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Harvestable biomass of *Katelysia* spp. in the South Australian Vongole Fishery

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EXECUTIVE SUMMARY

This report provides estimates of harvestable biomass for Vongole (*Katelysia* spp., also known as mud cockles) to inform setting of annual total allowable commercial catches (TACCs) under the harvest strategy in the Management Plan. Stock status was determined using a weight-of-evidence analysis under the National Fishery Status Reporting Framework (NFSRF; Stewardson *et al.* 2018).

The South Australian Vongole Fishery consists of three fishing zones and targets three species: *Katelysia scalarina* ("greys"), *K. rhytiphora* ("yellows"), and *K. peronii* ("whites").

Coffin Bay Fishing Zone

The TACC of 50 t in 2018/19 was less than one third of catch levels in the mid-2000s, which exceeded 150 t.

The biomass survey program varied among years. In 2015, all transects were sampled (n = 223). In each year from 2016-2018, all transects were sampled in at least one of the four primary fishing grounds; other fishing grounds were sub-sampled.

Length-frequency data demonstrate there has been recent recruitment events for greys and yellows, but the frequency of legal and large Vongole for both species has declined compared to historical values.

Estimates for legal density of greys and yellows declined from 2011 and 2013 onwards, respectively. There were long-term reductions in the frequency of transects with high densities for both species.

The median estimates of harvestable biomass (determined via bootstrapped sampling) were 999.2 t, 1092.9 t and 739.9 t in 2016, 2017 and 2018, respectively. These differences among years reflect changes in the survey design as well as changes in abundance.

Subsampling during the surveys conducted between 2016 and 2018 means that each of these surveys cannot be compared to one another. However, they can be compared to a *post-hoc* subsampling of the 2015 survey where all transects were undertaken. Based on commensurate transects sampled in 2015 and each year being compared, harvestable biomass was stable between 2015 and 2016, but declined by 110 t (9%) from 2015 to 2017, and 211 t (22%) from 2015 to 2018. The 2016-2018 survey programs were also applied to the complete 2013 and 2015 datasets to evaluate the impact of sampling on the estimates of harvestable biomass and to

estimate a rudimentary correction factor. Applying the correction factor suggested that a reduction in harvestable biomass of 22% occurred between 2016 and 2018.

A data-limited stock assessment model (catch-only MSY (cMSY)) was applied to commercial fishery catch data. Outputs from the cMSY model are consistent with the trends in density and biomass from the survey program. Model outputs show a consistent decline in biomass from 2015 and indicate an MSY of approximately 30 t.

There is clear evidence that status of the Vongole stock has declined over recent years. Vongole density and the frequency of transects with high densities has decreased, harvestable biomass declined by ~22% from 2015 to 2018 and the frequencies of legal and large Vongole also declined. On this basis, the Coffin Bay Vongole Fishery in 2018/19 is classified as **'depleting'**, reflecting a change from a 'sustainable' classification in 2017/18.

West Coast Fishing Zone

The TACC in 2018/19 was 16.0 t, which was substantially lower than the catches in the mid-2000s that exceeded 30 t.

The sampling program changed during 2016-2018, compared to 2015. Each year, all transects were sampled in one of the three primary fishing grounds.

Estimates of median harvestable biomass were: Streaky Bay (303.5 t in 2016); Smoky Bay (139.3 t in 2017; and Venus Bay (100.6 t in 2018). Harvestable biomass and harvest fraction were not calculated for the zone because data from Streaky Bay and Smoky Bay were old.

There is insufficient information, either directly or via proxy, for estimating biomass or fishing mortality that are required for classifying stock status under the NFSRF. Consequently, the West Coast Vongole Fishing Zone in 2018/19 is classified as **'undefined'**, reflecting a change from a 'sustainable' classification in 2017/18.

Port River Fishing Zone

Vongole fishing ceased from 2011/12 due to low levels of stock biomass. The Port River Vongole Fishing Zone is classified as '**depleted**'.

Keywords: Vongole, *Katelysia* spp., stock status, harvestable biomass, harvest strategy

Table 1. Summary of TACC (t), stock status, biomass (t; at 80% CI), and the harvest fraction (%) from 2015 to present for Coffin Bay and the West Coast Fishing Zone. Port River has been closed since 2011 with a TACC of 0 t and a status of depleted. Note biomass cannot be directly compared across years because different transects were sampled each year from 2015/16-2018/19.

Coffin Bay

Year	TACC (t)	Stock Status	Biomass 80% CI (t)	Harvest Fraction (%)
2015/16	50.0	Sustainable[1]	867.7	5.8
2016/17	50.0	Sustainable[1]	730.4	6.8
2017/18	50.0	Sustainable[1]	791.8	6.3
2018/19	50.0	Depleting[2]	538.5	9.3

West Coast

Year	TACC (t)	Status	Biomass 80% CI (t)	Harvest Fraction (%)
2015/16	16.0	Sustainable[1]	478.1 (all bays)	3.3
2016/17	16.0	Sustainable[1]	236.4 (Streaky Bay)	N/A
2017/18	16.0	Sustainable[1]	109.1 (Smoky Bay)	N/A
2018/19	16.0	Undefined[3]	75.6 (Venus Bay)	N/A

[1] Biomass (or proxy) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (recruitment is not impaired) and for which fishing mortality (or proxy) is adequately controlled to avoid the stock becoming recruitment impaired (overfishing is not occurring) (Stewardson et al. 2018)

[2] Biomass (or proxy) is not yet depleted and recruitment is not yet impaired, but fishing mortality (or proxy) is too high (overfishing is occurring) and moving the stock in the direction of becoming recruitment impaired (Stewardson et al. 2018)

[3] Not enough information exists to confidently determine stock status (Stewardson et al. 2018)

1. INTRODUCTION

The genus *Katelysia* (Family Veneridae), commonly known as mud cockles or Vongole, is a group of commercially important bivalves that comprise a major faunal component of shallow estuarine and marine embayments (Roberts 1984). In Australia, the genus is represented by three species – *Katelysia scalarina* known as "greys", *K. rhytiphora* known as "yellows", and *K. peronii* known as "whites" – all of which are broadly distributed around the temperate coastline from Augusta, Western Australia to Port Jackson, New South Wales (Roberts 1984).

Vongole have been harvested in South Australia since the early 1960s, with management arrangements changing over that period (see Table 2). Prior to 1985, most catches were obtained from the Port River and Kangaroo Island for use as bait. Despite increasing demand for human consumption, the fishery remained lightly exploited until 1995/96, when the state-wide annual catch first exceeded 50 t. From 1996/97, catches increased rapidly to a peak of 375 t in 2005/06. Most of the catch during this period was obtained from the Port River and Coffin Bay. Given the large number of licenses (>600) with access to the resource and the rapid increases in catch, sustainability concerns led to implementation of a quota management system across the three Vongole Fishing Zones (Port River, Coffin Bay and West Coast; Figure 1) in October 2008.

The combined total allowable commercial catch (TACC) for all zones in 2008/09 was 195 t. In 2009/10, a fishery-independent sampling program was established to estimate harvestable biomass in each of the fishing zones, following advice from fishers (West Coast and Coffin Bay) and survey results (Port River fishing zone) that raised sustainability concerns. Following the first assessment of harvestable biomass (Gorman *et al.* 2010), TACCs for 2010/11 were reduced to 11.3 t for the Port River, 48.1 t for Coffin Bay and 21.0 t for the West Coast (total 80.4 t).

In response to further sustainability concerns, the Port River Vongole Fishing Zone was closed from 1 July 2011, and the TACC for the West Coast was reduced for the 2011/12 season (Table 2). The Port River fishing zone remains closed and is classified as 'depleted' (Stewardson *et al*. 2018).

The maximum exploitation rate in the Management Plan is 7.5% of the biomass estimate at the 80% confidence level (PIRSA 2013). Exploitation rates among similar bivalve fisheries are highly variable. For example, the OHV Dutch Hand Raked Cockle Fishery is 2.5% (Cappell 2019) whilst that for the Thames Estuary Cockle Fishery is 33% (Hough and Andrews 2019). The Tasmanian Vongole Fishery in Anson Bay (*K. scalarina*) uses similar methods to obtain estimates of

harvestable biomass from fishery-independent surveys, sets TACC at 10% of the most recent biomass estimate, and has a biomass limit reference point of 40 t. However, this fishery is environmentally limited and has been closed since 2015, likely due to low levels of pre-recruits post 2006, sporadically high natural mortality, and fishing mortality of recruits in 2012 and 2013 (Tarbath and Gardner 2015).

This report provide estimates of harvestable biomass in the Coffin Bay and West Coast Fishing Zones, following Gorman *et al.* (2010) and Dent *et al.* (2012, 2014, 2016). Outputs from a data-poor stock assessment modelling tool (Martell and Froese 2013) are also included. Stock status was determined using the weight-of-evidence assessment following the National Fishery Status Reporting Framework (NFSRF; Stewardson *et al*. 2018), because the current Management Plan (PIRSA 2013) does not provide a definition of stock status. The key data sources used to determine status were changes in (1) biomass relative to 2015, (2) frequency of transects with high Vongole densities, (3) frequency of large, legal Vongole, and (4) evidence of recruitment.

Changes in the sampling program in both zones complicated the comparison of historical estimates of harvestable biomass for the Coffin Bay Fishing Zone and prevented estimation of the total harvestable biomass or exploitation rates for the West Coast Fishing Zone. The absence of biomass and exploitation rates for the West Coast Fishing Zone prevents application of the Harvest Strategy.

Table 2. Management milestones in the South Australian Vongole Fishery

Year	Milestone
1960	Fishery started; Minimum legal length (MLL) set at 30 mm shell length (SL) state wide
1990	MLL at Coffin Bay increased to 38 mm SL for all three *Katelysia* species
2005	State wide catches peaked at 375 t
2008	TACCs introduced; 100.0 t Port River, 70.0 t Coffin Bay and 25.0 t West Coast
2009	TACCs reduced to 22.6 t Port River, 56.0 t Coffin Bay and 15.0 t West Coast
2010	MLL at Coffin Bay reduced to 33 mm SL for all three species by ministerial exemption (ME)
2010	TACCs amended to 11.3 t Port River, 48.1 t Coffin Bay and 21.0 t West Coast
2010	Trial to harvest Vongole at Coffin Bay in the ratio they exist (yellow to grey Vongole 2:1)
2011	Port River Vongole Fishing Zone closed due to concerns over sustainability
2011	TACCs amended to 48.1 t Coffin Bay and 18.0 t for West Coast
2012	TACCs increased to 50.0 t Coffin Bay and 18.5 t West Coast
2012	MLL for greys at Coffin Bay reduced to 30 mm SL by ME
2012	MLLs for yellows and whites at Coffin Bay returned to legislated 38 mm SL
2013	New Management Plan for SA commercial marine scalefish fishery (PIRSA 2013)
2014	TACCs reduced to 46.0 t Coffin Bay and 16.0 t West Coast
2015	TACC for Coffin Bay increased to 50.0 t
2015	MLL for yellows and whites at Coffin Bay amended to 35 mm SL by ME
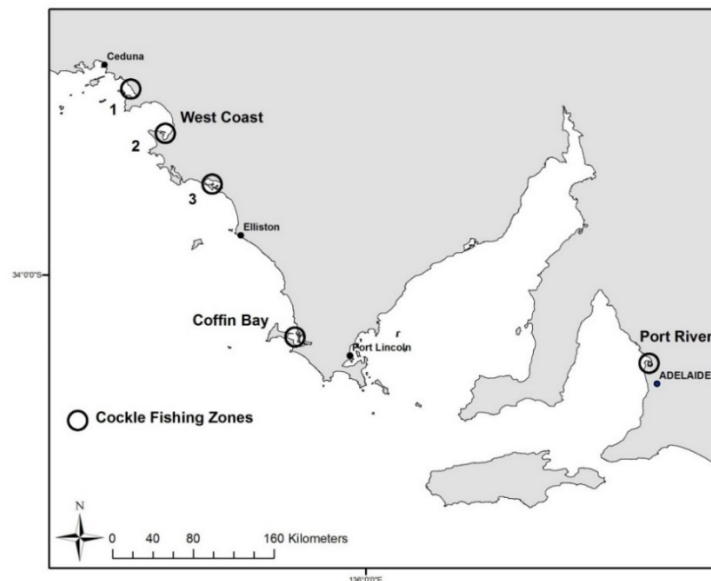
Figure 1. Map with locations of commercial Vongole Fishing Zones in South Australia: Port River, Coffin Bay and the West Coast. Coffin Bay contains four main fishing areas (Point Longnose, Long Beach, Little Douglas, and Oyster Farms), and the West Coast zone comprises Smoky Bay (1), Streaky Bay (2) and Venus Bay (3).

2. METHODS

2.1 Survey design and transect location

The overall survey design integrated principles of fishery-independent research with knowledge obtained from commercial fishers (Mayfield *et al.* 2008; 2009). Within each Vongole Fishing Zone, fishers identified areas of high and low productivity in the fishing grounds on large-scale aerial photographs, which were digitized using a Geographic Information System package (ArcGIS V10.3.1) and used to identify areas of high and low density strata. Maps depicting areas of varying Vongole density were generated and returned to fishers for confirmation. To improve survey precision, transects were then distributed systematically within the high and low density strata (Ault *et al.* 1999) with greater sampling intensity in areas with expected high densities of Vongole (high density strata, transects separated by 30-100 m) than those of expected low densities of Vongole (low density strata, transects separated by 250-360 m). Since 2015, the Coffin Bay survey comprised 12 strata, while the West Coast survey comprised 28 strata: 9 in Smoky Bay, 3 in Streaky Bay and 16 in Venus Bay. The strata areas from which the transects were sampled has remained consistent since 2015.

