AFMA Project 2016/0804

Australian Government
Australian Fisheries Management Authority

Bass Strait and Central Zone Scallop Fishery — 2016 Survey

Ian Knuckey, Matt Koopman
and Michael Davis

2016

fishwell
CONSULTING

Bass Strait and Central Zone Scallop Fishery 2016 Survey

Ian Knuckey, Matt Koopman
and Michael Davis

AFMA Project 2016/0804

2016

ISBN 978-0-9941559-8-6

Title: Bass Strait and Central Zone Scallop Fishery - 2016 Survey

AFMA Project 2016/0804

2016

Ownership of Intellectual Property Rights

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

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

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 2016 research surveys.

During May and June 2016, stratified random sampling surveys were conducted onboard the fishing vessel Dell Richey II on two beds off Flinders Island and seven beds off King Island. Boundaries of all survey beds (strata) were predefined based on results of the 2015 scallop survey, commercial fishing catch and effort during the 2015–16 season, and advice from the Scallop Resource Assessment Group (ScallopRAG) and the BSCZSF Co-management Committee. The total number of survey points was set at the number considered likely to be achievable with the resources available. The number of random survey points allocated to each bed was determined from a combination of the size of each bed, and where available, the level of error obtained during the 2015 survey (optimal allocation). The number of random tows actually conducted was adjusted slightly during the survey to enable all beds to be sampled.

The estimated biomass of scallops at both Flinders Island beds was above 1500 t (2307.2 t and 2304.6 t). The estimated biomass at each of four of the King Island beds was above 1500 t (ranging 1885.0 t – 6557.2 t), while two of those beds (KI2 and KI5) had an estimated biomass above 3000 t. The three beds with a mean biomass less than 1500 t (KI3, KIM and KIE) were the smallest in area, and while KI3 had the lowest density of all beds, KIE had the highest density.

Biomass estimates were also made for each bed based on scallops greater than 85 mm width. The percentage of scallops less than 85 mm was highest at the two beds off Flinders Island. Nevertheless, all seven beds with an estimated total biomass greater than 1500 t also had an estimated biomass above 1500 t for scallops greater than 85 mm width. Similarly, KI2 and KI5 both had a mean biomass of scallops greater than 85 mm above 3000 t.

Meat weights were 77–95 meats to the kg at the Flinders Island beds compared to 39–56 meats per kg at the King Island beds. Size (width) composition during the 2016 survey was similar to the previous year at Flinders Island, while mean widths from the resurveyed King Island beds were slightly larger during the 2016 survey.

Catch composition varied greatly between beds, and also compared to the 2015 survey. In general, there was high proportions of old single shell at the two Flinders Island beds and KI1 and KI2, while the other beds were dominated by live Commercial Scallops. Compared to the 2015 survey, old single shell comprised a greater portion of the catch in 2016 at the two Flinders Island beds and KI1 and KI2, while the proportion of new single shell caught at KIE and KIM increased.

Survey results were presented to ScallopRAG on 22/6/2016 and the Scallop Management Advisory Committee (ScallopMAC) on 23/6/2016. The outcome was that the season was opened

under Tier 2 management arrangements, also incorporating two fisheries closures: one off Flinders Island (FI2); and one off King Island termed KI-New – a closure comprising parts of KI4, KI5 and all of KIE (which was closed the previous year). Scallop densities at these beds were estimated at 0.467, 0.479 and 0.885 individuals per m^2 respectively, assuming a dredge efficiency of 33%. These are higher densities than any of the other beds.

During ScallopRAG and ScallopMAC, industry members presented anecdotal information regarding an unsurveyed bed of scallops in high densities to the north of KI-New closure that were smaller than those in the KI-New closure, and in apparent "good" condition. There was concern that with the KI-New closure in place, this unsurveyed bed (referred to as the "Blue Dot" bed) would receive significant fishing pressure, potentially damaging a bed that could provide substantial future recruitment and harvestable stock. It was suggested that closure of the Blue Dot bed might be more productive for the fishery's reproductive capacity than closing KI-New. To protect the Blue Dot bed, a voluntary industry close was put in place until it could be surveyed.

The survey of the Blue Dot bed was carried out during August 2016, and results supported the anecdotal information provided by industry members. Estimated biomasses within the Blue Dot bed was 6332.1 t (95%CI 4752.2 t – 7911.9 t). Just under 90% of the scallop biomass was 85 mm or greater, resulting in a biomass of scallops greater than 85 mm of 5627.8 t (95%CI 4223.7 t – 7031.9 t). This is a greater biomass than that estimated for the KI-New area that was closed at the start of the 2016 season (4822 t total; 4758 t >85 mm). Scallops from Blue Dot bed were substantially smaller than those from the other King Island Beds, with a median width of 91 mm, only a small number of scallops greater than 105 m and meat weights averaging 81 meats per kg. Scallop densities were estimated at 166.1 kg / 1000m2 or 2.242 individuals per m2 assuming a dredge efficiency of 33%.

Based on the results of the subsequent survey of the Blue Dot bed, it would appear that this could be equally suitable if not a better replacement for the current KI-New closure with regard to both biomass, density, and scallop size.

Table of Contents

List of Tables

List of Figures

Acknowledgements

We would like to thank Stuart Richey and John Richey and the crew of the Del Richey II for all of their assistance and hard work in undertaking the 2016 survey. Jayson Semmens (IMAS), Sally Weekes and Clayton McCloud (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 2016 stratified random surveys.

Objectives

1. Estimate the scallop biomass and potential commercial catch rates in nine different areas of the BSCZSF.
   1.1. Estimate the scallop biomass and potential commercial catch rates at the Blue Dot bed (added after the opening of the season).
2. Measure the size frequency distribution of scallops in each area to calculate discard rates.
3. Report results to AFMA and ScallopRAG.

Methods

Survey Design

Survey methods follow those of Knuckey *et al.* (2015), which were based on those described in Harrington *et al.* (2008). A commercial scallop vessel was used to undertake a stratified random survey of scallop beds with an independent observer onboard to collect all of the necessary survey data. Three general survey areas were identified before the 2015 survey, two off King Island and one off Flinders Island (Knuckey et al., 2015). From those areas in 2015, three survey beds near King Island (Figure 1) were predefined based on industries knowledge, and one survey bed near Flinders Island (Figure 2) was defined based on results of exploratory surveys.

The 2016 survey was designed to include more beds than in 2015 to provide greater flexibility in management arrangements regarding closures, but again focussed on beds around Flinders Island (FI) and King Island (KI). Unlike in 2015, the boundaries of all survey beds were predefined. Selection of survey beds and their boundaries were based on: 1) results of the 2015 scallop survey; 2) commercial fishing catch and effort during the 2015–16 season; and 3) advice from ScallopRAG and the BSCZSF Co-management Committee. The initial total number of survey points was set based on that considered likely to be achievable with the resources available. For beds that were (at least) partially surveyed in 2015, the number of survey points was allocated using optimal allocation (Francis, 2006), considering the size of each bed and the level of error obtained during the 2015 survey (Knuckey *et al.,* 2015). The number of survey points for other beds were allocated based on size. Tows within each bed were randomly allocated using the QGIS Random Points Tool. An additional five survey points were allocated to each bed as "backup sites", to be used where "primary sites" were unfishable. Interruptions to survey trips due to unfavourable weather increased the amount of travelling time required to complete all of the beds, and consequently, the number of tows actually conducted was adjusted down during the survey to enable all beds to be sampled.

During 2016, surveys were conducted onboard the fishing vessel Dell Richey II. The initial beds were surveyed during May and June. To be considered a valid tow, the vessel must dredge within 100 m of the tow location provided (Appendix Figure 22). A Lotek LAT1400-64kb temperature-depth logger was attached to the dredge at the start of the first tow, and set to record an observation every six minutes. The temperature-depth logger was deployed for every tow except those undertaken at the Blue Dot bed.

An additional KI bed was added to the 2016 scallop surveys after the opening of the season as a potential replacement for the King Island closure. The area — referred to as the "Blue Dot" bed

(KIBD) during discussions — was defined by the skipper of the Dell Richey II (John Richey) based on exploratory tows (Figure 3). A total of 30 tows were randomly allocated to KIBD using the QGIS Random Points Tool. An additional 5 survey points were allocated KIBD as "backup sites", to be used where "primary sites" were unfishable. This survey was undertaken on the 23 August 2016.

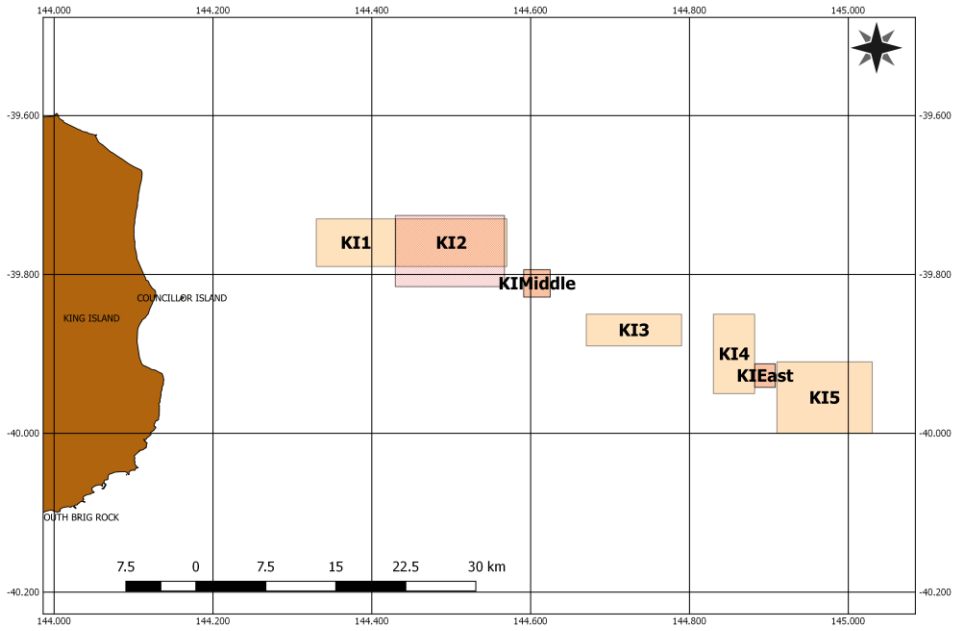

Figure 1. Location of the seven King Island scallop beds surveyed during 2016. Beds surveyed during 2015 are shaded red. Note that the areas of KIMiddle and KIEast surveyed in each year are identical, and the 2015 bed that overlaps with KI2 was titled KI Main Bed in Knuckey *et al*. (2015).

