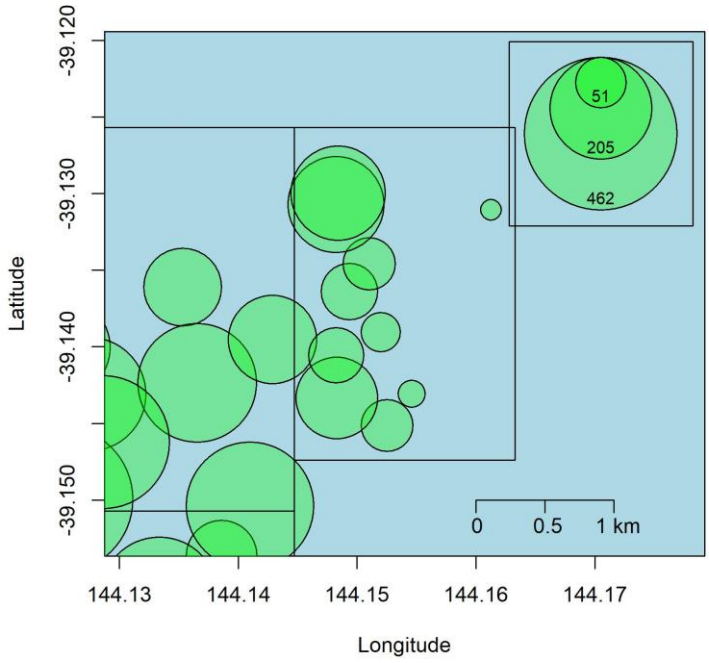

Figure 14. Scallop density (kg / 1000 m^2) within the defined stratum of the AB-3 bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

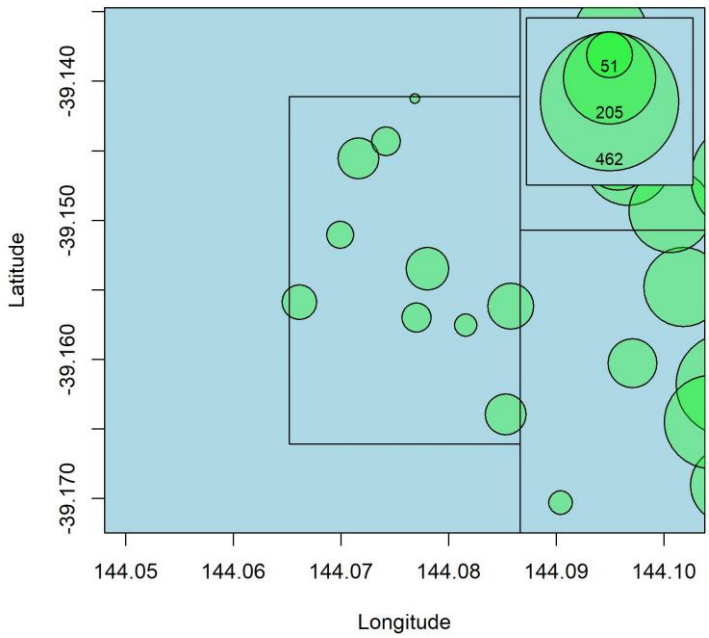

Figure 15. Scallop density (kg / 1000 m^2) within the defined stratum of the AB-4 bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

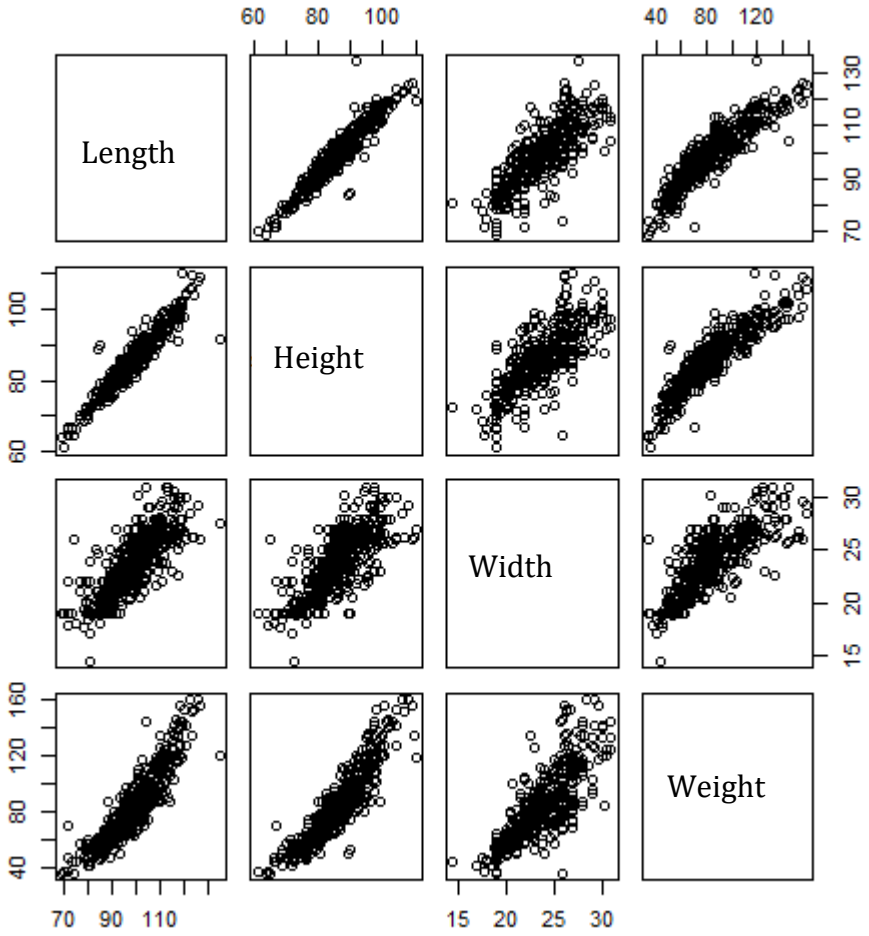

Figure 16. Scatterplot matrix of size measurements and total weight for all samples combined.

