Three Year Comprehensive Review of the Live Wrasse Fishery in Devon and Severn IFCA's District

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Contents

Executive Summary

A fishery for the live capture of wrasse for use as cleaner fish in Scottish salmon farms developed in the Devon and Severn Inshore Fisheries and Conservation Authority's (D&S IFCA's) District in 2015. Management was introduced in 2017 via the D&S IFCA Potting Permit Byelaw. These early management measures were largely based on best practice identified in the literature and included minimum and maximum Conservation References Sizes (CRSs), a closed season and a cap on effort. A fully documented fishery was also implemented and as such an intensive data collection programme has been conducted since 2017, consisting of on-board observer surveys and fishers' landings forms. A comprehensive review of the fishery for the 2017–2019 period has been undertaken and the results are presented in this report. This revised version of the report has been prepared as a result of sharing anonymised data with Lauren Henly, which she reviewed and re-analysed using the methods set out in the report. The data review process incorporated cross-checking and verification of data sources, which resulted in small changes to the results of the data analyses. These changes are reflected in this report, but the overall conclusions and recommendations are the same as those presented in version 1.5 of the Three Year Comprehensive Review of the Live Wrasse Fishery in D&S IFCA's District.

D&S IFCA's Environment Officers achieved a 9% coverage of days fished with on-board observer surveys, though observer coverage varied substantially between vessels and months for logistical reasons. On-board observer surveys have enabled D&S IFCA Officers to assess, in detail, the catch and landings of the fishery on a species-by-species basis, including detail regarding the size and spawning state of these species. The other primary source of data was landings forms, completed and submitted by fishers. These allow D&S IFCA to assess spatial and temporal patterns in reported effort and landings for the fishery as a whole. These data sources have enabled D&S IFCA to monitor and evaluate the status of the fishery, but this process is at risk due to repeated non-compliance issues, which relate primarily to a single fisher. In future, the obligations of fishers under Paragraph 17 of the Potting Permit Byelaw ('the permit holder shall provide any relevant fisheries information required by the Authority for the discharge of its functions') need to be reiterated and fully enforced to ensure compliance with this Byelaw condition, and enable accurate monitoring of the fishery.

Over the fishery as a whole, Landings Per Unit Effort (LPUE) and Catch Per Unit Effort (CPUE) have remained stable over the 2017–2019 period, indicating that the fishery as a whole is not overexploited and that the current management measures are an effective way to manage the fishery. However, the fishery-level measures of LPUE and CPUE mask other patterns at the species level, which need to be considered in more detail. LPUE and CPUE for ballan and goldsinny wrasse have remained stable through 2017–2019, while stable LPUE and increasing CPUE for corkwing suggests no detrimental effects of fishing on these species in the District. Both LPUE and CPUE have declined for rock cook, which is a cause for concern for this species, particularly as the fishery to date has been targeting the larger size classes.

The size class distributions for the majority of species appear to have remained stable for the 2017–2019 period, though assemblage composition over the three-year period appears

to have changed as the catches of rock cook have declined and catches of corkwing have increased. Declines in CPUE for rock cook are somewhat surprising, given that most are below the minimum CRS, and are therefore returned to the sea. Fisheries-independent data, such as mark-release-recapture studies, would be beneficial to establish mortality rates of returned wrasse, but this would require significant extra resource which is not currently available to D&S IFCA. Other requirements for a better understanding of the wrasse populations and fishery include a more detailed knowledge of the impacts of environmental drivers on local wrasse abundance, as well as additional survey effort – distributed evenly across the year – in order to more accurately detect spawning activity. The spawning data currently suggest that the number of individuals that are observed to be spawning has varied between years. However, due to the nature and timing of wrasse spawning, it is not currently possible to confirm if the observed changes in spawning are real phenomena or simply an 'artefact' of the temporally uneven observer effort achieved by D&S IFCA's Officers. Additional survey effort is beyond the current resource capabilities of D&S IFCA's Officers. Nonetheless, it is recommended that observer coverage should at least maintain the current effort, but with more even coverage of vessels and months where practicable.

Overall, the fishery is showing promising signs of sustainability and productive management. Given the evidence outlined in this report, the following actions are recommended in order to maintain the environmentally, economically and socially sustainable nature of the live wrasse fishery in D&S IFCA's District:

(i) Continue to manage the fishery as outlined in the D&S IFCA's Policy Statement and Potting Permit Conditions for the Live Wrasse Fishery (1st August 2018), except in the case of rock cook (ii, below)

(ii) In the case of rock cook, all catch taken from within the D&S IFCA's District must be returned to the sea immediately. No rock cook can be retained on board while fishing in the D&S IFCA's District.

(iii) Continue with at least the current level of on-board observer effort for this fishery, and

(iv) To use Paragraph 17 of the Potting Permit Byelaw to formally require relevant fisheries information from fishers.

1. Introduction

As described in the 2018 report, wrasse (Labridae *spp.*) are being commercially targeted for use as a cleaner fish in the Scottish salmon aquaculture industry (Powell *et al.,* 2017; Riley *et al.,* 2017; Curtin and West, 2018). In Devon a fishery targeting live wrasse began in 2015. Four commercial vessels currently operate within Plymouth Sound and the surrounding coastal waters. Four species are targeted; ballan (*Labrus bergylta*), corkwing (*Symphodus melops*), goldsinny (*Ctenolabrus rupetris*) and rock cook (*Centrolabrus exoletus*). As these species have specialised life history traits such as sexual dimorphism, territoriality, small home ranges, nest building and parental care, they may be vulnerable to overexploitation (Darwall *et al.*, 1992; Halvorsen *et al*., 2016). For example, declines in Catch Per Unit Effort (CPUE) over two years in an Irish wrasse fishery have been attributed to reduced wrasse abundance following local overfishing (Darwall *et al.*, 1992).

Devon and Severn Inshore Fisheries and Conservation Authority (D&S IFCA) implemented management measures in June 2017, through the Potting Permit Byelaw permit conditions (Clark and Townsend 2017). These included a fishery limit of 480 pots (currently shared equally among four vessels), Minimum and Maximum conservation reference sizes (Min. and Max. CRSs) for each species landed, temporal and spatial closures and the implementation of a fully documented fishery. As part of this fully documented fishery, an intensive data collection programme has been conducted since 2017 in order to capture spatial and temporal trends in CPUE and Landings Per Unit Effort (LPUE). Specifically, fishers are required to complete landings forms and D&S IFCA's Environment Officers carry out onboard observer surveys.