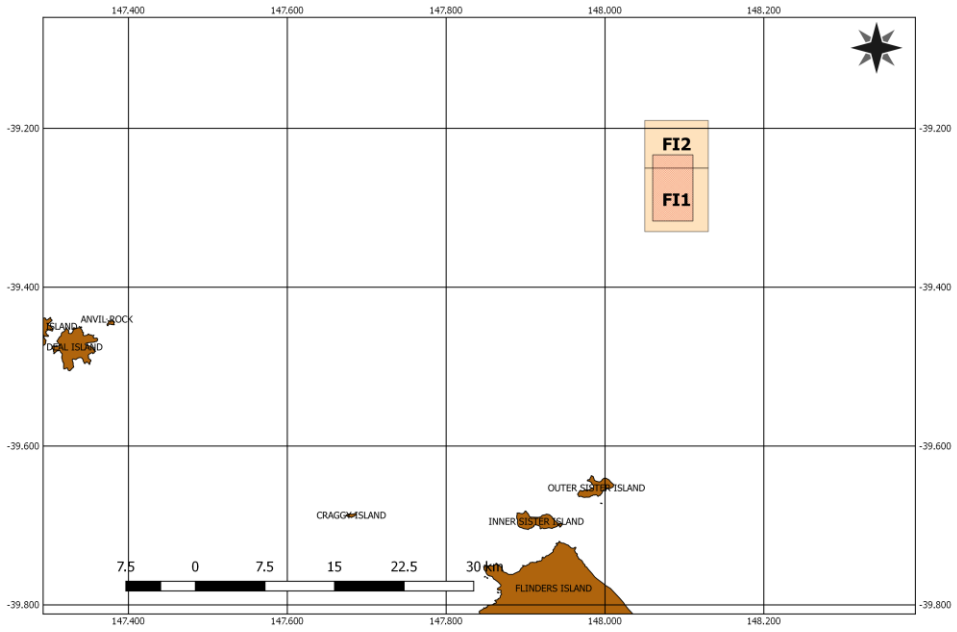

Figure 2. Location of the two Flinders Island (FI) scallop beds surveyed during 2016. The bed surveyed during 2015 is shaded red.

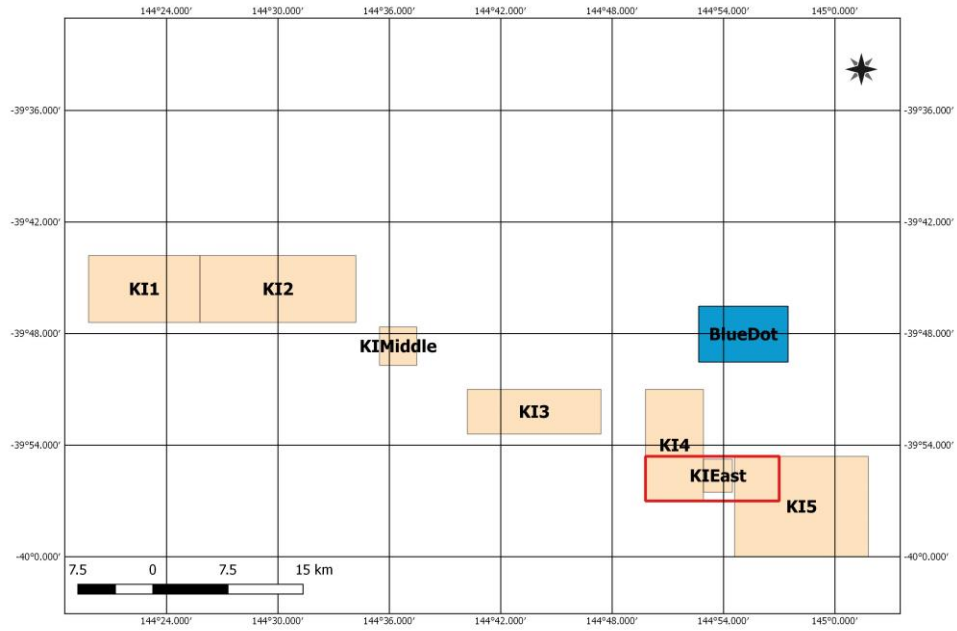

Figure 3. Location of the "Blue Dot" bed (KIBD) and initial 2016 fishery closure (red box termed KI-New).

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 width of those scallops using either an electronic measuring board. Either the first or last (or both) scallop from each shot measured usnig 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 8 and Table 9 based on Harrington *et al.,* (2010) (see Appendix). Adductor meat and gonad were removed from the shell and weighed together to calculate number of meats per kg.

Data analysis

All data processing and analysis was undertaken in R (R Core Team, 2014), 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 width of the dredge was measured at 4.1 m and in accordance with Semmens and Jones (2014), a dredge efficiency of 33% was assumed (Table 1).

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:

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

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

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

There was no difference in the weight-width relationship from data collected during the 2015 survey, and so data were pooled for use in catch-weighted size frequencies to calculate the discard rate at 85 mm. Because the 2016 survey was prolonged due to bad weather, the width-weight relationship was not available for analyses presented to the ScallopRAG and ScallopMAC. The width–weight relationship from the 2015 survey was used for these calculations, and that is what is presented in this report. While there were a statistically significant difference in slopes and intercepts of the width–weight relationship between years ($p<0.01$ and $p<0.05$ respectively), the distribution of weight at width generally overlapped (Figure 4). The effect of this on estimates of discard rates (and consequently estimates of biomass >85 mm) presented in this report and to the ScallopRAG and ScallopMAC would likely be very small, and would be to overestimate the proportion of undersized scallops, and overestimate discard rates. Estimates of estimates of biomass >85 mm can therefore be considered conservative. The final width–weight relationships for 2016 are presented in the results section.

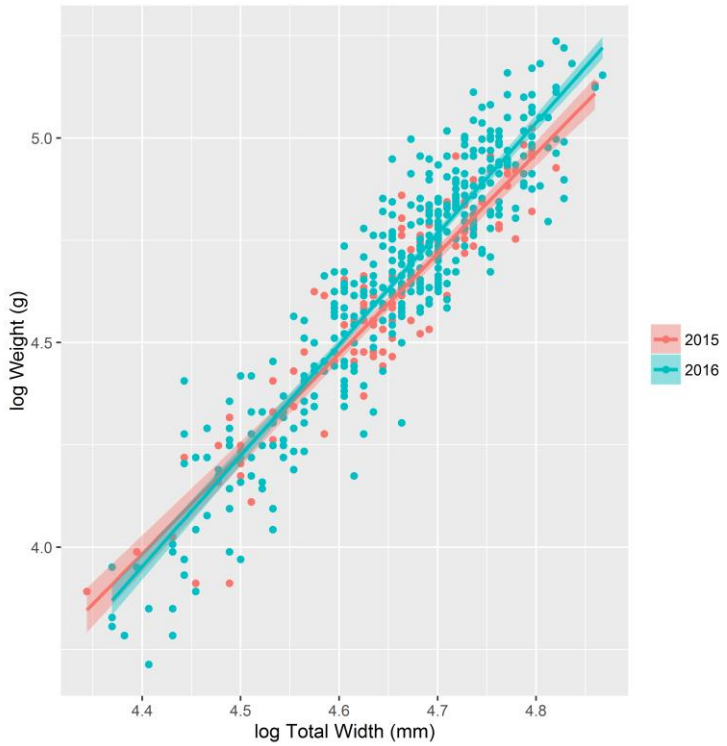

Figure 4. Comparison of width-weight relationship between survey years.

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, 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 49 valid, random, non-targeted tows were undertaken during 24–27 May 2016 inside the two Flinders Island beds. The total area of the Flinders Inland beds — FI1 and FI2 — were 61.30 km^2 and 46.02 km^2 respectively (Figure 2, Table 2). Depth of survey tows ranged 45–55 m and bottom temperatures ranged 14.8–15.6°C. Mean distances towed were 567 m (range 434 m–647 m) at FI1 and 557 m (498 m–595 m) at FI2.

Coordinates that defined the seven King Island beds (Figure 1) are shown in Table 2. The total areas of the beds labelled KI1, KI2, KI3, KI4, KI5, KIE and KIM are 57.09 km^2, 79.92 km^2, 45.60 km^2, 49.38 km^2, 102.47 km^2, 7.32 km^2 and 10.99 km^2 respectively. A total of 151 valid, random, non-targeted tows were conducted over three trips undertaken from 29–31 May, 1–3 June and 14–16 June. Depths fished ranged 31–54 m and bottom temperatures ranged 13.0–15.3°C. Mean distances towed at beds KI1, KI2, KI3, KI4, KI5, KIE and KIM were 569 m (500 m–691 m), 572 m (510 m–682 m), 570 m (554 m–601 m), 570 m (422 m–670 m), 573 m (530 m–648 m), 571 m (548 m–605 m), 570 m (541 m–639 m).

A total of 30 valid, random, non-targeted tows were undertaken on 23 August 2016 inside the bed off King Island referred to as the Blue Dot bed (Figure 3). Coordinates that defined the Blue Dot bed are shown in Table 2. It has a total area of 38.13 km^2 (Table 2). Depth of survey tows ranged 52–53 m and the surface temperature was 13.2°C. Mean distances towed were 576 m (range 547 m–656 m).

Biomass, size and potential commercial catch rates

Estimated mean biomasses within FI1 and FI2 were 2307.2 t (95%CI 1388.0 t – 3226.3 t) and 2304.6 t (95%CI 1097.0 t – 3512.2 t) (Table 3Table 3). Using discard rate of 15.9% (84.1% > 85 mm) and 19.3% (80.7% > 85 mm), mean biomasses for scallops > 85 mm were 1940.2 t and 1859.1 t respectively (Table 4).

At FI1, scallop density was generally higher in the north and north-western areas of the bed (mostly about 60–120 kg / 1000m^2), while in the south of the bed there were many low density tows including three tows with zero scallops (Figure 5). The high density in the north of bed FI1 continued into the southern and south-western areas of FI2. Densities were generally low (<15 kg / 1000m^2) in the north and north-eastern area of that bed apart from one very dense

tow of 180 kg / 1000m^2 (Figure 6). Estimated densities in numbers were 0.409 and 0.670 individuals per m^2 (Table 3).

Near King Island, estimated mean biomasses ranged from 620.7 t (95%CI 33.9 t – 3512.2 t) at the second smallest bed (KI3), to 6557.2 t (95%CI 4539.1 t – 8575.3 t) in the largest bed (KI5) (Table 2,Table 3). Mean biomass estimates for four of the beds (KI1, KI2, KI4 and KI5) near King Island were greater than 1500 t, while the lower 95%CIs were greater than 1500 t for three beds (KI2, KI4 and KI5). The percentage of scallops <85mm was less than 8.2% for KI3 and 4.8% for KI4, and 0–0.6% for the other beds near King Island (Table 4 and Figure 16). Consequently, mean biomasses of scallops > 85 mm were either the same, or only slightly lower than total biomass estimates.