Surveys undertaken from 2016 to 2018 were based on a triennial method with (1) each year, complete sampling of all established transects in at least one Coffin Bay primary fishing ground and subsampling of transects in the remaining Coffin Bay fishing grounds (Table 3); and (2) sampling of one West Coast bay in each year (i.e. Streaky Bay in 2016, Smoky Bay in 2017, and Venus Bay in 2018). Hence, triennial sampling differed from the biennial methods described in previous assessments (i.e. complete sampling of all fishing grounds; Gorman *et al.* 2010; 2011; Dent *et al.* 2012; 2014, 2016).

2.2 Data collection

The fishery-independent surveys were conducted by survey teams, each of which included a SARDI observer and a commercial fisher. Sampling was completed at established sampling sites with fixed transects located using coordinates (latitude, longitude) stored in handheld global positioning system (GPS) units. At each sampling site, a commercial fisher used a Vongole rake of known size (~40 cm in width by ~20 cm in height) with a mesh bag insert (2 cm diagonal mesh size) to collect Vongole along a transect length of 2 m (*i.e.* ~0.8 m^2). Samples were sieved through 7 mm square mesh in the base of a plastic crate to remove sand. Live and dead Vongole were bagged, labelled and frozen for subsequent processing in the laboratory. Note that the 2015/16 survey, hereafter, is referred to as 2015, the 2016/17 as 2016, etc.

Table 3. The number of established transects in each of the primary fishing grounds in Coffin Bay (i.e. 2015 biennial sampling), and the number of established transects sampled during the triennial sampling program from 2016 to 2018. Note bold font denotes primary fishing ground sampled and * denotes subsampling, where approximately every second established transect from the 2015 survey design was sampled.

	Number of transects sampled			
	Point Longnose	Oyster Farms	Little Douglas	Long Beach
2015	91	38	33	61
2016	**91**	26*	13*	19*
2017	33*	**37**	**33**	21*
2018	33*	26*	13*	**61**

In the laboratory, each sample was sorted to remove dead shells and identify Vongole to species (Cantin 2010). Legal and sub-legal Vongole were sorted, weighed, and counted. In Coffin Bay, the MLL was 30 mm shell length (SL) for greys and 35 mm SL for yellows and whites, while in the West Coast, MLL was 30 mm shell length (SL) for all species.

Methods for determining total weights and counts for sub-legal and legal Vongole have varied among years. Prior to 2015 and in 2016, for each sample, Vongole were separated into legal and sub-legal components, and size categories were counted and weighed to the nearest gram. In 2017 and 2018, each individual was measured using digital calipers to the nearest 0.1 mm along the longest axis (SL) and weighed to the nearest gram (Gorman *et al.* 2010; Dent *et al.* 2012; 2014). All Vongole were measured unless abundance at a transect was >300, in which case ~300 individuals were randomly chosen and individually measured and weighed; the remaining Vongole were grouped into size classes and weighed. A total weight and count was calculated for legal and sub-legal Vongole in each sample. Length-weight relationships (power regression; weight = a*length^b) were also established for each bay and species in 2016, 2017 and 2018 and were evaluated as an alternative method to weighing individual Vongole. Analyses were completed using R statistical software v3.5.0 (R Core Team, 2018).

2.3 Temporal change in density and length-frequency distribution

To evaluate changes in biomass in Coffin Bay, equivalent transects from each set sampled from 2016 to 2018 (149 transects from 2016, 124 from 2017, and 133 from 2018) were applied to the 2015 data using the current size limits for each species. Data from 2015 were used as a historical reference because it was the most recent dataset containing samples from all transects in all

fishing grounds (n = 223 transects). Use of historical data was not required for the West Coast because the transects sampled during triennial sampling remained consistent with 2015 surveys (i.e. 42 in Streaky, 53 in Smoky, and 98 in Venus).

To evaluate longer-term changes in legal and sub-legal-sized Vongole density and length-frequency distributions, these were calculated using (1) only those transects consistently sampled in each year from 2009 to 2018; and (2) current size limits for each species. The number of consistent transects used to calculate historical density for Coffin Bay was 79, while, for length-frequency analyses, 13 consistent transects were used for greys and 79 for yellows. Due to historical subsampling of yellows and multiple changes in the MLL across years, density estimates for yellows in Coffin Bay were calculated using length-frequency data enabling re-analysis of historical data using current MLLs, from 2011 onwards. Since length-frequency data were subsampled differently among years, density calculations were likely conservative.

2.4 Estimates of harvestable biomass

Harvestable biomass for each of Coffin Bay, Streaky Bay, Smoky Bay and Venus Bay was estimated by (1) calculating weighted-means, by using the mean biomass per transect area (i.e. g/~0.8 m^2) for each stratum multiplied by its respective stratum area (m^2) and then (2) summing the weighted-means:

$$\text{Harvestable biomass (G)} = \sum_{k=1}^{n} N_h \, \bar{x}_h, \text{where } N_h = \text{stratum area and } \bar{x}_h = \text{ mean biomass}$$

A non-parametric bootstrap method (after McGarvey *et al.* 2008) was used to determine quantiles of the estimates of legal-sized biomass for each species, in each fishing ground, using R statistical software v3.5.0 (R Core Team, 2018). All strata and survey areas within each fishing ground were included in the analysis. The bootstrap procedure accounted for the random variation among the primary sample units (i.e. the transect sample locations). The 50,000 bootstrap iterations of estimated biomass were ranked and the 10%, 20% to 90% quantile confidence intervals extracted, and a table for each fishing ground was formulated based on the nine quantile levels of lower-bound, survey-estimated biomass (Mayfield *et al.* 2008; Gorman et al. 2011). Each value specified the cumulative confidence probability that the actual harvestable Vongole biomass is greater than or equal to the estimated biomass values. Values in the tables were considered conservative since the assumption that the sampling gear was 100% efficient was unlikely to be true. These tables provide a risk assessment framework for TACC determination. The sum of

harvestable biomass values for each species at the 80% quantile was used to determine the harvest fraction for the Coffin Bay Fishing Zone.

Harvestable biomass in Coffin Bay was calculated using data from each year of the triennial survey (i.e. 2016, 2017, and 2018). The 2016, 2017 and 2018 sampling programs were also applied to the 2015 and 2013 data using the current size limits for each species. This enables (1) a more direct comparison of harvestable biomass in 2016, 2017 and 2018 to that in 2015 and (2) an evaluation of the potential impact of sub-sampling on harvestable biomass estimates. For the latter, the percent difference between biomass from complete sampling of 223 transects in Coffin Bay and biomass from each of the triennial sampling programs applied to the 2015 and 2013 data was calculated for legal and sub-legal Vongole. Data from 2015 and 2013 were used as a historical reference as 2015 was the most recent dataset containing samples from all transects in all fishing grounds (n = 223 transects) and 2013 being the second most recent dataset containing all transects in all fishing grounds except "Dead Man's Corner" (n = 219 transects). Frequent changes to survey and sampling methods complicated calculation of harvestable biomass and estimates prior to 2013 were not calculated. Harvestable biomass estimates for the West Coast Fishing Zone were calculated for each bay/year combination.

2.5 Catch-only model

A fishery modelling approach was undertaken to aid assessment of stock status. This approach used a catch-only model that estimates MSY (cMSY), which is a model-assisted, data-poor stock assessment tool (Martell and Froese 2013). The cMSY model used a time-series of total commercial catch from 1985 to 2018, as well as basic life history information to generate estimates of maximum sustainable yield (MSY), the biomass required to support the MSY (BMSY) and the harvest fraction of the BMSY to provide the MSY (HMSY), along with a time-series of biomass and harvest fraction. Recognising catches have been controlled by a TACC since 2008, an alternate time-series of total commercial catch from 1985 to 2011 was also used. The cMSY model determines MSY through a Schaefer production model (Schaefer 1954), which is assisted by a stock reduction analysis (Walters et al. 2006). The parameters *r* (intrinsic rate of population increase) and *K* (carrying capacity) were determined through this process and then used to estimate MSY as:

$$MSY = \frac{rK}{4}$$

Appropriate levels of *r* and *K* were determined using the stock reduction analysis which applied pairs of these parameters to a Schaefer production model using catch data:

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t$$

where B_t is the biomass at time t and C_t is the catch at time t.

The stock reduction analysis simulated the stock biomass using catch data and pairings of *r* and *K* determined from priors. The analysis then kept all successful pairings of *r* and *K* by determining if a population simulation either led to an extinction outcome (which is implausible if the species was still being caught) or if the population increased exponentially beyond what is biologically reasonable. The successful pairings of *r* and *K* were then summarised as means and 95% quantiles and used to determine MSY. With information on catch, predicted biomass and MSY, estimates of BMSY and HMSY were then calculated.

2.6 Length-weight analyses

Length-weight analyses, and estimates of harvestable biomass derived from length measurements rather than weights, are provided in Appendix 4.

3. RESULTS

3.1 Coffin Bay

The total number of transects sampled (N_{2016} = 149; N_{2017} = 124; N_{2018} = 133) and number of Vongole collected (3,728 in 2016; 3,891 in 2017; 3,288 in 2018) varied among years. Greys were the dominant species by number and accounted for 60-64% of the Vongole collected each year. yellows were the second most abundant species (36-40% each year). Most greys were below the minimum legal size (MLS). Most yellows MLS in 2016 and 2017 and about half in 2018 were above the MLS. Overall, whites accounted for <2% of Vongole biomass in 2016, 2017, and 2018.

Based on 79 consistent transects, mean density of yellows has declined from about 4 Vongole.m^{-2} in 2011 and 2013 to < 1.5 Vongole.m^{-2} in 2018 (Figure 2). Grey densities were typically > 7 Vongole.m^{-2} before 2018 when they were 5 Vongole.m^{-2}. Historical surveys showed some high Vongole densities (> 50 yellow Vongole.m^{-2} and > 100 grey Vongole.m^{-2} (Appendix 1)), but there was a reduced frequency of transects with high Vongole densities in recent years. For example, for yellows, five transects in 2013 had > 25 Vongole.m^{-2}, but none in 2018. Similarly, in 2011 six transects had > 50 grey Vongole.m^{-2}, but this was reduced to one transect in 2018.

The time-series of length-frequency distributions provides evidence of a reduced frequency of legal and large (yellows > 40 mm and greys > 35 mm SL) Vongole over time. Between 2015 and 2018 (i.e. 133 consistent transects; Figure 3), the decline in total numbers was from 1,042 to 598 legal-sized yellows (or ~8 to ~4.5 Vongole /transect). The decline in total numbers of legal-sized greys was from 867 to 628 Vongole (or ~6.5 to ~5 Vongole /transect). These declines were also reflected in comparisons spanning 2011 to 2018 (n = 79 and 13 consistent transects for yellows and greys, respectively; Figure 4), including (1) a decline in total numbers legal-sized yellows of 301 to 89 Vongole (or ~4 to ~1 Vongole/transect), and (2) a decline in total numbers of legal-sized greys from 153 to 32 Vongole (~11 to ~2 Vongole/transect). Furthermore, the decline between 2011 and 2018 was higher for large yellows from 182 to 43 Vongole (~2 to ~0.5 Vongole/transect) and large greys from 37 to 4 Vongole (~3 to ~0.3 Vongole/transect).

Data from 2015 and 2018 provides evidence of recent recruitment of greys (Figures 3 and 4). For yellows, recruitment is apparent in 2015, 2016 and 2018 (Figures 3 and 4).

The estimates of median harvestable biomass (50% quantile) were 999.2 t, 1,092.9 t and 739.9 t for 2016, 2017 and 2018, respectively (Table 4). These changes between years reflect differences in the sampling program as well as variations in Vongole biomass.

Comparison of estimates of harvestable and sub-legal biomass from the complete and triennial sampling programs show the effects of modifications to the sampling program (Figure 5). For example, (1) applying the 2016 and 2018 sampling program to the 2013 and 2015 datasets resulted in lower estimates of harvestable biomass (means of 17 and 21.5%, respectively) when compared to the full dataset and (2) applying the 2017 sampling program resulted in a slightly higher estimate of harvestable biomass (mean of 1.2%). Using these percentage differences as rudimentary correction factors, to simulate sampling of all transects in Coffin Bay, resulted in median estimates of harvestable biomass of 1,204.8 t, 1,078.8 t and 942.5 t for 2016, 2017 and 2018, respectively (Figure 6). The value for 2018 was 22% lower than 2016 and 18% below 2015 (1,148 t, Dent et al. 2016).
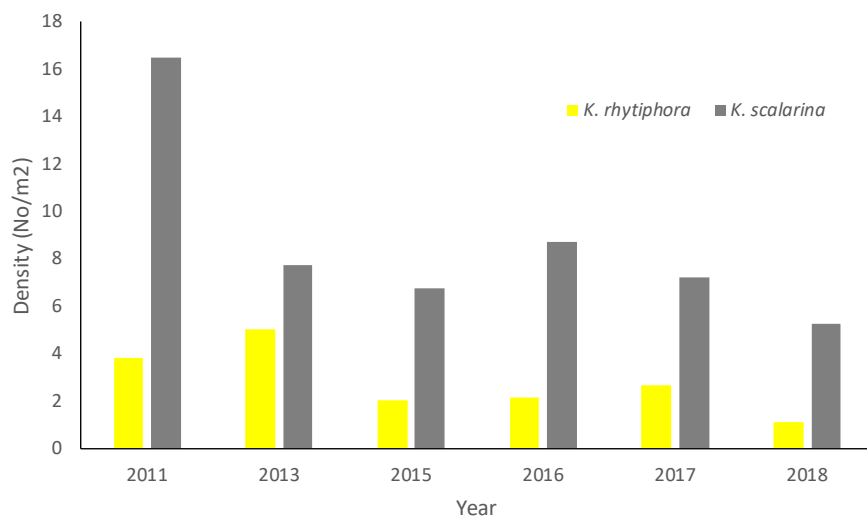
Figure 2. Mean legal density (Vongole.m^{-2}) of yellows (*K. rhytiphora*; yellow) and greys (*K. scalarina*; grey) in Coffin Bay from 79 transects sampled consistently across years.