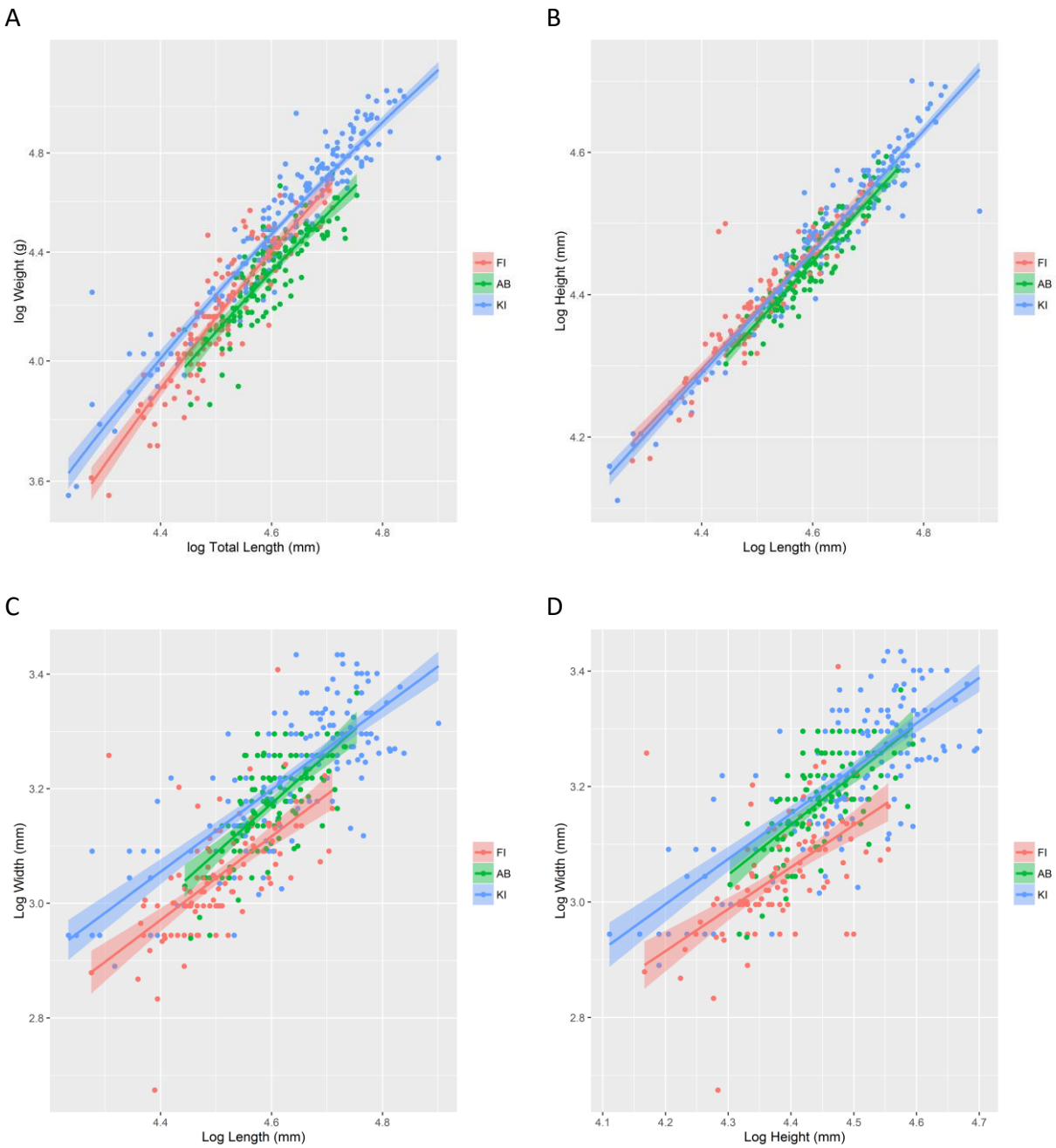

Figure 17. Log transformed A) length and weight, B) length and height, C) length and width and D) height and width from each bed.

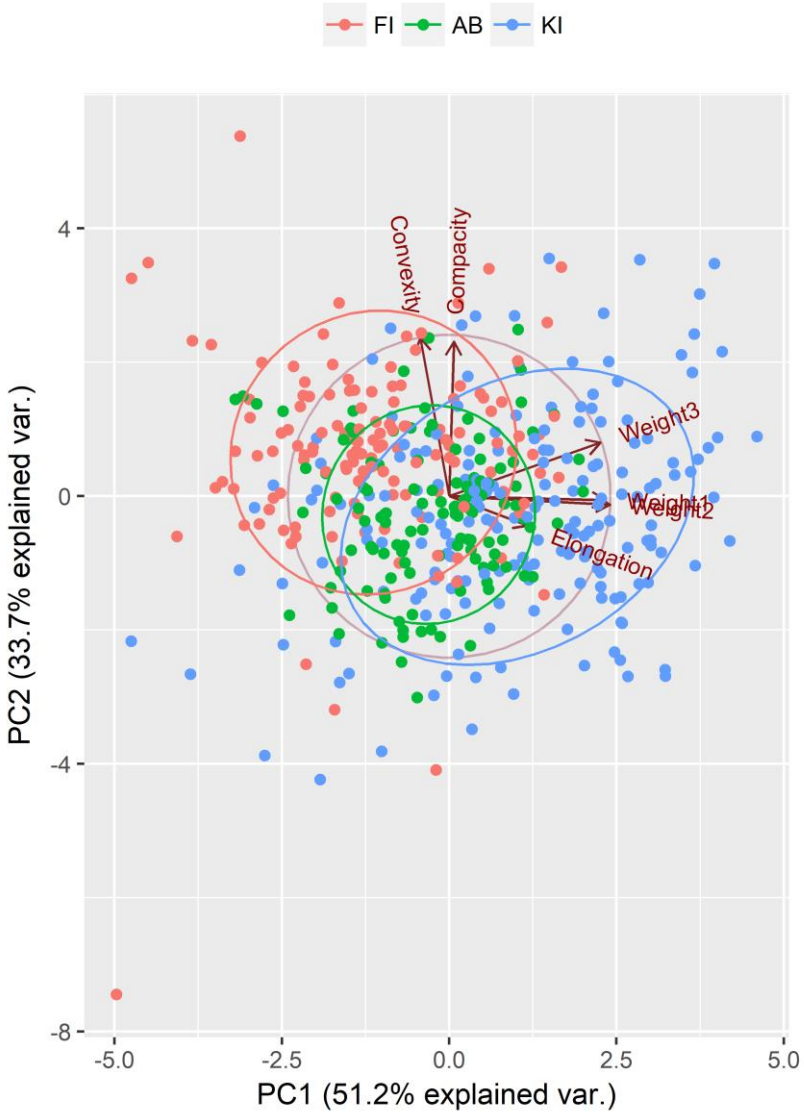

Figure 18. Principle component analysis on ratios of different shell measurements and weight: Elongation – length/width; Convexity – height/ width; Compacity - length / width; Weight1 – weight/ length, Weight2 – weight/ height, Weight1 – weight/ width.

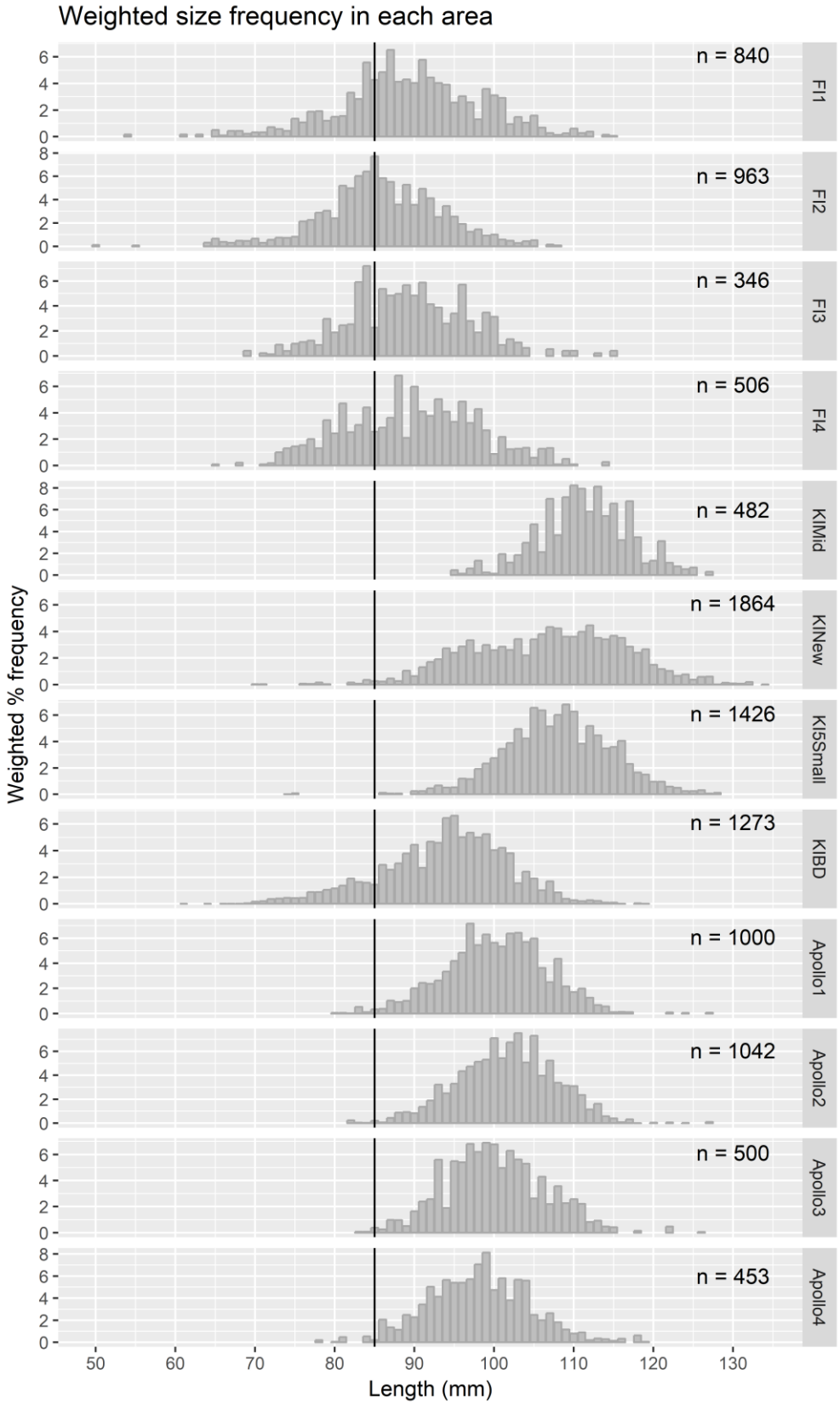

Figure 19. Catch weighted size frequency from shots included in biomass estimates from each bed. The vertical line is at 85 mm.