Densities at KI1 varied throughout the bed, with some of the highest and lowest densities in tows to the north-west (Figure 7). The highest density in KI1 (164 kg / 1000m^2) was found near the centre of the bed (Figure 7). Medium to high densities were found throughout KI2, except for the north-eastern corner in which there were five tows with zero, and a number of tows with catches less than 30 kg / 1000m^2 (Figure 8). Scallop densities were highly variable at KI3, and no tows in the western half of the bed had densities greater than 6.7 kg / 1000m^2 (Figure 9). The two tows with highest densities (45 kg / 1000m^2 and 75 kg / 1000m2) in that bed were the two most eastern tows. This variability and the relatively small number of tows undertaken at KI3 resulted in the very large confidence intervals around the estimated mean biomass (Table 3). Densities were more consistent at KI4, with only two tows less than 18 kg / 1000m^2, and more than half above 30 kg / 1000m^2 (Figure 10). Random survey tows fell largely in the centre and south-eastern quarter of the bed where densities were highest. Scallop densities in the south-western corner of KI5 were generally lower, increasing to the north and north-west (Figure 11). More than half of tows from KI5 had densities of greater than 60 kg / 1000m^2. Mean density was highest at KIE (126.9 kg / 1000m^2) and variability between tows the lowest (densities ranged 103.0–148.5 kg / 1000m^2) resulting in a tight 95%CIs despite only 12 survey tows (Figure 12, Table 3). At KIM, scallop densities were consistently 12–18 kg / 1000m^2 across the south and south-eastern area of the bed, and then 51–140 kg / 1000m2 in the remaining area (Figure 13). Estimated densities in numbers ranged from 0.118 individuals per m^2 at KI3 to 0.885 individuals per m^2 at KIE (Table 3).

Estimated biomasses within the Blue Dot bed was 6332 t (95%CI 4752.2 t – 7911.9 t) (Table 3). Using discard rate of 11.1% (88.9% > 85 mm), mean biomasses for scallops > 85 mm was 5627.8 t (Table 4). Mean density of scallops at the Blue Dot bed (166.1 kg / 1000m2) was much higher than densities from other King Island beds which ranged 13.6 – 126.9 kg / 1000m^2. (Table 3). Densities were greatest through a line running approximately south-east to north-west (Figure 14). There were little to no scallops in shots conducted in the south-west, and moderate densities in the north-east and very north western corners. While all tows included in analyses were randomly allocated and could not be considered to represent commercial fishing activity, average potential catch rate based on those tows was 657.7 kg / hr (Table 3). The bed with next highest potential commercial catch rate was 502.4 kg / hr at KIE. Estimated density in numbers was 2.242 individuals per m^2 (Table 3).

Biologicals

With the exception of KI3, the mean widths of scallops from King Island beds were generally much larger than those from the Flinders Island beds (Table 5). The distribution of widths from scallops at the Flinders Island beds were broadly spread from 80–100 mm with long tails extending below 60 mm (Figure 16). Width distributions of scallops from KI3 and KI4 were different to all other beds, being bimodal with peaks at 85–90 mm and 108–112 mm (Figure 16). Apart from being slightly larger at KI1, width distributions of scallops from the other King Islands beds were similar to each other with the majority of scallops 100–120 mm (Figure 16).

The size distribution of scallops at the Blue Dot bed was substantially different to that of the other King Island beds (Figure 16). Some very small (<55 mm) scallops were measured from that bed, and about 11% of the biomass was less than 85 mm (Table 5). Median and mean widths were much smaller than those from most other King Island beds (Table 5) the exception being KI3. However the size frequency distribution from KI3 is bi-modal, with the larger mode comprising scallops greater than 100 mm (Figure 16). In comparison, scallops from the Blue Dot bed were largely 85 – 100 mm, and there were only small numbers of scallops greater than 105 m.

Overall, both the intercept ($p<0.001$) and interaction terms ($p<0.05$) of the width-weight relationships differed between beds (not including the Blue Dot bed) (Figure 15). Parameter estimates for the width-weight relationship are very similar for the two Flinders Island beds (Table 6), and there was no difference in the slope or intercept between them ($p=0.93$; $p=0.07$), while within the King Island beds, only the intercepts were different ($p=0.15$; $p<0.0001$).

Reflecting the smaller size of scallops measures there, scallop meats from FI1 and IF2 averaged 77 and 95 meats per kg, compared with 39–56 meats per kg from the King Island beds (Table 5, Figure 17). Of the King Island beds, meat weights were by far the smallest at KI3, and largest at KI1. Average meat weights from the Blue Dot bed (81 meats per kg) were similar to those from Flinders Island.

In general, gonads from Flinders Island were far less developed than those from the King Island beds (Figure 18). About 35% and 65% of scallops at FI1 and FI2 were at 4 or less, while less than 25% of scallops from the King Island beds were at 4 or less. KI4 and KI5 has the highest proportions of stage 5.2 gonads. Not surprisingly given the later sampling time, the Blue Dot be had a higher proportion of more mature gonads than the other beds.

Bycatch

A total of 66 different bycatch species / groups were identified during the main surveys (Table 7). Catch composition varied greatly between beds. At the two Flinders Island beds about half of the total catch was old single shell, 8% was new single shell, and live Commercial Scallops comprised 12% and 20% of the catch at FI1 and FI2 respectively (Figure 19). The catch at KI1 and KI2 was dominated by mollusc shell and 18–21% of the catch was live Commercial Scallops at each bed. Old single shell made up a larger percentage of the catch at KI1 and KI2 than at the other King Island beds, and they were the only beds at which significant quantities of spider crabs were caught. 25% of the total catch at KI3 was Eleven Armed, and 24% was live Commercial Scallop. Catches at the 5 other beds comprised 67–84% live 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 (>60%) than other beds, compared to about 25–40% at KI1, KI2 and KI3less than 10% at the other beds (Figure 21). Very few clappers were caught and the percentage of new single shell was highest at KIM.

A total of 34 different bycatch species / groups were identified during the Blue Dot survey (Table 7). The catch was dominated by live Commercial Scallop (37%) and mollusc shell (30%) (Table 7, Figure 20). Considering only the four different scallop "groups" (Commercial Scallops, old single, new single, and clappers), the Blue Dot bed had a higher proportion of live Commercial Scallop than KI 1 and KI 2, but less than the other five King Island beds (Figure 21). Proportion of new singles was similar to that of other King Island beds apart from KI E and KI M which had the highest proportions of new singles, but no old singles.

Table 1. Inputs used in biomass calculations for Flinders Island Bed and King Island Beds.

Inputs	Values
Dredge width	4.1 m
Dredge efficiency	33%

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

Boundary	Latitude		Longitude		Total
	Northern	Southern	Western	Eastern	Area (km^2)
Flinders Island Bed 1	-39.25	-39.33	148.05	148.13	61.30
Flinders Island Bed 2	-39.19	-39.25	148.05	148.13	46.02
King Island Bed 1	-39.73	-39.79	144.33	144.43	57.09
King Island Bed 2	-39.73	-39.79	144.43	144.57	79.92
King Island Bed 3	-39.85	-39.89	144.67	144.79	45.60
King Island Bed 4	-39.85	-39.95	144.83	144.882	49.38
King Island Bed 5	-39.91	-40	144.91	145.03	102.47
King Island East Bed	-39.9125	-39.9422	144.882	144.908	7.32
King Island Middle Bed	-39.794	-39.8285	144.5912	144.6247	10.99
King Island Blue Dot	-39.77545	-39.8255	144.8778	144.958	38.13

°

Table 3. 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.

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)
FI1	28	37.6	38.7	1388.0	2307.2	3226.3	149.1	0.409
FI2	21	50.1	57.6	1097.0	2304.6	3512.2	198.3	0.670
KI1	30	33.0	41.4	1002.4	1885.0	2767.6	130.8	0.218
KI2	31	39.9	38.6	2056.5	3189.3	4322.2	158.0	0.364
KI3	14	13.6	22.3	33.9	620.7	1207.5	53.9	0.118
KI4	19	58.9	42.6	1894.7	2908.7	3922.7	233.3	0.467
KI5	30	64.0	52.7	4539.1	6557.2	8575.3	253.4	0.479
KIE	12	126.9	13.3	866.9	928.8	990.7	502.4	0.885
KIM	15	54.7	47.0	314.9	600.7	886.5	216.5	0.391
KIBD	30	166.1	110.1	4752.2	6332.1	7911.9	657.7	2.242

Table 4. Percent weight of scallops greater than 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)
FI1	84.1	1167.2	1940.2	2713.1
FI2	80.7	884.9	1859.1	2833.2
KI1	99.7	999.4	1879.4	2759.3
KI2	99.4	2044.7	3171.1	4297.5
KI3	91.8	31.1	570.0	1108.9
KI4	95.2	1803.8	2769.1	3734.4
KI5	99.8	4529.9	6543.9	8557.9
KIE	100.0	866.9	928.8	990.7
KIM	100.0	314.9	600.7	886.5
KIBD	88.9	4223.7	5627.8	7031.9

Table 5. Number of width 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 from each bed.

		Width (mm)			85 mm		Meats / kg
Bed	N	Median	Mean	SE	%<	%>	Mean
FI1	693	92	91.7	0.32	15.9	84.1	77
FI2	725	90	89.7	0.29	19.3	80.7	95
KI1	697	113	111.5	0.36	0.3	99.7	39
KI2	902	109	108.7	0.27	0.6	99.4	46
KI3	343	91	95.5	0.67	8.2	91.8	56
KI4	612	101	100.1	0.45	4.8	95.2	46
KI5	789	105	104.6	0.28	0.2	99.8	45
KIE	373	110	109.6	0.36	0.0	100.0	45
KIM	658	108	108.7	0.24	0.0	100.0	51
KIBD	1383	91	90.5	0.19	11.1	88.9	81

Table 6. Number of scallops retained for biological sampling, and parameter estimates for length weight relationships.