Re-estimating harvestable biomass from 2015 using transects sampled in each year enabled more direct comparison of harvestable biomass in 2016, 2017 and 2018, to that in 2015 (Figure 7). The median estimates of harvestable biomass were similar between 2015 (995.4 t) and 2016 (999.2 t; Tables 4 and 5). In contrast, the estimate of median harvestable biomass from 2017 (1,092.2 t; Table 4) was about 9% lower than the re-estimated 2015 value (1,203.3 t; Table 5). Similarly, the median harvestable biomass estimate in 2018 (739.9 t; Table 4) was substantially lower (22%) than that re-estimated for 2015 (951.1 t; Table 5).

Outputs from the cMSY model (Figure 8) suggest that MSY is approximately 30 t, and that current biomass (approximately 750 t) is 12% below B_{MSY} (846 t), and trending downwards. The current harvest fraction is also greater than H_{MSY} (0.04). Estimates of MSY, B_{MSY} and H_{MSY} were similar when the model was applied to the truncated dataset ending 2011.
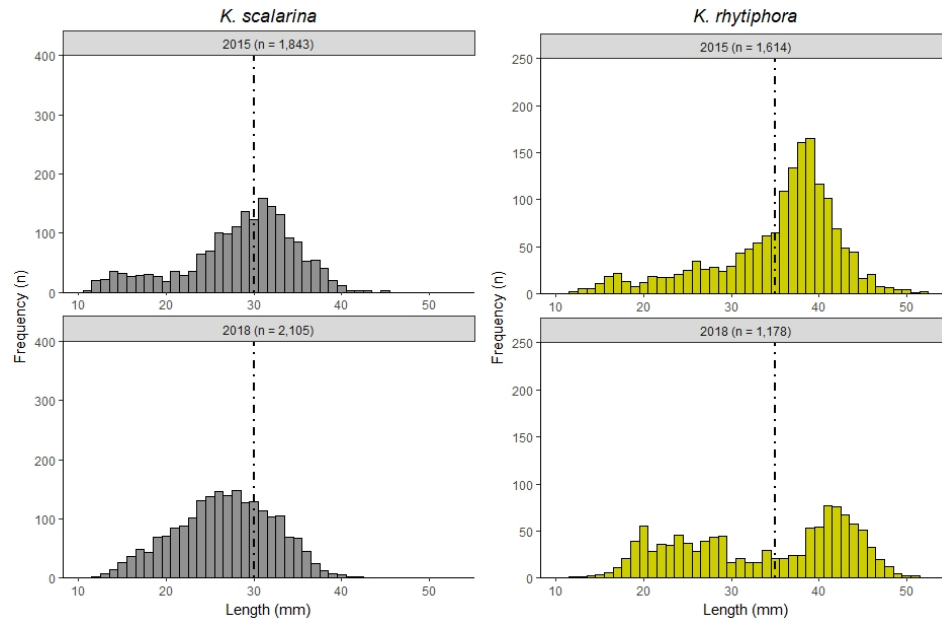
Figure 3. Coffin Bay shell length-frequency distributions (mm) for greys (*K. scalarina*; dark grey, left) and yellows (*K. rhytiphora*; yellow, right) using consistent transects and allowing for comparison between 2015 and 2018 (n = 133 transects; i.e. all transects sampled in 2018). Note scales on y-axes vary between species but not between years, and the vertical dashed line indicates the current MLLs in place under a Ministerial exemption (greys 30 mm SL and yellows 35 mm SL).
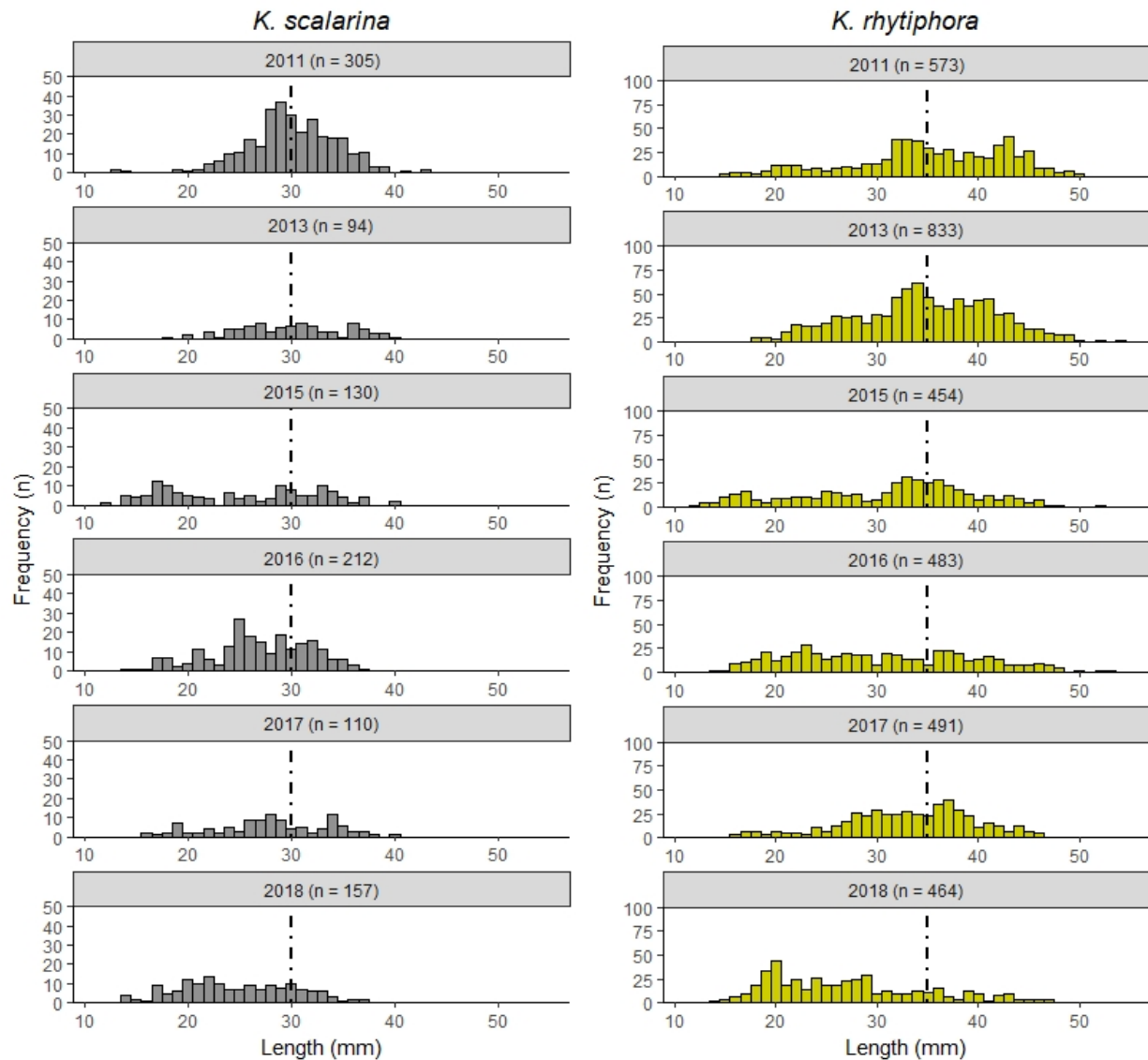
Figure 4. Coffin Bay shell length-frequency distributions (mm) for greys (*K. scalarina*; dark grey, left) and yellows (*K. rhytiphora*; yellow, right) using consistent transects allowing for comparison between 2011 and 2018 (n = 79 and 13 consistent transects for yellows and greys, respectively). Note scales on y-axes vary between species but not among years, and the vertical dashed line indicates the current MLLs in place under a Ministerial exemption (greys 30 mm SL and yellows 35 mm SL).
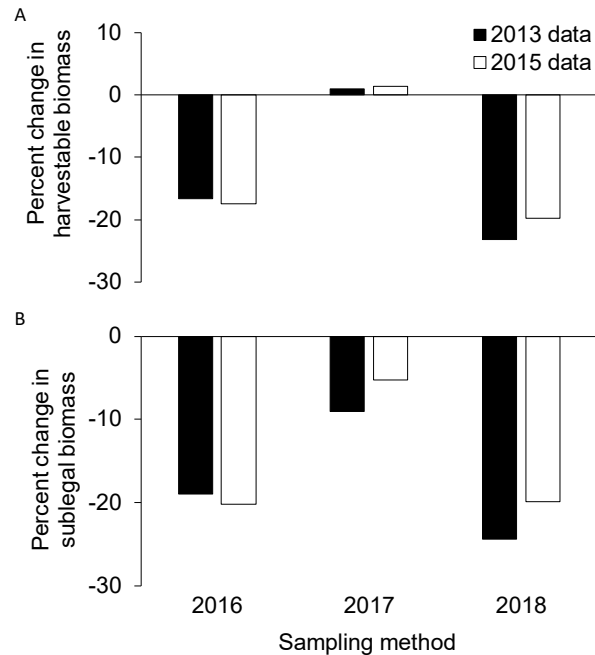
Figure 5. Percent difference in harvestable biomass in Coffin Bay for A) legal and B) sub-legal Vongole. These percentages were determined by subsampling the 2015 and 2013 datasets to match the design of each year (2016 – 2018). The percent change from the initial values in 2013 and 2015 indicate the correction factor used in the 2016-2018 surveys. Percent change reflects the potential uncertainty in the triennial sampling program and was calculated between estimates of harvestable biomass from biennial sampling (i.e. $N_{2013} = 219$ and $N_{2015} = 223$ transects) and each of the triennial sampling methods (i.e. $N_{2016} = 149$; $N_{2017} = 124$; $N_{2018} = 133$).
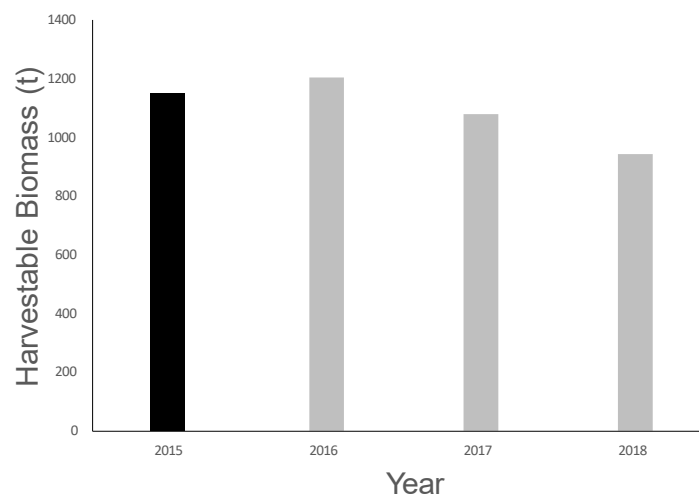
Figure 6. Biomass estimate from 2015 (black bar, Dent et al. 2016) and estimates of biomass for 2016 to 2018 obtained after correcting for the potential effects of the sampling program to simulate sampling of all transects in Coffin Bay (grey bars). Biomass estimates provided at 50% quantile or median.
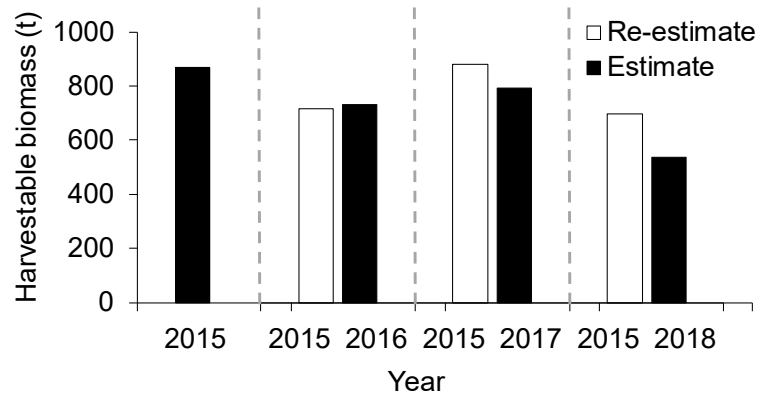
Figure 7. Harvestable biomass (t) in Coffin Bay at 80% quantile using 2015 data from all transects, triennial survey data, and the 2016, 2017 and 2018 triennial sampling programs applied to the 2015 data (i.e. re-estimates). Dashed lines represent comparisons of consistent transects (e.g. re-estimate of 2015 data and estimates from trienniel data) between 2015 and 2016, 2015 and 2017, and 2015 and 2018. The number of transects sampled varied among comparisons (i.e. N_{2015} Estimate = 223 transects and for each of the trienniel estimates and re-estimates N_{2016} = 149; N_{2017} = 124; N_{2018} = 133).
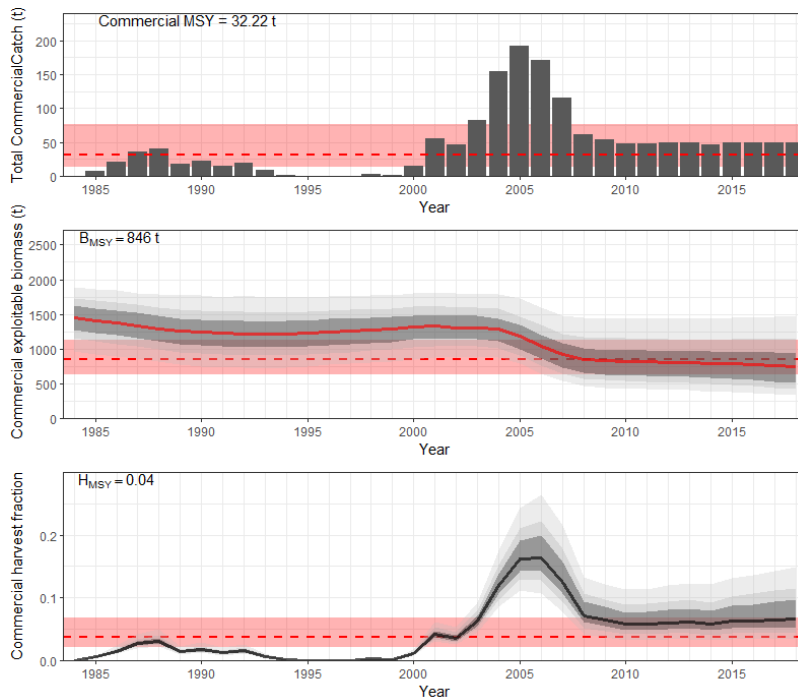
Figure 8. Summary of results from the cMSY modelling for Coffin Bay Vongole. a. Top panel - time series of estimates of total commercial catch and MSY. Middle panel - Time series of estimates of biomass and the BMSY estimate. Bottom panel - Time series of the estimates of harvest fraction and the HMSY. For MSY, B_{MSY} and H_{MSY} the red line indicates the mean and the red shading is the 95%CI. The grey bands in the time-series (catch, biomass and harvest fraction) are the 50, 75 and 95 percentiles (from dark to light) from the model simulations while the black line is the model estimate.