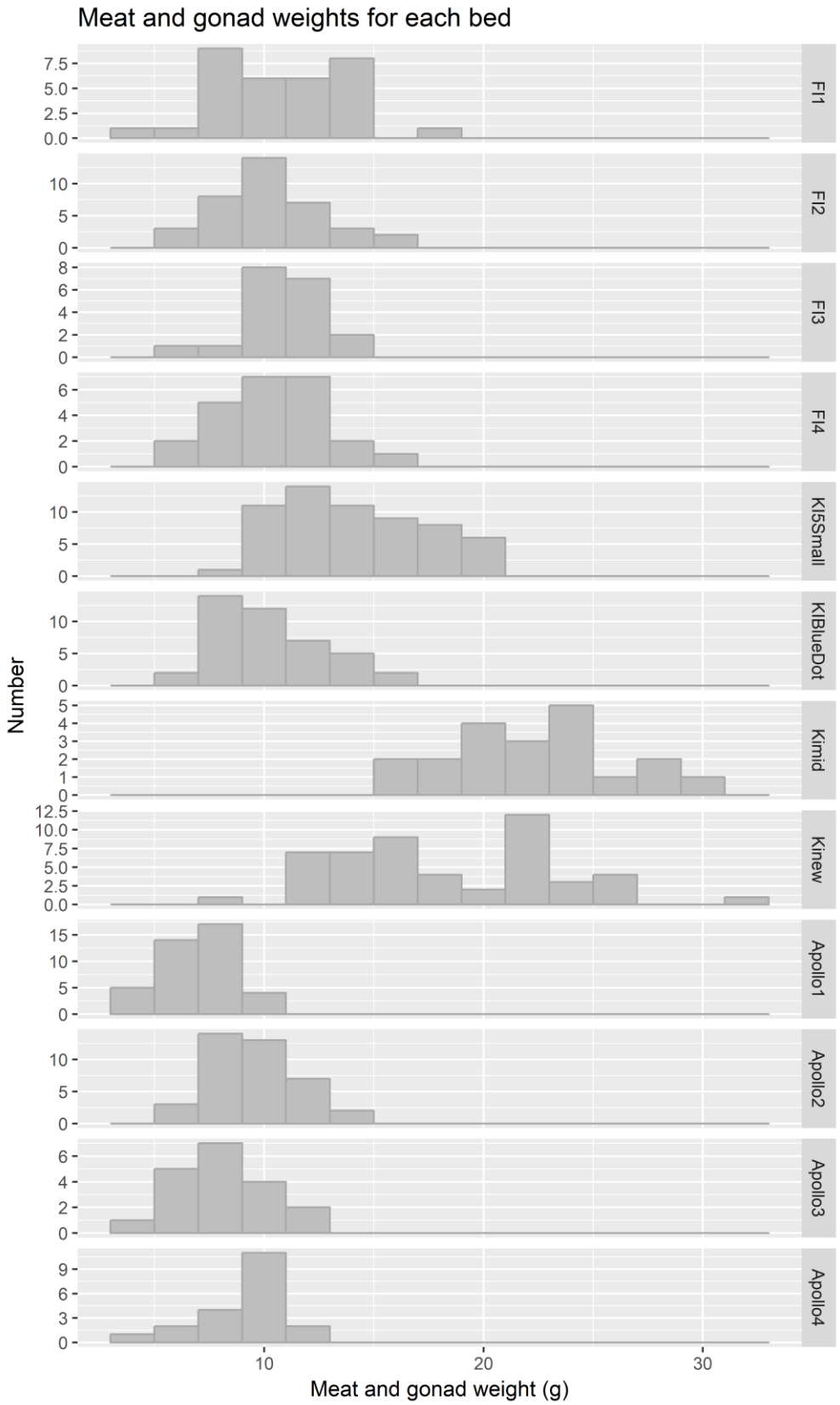

Figure 20. Frequency of combined meat and gonad weights of scallops >85 mm measured from each bed binned into 2 g weight categories.

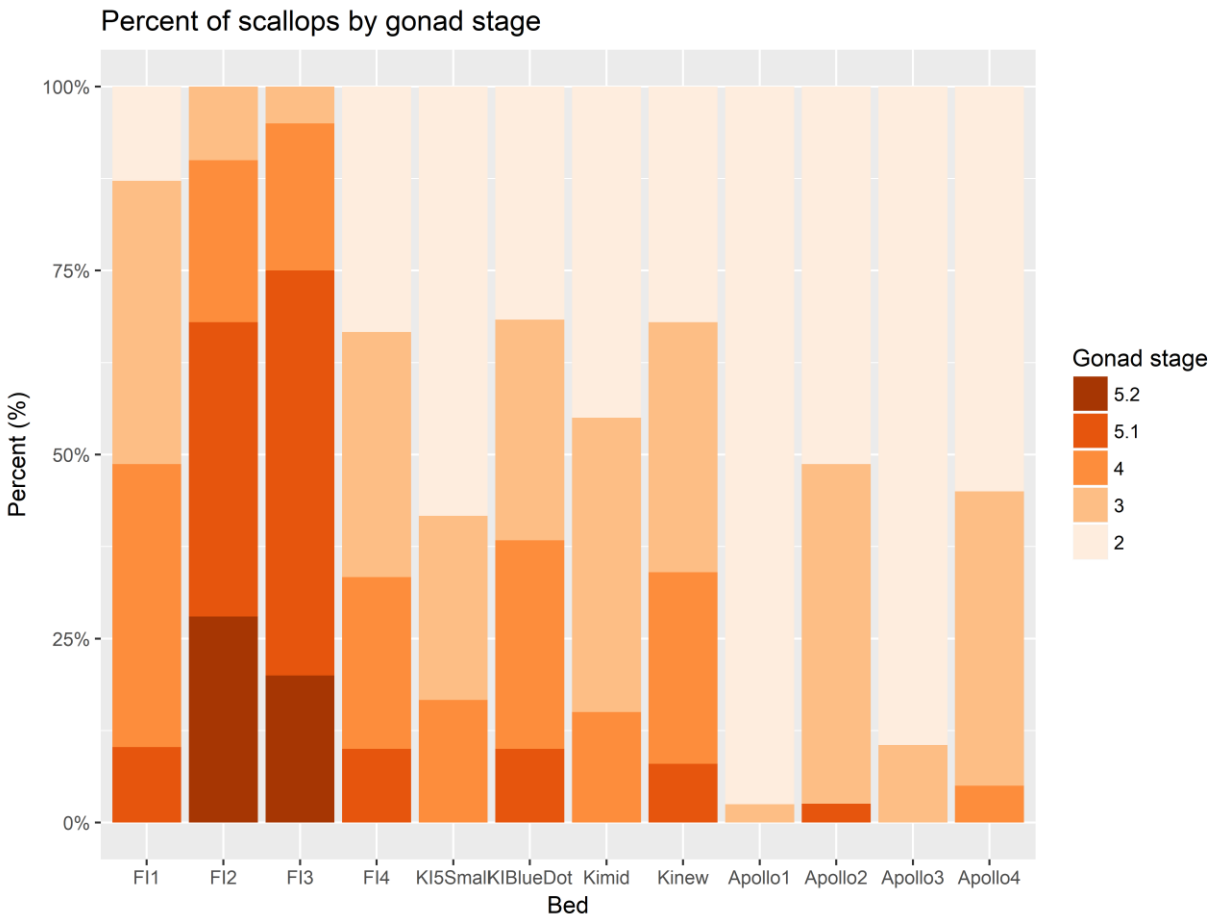

Figure 21. Percent of scallops at each stage from each bed based on macroscopic staging criteria.