Bed	N	a	b	Adjusted R^2
FI1	60	-7.1228	2.5123	0.80
FI2	40	-7.0514	2.4872	0.74
KI1	60	-4.2265	1.9314	0.56
KI2	60	-4.5213	1.9805	0.53
KI3	20	-6.8159	2.4751	0.96
KI4	40	-4.2525	1.9201	0.78
KI5	60	-3.7436	1.8119	0.60
KIE	20	-5.8209	2.2556	0.61
KIM	30	-3.6045	1.7738	0.52
KIBD	49	-6.0507	2.2819	0.74

Table 7. 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	KI 1	KI 2	KI 3	KI 4	KI 5	KI E	KI M	KI BD
Commercial Scallop	816	791	682.3	946	148.1	853	1487.4	1175	635	3836.6
Clappers	28	30.7	1	0.5	0.1	2	0	4.3	8	2
New Single	535	310.4	94.9	82.6	7.8	34.9	93.6	95	149	236.5
Old Single	3670	1865	331.7	613.1	17.2	51.3	163	0	0	950
Algae - Ecklonia			1	1.5						
Algae - Phylospora			1							3
Ascidian (u)	147	0	225.8	114.1	4.6	35	161	61	2.5	230.7
Australian Burrfish			0.1	0.4						
Banded Stingaree	5.3	0	0.6	4	0.1		0.1	1.5		4
Barber Perch	0.1	0								
Basket Star (u)	0	0.1								
Bassina spp.										0.1
Blue Mussel			0.1							
Bug (u)	2	0.2		0.1		0.3	0.1			1
Butterfly Gurnard			0					0.2	0.2	
Cephaloscyllium (u)									2	
Cocky Gurnard			0.1	0.2		0.1	0.4	0.1		3.1
Common Stargazer	0	2		5		1	2			2
Common Stinkfish			0.2	0.1		0.2				
Congridae (u)							0.1			
Coral (u)	5	0.8								2
Cowrie Shell	1	0								0.2
Crassatelloidea (u)	3.7	4.1	0.3	0.7		0.1		0.2		
Decapod (u)	0	0.1	0	0.1			0.1	0.1		0.1
Doughboy Scallop	110	239	69.1	0.1		0.2	87.3	1		1251.5
Doughboy Scallop shell			29.6	484	1.8	0.1	9.3			
Draughtboard Shark	2	0		1					1	
Echinoderm (u)										0.1
Eleven Armed Seastar			1	5	49				70	1
False Bailer Shell			1	0.2			0.5		0.1	1
Gastropod (u)										1
Gould's Squid	1	0		0.5						
Greenback Stingaree			0					0.5		
Hermit Crab	29.7	40	0.4	2.3	0.2	4.1	1.7	6.4	0.7	59.7
Inshore Ocean Perch	0.2	0								
Leptosynapta dolabrifera										6.5
Limopsoidea (u)	23.3	11								
Maori Octopus	2	0	1.5							
Mollusc (u)	1.4	0.1	1.5	7.4	0.3	0.6	2.8	4.2	3.4	99.8
Mollusc Shell	39	34.5	1555	1091	60.6	7.7	3.9	13.5	8.2	2408
Octopus berrima										8
Ostreidae (u)			0.2	1.5						
Pale Octopus	4.1	6.3	0.4	0.5		1.2	1.4	0.2		7
Peacock Skate			0.4	2.1						
Pencil Urchin			0					0.1		
Pleuronectidae (u)	0	0.1								
Polychaete (u)			0					0.2		
Polymastia spp.										7
Port Jackson Shark							1			2
Ranellidae (u)	33.9	13.8	6.1	6	0.8	10.1	20.7	6	0.8	
Razor Clam	14	0.3	0.9	1.2	0.1		1.1	0.2	0.2	
Sandyback Stingaree				1						
Screwshell (u)	550	197.5	1.1	0.3		0.1	0.2	1.4		
Sea Pen (u)	2.1	1.2		0.9			0.2		2.1	
Sea Urchin (u)	5	6.4				0.1	10.4			
Seastar (u)	0	0.3	0.1	0.1		0.1	0.5	0.3	0.1	
Sediment	665	285	215	112			70			
Shaw's Cowfish									0.1	
Silverbelly	0.1	0		0.1						1
Solidae (u)			0.1		0.1		0.1			
Southern Blue-ringed Octopus	0.1	0.1								
Southern Sand Flathead	1	0	1.7	1.5			0.7	0.5	0.5	
Sparsely-spotted Stingaree										4.3
Spider Crab (u)	7.1	0.1	471	1030	4.2	23.7	21.6	10	2.5	259
Sponge (u)	310	99.2	19.2	18.5	1.2	43.7	74	14	4	435
Substrate Rock	6	0								
Swimmer Crab (u)			0.1							
Tasmanian Numbfish			0.5	1.4	1.2		0.5		0.5	0.2
Thornback Skate										0.2
Tiger Flathead	1	0								
Veneroidea (u)	0.1	0								
Wavy Volute	3	0.6	0.5	0.4	0.1	1.8	2.1	0.7		
White-spotted Skate							0.1		1	

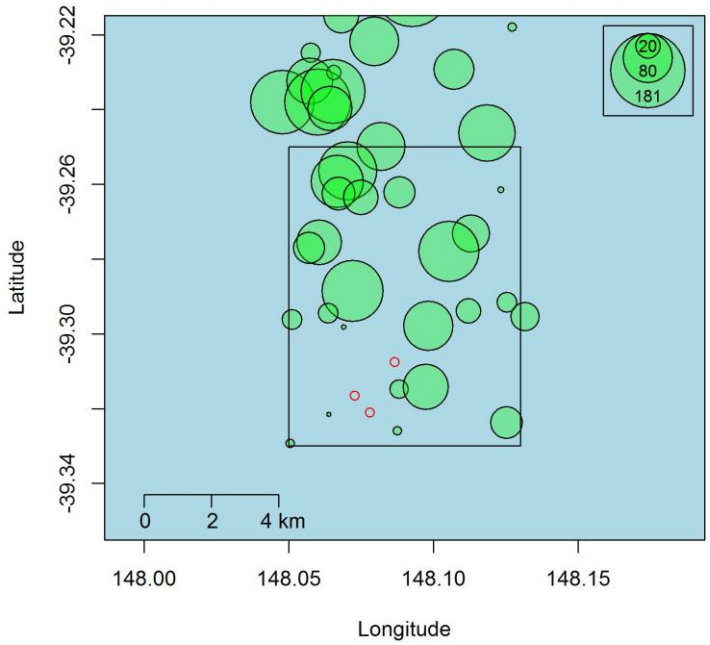

Figure 5. Scallop density (kg / 1000 m^2) within the defined stratum of the FI1 bed near Flinders Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

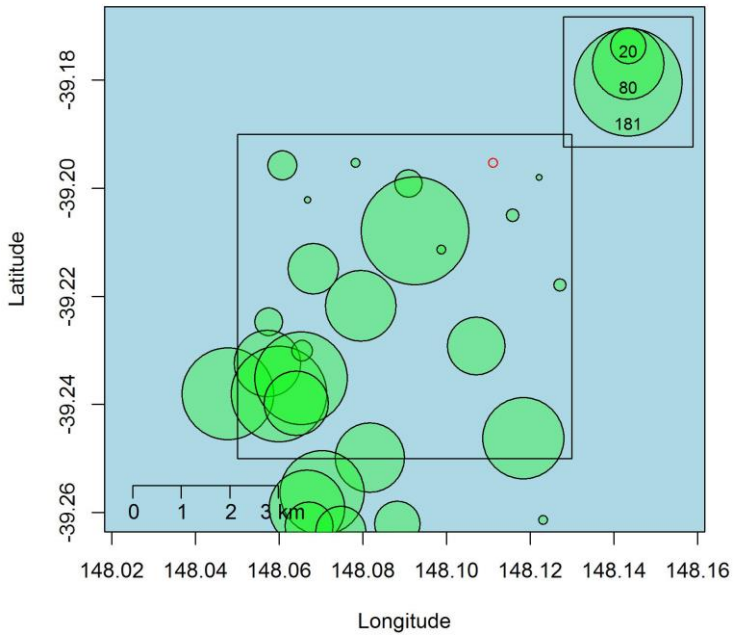

Figure 6. Scallop density (kg / 1000 m^2) within the defined stratum of the FI2 bed near Flinders Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

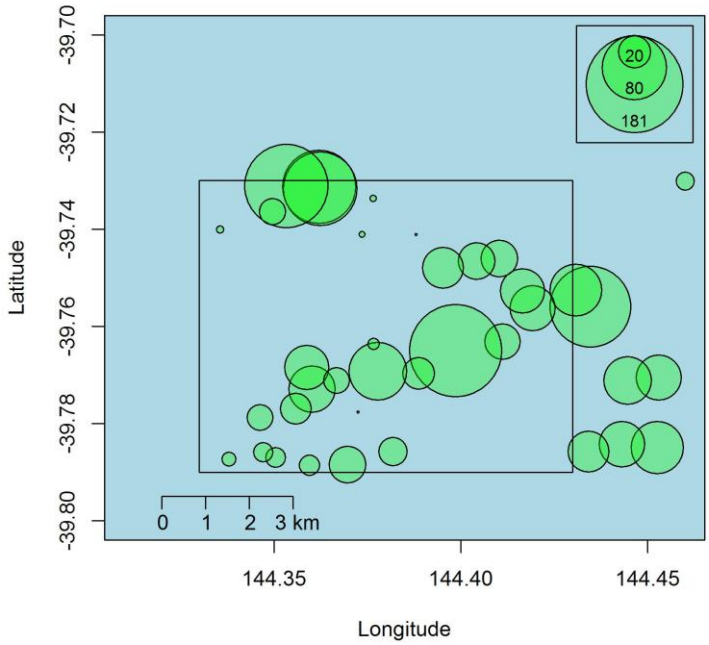

Figure 7. Scallop density (kg / 1000 m^2) within the defined stratum of the KI1 bed near King Island. The top right scale bubbles reflect the scallop density of each tow.

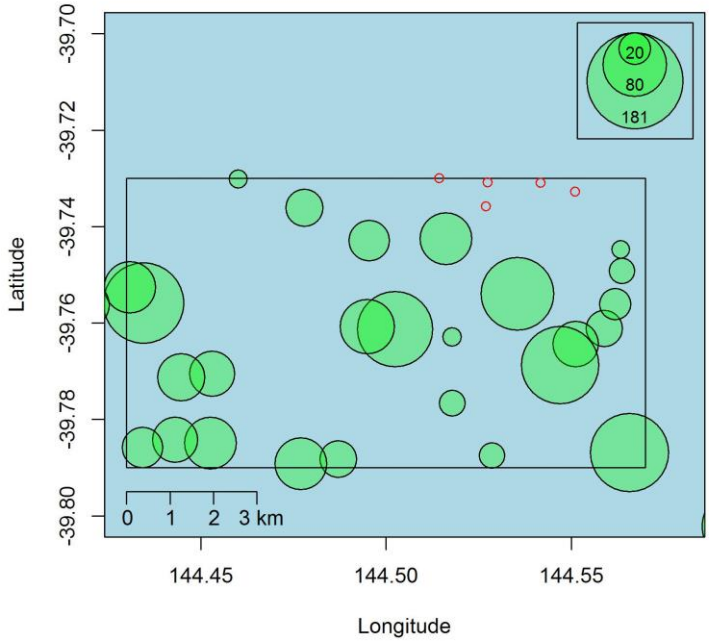

Figure 8. Scallop density (kg / 1000 m^2) within the defined stratum of the KI2 bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

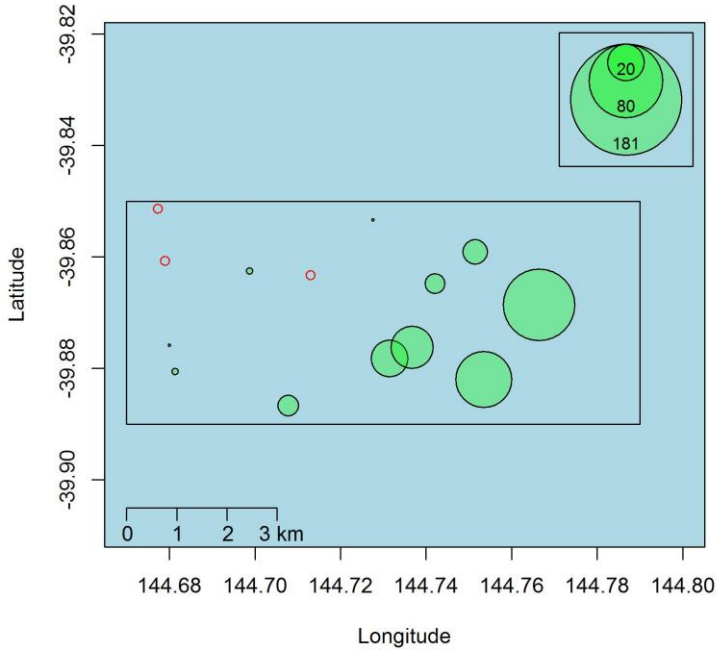

Figure 9. Scallop density (kg / 1000 m^2) within the defined stratum of the KI3 bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. Red circles denote zero catches.