Since 2017, management measures have been altered to (i) shift the closed season in order to better protect spawning individuals, and (ii) alter the CRSs for corkwing to protect more mature males and juvenile females. Following an initial assessment of CPUE and LPUE differences between 2017 and 2018 (Curtin and West, 2018), the Byelaw and Permitting Sub-Committee agreed to continue the fishery in 2019 with existing management measures, and requested that a comprehensive review be undertaken in February 2020 in order to determine the future of the fishery. This report therefore presents the results of data collected during 2019, assesses changes over the 2017–2019 period, and discusses the causes and implications of these changes.

2. Methods

Data were obtained from two sources: (i) landings data, recorded and submitted by the fishers and (ii) on-board observer surveys, undertaken by D&S IFCA Environment Officers. The relative strengths and weaknesses of these two datasets (described below) are summarised in Table 1. The fishers' data refer to landings only, not total catch: they do not account for the fish returned to the sea, such as those that are above or below the CRSs. Data from the on-board observer surveys (Section 2.2) include numbers of fish caught and retained (landed), and also those returned to the sea. Therefore, fishers' data are reported as landings and observer surveys are reported as catch.

2.1. Landings Data

Fishers completed landings forms which included the total numbers of wrasse retained per trip (total catch, not split by wrasse species), and an estimate of the fishing effort for each trip (pots fished). Fishers often work single-handed, and cannot record the species composition of their catches on-board as they need to keep fish handling and processing time to a minimum. Fishers recorded the spatial distribution of their daily fishing activity relative to a set of 1 km^2 grid cells, but were not required to report their landings on a grid cell by grid cell basis, as this would be disruptive to their normal fishing behaviour. The major strength of the fishers' logbook dataset is that it has the potential to record every day of fishing activity, and results in the documentation of all retained wrasse. These logbooks allow for the continuation of data collection when on-board observer surveys cannot be carried out due to weather or logistical constraints, and for boats which are too small to host an observer. The spatial information permits an assessment of fishers' compliance with voluntary closed areas.

Table 1. Summary of data obtained via landings data and on-board observer surveys

Fisheries data	Landings data (from fishers)	On-board observer surveys
Data from every day of fishing effort	✓	
Fishing effort (no. pots per day)	✓	✓
Daily total number of fish caught	✓	✓
Daily total number of fish returned		✓
Total number of fish caught per string		✓
Spatial LPUE/CPUE		✓
Species-level data recording		✓
Sizes of fish (kept and returned)		✓
Spawning state of fish		✓
Approximate location of fishing effort (1 km^2 grid)	✓	✓
Precise location of fishing effort		✓

2.2 On-board Observer Surveys

Observer surveys were planned to allow approximately a 10% coverage of days fished, with even coverage over the four vessels engaged in the fishery over the survey season. Observer surveys were not conducted between 1 January and 1 May 2019 due to an issue with D&S IFCA's insurance, and the fishery was closed from 1 May to 16 July 2019. Once the fishery reopened, officers' observations took place on the fishers' routine fishing trips between July and December 2019. D&S IFCA officers noted the weather, fishing start and end times, date and tide times, and recorded the start and end position of each string pots with a GPS. Pots were hauled by the fisher and wrasse were emptied into a bucket of seawater. All wrasse were identified to species level, measured, sexed where possible and spawning status was recorded based on the presence of milt or eggs. Individuals within the minimum and maximum CRS were retained in large tanks or barrels with a continuous flow of seawater. Individuals below the Min. CRS and above the Max. CRS were immediately returned to the sea by hand to minimise the risk of predation by seabirds. No observer surveys were carried out for vessel 3 due to onboard space constraints, and ongoing health and safety concerns for D&S IFCA Officers regarding the vessel in question.

2.3. Data Analysis

All data management, plotting and analysis was performed in Microsoft Excel and R statistical software, version 3.5.1 or later (R Core Team, 2018).

2.3.1. Total Landings

Total landings were calculated using the fishers' landings forms, and were verified by transport documents supplied to the Marine Management Organisation (MMO) by the fishers.

2.3.2. Observer Effort

The percentage of observer effort was calculated by the number of days fishing within a month, divided by the number of surveys carried out that month.

2.3.3. Landings Per Unit Effort

Landings Per Unit Effort (LPUE) across the 2017–2019 period were calculated using the fishers' landings forms and therefore only represent fish between the Min. and Max. CRS. Raw data were used to create barplots for each year showing the mean LPUE and standard deviation to indicate variation around each mean. No landings forms were received from vessel 3 for the 2019 period, so landings for this vessel were removed from the 2017–2018 dataset in order to provide a more standardised comparison across years. Mean LPUE for the fleet was calculated as:

$$\text{Mean LPUE} = (L_1+L_2+\ldots L_n)_t / (E_1+E_2+\ldots E_n)_t$$

Where L_1 is the number of wrasse landed by vessel 1, L_2 is the number of wrasse landed by vessel 2, up to vessel n, during time period, t. E_1 is the number of pots fished (effort) by vessel 1, E_2 is the number of pots fished by vessel 2, up to vessel n during time period t.

As fishers are unable to sort their catch by species, LPUE breakdowns for each species were calculated using the catch data obtained during observer surveys (CPUE minus those fish that were returned or dead). This form of LPUE is referred to as Landings Per Unit Effort from catch ($LPUE_{fc}$).

Generalised linear models were used to test for differences in $LPUE_{fc}$ over the 2017–2019 period. Details of this method and model assessment are presented in Appendix 1. In summary, Generalised Linear Models (gamma error structure with identity link function; see Appendix 1) were used to model $LPUE_{fc}$ as a function of year and vessel number. This permits assessment of whether changes in $LPUE_{fc}$ have occurred over the 2017–2019 period, while accounting for changes between years that are due to changes in LPUE across vessels. In two cases (ballan and goldsinny) it was not possible to fit an appropriate model (see Appendix 1) to the data, so a one-way Kruskal-Wallis test was used to assess differences in $LPUE_{fc}$ between 2017, 2018 and 2019. Where the Kruskal-Wallis test suggested a significant difference in $LPUE_{fc}$ between years, post-hoc pairwise tests were used to determine which years were significantly different from others (Dunn 1964). LPUE and $LPUE_{fc}$ for 2017 has been recalculated for this report due to an error in the number of pots recorded in the original dataset. Bar plots were created to show mean LPUE and $LPUE_{fc}$ in each year, with standard deviation as a measure of variability about the mean. Comparisons of fishery-level (non-species-specific) LPUE were conducted using a one-way Kruskal-Wallis and post-hoc pairwise tests.