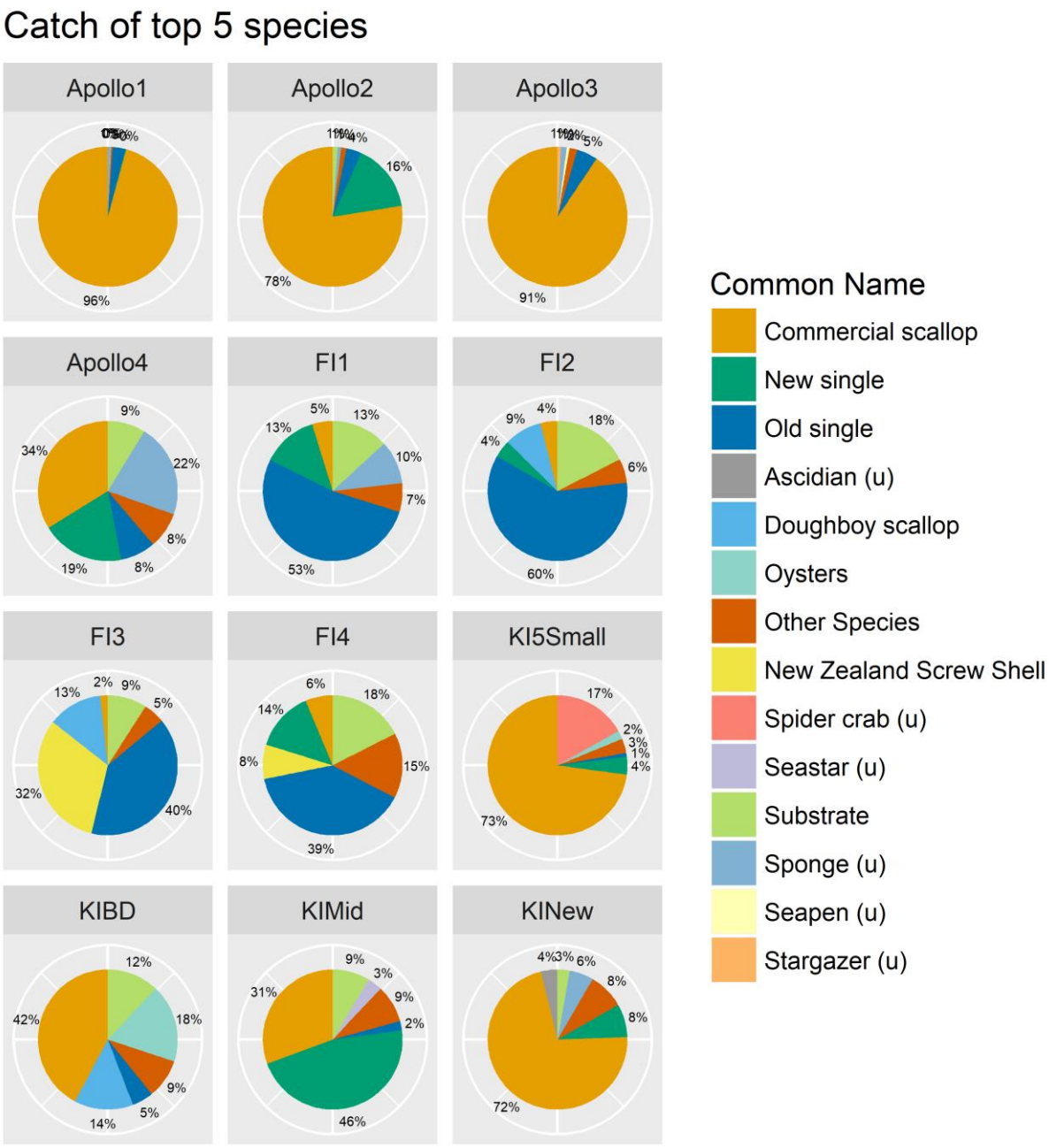

Figure 22. Percent catch composition in each bed sampled by weight from all beds.

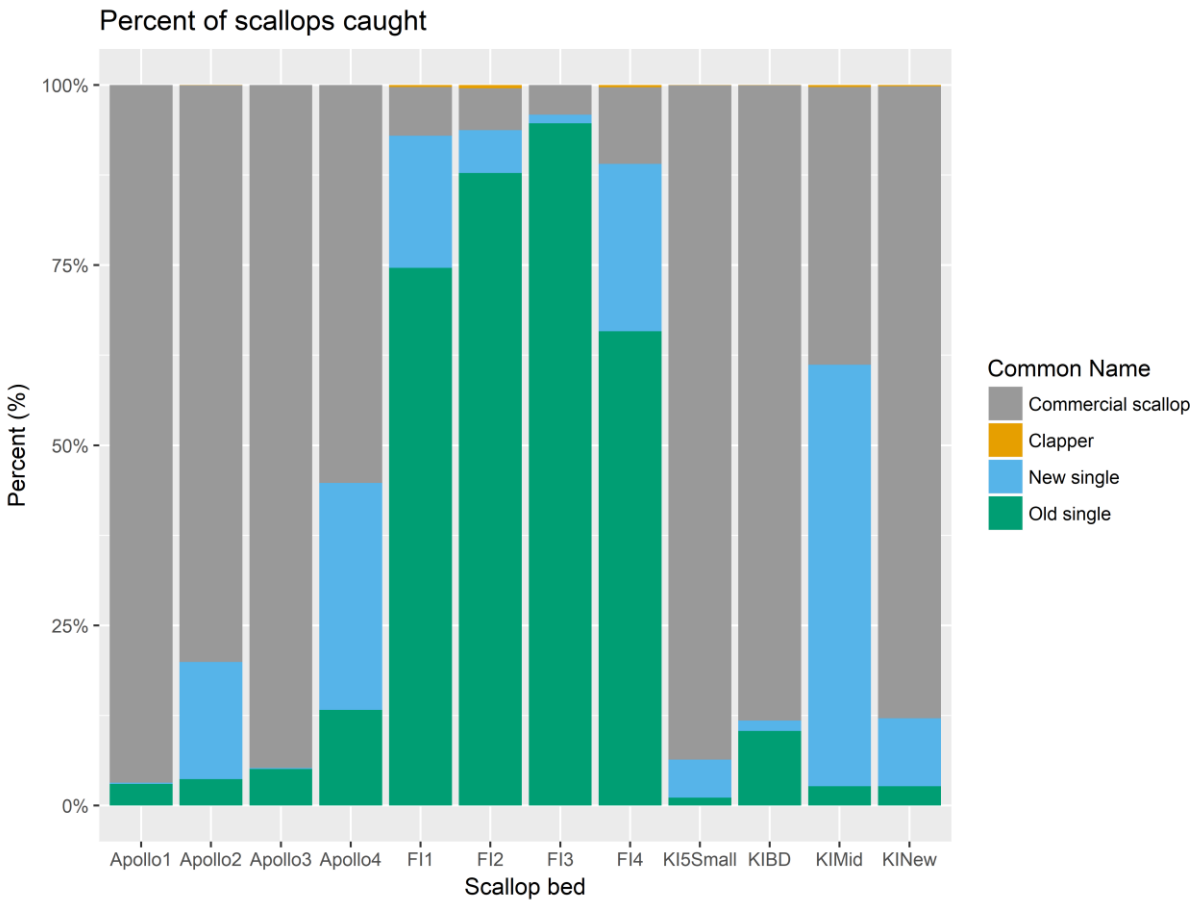

Figure 23. Percent composition of clappers, live scallop, new single and old single shell from each Bed.

Discussion

Main survey

Random stratified surveys were successfully undertaken on four scallop beds off each of Flinders Island, King Island and Apollo Bay (Figure 2, Table 5). Beds were selected based on a combination of previous surveys, advice from ScallopRAG and the BSCZSF Co-management Committee and marks provided by industry. In total, 259 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 had substantially reduced at the Flinders Island beds that had been previously surveyed, with the four Flinders Island beds totalling 1,462.9 t, of which only 1,090.8 t was above 85 mm (Table 10). The % weight of shell >85mm (determining the discard rate) was just above 80% at FI-1, but were below that level at the other Flinders beds, and only 66% at FI-2 (Table 10). Densities at Flinders Island were all below 0.203 individuals per m^2 (Table 10). No commercial catch was recorded from any of the Flinders Island beds (Table 3) during 2016, and combined with a progressive increases in the percentage of dead shell compared to live

scallops and a decrease in the proportion of large (>90 mm), there appears to be significant natural mortality in this area since 2015 (Appendix 2).