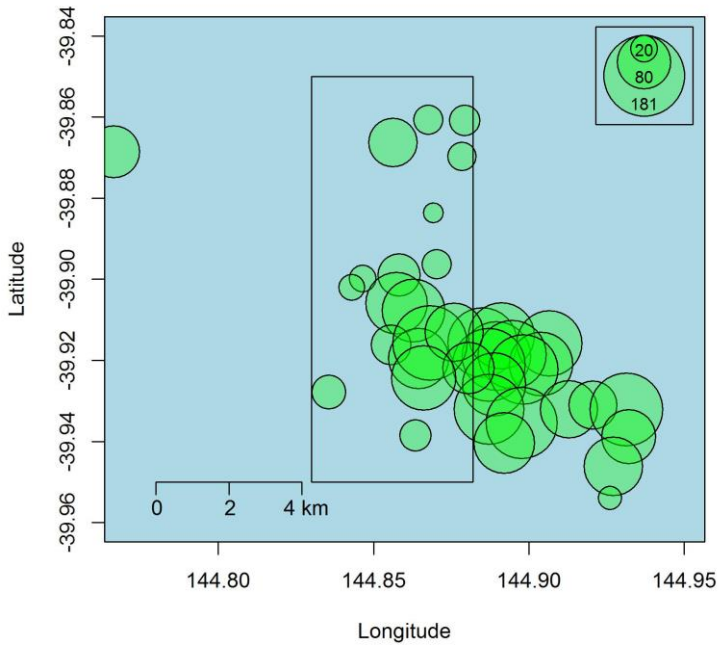

Figure 10. Scallop density (kg / 1000 m^2) within the defined stratum of the KI4 bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%.

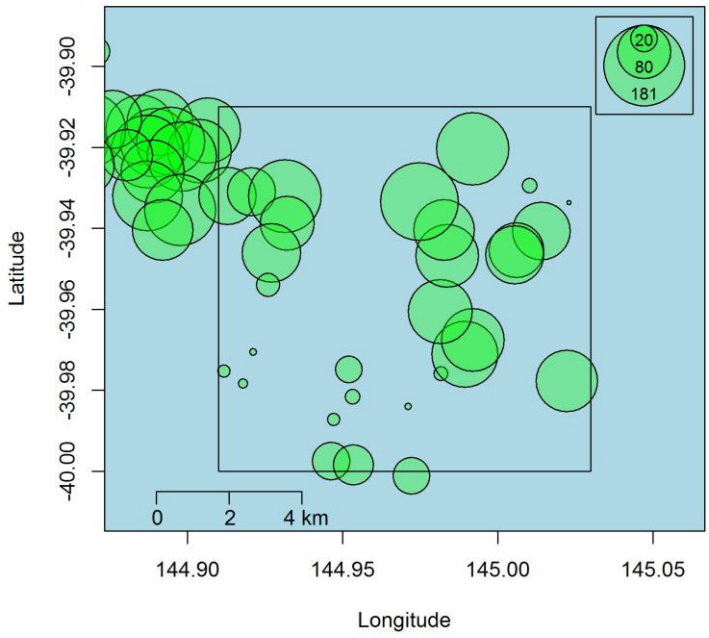

Figure 11. Scallop density (kg / 1000 m^2) within the defined stratum of the KI5 bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%.

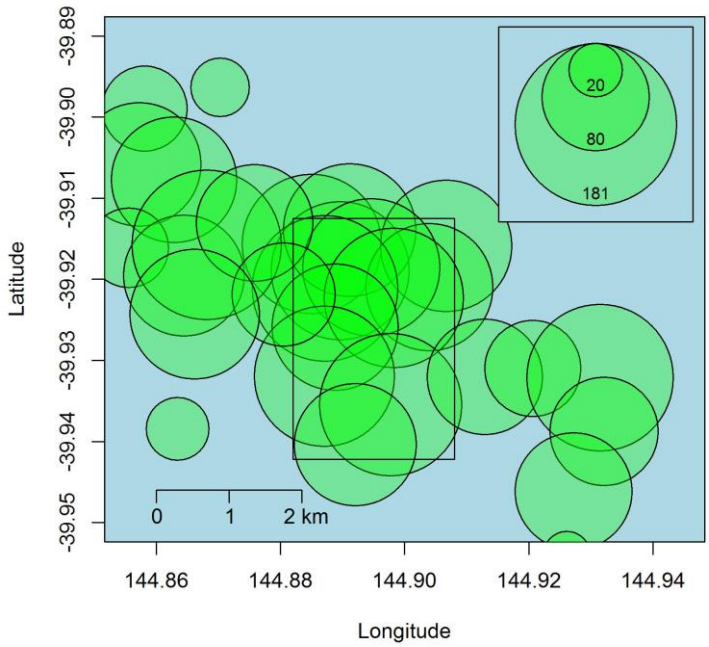

Figure 12. Scallop density (kg / 1000 m^2) within the defined stratum of the KIE bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%.

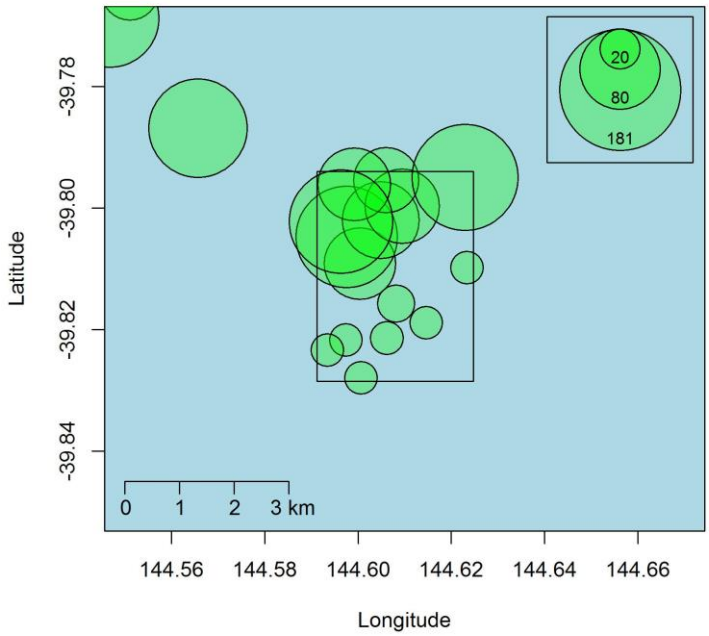

Figure 13. Scallop density (kg / 1000 m^2) within the defined stratum of the KIM bed near King Island. The top right scale bubbles reflect the scallop density of each tow.

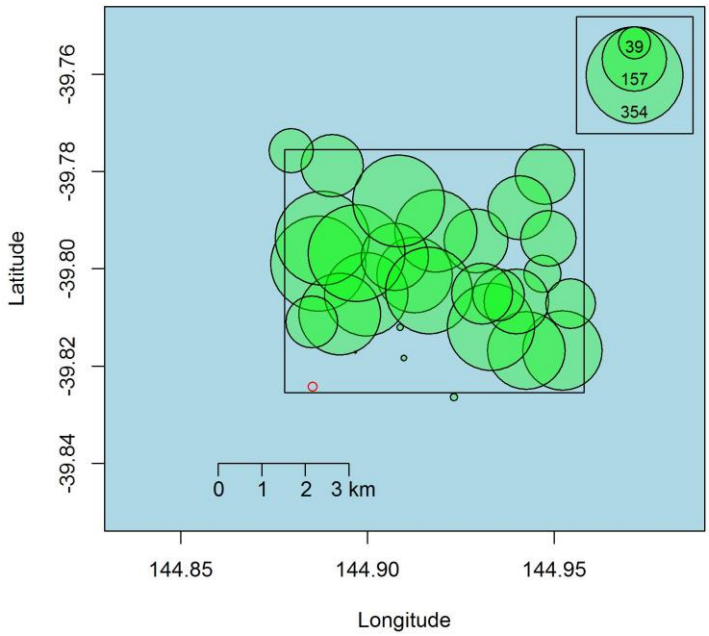

Figure 14. Scallop density (kg / 1000 m^2) within the defined stratum of the KIBD bed near King Island. The top right scale bubbles reflect the estimated scallop density of each tow assuming a dredge efficiency of 33%. The red circle represents a zero catch. Note that scale is larger than in previous figures.