2.3.4. Catch Per Unit Effort

Catch Per Unit Effort (CPUE) was calculated for every string fished during observer surveys as the total amount of fish caught (including both those kept and those returned) for each string divided by the number of pots in that string. No adjustment was made for the soak time, as a previous pot saturation experiment was unable to confirm whether soak time influences CPUE (Curtin 2018). The string therefore served as the sampling unit or replicate. The CPUE data include all wrasse, including those above and below the Min. and Max. CRS. In previous reports catches in the area of Plymouth Sound that lies within Cornwall IFCA (CIFCA) District were included in the analyses. However, a lack of available data from CIFCA for 2019 led to the removal of all CIFCA from the 2017–2019 dataset. This allows for a more standardised analysis of CPUE changes across years for the D&S IFCA’s District.

Generalised linear models were used to test for differences in CPUE over the 2017–2019 period. Details of this method and model assessment are presented in Appendix 1. In summary, Generalised Linear Models (gamma error structure with identity link function; see Appendix 1) were used to model CPUE as a function of year and vessel number. This permits assessment of whether changes in CPUE have occurred over the 2017–2019 period, while accounting for changes between years that are due to changes in CPUE across vessels. In one case (goldsinny) it was not possible to fit an appropriate model (see Appendix 1) to the data, so a Kruskal-Wallis test to assess differences in CPUE between 2017, 2018 and 2019. Where the Kruskal-Wallis test suggested a significant difference in CPUE between years, post-hoc pairwise tests were used to determine which years were significantly different from others (Dunn 1964). Barplots were created to show mean CPUE in each year, with standard deviation as a measure of variability about the mean. Comparisons of fishery-level (non-species-specific) CPUE were conducted using a one-way ANOVA and post-hoc pairwise tests; for these tests, CPUE was square-root transformed towards normality.

2.3.5. Spatial and Temporal Fishing Effort

Fishing effort was recorded per 1 km^2 grid square based on fishers' landings forms and the GPS coordinates of strings fished during on-board observer surveys. Fishing effort maps were produced in QGIS v3.4, showing the number of pots hauled per grid square.

2.3.6. Catch Composition

Pie charts of catch composition were produced based on the frequency of each species caught during on-board observer surveys. These were projected onto maps of the Plymouth Sound region using QGIS v3.4 to investigate spatial catch composition. Due to inaccurate recording of GPS coordinates, data from one string of pots (from vessel 6 in 2019) were removed from the data used to investigate spatial patterns of effort and catch composition.

2.3.7. Size Frequency

Size frequency histograms were produced to show the number and size of each species that were caught during on-board observer surveys, using size categories of 0.5cm.

2.3.8. Spawning State

The presence of milt or eggs, identified using a technique known as stripping, was used as an indicator of spawning for each individual fish caught during on-board observer surveys in the D&S IFCA's District. These data were collected at every available opportunity, but logistical constraints prevented uniform collection of these data for every fish. The number of spawning individuals of each species was plotted for each year in the 2017–2019 period.

3. Results

3.1. Total Landings

Based on fishers' landings forms, a total of 9,155 wrasse (excluding cuckoo wrasse) have been recorded as landed from the three vessels which fished in the D&S IFCA's portion of Plymouth Sound between March and mid December 2019 and returned landings forms to D&S IFCA (Table 2). No landings data were available for Vessel 3. These 9,155 wrasse represent 50.5% of the total wrasse landed from Plymouth Sound: sales notes, supplied to the MMO by the salmon farm company, indicate that 18,120 fish were landed, which include landings from vessel 3 and from vessels operating in Plymouth Sound within the CIFCA District. However, the sales notes only cover the period April – October 2019. Of the landed fish, 0.6% were dead on arrival, 0.5% were damaged, and none were undersized (Table 3). Additional mortalities may have occurred in holding pens before loading to transport, but these data are unavailable.

Table 2. Landings data (number of fish retained) from the fishers' landings forms.

	Date		Returns
Vessel	First entry	Last entry	Total
Vessel 2	15/03/2019	28/10/2019	1,363
Vessel 4	22/03/2019	07/12/2019	1,849
Vessel 6	15/08/2019	12/12/2019	5,943
Totals			**9,155**

3.2. Survey Effort

In 2017, 5.5% of fishing trips in the D&S IFCA's District had an observer onboard. This rose to 12% in 2018. It was agreed by members of the D&S IFCA that survey effort should remain the same in 2019. Whilst survey effort was planned to achieve this level during the sampling period, only 9% of fishing trips in the D&S IFCA's District during the March to December 2019 period had an observer onboard (Table 4). The reduction in survey effort was due to an issue with D&S IFCA's insurance which resulted in no observer surveys being conducted during March or April 2019. Observer effort remained at 12% for the months May–December, in which it was possible to conduct surveys.

Whilst survey effort was planned to achieve even coverage across the four vessels, observer coverage varied from 4–15% of trips per vessel (Table 4). This uneven coverage was caused by unexpected variation in vessel availability due to vessel maintenance, interruption of planned surveys by inclement weather, and difficulties in coordinating officer availability with sporadic fishing activity on an *ad hoc* basis. Vessel 3 was deemed to be unsafe for observer surveys, so observations were planned using D&S IFCA's RIB David Rowe. However, a combination of inclement weather and difficulties in communicating with vessel 3 meant that no surveys were conducted for vessel 3. Despite these challenges, ten surveys were undertaken across three vessels between July and December 2019 (Table 5).

Table 3. Transport data taken from the sales notes of the number of wrasse species landed per vessel and the total number of payable fish. Sales notes were provided by the Marine Management Organisation. Figures and dates in green represent ballan landings only.