KI-BDE, the bed that formed the spatial closure part way through the 2016 season, increased in biomass since the 2016 survey (see Appendix 2) with an estimated 11,809.2 t biomass (Table 10), of which 10,760.4 t was greater than 85 mm (Table 10). There was no commercial catch reported from within this bed during 2016 (there was one record from within the bed from the date of the survey), and the size distribution increased from 2016 (Figure 28). Density at this site was 2.4 individuals per m^2 (Table 10). KI-5S and KI-New both had biomasses of scallops >85 mm of greater than 1,500 t. About 300 t and 200 t of commercial catch was reported from these beds respectively during 2016 (Table 3), and densities at both were above 0.203 individuals per m^2 (Table 10). KI-Mid appears to have experienced significant natural mortality since 2016, and shows no sign of recent recruitment. While no commercial catch was reported from within that bed (Table 3), biomass dropped considerably at the same time as a large increase in dead shell was observed (Figure 29).

The surveyed beds off Apollo Bay had very dense aggregations of scallops (2.6 and 1.6 individuals per m^2 in AB-1 and AB-2 respectively), and a total biomass of 5,483.5 t (Table 10), of which 5464.0 t was >85 mm (Table 10).

Table 10. Summary of data used to inform the ScallopRAG and ScallopMAC recommendation for 2017 harvest strategy requirements and TAC.

Area	Bed	Estimated biomass (t)	% weight > 85 mm	Estimated biomass (t)>85 mm	Density (ind/m^2)	Mean size	Meats / kg
FI	FI-1	737.3	80.8	595.4	0.153	90	89
FI	FI-2	585.1	66.0	385.9	0.167	86	94
FI	FI-3	56.5	77.6	43.9	0.095	90	90
FI	FI-4	84.0	78.1	65.6	0.114	90	93
	Sub-total	**1,462.9**		**1090.8**			
KI	KI-5S	3059.2	100.0	3058.0	0.327	108	69
KI	KI-BDE	11809.2	91.1	10760.4	2.400	91	92
KI	KI-Mid	92.0	100.0	92.0	0.070	111	44
KI	KI-New	2332.5	99.5	2320.7	0.405	107	53
	Sub-total	**17,292.9**		**16231.1**			
AB	AB-1	2856.1	99.5	2842.0	2.331	100	134
AB	AB-2	2182.0	99.8	2178.2	1.604	101	99
AB	AB-3	301.3	99.9	300.9	0.987	99	117
AB	AB-4	144.1	99.2	142.9	0.279	98	106
	Sub-total	**5,483.5**		**5464.0**			
	Total	**24,239.3**		**22785.9**			

References

Gerritsen, (2014). Mapplots: Data Visualisation on Maps. R package version 1.5. http://CRAN.R-project.org/package=mapplots

Haddon, M., Harrington, J. and Semmens, J. (2006). Juvenile Scallop Discard Rates and Bed Dynamics: Testing the Management Rules for Scallops in Bass Strait. FRDC Project 2003/017. 175pp

Harrington, J.J., MacAllistar, J., Semmens, J.M. (2010). Assessing the immediate impact of seismic surveys on adult commercial scallops (*Pecten fumatus*) in Bass Strait. Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, 2010.

Harrington, J.J., Semmens, J. and Haddon, M. (2008). Commonwealth Bass Strait Central Zone Scallop Fishery Survey. Survey Final Report. Tasmanian Aquaculture and Fisheries Institute. University of Tasmania.

Hijmans, R.J., William, E. and Vennes, C. (2015). Geosphere. http://cran.r-project.org/web/packages/geosphere/geosphere.pdf

Knuckey, I., Koopman, M., and Davis, M. (2015). Bass Strait and Central Zone Scallop Fishery - 2015 Survey. AFMA Project 2015/001291. Fishwell Consulting 22pp.

Knuckey, I., Koopman, M., and Davis, M. (2016). Bass Strait and Central Zone Scallop Fishery - 2016 Survey. AFMA Project 2016/0804. Fishwell Consulting. 30pp.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Semmens, J. and Jones, N. (2014). Draft 2014 BSCZSF survey report. Institute for Marine and Arctic Studies. July 2014.

Appendix 1 –methods

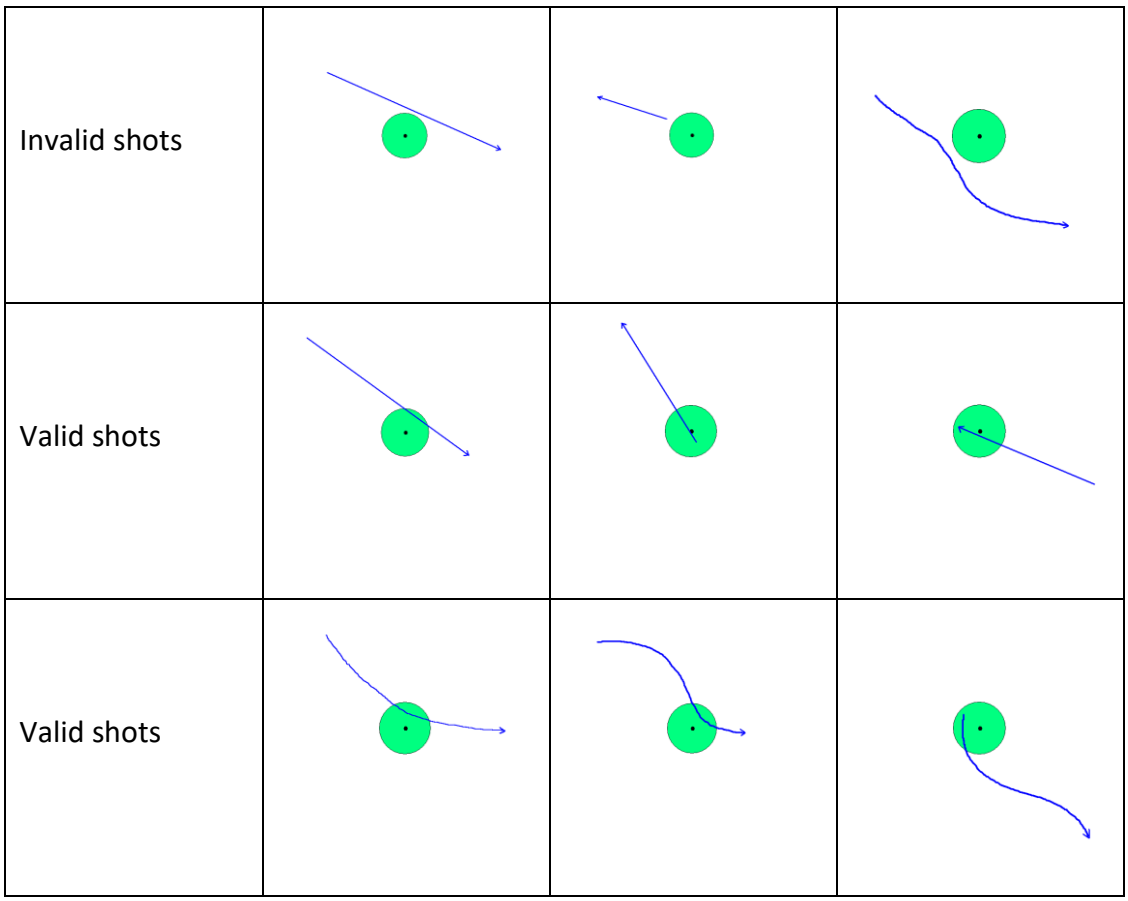

Figure 24. How to conduct a valid survey shot. Green circle is 100 m radius.