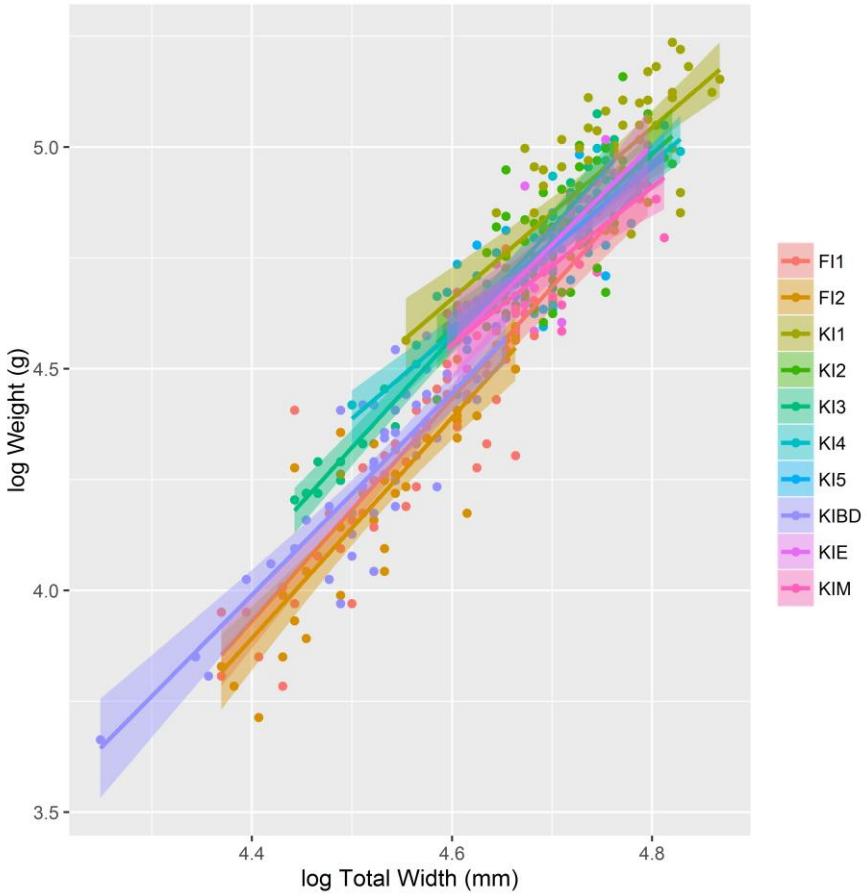

Figure 15. Log transformed width and weight and line of best fit of scallops collected from Flinders Island and King Island beds.

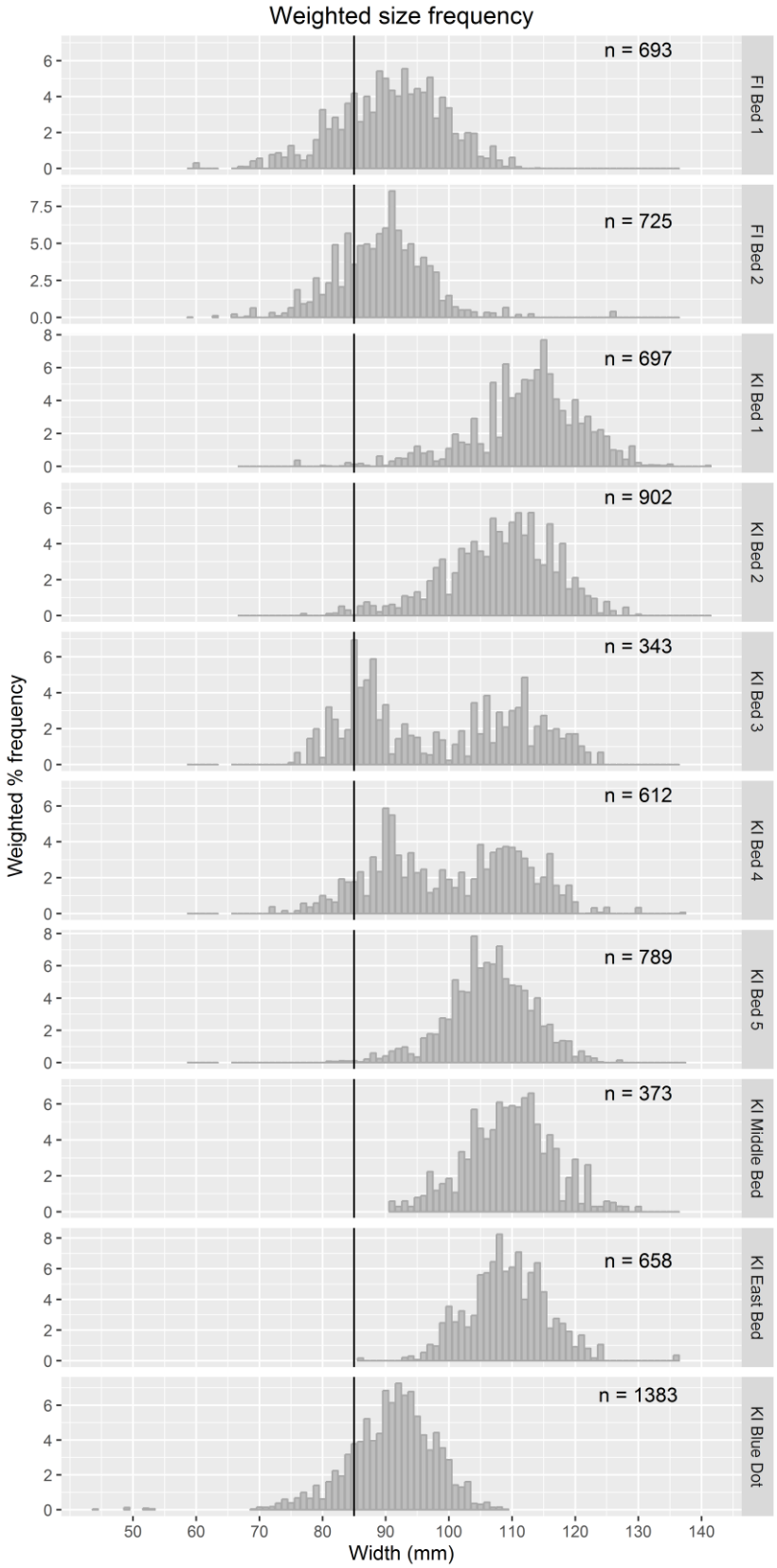

Figure 16. Catch weighted size frequency from shots included in biomass estimates from each bed. Vertical line is at 85 mm.

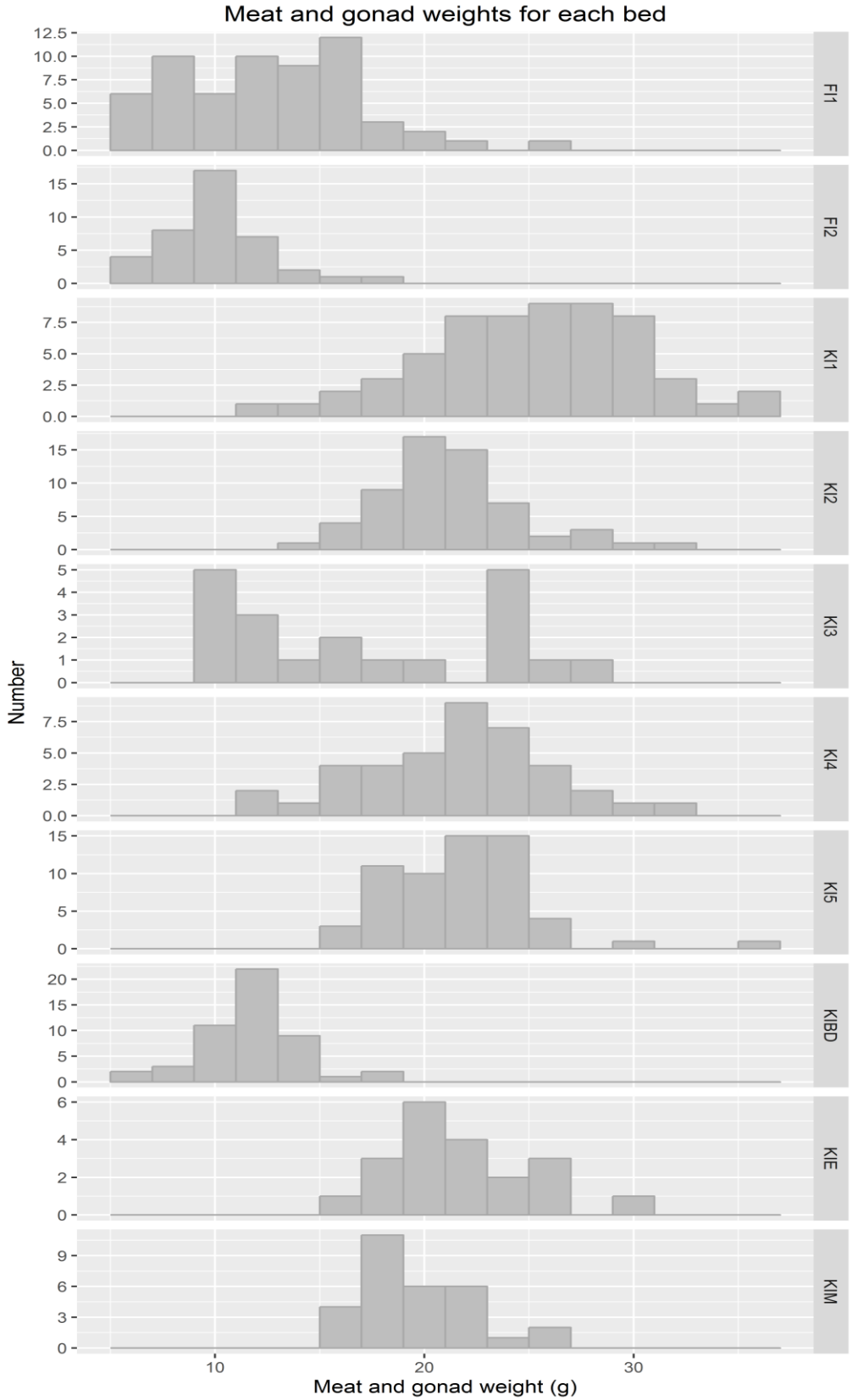

Figure 17. Frequency of combined meat and gonad weights measured from each bed binned into 2 g weight categories.