	Number of fish loaded per vessel								
Transport Date	**Vessel 2**	**Vessel 3**	**Vessel 4**	**Vessel 6**	**Total Landed**	**No. of fish dead on arrival**	**No. of fish damaged**	**No. of undersized fish**	**Total amount of payable fish**
11/04/2019	58	163	126	0	347	0	9	0	338
27/04/2019	92	125	104	0	321	0	15	0	306
27/05/2019	69	142	60	0	271	0	15	0	256
16/07/2019	247	186	65	0	498	0	0	0	498
04/08/2019	295	1002	0	0	1297	0	0	0	1297
18/08/2019	64	690	0	87	841	5	0	0	836
25/08/2019	171	747	168	55	1141	9	0	0	1132
01/09/2019	281	718	735	300	2034	32	0	0	2002
08/09/2019	524	1002	978	600	3104	0	60	0	3044
15/09/2019	282	848	853	630	2613	0	0	0	2613
25/09/2019	185	560	808	1034	2587	62	0	0	2525
13/10/2019	0	723	1030	730	2483	0	0	0	2483
Totals	**2268**	**6,906**	**4,927**	**3436**	**17,537**	**108**	**99**	**0**	**17,330**
Mixed species FOC 11/04/2019					400				
Mixed species FOC 27/04/2019					183				
New total	**2268**	**6906**	**4927**	**3436**	**18,120**	**108**	**99**	**0**	**17330**

Table 4. Survey effort coverage per vessel for March to December 2019.

Vessel	Days fished	Surveys	Observer coverage (%)
Vessel 2	47	2	4
Vessel 4	27	4	15
Vessel 6	42	4	10
All vessels	**116**	**10**	**9**

Table 5. On-board observer surveys completed during 2019.

Vessel	Date	Month
Vessel 2	24/07/2019	July
Vessel 6	27/08/2019	August
Vessel 4	13/09/2019	September
Vessel 6	13/09/2019	
Vessel 2	16/09/2019	
Vessel 4	02/10/2019	October
Vessel 4	22/10/2019	
Vessel 6	18/11/2019	November
Vessel 4	04/12/2019	December
Vessel 6	05/12/2019	

3.3. Landings Per Unit Effort and Catch Per Unit Effort 2017–2019

3.3.1. Landings Per Unit Effort

LPUE per month for the period July – October 2017–2019 period shows month-to-month variation within years (Figure 1), but has not changed significantly between years over the period 2017–2019 (X^2 =1.82, df=2, p=0.40; Figure 2). The number of days fished declined from 362 in 2017 to 114 in 2018. Effort increased marginally to 116 days in 2019 (Table 4).

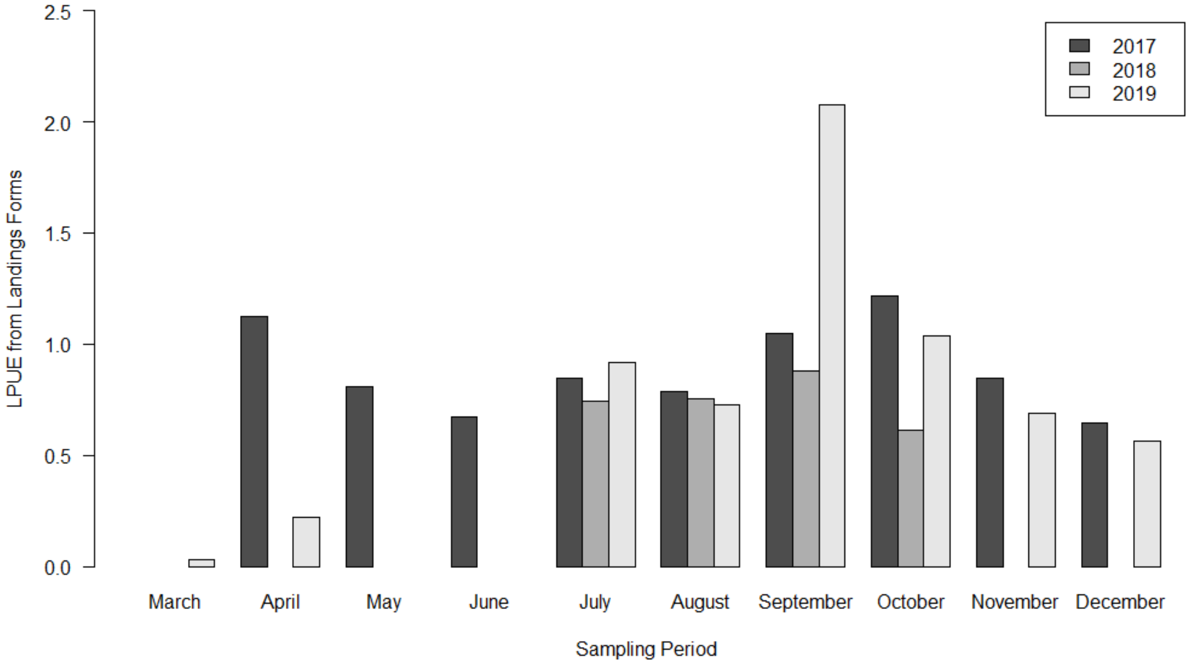

Figure 1. Monthly Landings Per Unit Effort (LPUE) for all species and vessels during 2017, 2018 and 2019. Data taken from the fishers' landings forms excluding vessel 3 data.