Table 11. 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 1b)
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 12. 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 1 (FI-1)

2016 commercial catch	0 t
2017 biomass	737 t
Change since 2015	-3174 t

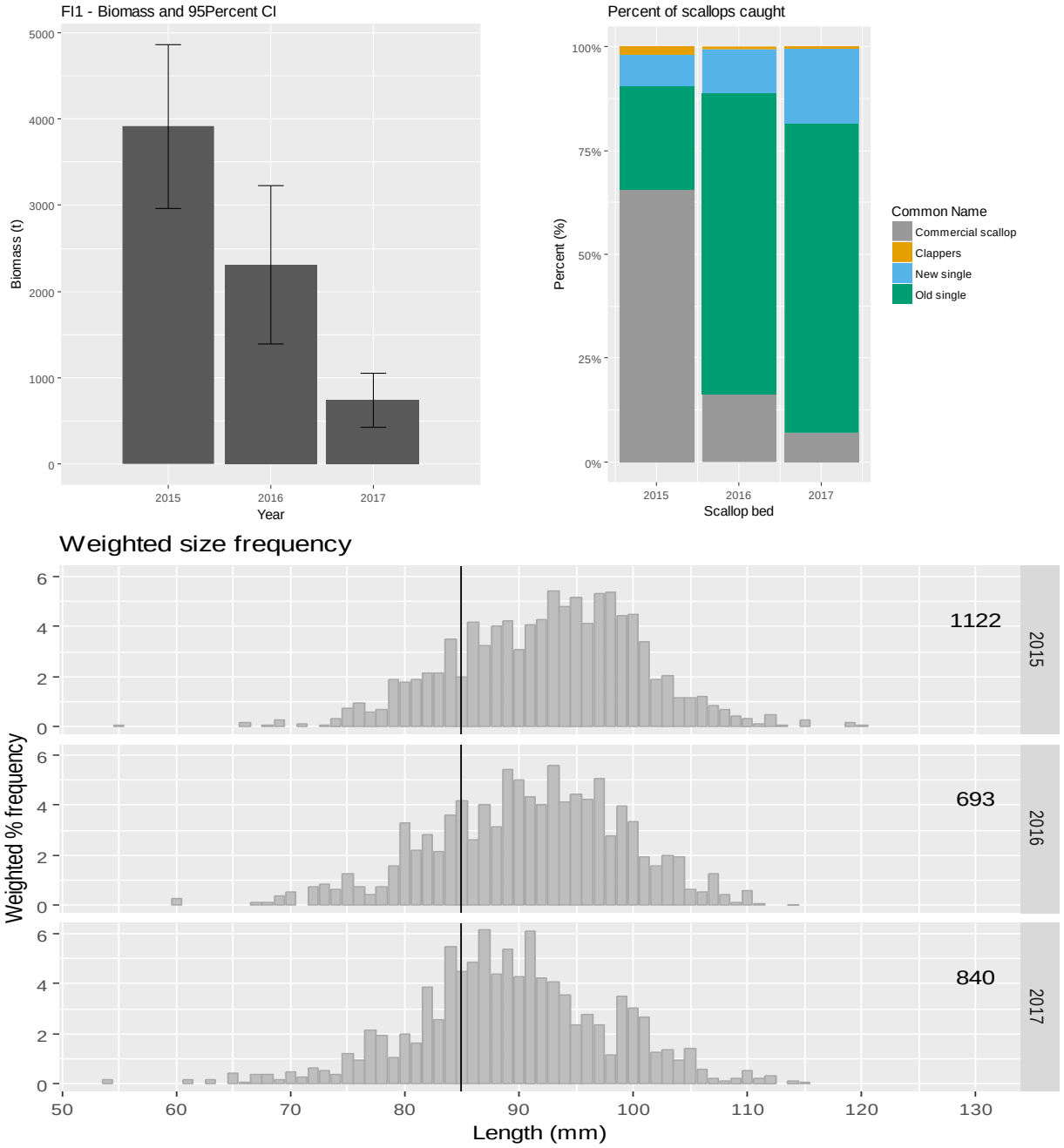

Figure 25. Summary of commercial catch, biomass, change in biomass, percent composition of liver scallops and dead scallop shell and size frequency distribution from 2015 to 2017 from within the FI-1 bed boundaries used during the 2017 survey. Note that while data included in these results are from tows conducted within the FI-1 bed boundaries used during the 2017 survey, the 2015 survey designed was based on a larger area (Figure 1, Table 1).

Flinders Island 2 (FI-2)

2016 commercial catch	0 t
2017 biomass	585 t
Change since 2015	-1186 t

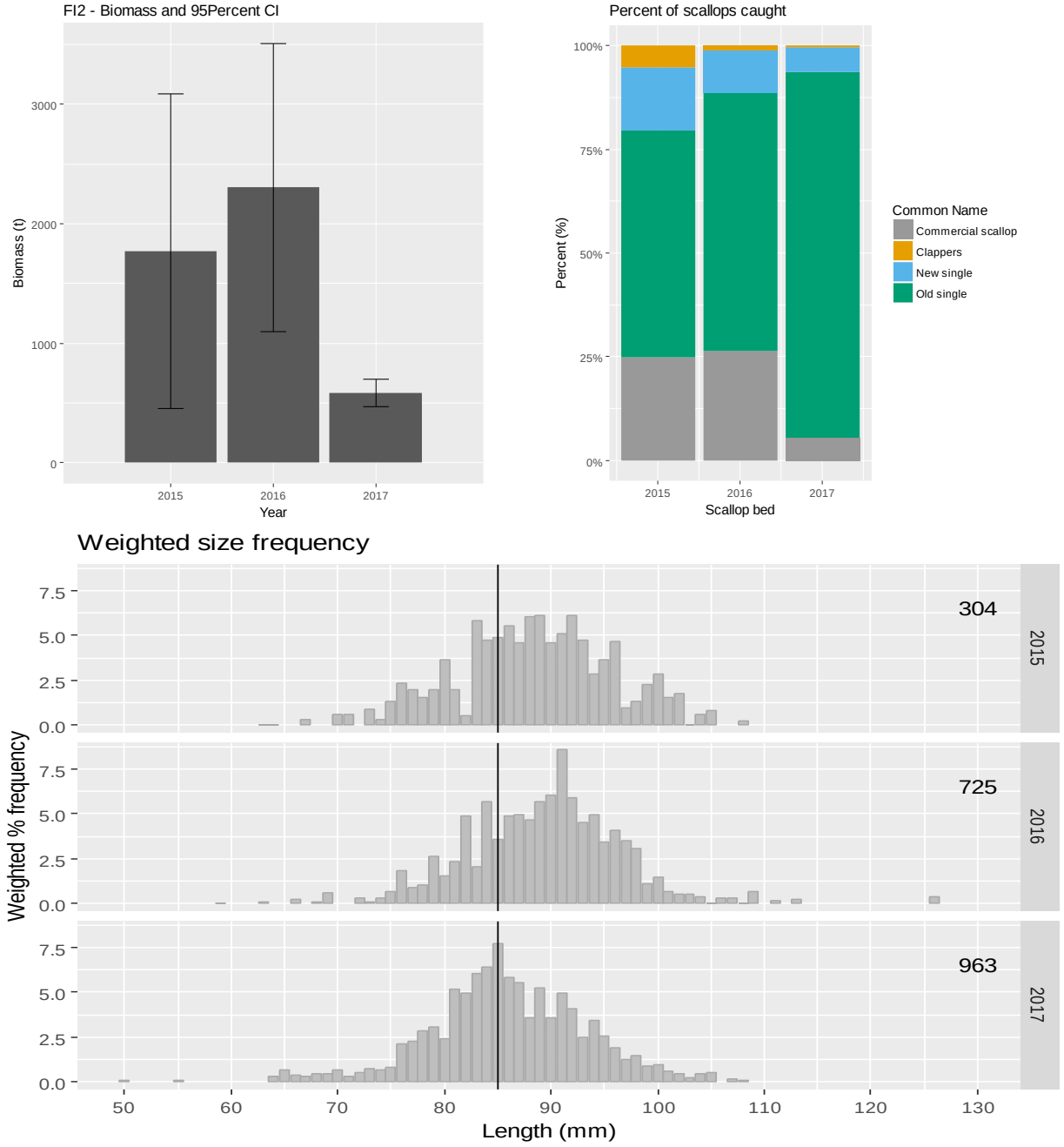

Figure 26. Summary of commercial catch, biomass, change in biomass, percent composition of liver scallops and dead scallop shell and size frequency distribution from 2015 to 2017 from within the FI-2 bed boundaries used during the 2017 survey. Note that while data included in these results are from tows conducted within the FI-2 bed boundaries used during the 2017 survey, the 2015 survey designed was based on a larger area (Figure 1, Table 1).