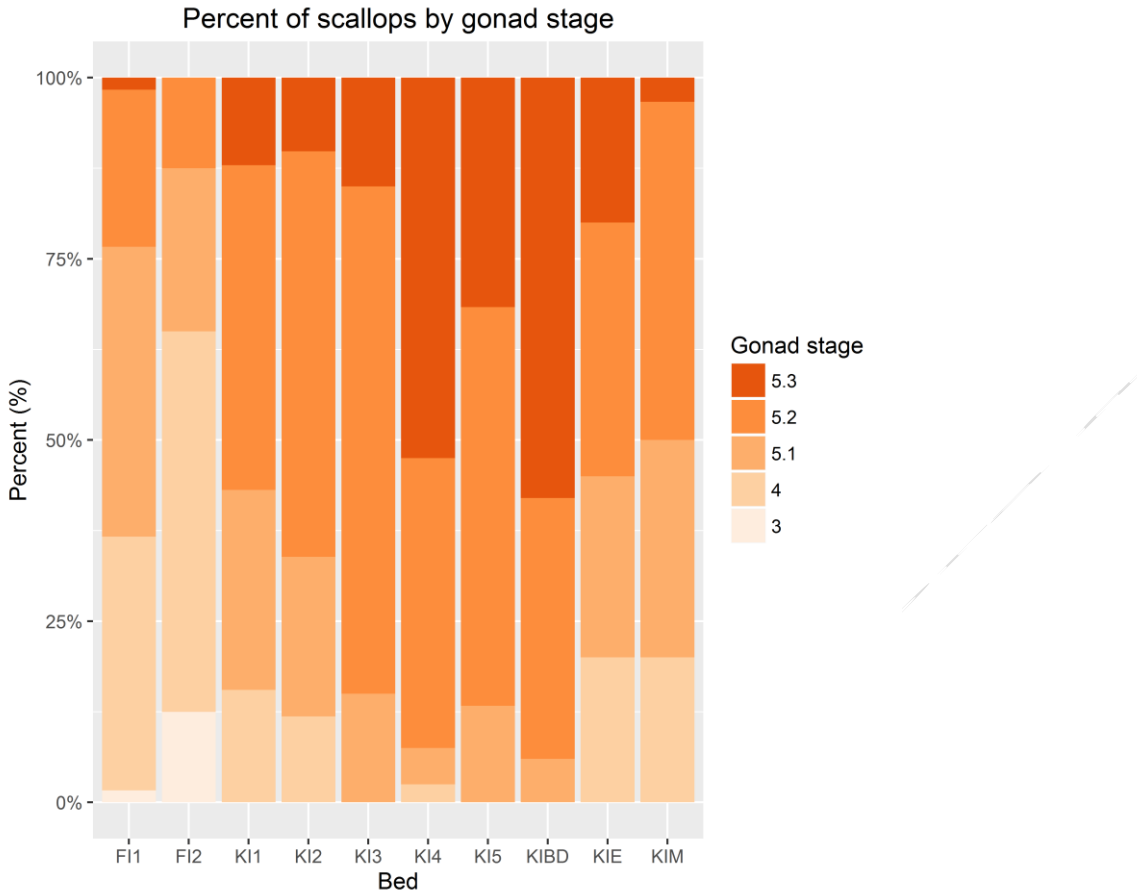

Figure 18. Percent of scallops at each stage from each bed based on macroscopic staging criteria.

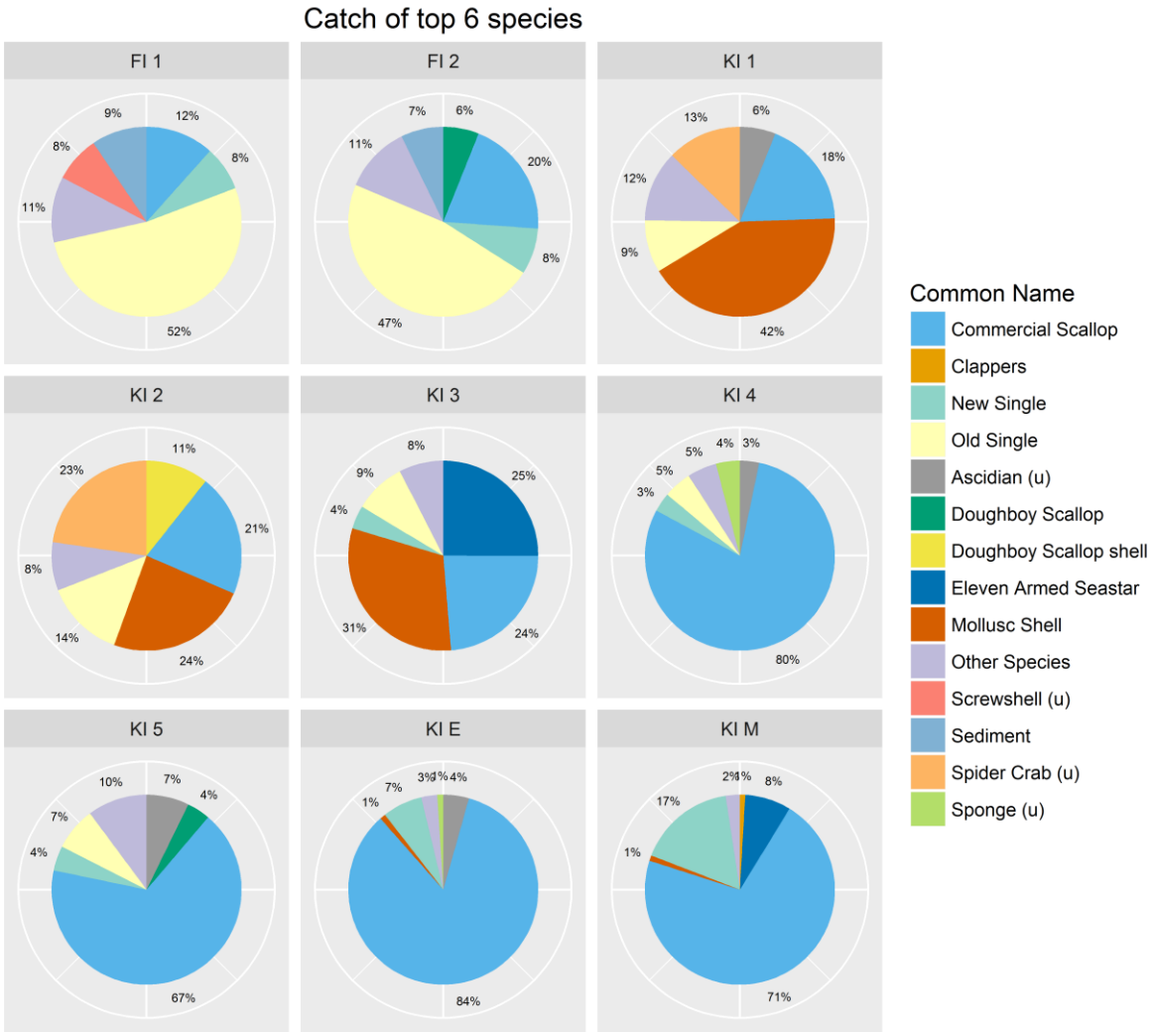

Figure 19. Percent catch composition in each bed sampled by weight from all beds other than the Blue Dot bed.

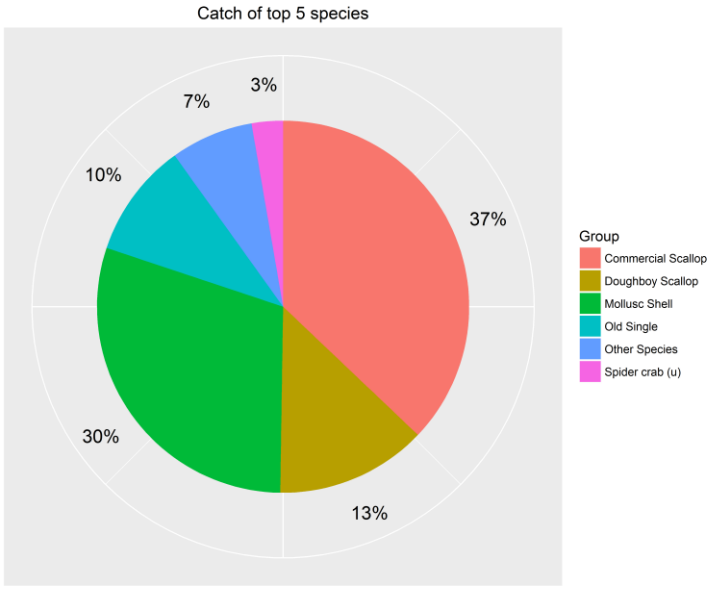

Figure 20. Percent catch composition in each bed sampled by weight from the Blue Dot bed

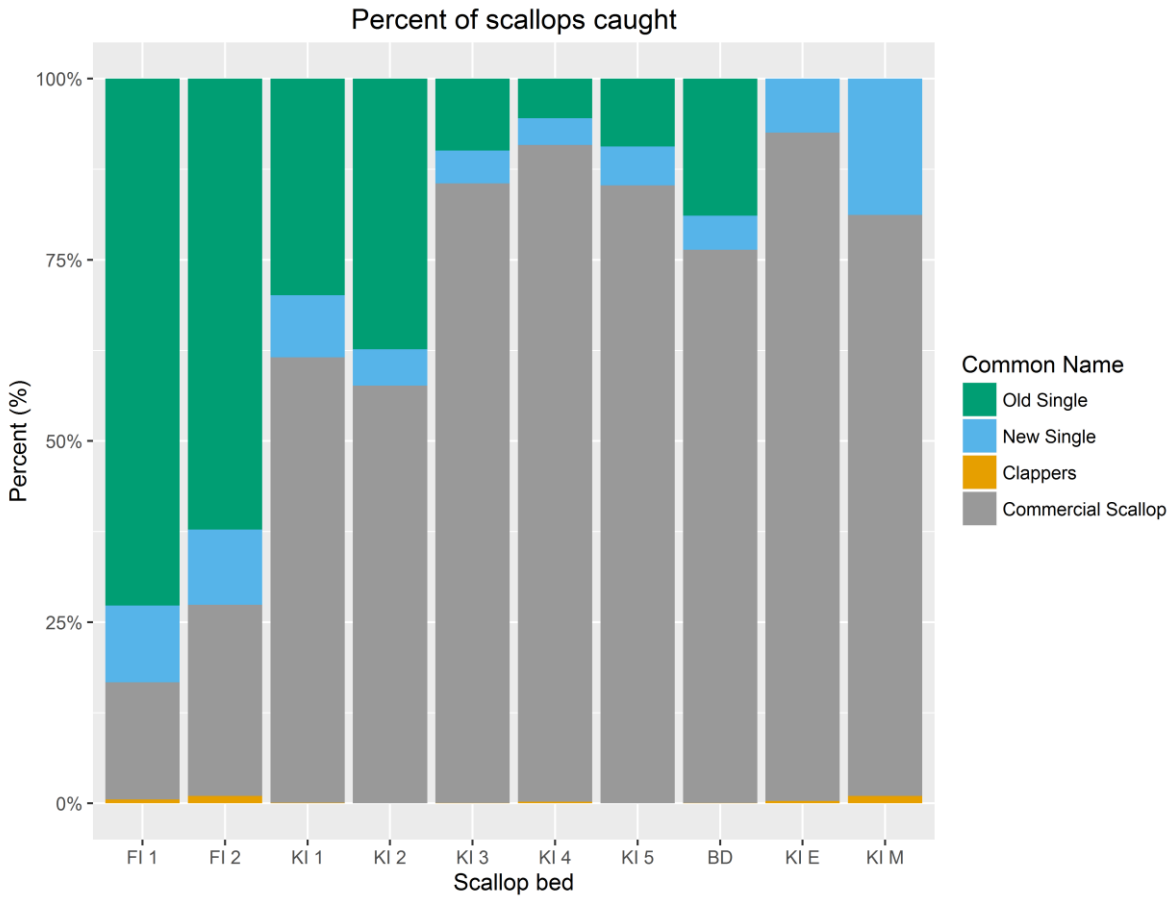

Figure 21. Percent composition of clappers, live scallop, new single and old single shell from each Bed.