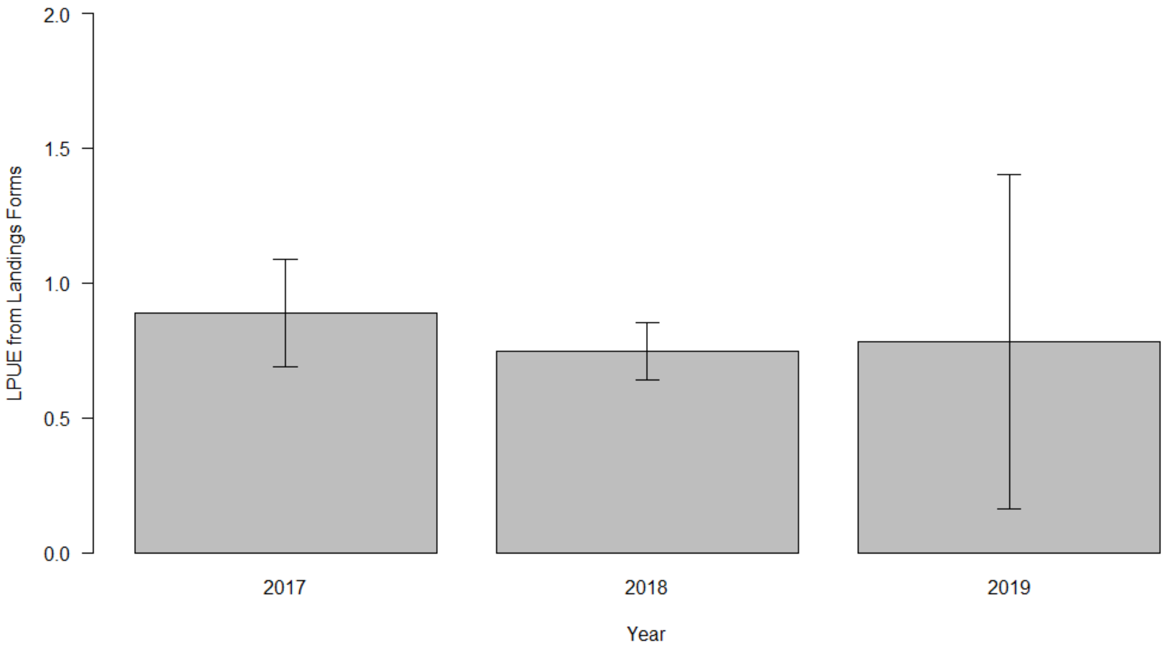

Figure 2. Landings Per Unit Effort (LPUE) (all species), for all vessels during 2017, 2018 and 2019 (mean ± sd). Data taken from the fishers' landings forms excluding vessel 3 data. Kruskal-Wallis test found no significant differences between year (X^2 =1.82, df=2, p=0.40).

3.3.2. *Catch Per Unit Effort*

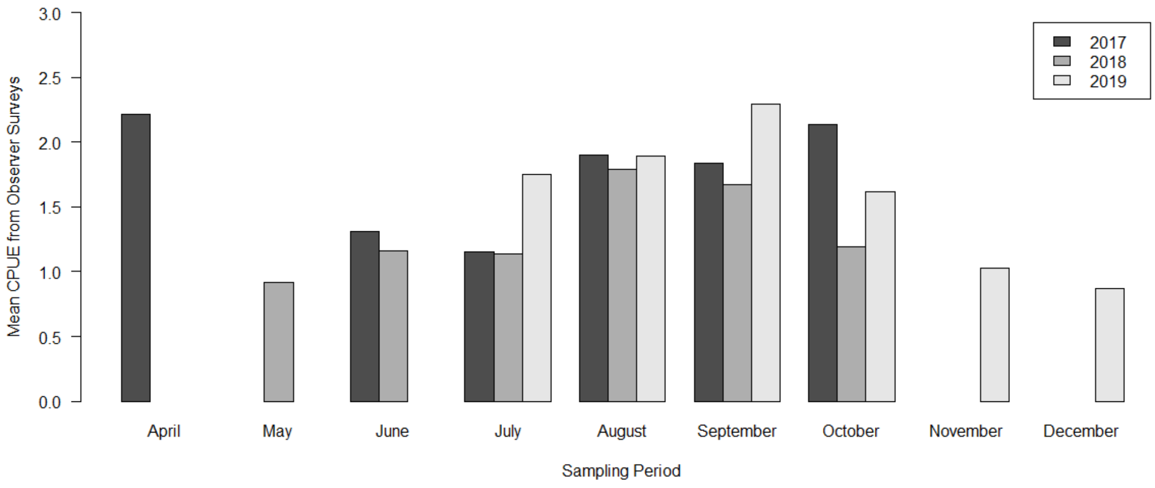

Figure 3. Monthly Catch Per Unit Effort (CPUE) for all species caught during on-board observer surveys across all vessels during 2017, 2018 and 2019.

Mean CPUE also shows considerable month-to-month variation within years but appears to peak in August/September (Figure 3). Mean annual CPUE has not changed significantly across the three-year period, as confirmed by a one-way ANOVA ($F_{2, 147}$ = 0.754, p = 0.472; Figure 4). Catch data presented for May and June 2018 are from D&S IFCA surveys that were not part of regular fishery activity, and all fish were returned to the sea. Therefore, these data are not represented in the landings data above.

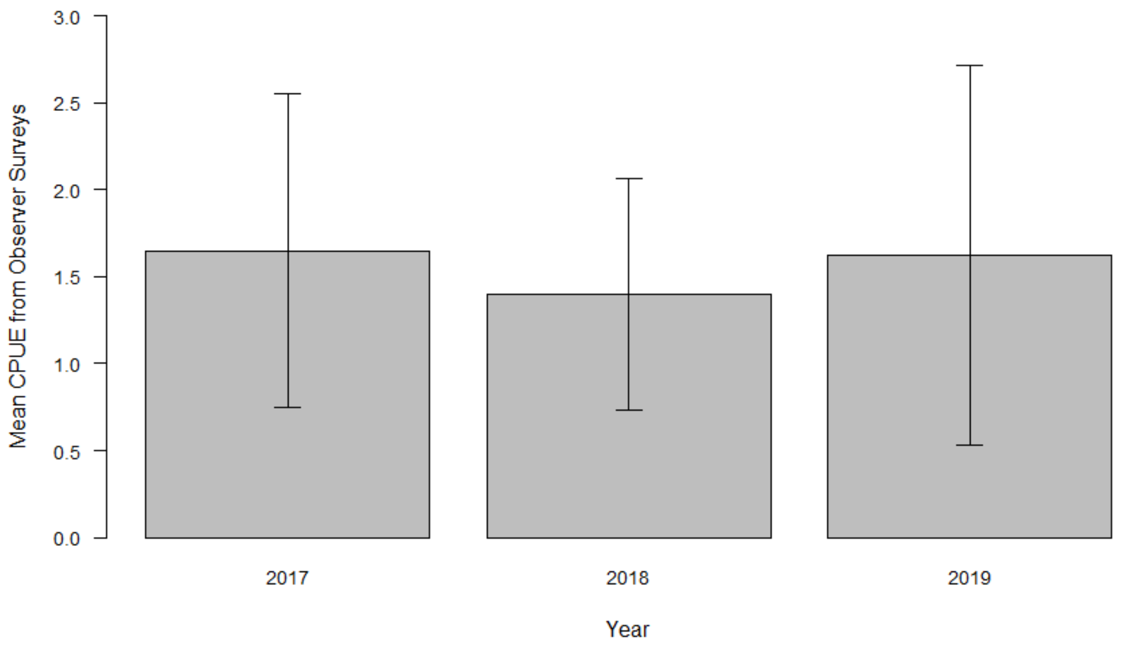

Figure 4. Catch Per Unit Effort (CPUE) for all species caught during on-board observer surveys across all vessels during 2017, 2018 and 2019 (mean ± sd). A one-way ANOVA found no significant differences between years ($F_{2, 147}$ = 0.75, p = 0.47).