King Island 5 Small (KI-5S)

2016 commercial catch	298.2 t
2017 biomass	3059.2 t
Change since 2016	-1759 t

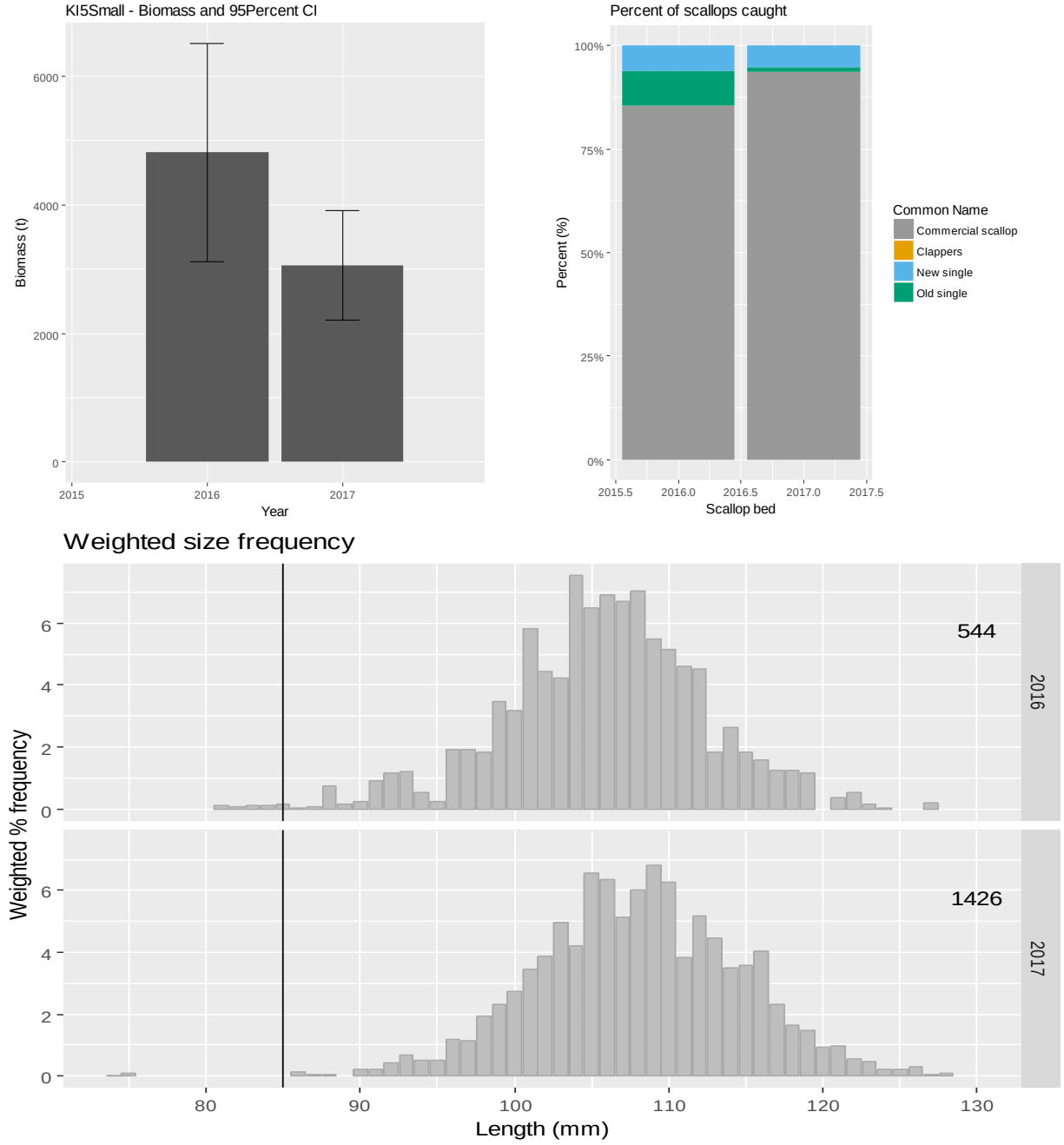

Figure 27. Summary of commercial catch, biomass, change in biomass, percent composition of liver scallops and dead scallop shell and size frequency distribution from 2016 to 2017 from within the KI 5 Small bed boundaries used during the 2017 survey. Note that while data included in these results are from tows conducted within the KI-5S bed boundaries used during the 2017 survey, the 2016 survey designed was based on a much larger area, and the southern boundary of the 2016 bed was further north than in 2017 (Figure 1, Table 1).

King Island Bluedot Extended (KI-BDE)

2016 commercial catch	0 t
2017 biomass	11809.2 t
Change since 2016	+2422 t

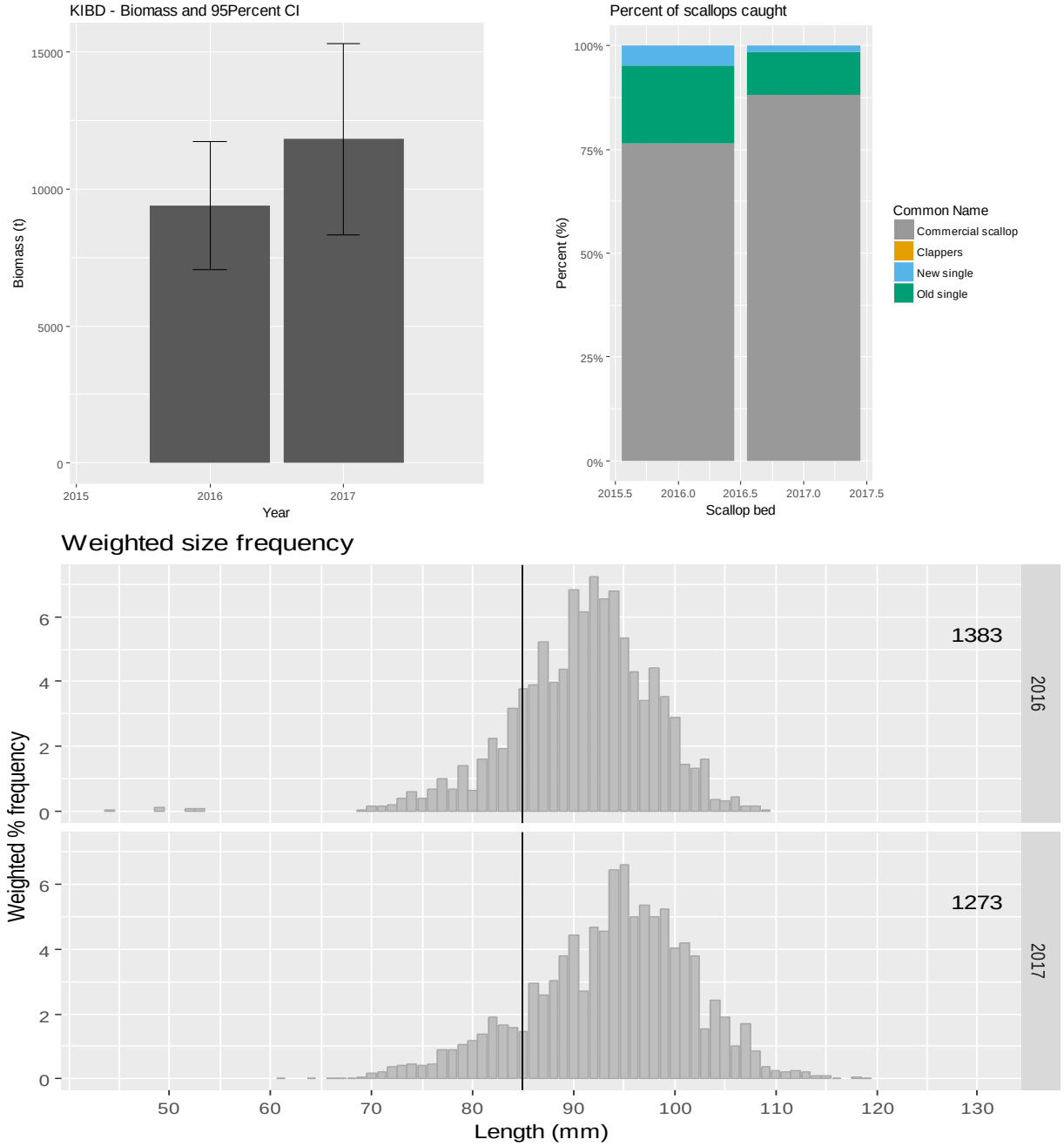

Figure 28. Summary of commercial catch, biomass, change in biomass, percent composition of liver scallops and dead scallop shell and size frequency distribution from 2016 to 2017 from within the KI-BDE bed boundaries used during the 2017 survey. Note that while data included in these results are from tows conducted within the KI-BDE bed boundaries used during the 2017 survey, the 2016 survey designed was based on a smaller area (Figure 1, Table 1).