Discussion

Main survey

Random stratified surveys were successfully undertaken on two scallop beds off Flinders Island and seven beds off King Island (Figure 1, Figure 2). Beds were selected based on a combination of catch and effort data from the 2015/16 BSCZSF season, the 2015 scallop survey and advice from ScallopRAG and the BSCZSF Co-management Committee. In total, 200 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 dredge.

Estimated biomass at both Flinders Island beds were above 1500 t (2307.2 t and 2304.6 t), while the estimated biomass of four of the King Island beds were above 1500 t (ranging 1885.0 t – 6557.2 t), while two of those beds (KI2 and KI5) had an estimated biomass of above 3000 t (Table 3). The three beds with an estimated biomass less than 1500 t (KI3, KIM and KIE) were the smallest in area (Figure 2), and while KI3 had the lowest density of all beds, KIE had the highest density (Table 3). The percent of scallops less than 85 mm was highest at the two beds off Flinders Island. Nevertheless, all seven beds with a mean biomass greater than 1500 t also had a mean biomass of scallops greater than 85 mm above 1500 t (Table 4). Similarly, taking into account discard rates, KI2 and KI5 had a mean biomass of scallops greater than 85 mm above 3000 t (Table 4).

Mendo et al. (2014) reported diminishing synchronization of spawning by commercial scallop in coastal Tasmanian waters. They found that for scallops at a site with a density (as measured by divers) of 0.203 individuals per m^2, only 25% of individuals were within their optimum nearest neighbour distance, and so were effected by gamete dilution. Estimated densities in number from this survey are shown for each bed in Table 3. The Flinders Island beds were two and three times higher than 0.203 individuals per m^2. Density at KI3 was much lower than 0.203 individuals per m^2, while at KI1 it was just over that level. All other King Island beds were well over 0.203 individuals per m^2, and KIE was more than 4 times that level.

Because the 2016 survey repeated sampling on some beds surveyed during 2015 (Figure 1, Figure 2) using the same method (Knuckey et al., 2015), comparisons can be made of size distribution and density. The 2015 Flinders Island bed overlaps mostly (but did go into the 2016 FI2) with the 2016 FI1 beds, and mean (91.7 mm) and median (92 mm) lengths were identical, and their distributions very similar. Mean density in 2015 (56.7 kg / 1000 m^2) was higher than that from FI1 in 2016 (37.6 kg / 1000 m^2) — although when 2016 survey data is restricted to the boundaries of the survey bed used in 2015, the mean density is 60.9 kg / 1000 m^2. Mean widths were about 4 mm bigger in 2016 at KI2 (KI Main in 2015) and KIE (KI East in 2015), and about 1.3 mm bigger at KIM (KI Middle in 2015). 2016 scallop density at KIE was nearly double that in 2015, almost identical at KIM and about 55% of the 2015 density at KI2 (noting that KI Main in 2015 extended further north and south than KI2 in 2016).

As for the 2015 survey, scallops sampled from the King Island beds were larger in width, at a more advanced stage of maturity and had much less meats per kg than the Flinders Island beds. This is somewhat skewed by timing of the survey — the Flinders Island beds were the first to be surveyed during mid-May, while the last three King Island beds were surveyed during mid-June.

Scallops from KI3, and to a lesser extent KI4, were very different to scallops from other King Island beds in their small size, bimodal width frequency distribution and relatively large number of meats per kg.

Catches of old single shell and live Commercial Scallop at the Flinders Island bed comprised 28% and 32% of the total catch during the 2015 survey respectively (Knuckey *et al*., 2015). The percent composition of old single shell caught in the 2016 survey has greatly increased (to about 50%), while the percent of live Commercial Scallops was 12% at FI1 and 20% at FI2. Compared to data from the KI Main bed surveyed during 2016, the proportion of live Commercial Scallop and new single shell has decreased, while the proportion of old single shell increased. Of the other two 2015 survey beds that were resurveyed, both showed increases in new single shell, from 1% to 7% of the total catch at KIE and from 7% to 17% at KIM.

Consideration of survey results by ScallopRAG and ScallopMAC

Survey results were presented to ScallopRAG on 22/6/2016 and the Scallop Management Advisory Committee (ScallopMAC) on 23/6/2016. The outcome was that the season was opened under Tier 2 management arrangements, also incorporating two fisheries closures: one off Flinders Island (FI2); and one off King Island termed KI-New – a closure comprising parts of KI4, KI5 and all of KIE (which was closed the previous year). Scallop densities at these beds were estimated at 0.467, 0.479 and 0.885 individuals per m^2 respectively, assuming a dredge efficiency of 33%. These are higher densities than any of the other beds.

During ScallopRAG and ScallopMAC, industry members presented anecdotal information regarding an unsurveyed bed of scallops in high densities to the north of KI-New closure that were smaller than those in the KI-New closure, and in apparent “good” condition. There was concern that with the KI-New closure in place, this unsurveyed bed (referred to as the “Blue Dot” bed) would receive significant fishing pressure, potentially damaging a bed that could provide substantial future recruitment and harvestable stock. It was suggested that closure of the Blue Dot bed might be more productive for the fishery’s reproductive capacity than closing KI-New. To protect the Blue Dot bed, a voluntary industry close was put in place until it could be surveyed.

Blue Dot survey

A further stratified random survey was undertaken on the Blue Dot bed off King Island (Figure 3). The survey bed was defined by an industry member based on exploratory tows undertaken in the past two months. A total of 30 valid, random survey tows were undertaken. Biomass was calculated using area swept calculated from the straight line distance between the start and end tow points and the measured internal width of the dredge.

The high density of small scallops observed is consistent with anecdotal reports by industry members. Mean density was 30% higher than any other bed surveyed (Table 3). Estimated biomass at the Blue Dot bed was 6332.1 t (95%CI 4752.2 t – 7911.9 t), and the estimated biomass of scallops greater than 85 mm was 5627.8 t (95%CI 4223.7 t – 7031.9 t) (Table 3). This is a greater biomass than that estimated for the KI-New area that was closed (see the red box in Figure 3) at the start of the 2016 season (4822 t total; 4758 t >85 mm). About 89.9% of the biomass was greater 85 mm or greater in width (Table 4). The modal width of scallops at the Blue Dot bed was identical to that from KI3 (Table 5), however the size frequency distribution

was very different to that from all other King Island beds, being consistently smaller with a lack of large (>105 mm) scallops (Figure 16). Meat weights were also much smaller than any of the other King Island beds (Table 5). Density in numbers was considerably higher at the Blue Bot bed (2.242 individuals per m^2) than in any other bed surveyed, meaning that synchronization of spawning could potentially be higher compared to other beds.

Based on the results of the subsequent survey of the Blue Dot bed, it would appear that this could be equally suitable if not a better replacement for the current KI-New closure with regard to both biomass, density, and scallop size.

References

Francis, R.I.C.C. (2006). Optimum allocation of stations to strata in trawl surveys. New Zealand Fisheries Assessment Report 2006/23. 50 p.

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.

Mendo, T., Moltschaniwskyj, N., Lyle, J.M., Tracey, S.R. and Semmens, J.M. (2014). Role of density in aggregation patterns and synchronization of spawning in the hermaphroditic scallop *Pecten fumatus*. Mar. Biol. 161: 2857–2868.

R Core Team (2014). 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

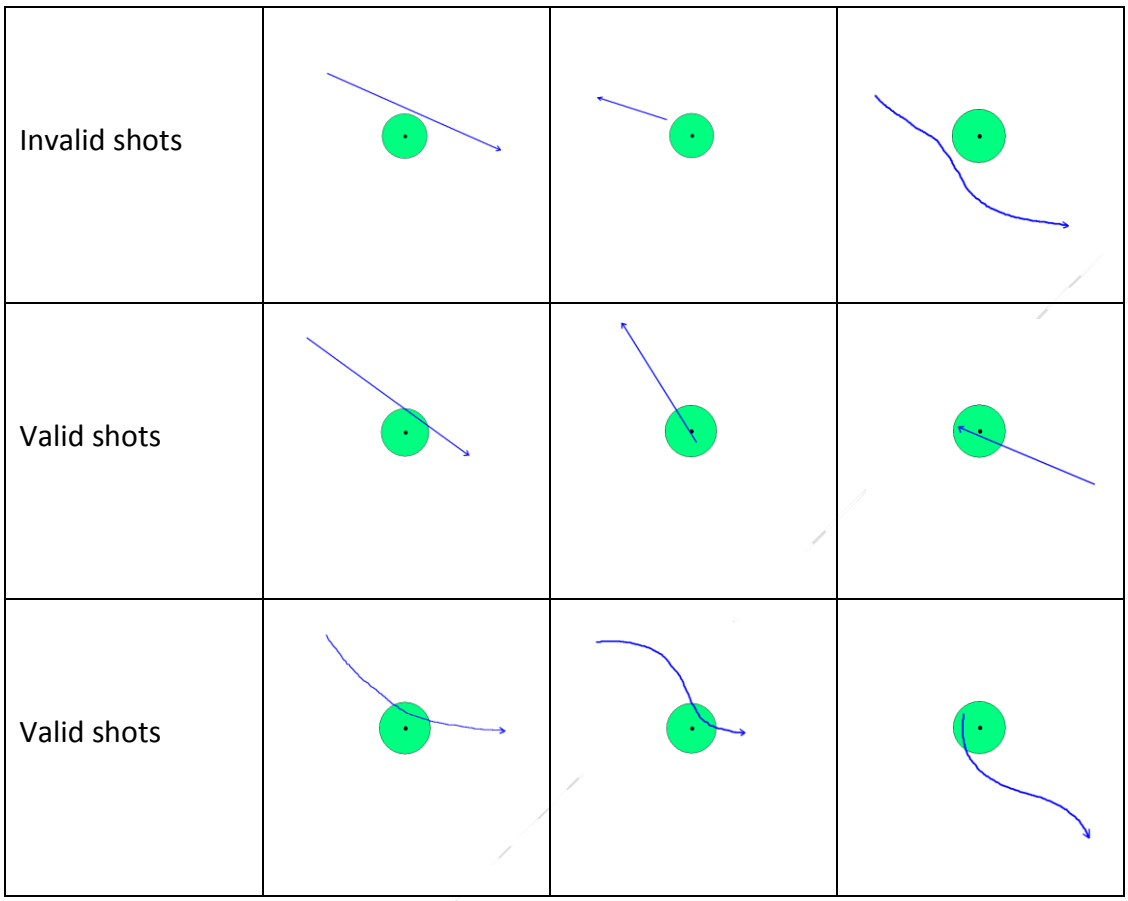

Figure 22. How to conduct a valid survey shot. Green circle is 100 m radius.

Table 8. 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 9. 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.