3.4. Species-specific results

3.4.1. Ballan

Mean $LPUE_{fc}$ for ballan wrasse has changed significantly over the 2017–2019 period (X^2=8.73, df=2, p=0.013; Figure 5). Specifically, $LPUE_{fc}$ declined from 0.13 in 2017 to 0.07 in 2018, though by 2019 the $LPUE_{fc}$ was not significantly different from that in 2017, indicating a return to previous landings levels for ballan (Table 6). However, results of a GLM indicated that mean CPUE has not changed significantly over the 2017–2019 period (Figure 6; Table 7).

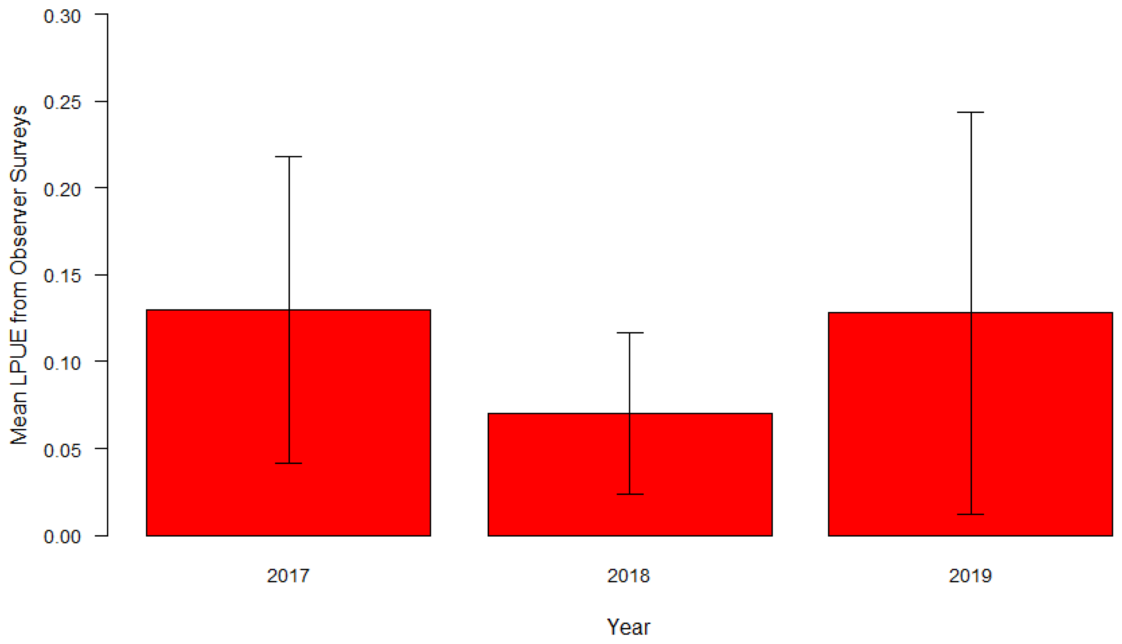

Figure 5. Landings Per Unit Effort ($LPUE_{fc}$), for ballan wrasse caught during on-board observer surveys across all vessels during 2017, 2018 and 2019 (mean ± sd). Kruskal-Wallis test (X^2 =8.73, df=2, p=0.013).

Table 6. Summary of *post-hoc* tests for differences in LPUE between years for ballan wrasse.

Comparison	Z	$p_{unadjusted}$	$p_{adjusted}$
2017–2018	2.91	0.003	0.011
2017–2019	1.37	0.171	0.171
2018–2019	-1.46	0.145	0.291

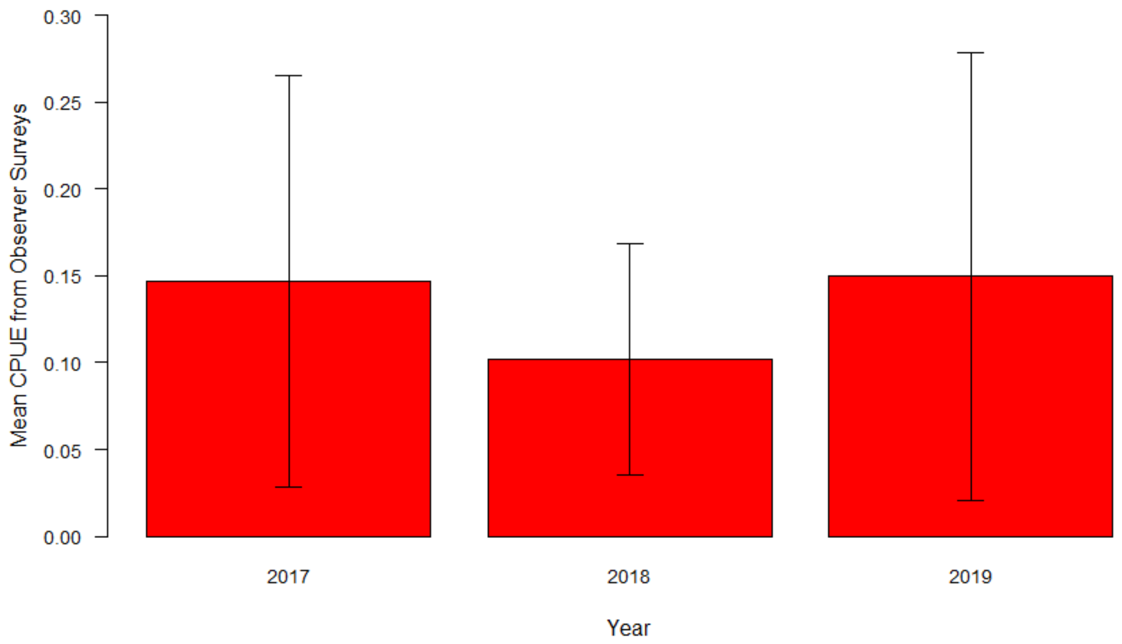

Figure 6. Catch Per Unit Effort (CPUE), for ballan wrasse caught during on-board observer surveys across all vessels during 2017, 2018 and 2019 (mean ± sd).