Table 4. Coffin Bay Fishing Zone estimated total harvestable biomass (t, whole weight) 10-90% quantiles for each year of the triennial survey and for greys (*K. scalarina*); yellows (*K. rhytiphora*) and whites (*K. peronii*). Surveys were completed in A) March 2017 (N = 149 transects), B) November 2017 (N = 124 transects), C) October and November 2018 (N = 133 transects). Minimum legal lengths vary among species: greys (30 mm); yellows (35 mm); and whites (35 mm). Total harvestable biomass estimates for each year in bold.

A Coffin Bay 2016

Species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
Greys (*K. scalarina*)	125.2	148.1	175.6	203.8	224.0	243.5	271.0	308.3	350.6
Yellows (*K. rhytiphora*)	488.7	581.9	651.8	714.5	773.5	834.3	901.2	981.9	1097.0
Whites (*K. peronii*)	0.0	0.3	0.7	1.4	1.7	1.7	2.0	2.7	3.4
Total	**613.9**	**730.4**	**828.1**	**919.6**	**999.2**	**1079.6**	**1174.3**	**1292.9**	**1451.0**

B Coffin Bay 2017

Species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
Greys (*K. scalarina*)	83.3	94.5	103.3	111.3	118.8	126.7	135.7	146.4	161.7
Yellows (*K. rhytiphora*)	564.5	696.1	795.4	882.7	968.9	1053.7	1148.7	1261.7	1423.2
Whites (*K. peronii*)	0	1.3	2.5	3.9	5.2	5.2	6.5	7.9	10.4
Total	**647.8**	**791.8**	**901.2**	**997.9**	**1092.9**	**1185.6**	**1290.9**	**1415.9**	**1595.2**

C Coffin Bay 2018

Species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
Greys (*K. scalarina*)	89.7	98.8	105.9	112.2	118.3	124.7	131.5	140.0	151.9
Yellows (*K. rhytiphora*)	354.3	439.7	506.0	566.3	621.6	679.4	743.7	818.5	930.0
Whites (*K. peronii*)	0	0	0	0.4	0.4	0.4	0.4	0.8	0.8
Total	**444.0**	**538.5**	**611.9**	**678.9**	**739.9**	**804.5**	**875.6**	**959.3**	**1082.7**

Table 5. Re-estimates of Coffin Bay Fishing Zone total harvestable biomass 10-90% quantiles calculated using the 2016, 2017 and 2018 triennial sampling programs applied to November 2015 data (t, whole weight) for greys (*K. scalarina*); yellows (*K. rhytiphora*) and whites (*K. peronii*). Surveys were completed A) using data restricted to transects that were consistent with those surveyed in March 2017 (N = 149 transects), B) using data restricted to transects that were consistent with those surveyed in November 2017 (N = 124 transects), C) using data restricted to transects that were consistent with those surveyed in October and November 2018 (N = 133 transects). Minimum legal lengths vary among species: greys (30 mm); yellows (35 mm); and whites (35 mm). Bold indicates total harvestable biomass estimates for each year.

A Coffin Bay 2015 data re-estimated with 2016 transects

Species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
Greys *(K. scalarina)*	140.6	163.2	180.7	196.6	212.0	228.1	246.0	267.6	298.9
Yellows *(K. rhytiphora)*	441.7	553.7	636.0	711.8	783.4	856.9	938.1	1036.0	1174.6
Whites *(K. peronii)*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**582.3**	**716.8**	**816.7**	**908.5**	**995.4**	**1085.1**	**1184.2**	**1303.7**	**1473.4**

B Coffin Bay 2015 data re-estimated with 2017 transects

Species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
Greys *(K. scalarina)*	116.9	138.2	154.5	169.2	183.4	197.9	214.3	233.9	262.6
Yellows *(K. rhytiphora)*	609.9	741.7	843.7	932.9	1019.9	1109.2	1206.5	1321.6	1483.2
Whites *(K. peronii)*	0	0	0	0	0	0	0	0	0
Total	**726.8**	**879.9**	**998.2**	**1102.1**	**1203.3**	**1307.2**	**1420.8**	**1555.5**	**1745.8**

C Coffin Bay 2015 data re-estimated with 2018 transects

Species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
Greys *(K. scalarina)*	116.5	127.6	135.9	143.5	150.7	158.1	166.4	176.1	190.2
Yellows *(K. rhytiphora)*	457.2	568.5	651.1	726.9	800.4	872.8	954.5	1050.5	1189.5
Whites *(K. peronii)*	0	0	0	0	0	0	0	0	0
Total	**573.7**	**696.1**	**787.0**	**870.4**	**951.1**	**1030.9**	**1120.9**	**1226.6**	**1379.7**

3.2 West Coast

A total of 10,525 Vongole were collected with 2,735 individuals obtained at Streaky Bay in 2016, 4,853 at Smoky Bay in 2017, and 2,937 at Venus Bay in 2018 (N_{2016} = 42; N_{2017} = 53; N_{2018} = 98). The dominant species by number at Streaky Bay and at Smoky Bay was greys, which comprised 95% and 80% of the total abundance, respectively. In contrast, at Venus Bay, the abundance of whites and greys were similar at 44% and 40%, respectively.

Historical densities, calculated using consistent transects, exhibited different trends among species (Appendix 2). In Smoky Bay, densities of legal-sized greys were low since 2013, while sub-legal densities were highest in 2015 and 2017. Densities of legal-sized yellows in Smoky Bay were similar and higher in 2009, 2013 and 2017. Greys in Streaky Bay showed similar trends to greys in Smoky Bay, with lower legal-sized densities in 2014 and 2015 and higher recent sub-legal densities. In contrast, the densities of yellows in Streaky Bay were lowest in 2016, although densities were variable across the years. In Venus Bay, densities of greys were lowest in 2015 and 2018, with yellow and white densities being consistently low.

The length-frequency distributions provide evidence of recent recruitment for most species in most bays (Figure 9 and Appendix 3). However, there was no evidence of recruitment of yellows in Streaky Bay in 2015 or 2016 (Figure 9 and Appendix 3).

The median estimates of harvestable biomass were 303.5 t at Streaky Bay in 2016, 139.3 t at Smoky Bay in 2017 and 100.6 t at Venus Bay in 2018 (Table 6), with similar trends observed at other quantiles.