King Island Middle (KI-Mid)

2016 commercial catch	0 t
2017 biomass	92.0 t
Change since 2015	-486 t

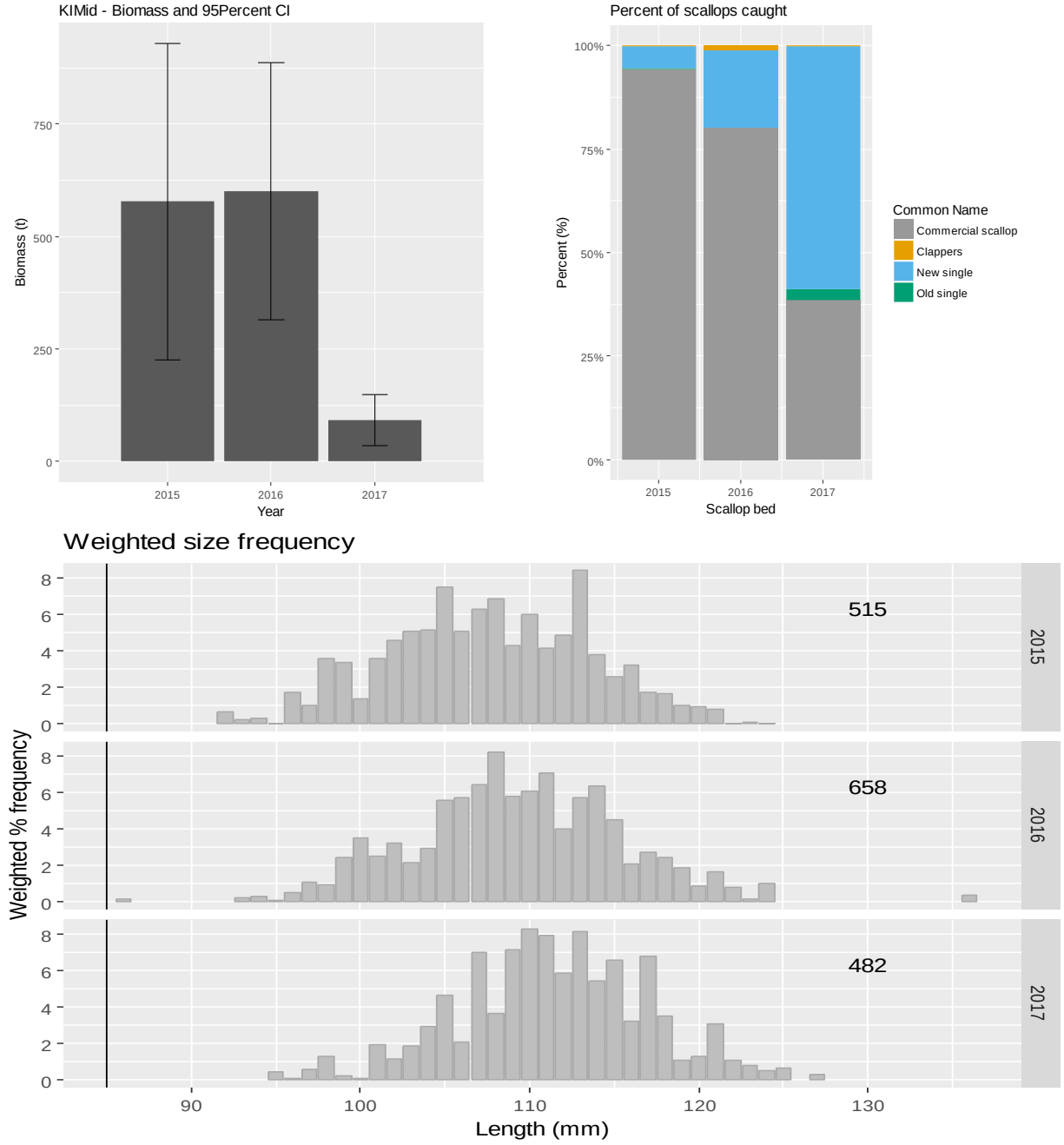

Figure 29. Summary of commercial catch, biomass, change in biomass, percent composition of liver scallops and dead scallop shell and size frequency distribution from 2015 to 2017 from within the KI Middle bed boundaries used during the 2017 survey.

King Island New (KI-New)

2016 commercial catch	198.4 t
2017 biomass	2332.5 t
Change since 2015	-327 t

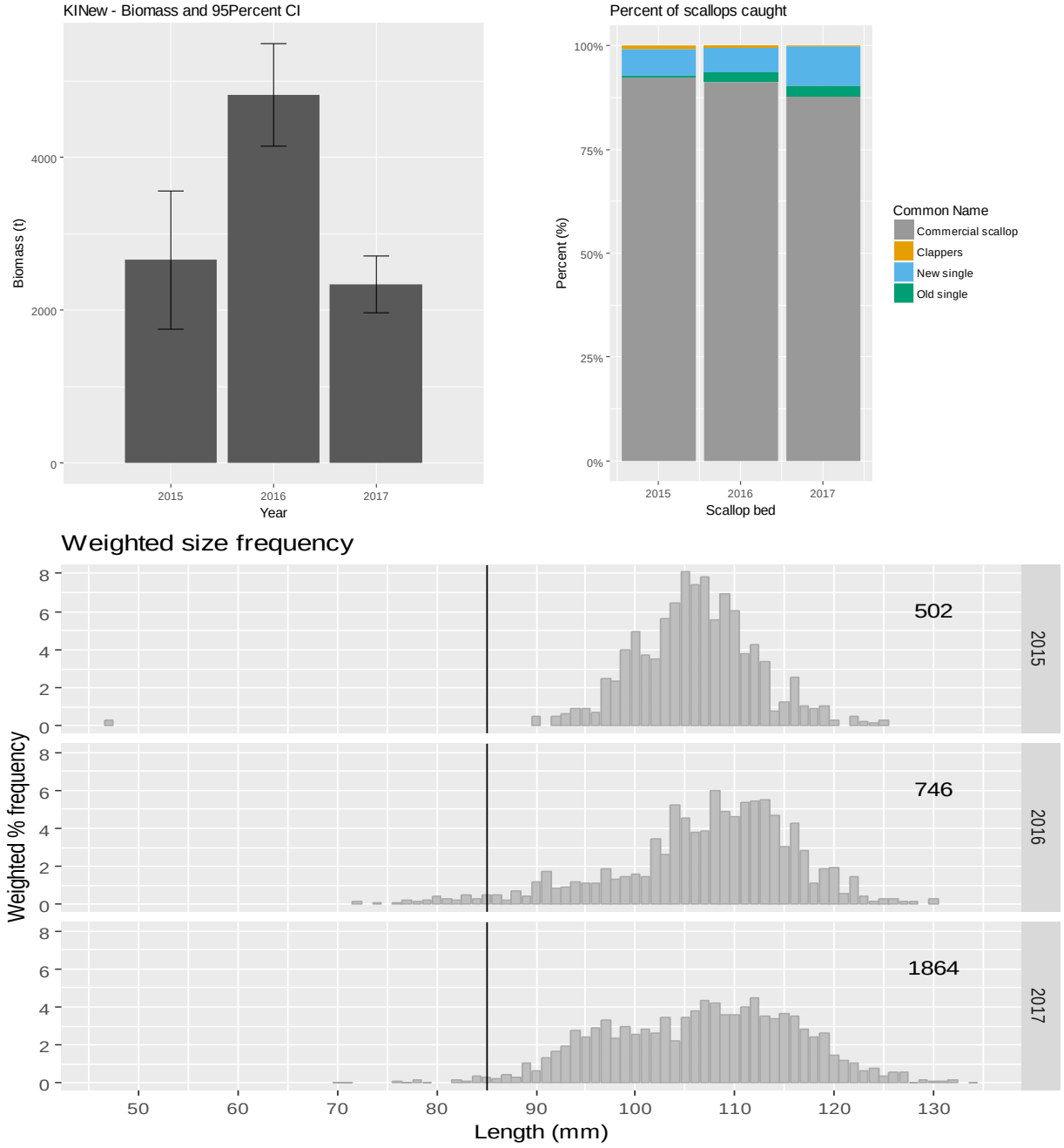

Figure 30. Summary of commercial catch, biomass, change in biomass, percent composition of liver scallops and dead scallop shell and size frequency distribution from 2015 to 2017 from within the KI New bed boundaries used during the 2017 survey. Note that while data included in these results are from tows conducted within the KI New bed boundaries used during the 2017 survey, this area comprises a combination for data from either parts of or the entirety of three different beds surveyed in 2016, as well as two small sections that were not surveyed (Figure 1, Table 1). Date from 2015 was solely from the bed KI East.