Table 7. Summary of GLM results testing for differences in CPUE between years for ballan wrasse, showing model coefficients and their standard errors; $p < 0.05$ indicates significance (i.e. CPUE is significantly different in the specified year relative to 2017). This table shows the results of the model that is most parsimonious with respect to the data (see Appendix 1 for full methods details and a summary of AIC analyses).

Coefficient	Parameter estimate	Standard error	*p*
Intercept	0.122	0.022	<0.001
Year:2018	-0.013	0.022	0.551
Year:2019	-0.021	0.028	0.461

Figure *7* illustrates the size range of ballan wrasse caught and recorded during the on-board observer surveys. The size of ballan wrasse caught in 2019 ranged from 7 to 30 cm. The average size of ballan has remained steady over the three-year period (18.5cm in 2017, 19cm in 2018 and 19cm in 2019), and the size class distribution appears to be fairly stable over the same period (Figure *7*). The percentage of ballan caught and recorded during the observer surveys that were landable (within the CRS limits) varied from 72% in 2017, 51% in 2018 and 62% in 2019. In 2019 25% of ballan caught were below the Min. CRS and 13% were above the Max. CRS. The number of ballan wrasse observed to be spawning during the on-board observer surveys remains low across the 2017–2019 period: no spawning individuals were observed in 2017, with only one observed per year in 2018 and 2019 (in June and August, respectively).

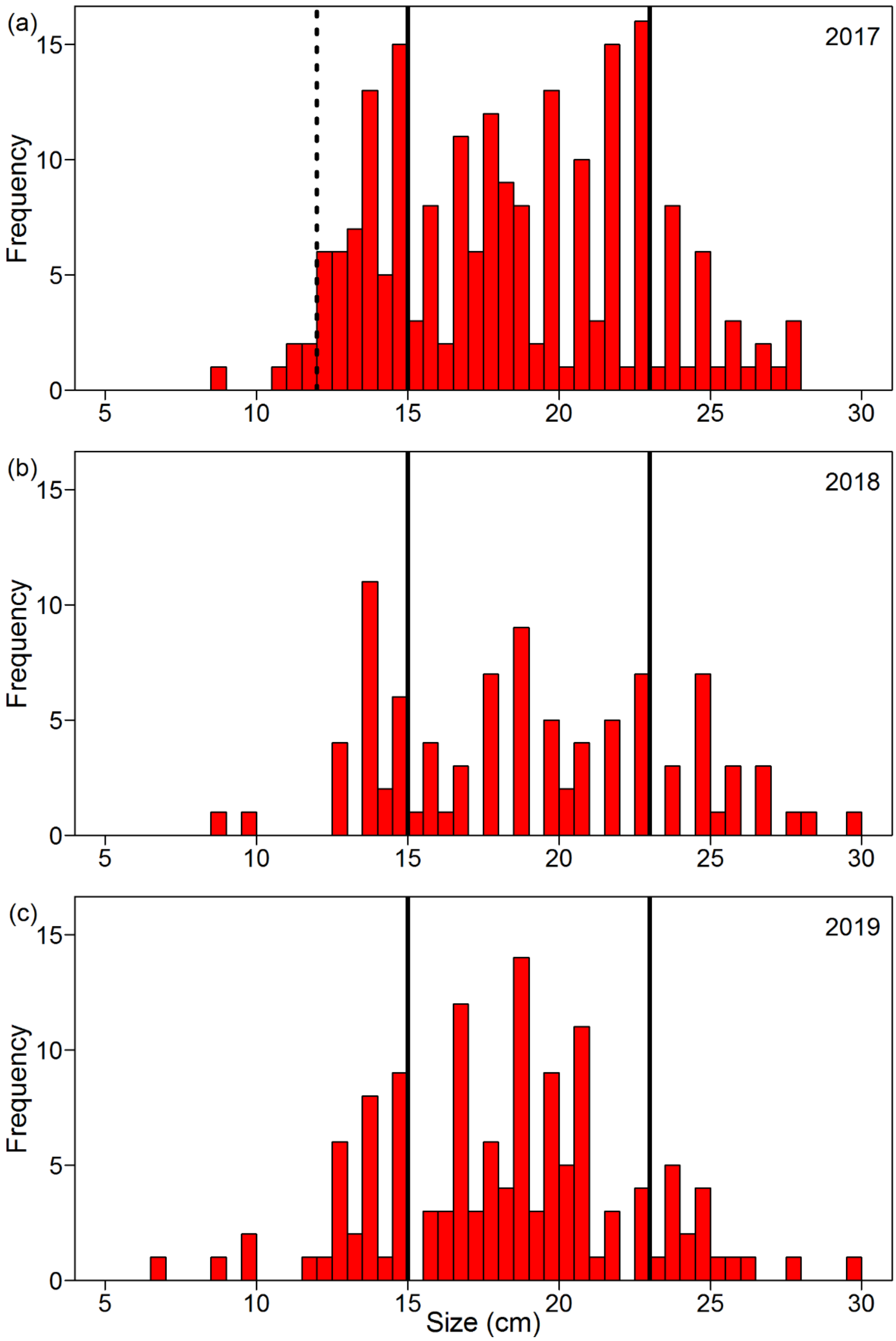

Figure 7. Size frequency histograms for ballan wrasse caught (regardless of whether they were retained or returned) during on-board observer surveys in (a) 2017, (b) 2018, and (c) 2019. Bold, vertical black lines indicate the minimum and maximum conservation reference sizes (CRS) for ballan wrasse after implementation of the potting permit byelaw condition in July 2017. The dashed, black vertical line indicates the different minimum CRS for ballan wrasse for the period before 30 June 2017. The maximum CRS for both periods was unchanged.

3.4.2. *Goldsinny*

Mean $LPUE_{fc}$ declined significantly over the 2017–2019 period (X^2 =7.45, df=2, p=0.024), as indicated by Figure 8. Initial post hoc comparisons indicate that the $LPUE_{fc}$ was lower in both 2018 and 2019 than in 2017, however, statistical adjustment for multiple comparisons demonstrates that there has been no significant change in $LPUE_{fc}$ between any of the monitored years (Figure 8; Table 8). Similarly, CPUE has not changed significantly over the 2017–2019 period (X^2 =5.47, df=2, p=0.065; Figure 9).