A)
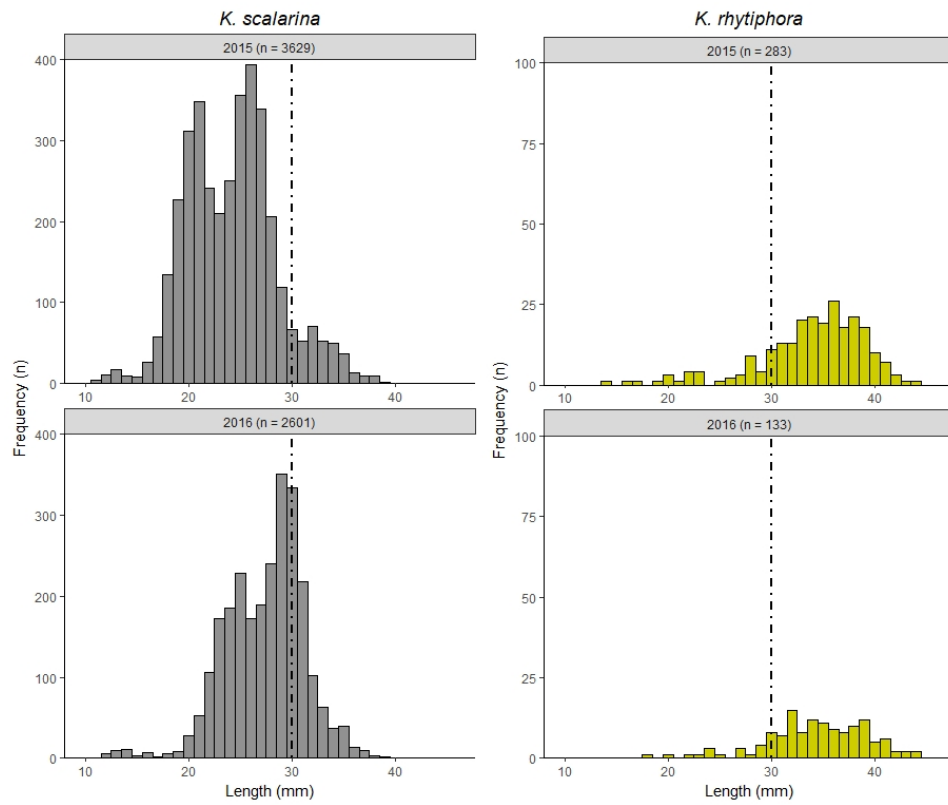
B)
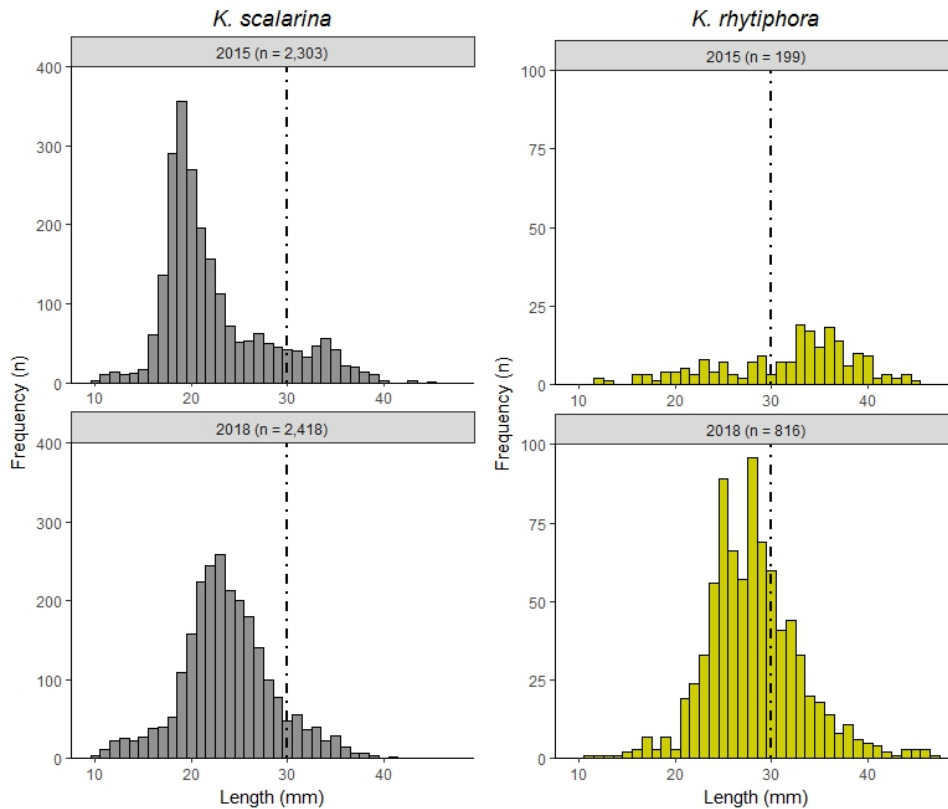
C)
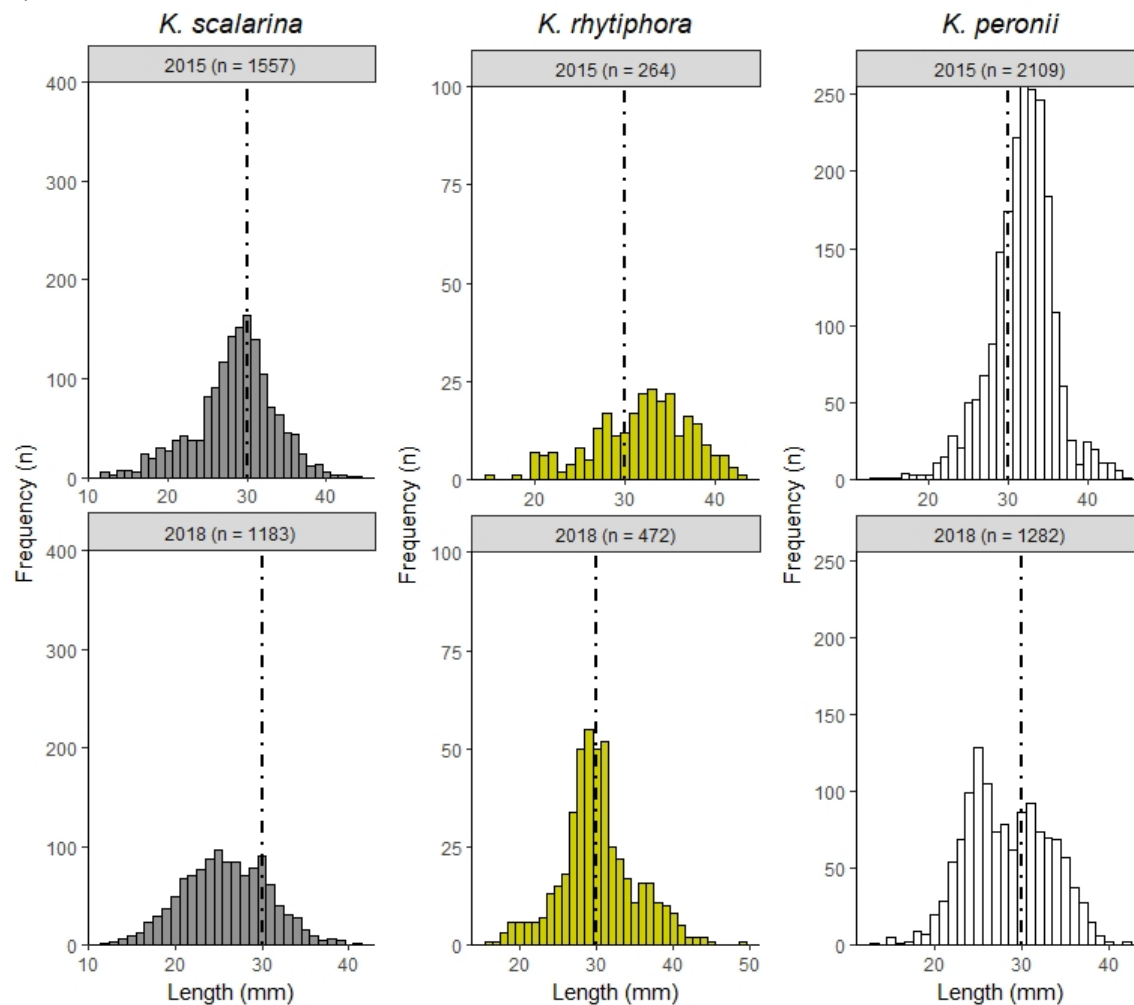
Figure 9. Length-frequency distributions (n = number of individuals measured) for greys (*K. scalarina*; grey bars) and yellows (*K. rhytiphora*; yellow bars) obtained in A) 2015 and 2016 in Streaky Bay, B) 2015 and 2017 in Smoky Bay, and C) 2015 and 2018 in Venus Bay; whites (*K. peronii*; white bars) was also obtained for Venus Bay. The vertical dashed line indicates the MLL of 30 mm SL. Transects were sampled consistently between surveys allowing for direct comparison (N_{2016} = 42; N_{2017} = 53; N_{2018} = 98 transects). Note scales on y-axes vary between species but not among years.

Table 6. West Coast Fishing Zone estimated total harvestable biomass (t, whole weight) 10-90% quantiles using aged for greys (*K. scalarina*); yellows (*K. rhytiphora*) and whites (*K. peronii*) in A) February 2017 at Streaky Bay, B) February 2018 at Smoky Bay, C) September 2018 at Venus Bay. Minimum legal lengths for each species was 30 mm SL. Bold indicates total harvestable biomass estimates for each bay.

Streaky Bay 2016

Species	Probability (%) of legal biomass estimate (t)								
	90%	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
Greys *(K. scalarina)*	160.4	181.4	197.7	211.6	225.0	238.7	254.1	271.9	297.0
Yellows *(K. rhytiphora)*	43.9	55.0	63.8	71.3	78.6	86.1	94.3	104.2	118.2
Whites *(K. peronii)*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**204.3**	**236.4**	**261.5**	**282.9**	**303.5**	**324.8**	**348.3**	**376.1**	**415.2**

Smoky Bay 2017

Species	Probability (%) of legal biomass estimate (t)								
	90%	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
Greys *(K. scalarina)*	51.0	57.8	62.9	67.3	71.6	76.1	80.8	86.5	94.4
Yellows *(K. rhytiphora)*	44.4	51.2	57.0	62.2	67.4	72.8	79.0	86.6	97.4
Whites *(K. peronii)*	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.5
Total	**95.5**	**109.1**	**120.1**	**129.7**	**139.3**	**149.1**	**160.1**	**173.4**	**192.2**

Venus Bay 2018

Species	Probability (%) of legal biomass estimate (t)								
	90%	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
Greys *(K. scalarina)*	40.6	43.4	45.5	47.3	49.0	50.7	52.5	54.7	57.7
Yellows *(K. rhytiphora)*	14.5	16.3	17.6	18.7	19.9	21.0	22.3	23.8	26.0
Whites *(K. peronii)*	12.6	15.8	20.8	28.9	31.7	34.3	38.6	47.5	53.3
Total	**67.7**	**75.6**	**78.9**	**94.9**	**100.6**	**106.0**	**113.4**	**126.0**	**137.0**

4. DISCUSSION

4.1 Current status

4.1.1 Coffin Bay

Vongole recruitment is episodic (Warner and Chesson 1985; Sakurai *et al.* 1998; Ripley and Caswell 2006, Cantin 2010, Dent et al. 2016). The length-frequency distributions show no evidence that recruitment has been impaired with evidence of recent recruitment of greys in 2015 and 2018, and yellows in 2015, 2016 and 2018. However, the datasets demonstrate long-term reductions in the abundance of both legal and large Vongole. Between 2015 and 2018, the decline for legal-sized yellows was 42% and legal-sized greys was 28%. From 2011 to 2018, the decline was 70% for legal-sized yellows and 80% for greys. Declines between 2011 and 2018 were slightly higher for large Vongole (yellows: 76%, greys: 89%).

Recent estimates of density for greys and yellows were among the lowest recorded. The density of yellows in 2018 was about 70% lower than those in 2011 and 2013. For greys, the 2018 estimate was about 30% of that in 2011. For both species, there was a long-term reduction in the frequency of transects with high Vongole densities.

The harvestable biomass continues to be dominated by yellows, with a small contribution from greys, which reflects the localised, higher densities of the larger yellows compared with the more broadly distributed and smaller greys. The median harvestable biomass estimates (50% quantile) were 999.2 t, 1,092.9 t and 739.9 t for 2016, 2017 and 2018, respectively. Similar trends were evident at other quantiles.

The differences in harvestable biomass between years reflect changes in the survey design as well as changes in Vongole abundance. Separating changes in harvestable biomass from changes in the sampling design was done in two ways. First, those transects sampled in 2016, 2017 and 2018 were used to re-estimate median harvestable biomass from 2015. The analysis showed (1) similar biomass between 2015 and 2016, (2) a 110 t (9%) decline from 2015 to 2017, and (3) a 211 t (22%) decrease from 2015 to 2018. Second, transects sampled in 2016, 2017 and 2018 were used with the 2013 and 2015 data to quantify the influence of the sampling program on estimates of harvestable biomass. These impacts ranged from one to -23%. Using the percentage difference of the sampling program as a crude correction factors to adjust the estimates for 2016 – 2018 resulted in estimates of median harvestable biomass of 1204.8 t in 2016, 1078.8 t in 2017 and 942.5 t in 2018. This suggests that harvestable biomass has reduced

by 22% over the past three surveys. The 'adjusted' value for 2018 of 942.5 t is 18% below that from the last complete survey in 2015 (1,148 t, Dent et al. 2016).

Outputs from the cMSY model are plausible, and consistent with the trends in density and biomass from the survey program. The model estimated biomass in 2018 was ~750 t which was similar to the survey (740 t) and corrected survey (942 t) estimates. Model outputs show a consistent decline in biomass from 2015 and indicate an MSY of approximately 30 t which is 60% of the current TACC (50 t). The model also indicates harvest fractions of <5% are suitable.

Despite current harvest fractions being considered conservative (PIRSA 2013), there is evidence that Vongole density and harvestable biomass have declined over recent years. This evidence includes (1) the 22% decline in biomass from 2015 to 2018, (2) a large reduction in frequencies of legal and large Vongole in 2018 compared to historical values, (3) reductions in Vongole density and frequency of transects with high densities between 2009 and 2018, and (4) outputs from the cMSY model indicating that catches have exceeded MSY. On the basis of the evidence available, the Coffin Bay Vongole Fishery in 2018/19 is classified as **'depleting'**, reflecting a change from a 'sustainable' classification in 2017/18. A full survey of all fishing grounds in planned for 2020/21.

4.1.2 West Coast

The median estimates of harvestable biomass were highest in Streaky Bay (2016: 303.5 t) and lowest in Venus Bay (2018: 100.6 t), with a harvestable biomass in Smoky Bay in 2017 of 139.3 t. It is notable that there is evidence of recent recruitment for most species in most bays. The exception was for yellows in Streaky Bay. Determining a combined estimate of harvestable biomass across the West Coast Fishing Zone was not appropriate because of the age of data from Streaky Bay (2016) and Smoky Bay (2017). There is insufficient information, either directly or via proxy, for estimating biomass or fishing mortality that are required for classifying stock status under the NFSRF because there is no estimate of total biomass or trends in biomass for the zone. Consequently, the West Coast Vongole Fishery in 2018/19 is classified as **'undefined'**, reflecting a change from the 'sustainable' classification in 2017/18. A full survey of all three bays in planned for 2021/22, which will then allow status to be re-determined.

4.2 Uncertainty in the assessment of density, biomass and recruitment

The most significant contributor to uncertainty around the assessment of the stock status of the South Australian Vongole Fishery has been the modifications to the fishery-independent surveys from 2016 onwards. The increased uncertainty reflects the change from biennial complete sampling to a triennial, rotational sampling program. This change complicated comparisons

among recent years and detection of inter-annual patterns. Fishers also identified that an area of Coffin Bay with high Vongole densities, that was a current focus during commercial fishing activity but has yet to be confirmed by sampling, was located outside the surveyed area. The biomass in this area would not be accounted for in the estimates of biomass. For the West Coast, there was also increased uncertainty under the triennial sampling program because each bay was surveyed in a different year, resulting in aged data that prevented calculation of both the total harvestable biomass estimate and the harvest fraction.

There are other contributors to uncertainty of the harvestable biomass estimates. These include (1) commercial fishers sampling using Vongole rakes of varying design, in addition to possible differences in operator efficiency, which are currently unaccounted for in results and analyses, and (2) the current Management Plan (PIRSA 2013) not identifying performance indicators and/or trigger or limit reference points below which the stock would be classified as 'depleting' or 'depleted' under the national stock status framework (Stewardson *et al.* 2018). The absence of definitions means this assessment uses a 'weight-of-evidence' approach to determine stock status. Further, identifying temporal changes for a species with a highly heterogeneous distribution and a high number of zero density values, such as Vongole, is complex, and likely requires the development of assessment techniques beyond typical comparisons using means +/- SE that are applicable for normally distributed data. There is also uncertainty associated with the cMSY model. This is because (1) these models rely solely on catch data and can only successfully be applied when population responses to exploitation are evident in the catch history, (2) they have more limited application for quota-managed fisheries (though estimates of MSY, B_{MSY} and H_{MSY} were similar when the model was applied to a truncated dataset ending 2011), and (3) model was for three species combined. Given this uncertainty, particularly the catch history for a species reflecting the consequence of a multiplicity of factors, not just the influence of the fishery on the population, the resulting estimates of population parameters in terms of stock dynamics should be interpreted cautiously.

4.3 Future research needs

The most important component of future research is to establish a consistent survey sampling program for the West Coast and Coffin Bay. This is because sustainable management of the stock requires a robust time series of harvestable biomass estimates that are readily comparable among years. A consistent survey design would also overcome a key challenge identified in this report which is uncertain and potentially biased estimates of harvestable biomass from changes to the survey design across years. The most appropriate sampling program would be to sample

all established transects annually or biennially (i.e. 2015 sampling program) in both fishing zones, with a periodic review to ensure all fishing grounds remain captured. However, given the dominance of yellows in Coffin Bay and the current low level of resourcing, a reduced but consistent sampling program that prioritises reduction in the uncertainty of the biomass estimates of yellows would be more appropriate than the current triennial sampling program.

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6. APPENDICES

6.1.   Appendix 1 – Coffin Bay historical density

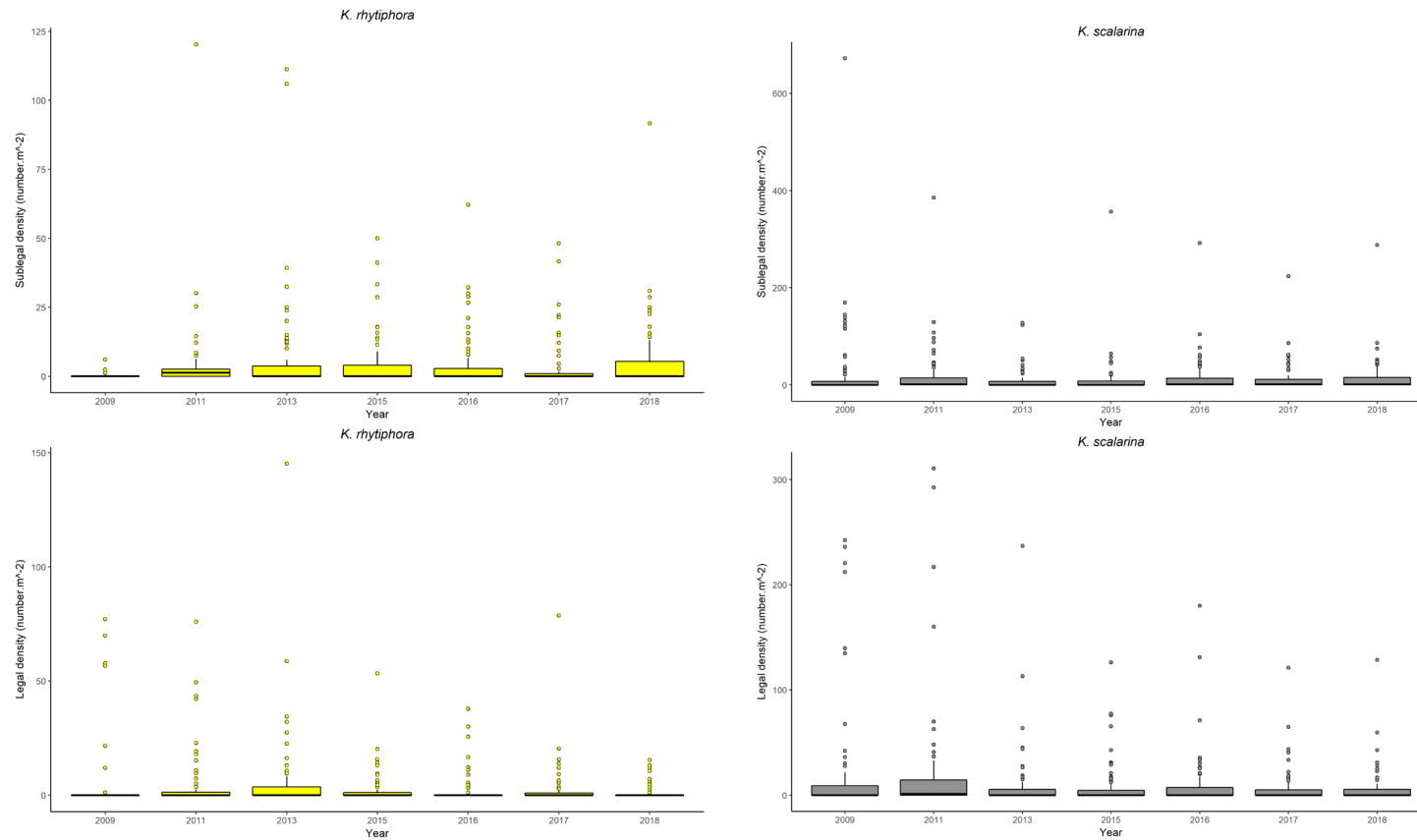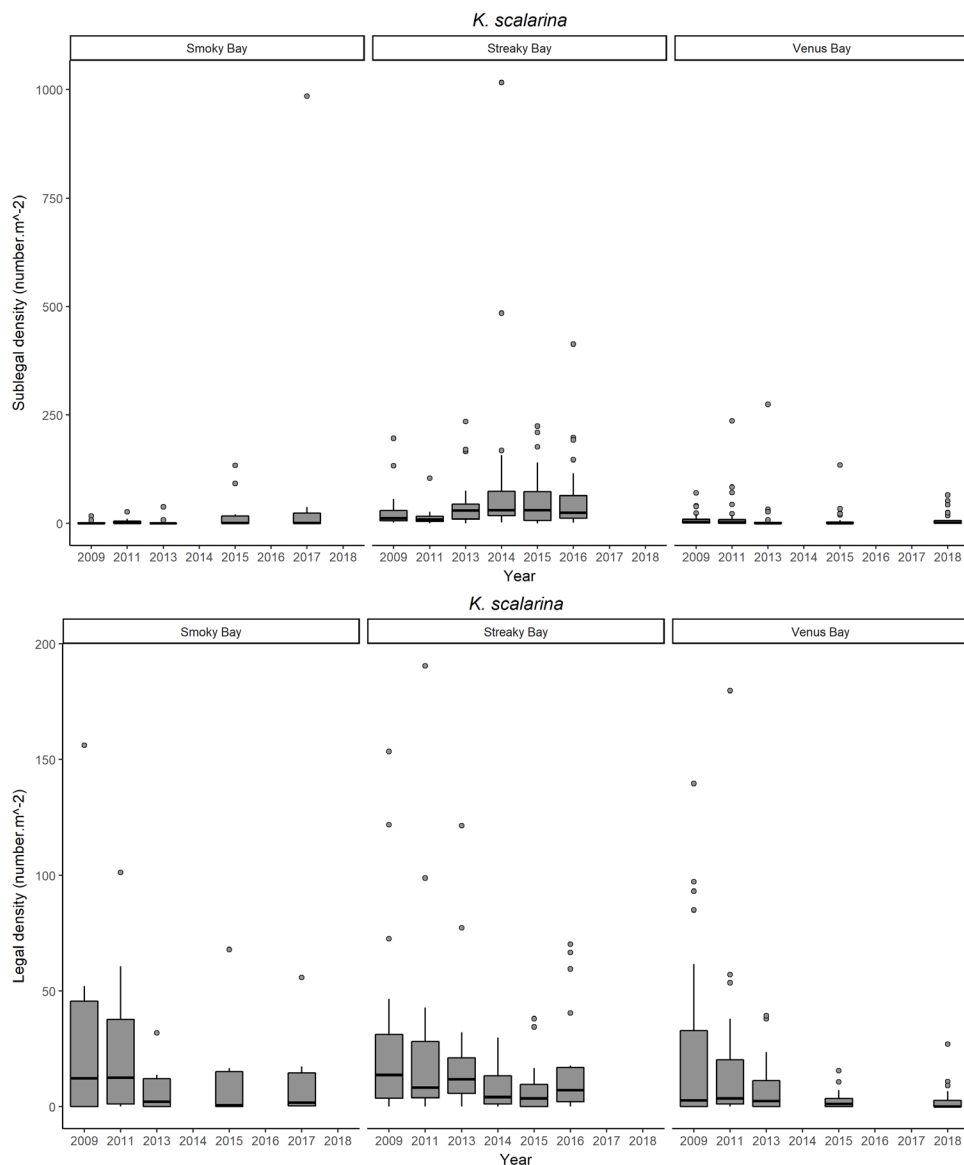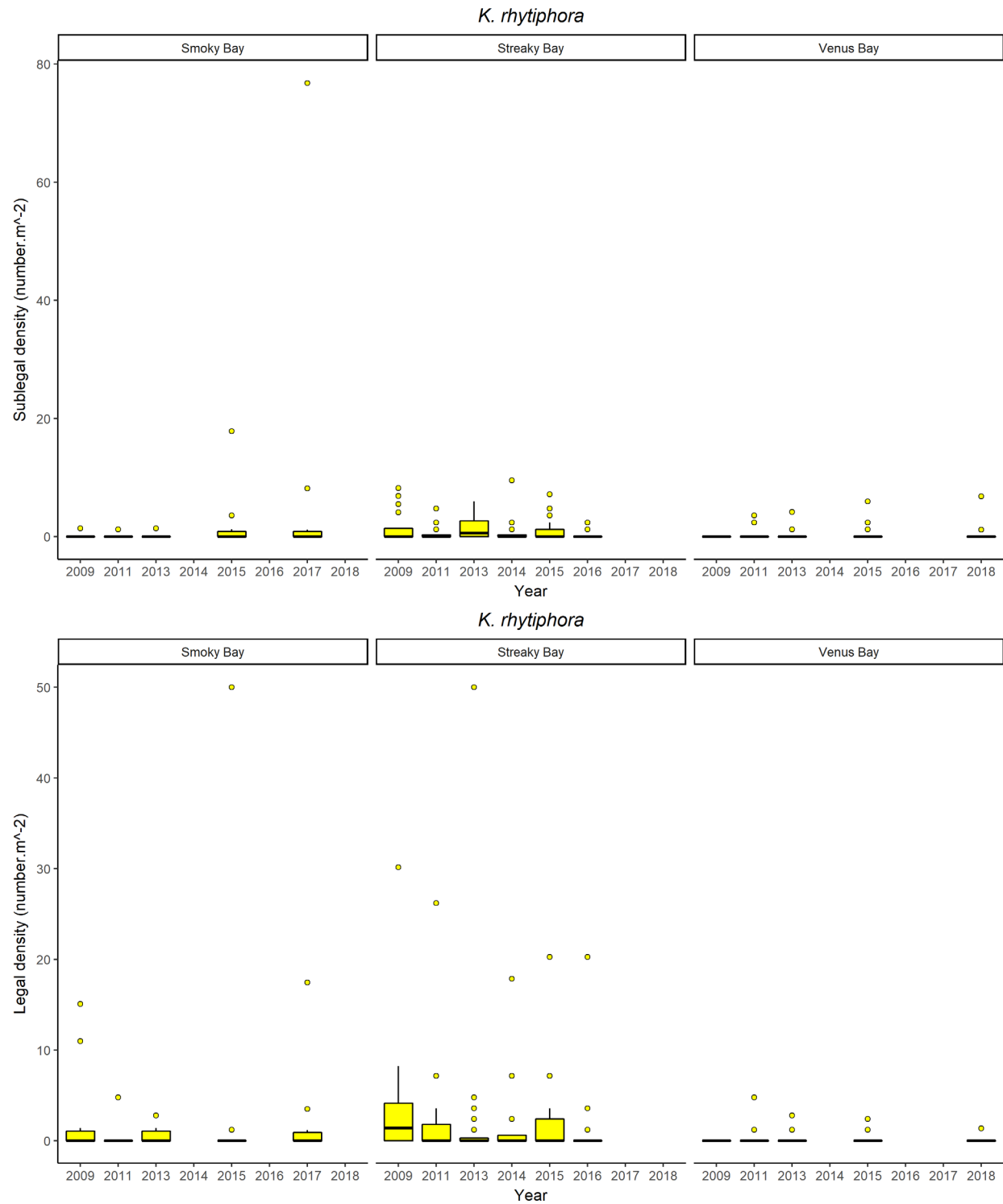**Figure A1**. Legal and sub-legal density boxplots(Vongole.m⁻²) of yellows (*K. rhytiphora*; yellow) and greys (*K. scalarina*; grey) in Coffin Bay from 79 transects sampled consistently across years (except for 2009 which consists of 49 transects).

6.2.   Appendix 2 – West Coast historical density

Trends in densities, calculated using consistent transects, varied through time, and in most cases, legal densities in recent years remained lower than historical densities. Sub-legal densities exhibited different trends to those of legal densities. The number of transects sampled consistently across years was 20 for Streaky Bay, 10 for Smoky Bay, and 31 for Venus Bay. Legal density estimates for the pre-dieoff in November 2013 and post-dieoff in February 2014 for Streaky Bay are included below (Dent et al. 2014).
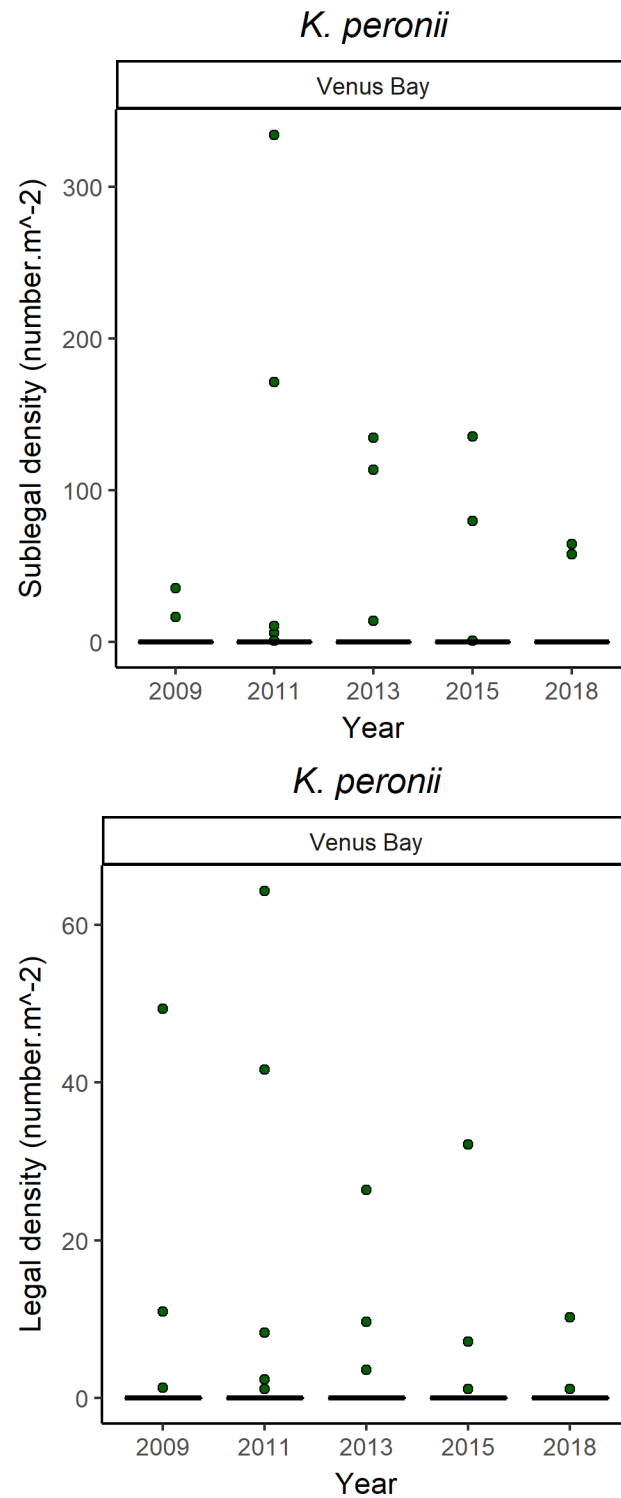
K. rhytiphora

K. rhytiphora

Figure A2. Historical density boxplots (Vongole.m^{-2}) of sub-legal and legal Vongole for each species in the West Coast Fishing Zones using consistent transects from 2009 to 2018. Note scales on y-axes vary between species and fishing zones.

6.3.   Appendix 3 – West Coast historical length-frequency

Trends in length-frequency through time, calculated using transects consistent across years. Recruitment in recent years varied across species and bays. The number of transects sampled consistently across years was 20 for Streaky Bay, 10 for Smoky Bay, and 31 for Venus Bay. Both the pre die-off November 2013 and post die-off February 2014 data for Streaky Bay were included, reflecting the additional sampling undertaken to quantify the mortality (Dent et al. 2014).

A) Streaky Bay
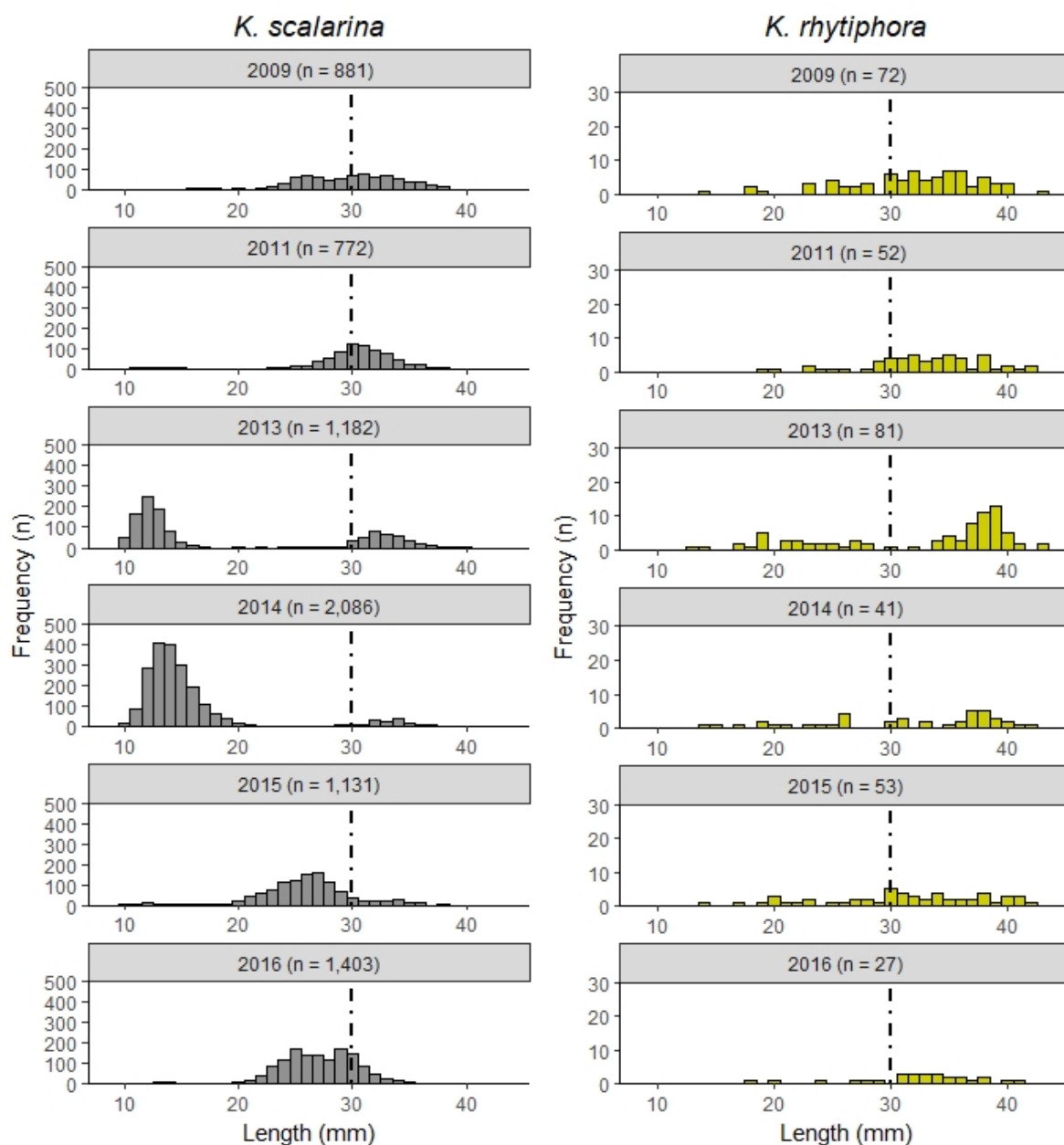
B) Smoky Bay
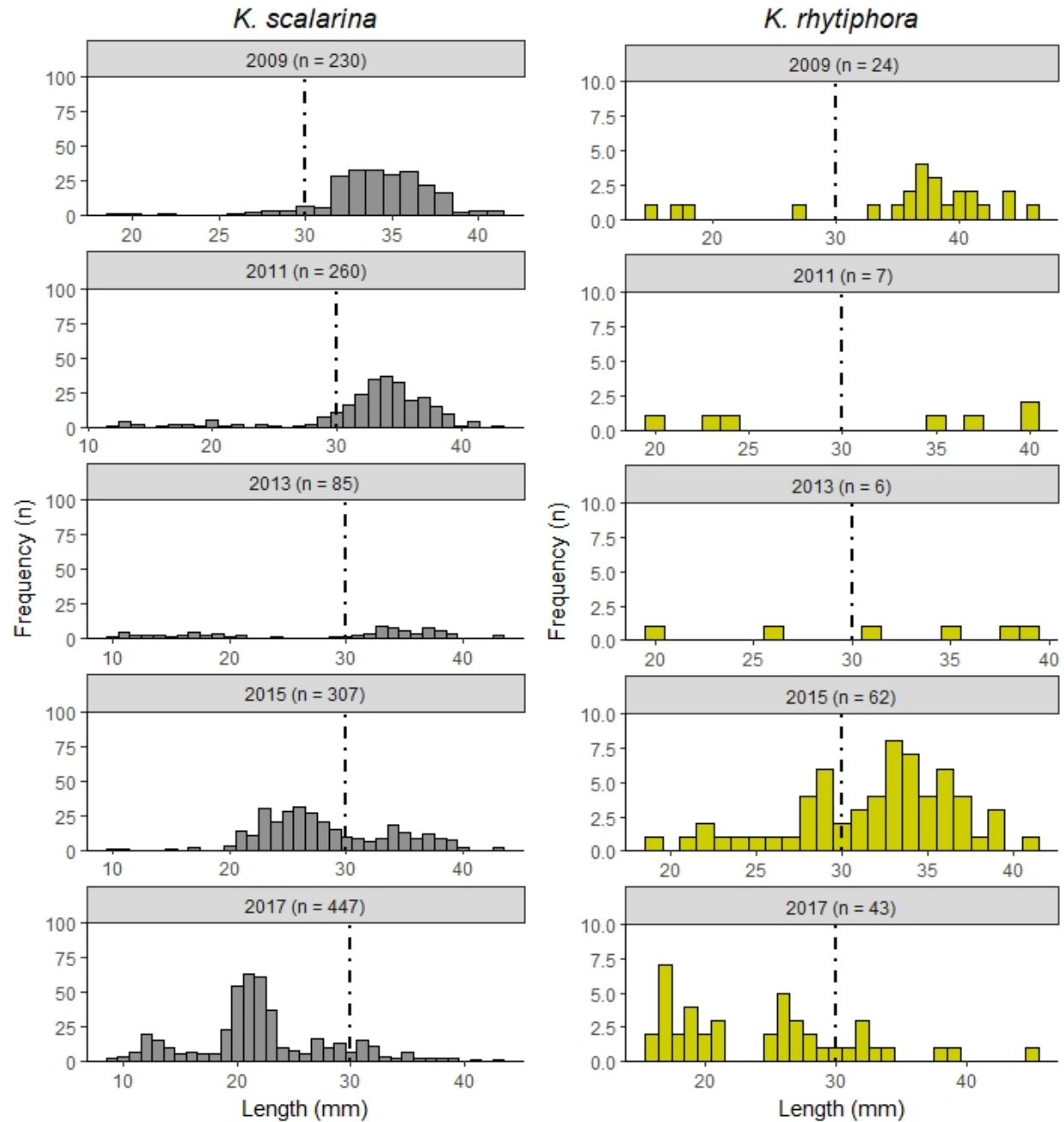
C) Venus Bay

Figure A3. Historical length-frequency for each species (n = number of individuals measured) in A) Coffin Bay and the West Coast, B) Streaky Bay, C) Smoky Bay, and D) Venus Bay using consistent transects from 2009 to 2018. Note scales on y-axes vary among species and fishing zones.

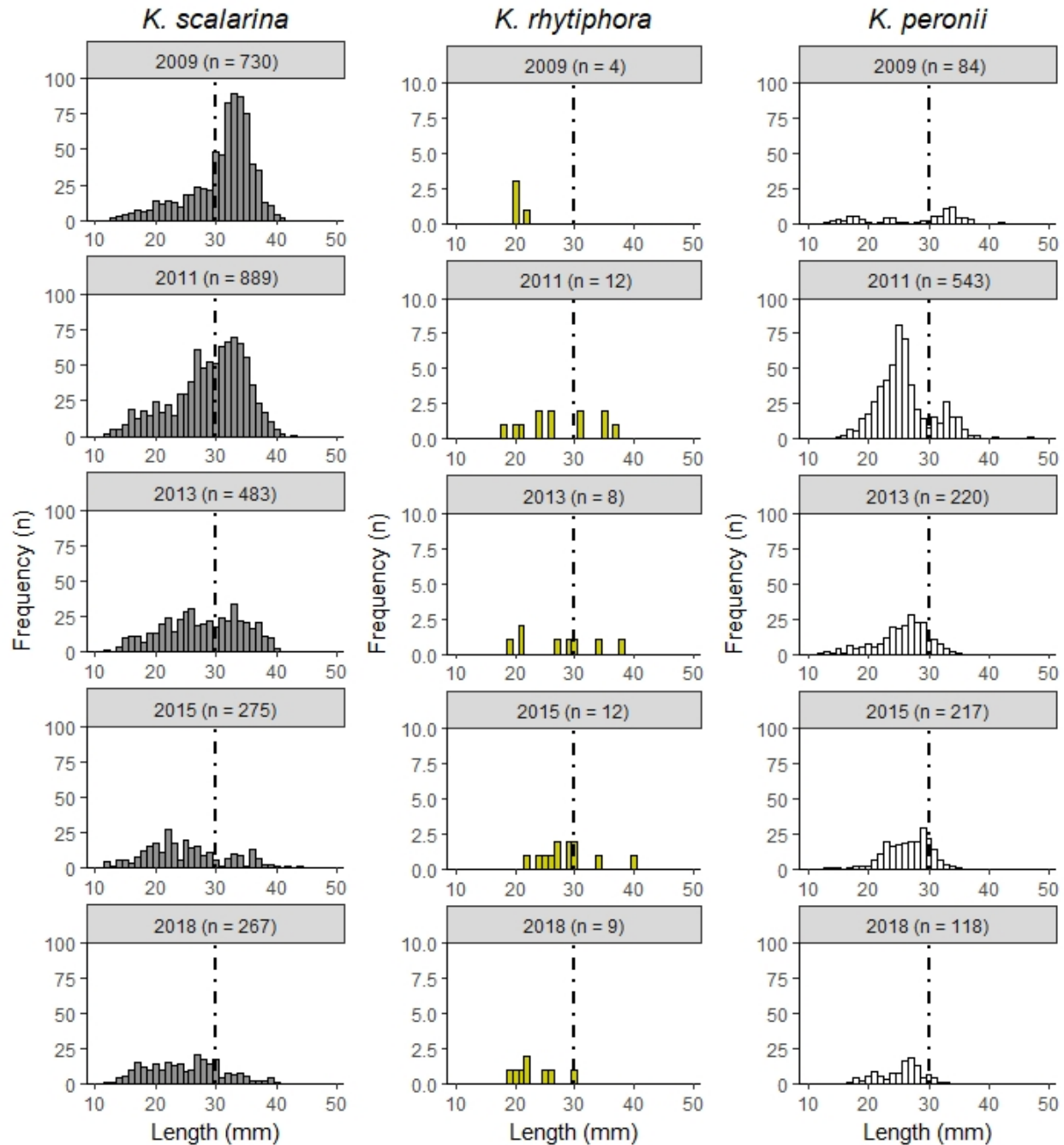## 6.4.   Appendix 4 - Length-weight relationships and harvestable biomass

Length-weight relationships differed among bays for whites and yellows, but not for greys (Figure A4). In each bay, sampling captured different numbers of individuals (e.g. Smoky yellows n = 816 and greys n = 2,418 and, Venus yellows n = 472 and greys n = 1,183). In addition, sampling captured different size ranges of whites, while greys and yellows size ranges were similar across bays. For example, in Coffin Bay, samples of yellows and Greys contained the widest range of lengths from ~ 10 to 50 mm SL (n = 1,548) and ~10 to 40 mm SL (n = 2,476), respectively (Figure A3). Whites sizes were ~ 5 to 35 mm SL in Smoky Bay in 2017 (Figure A3, n = 56) while sizes were ~ 10 to 40 SL in Venus Bay in 2018 (Figure A4C, n = 1,282). In contrast, the whites length-weight relationship was based on ~20 to 40 mm SL individuals in Coffin Bay (n = 26; Figure A4). Relationships were not established for Streaky Bay as individuals were not individually weighed.

In Coffin Bay, 2017 length-weight relationships differed slightly among fishing grounds (Figure A5). Greys length-weight relationships did not differ among fishing grounds while yellows length-weight relationships were similar between Oyster Farms and Long Beach, which differed slightly from Point Longnose and Little Douglas. Use of length-weight relationships showed that 2015 harvestable biomass estimates, calculated using 2017 weight estimates from power regression, were within 9 t of 2015 harvestable biomass estimates (e.g. manually measured weights). Harvestable biomass estimates using power regression specific to species and fishing ground were more accurate (i.e. 1 t > 2015 harvestable biomass estimates) than power regression only specific to species (i.e. 9 t < 2015 harvestable biomass estimates), primarily due to differences among fishing grounds for yellows.

Harvestable biomass estimates calculated using estimated weights from length-weight relationship models (i.e. power regression) were similar to those from harvestable biomass estimates calculated using weights measured in the laboratory. Estimates of harvestable biomass using length-weight relationships were found to be more efficient and cost effective.

Table A1. Coffin Bay 2015 harvestable biomass estimates calculated using weights from 2017 length-weight relationships (e.g. power regression) established for each species in Coffin Bay.

Coffin Bay 2015 by species

Species	Probability (%) of legal biomass estimate (t)								
	90%	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
Greys *(K. scalarina)*	103.6	112.6	119.2	125.0	130.8	136.6	142.9	150.5	161.5
Yellows *(K. rhytiphora)*	616.5	746.3	844.8	932.3	1012.8	1098.6	1191.3	1304.7	1463.7
Whites *(K. peronii)*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**720.1**	**858.9**	**946.0**	**1057.3**	**1143.6**	**1235.2**	**1334.2**	**1455.2**	**1625.2**

Table A2. Coffin Bay 2015 harvestable biomass estimates calculated using weights from 2017 length-weight relationships (e.g. power regression) established for each species and fishing ground in Coffin Bay. Note that whites data are not presented by fishing ground due to low sample size.

Coffin Bay by species and fishing ground*

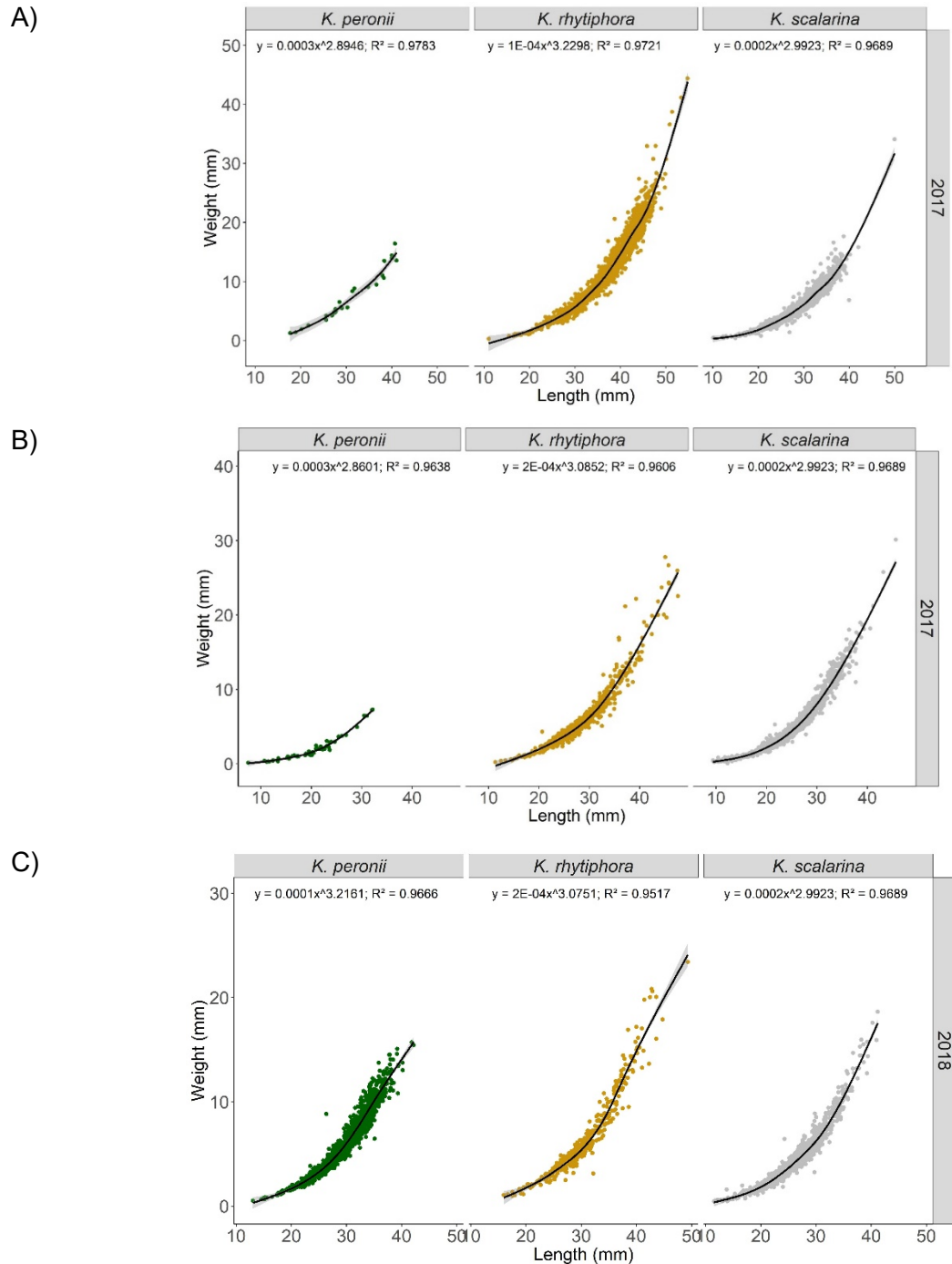| Species	Probability (%) of legal biomass estimate (t)								
	90%	**80%**	**70%**	**60%**	**50%**	**40%**	**30%**	**20%**	**10%**
Greys *(K. scalarina)*	103.8	112.6	119.0	124.8	130.4	136.2	142.6	150.3	161.3
Yellows *(K. rhytiphora)*	624.8	756.2	856.9	943.0	1026.5	1114.1	1208.2	1323.0	1485.4
Whites *(K. peronii)*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**728.6**	**868.8**	**975.9**	**1067.8**	**1156.9**	**1250.3**	**1350.8**	**1473.3**	**1646.7**

A)

B)

C)

Figure A4. Length-weight relationships for yellows (*K. rhytiphora*; yellow circles), greys (*K. scalarina*; grey circles), and whites (*K. peronii*; green circles) in A) Coffin Bay 2017, B) Smoky Bay 2017, and C) Venus Bay 2018. Relationships were not established for Streaky Bay as individuals were not individually weighed.
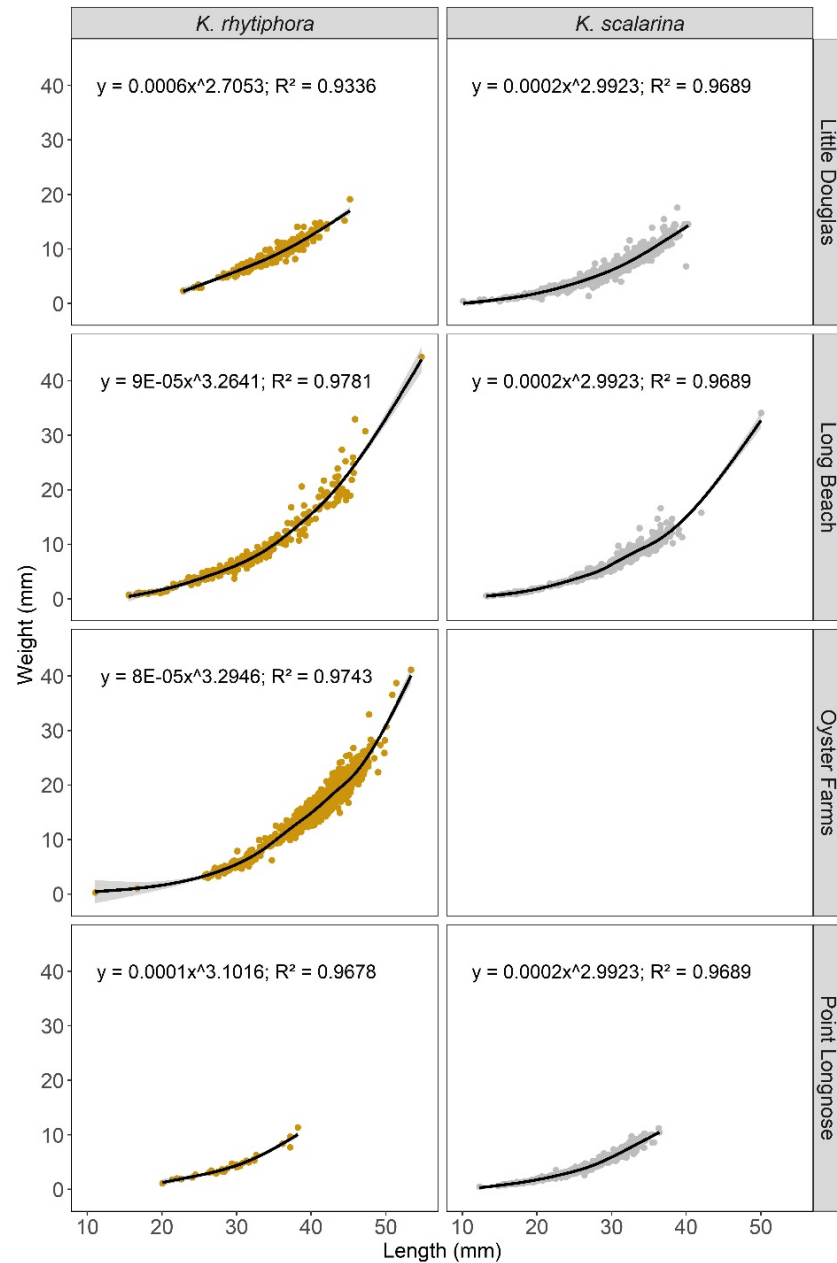
Figure A5. Length-weight relationships in 2017 for yellows (*K. rhytiphora*; yellow circles) and greys (*K. scalarina*; grey circles) by fishing ground (i.e. Point Longnose, Little Douglas, Oyster Farms and Long Beach in Coffin Bay). Note that greys was not present in Oyster Farms in 2017.