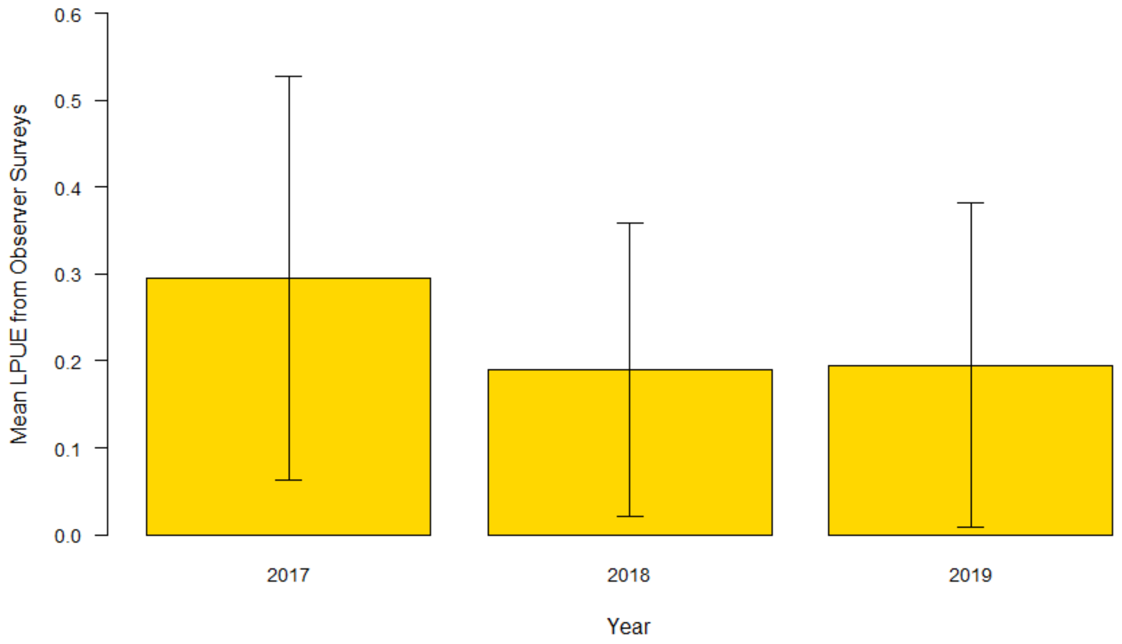

Figure 8. Landings Per Unit Effort ($LPUE_{fc}$), for goldsinny wrasse caught during on-board observer surveys across all vessels during 2017, 2018 and 2019 (mean ± sd). Data taken from the on-board observer surveys. Kruskal-Wallis test (X^2 = 7.45, df=2, p=0.024).

Table 8. Summary of *post-hoc* tests for differences in LPUE between years for goldsinny wrasse.

Comparison	**Z**	$p_{unadjusted}$	$p_{adjusted}$
2017–2018	2.08	0.037	0.074
2017–2019	2.32	0.020	0.061
2018–2019	0.25	0.806	0.806

Figure 10 illustrates the size range of goldsinny caught and recorded during the on-board observer surveys. The majority of goldsinny caught (80%) were under the Min. CRS, resulting in a high proportion of these species being returned. The percentage of goldsinny observed during the surveys that were returned has marginally increased over the last three years from 73% in 2017, 74% in 2018 to 80% in 2019. Over the three year period, the size of goldsinny caught ranged from 5.5cm to 14.5cm, and the average size of goldsinny caught remained fairly consistent over the three-year period (10.9cm in 2017, 11.1cm in 2018, and 10.6cm in 2019). The number of goldsinny observed spawning increased from 10 in 2017 to 30 in 2018, but decreased to 11 in 2019. Spawning was first observed in July in 2019; however, 21 goldsinny were spawning during the June 2018 survey, suggesting that the 2019 surveys may have missed the majority of the goldsinny spawning period.

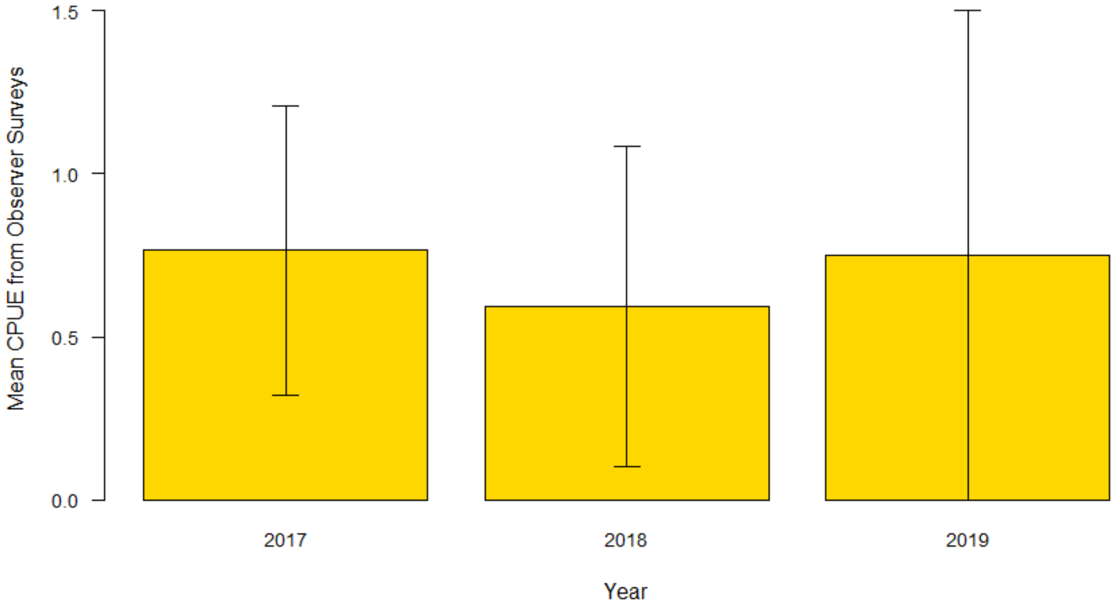

Figure 9. Catch Per Unit Effort (CPUE), for goldsinny wrasse caught during on-board observer surveys across all vessels during 2017, 2018 and 2019 (mean ± sd). Data taken from the on-board observer surveys. Kruskal-Wallis test (X^2 = 5.47, df=2, p=0.064).

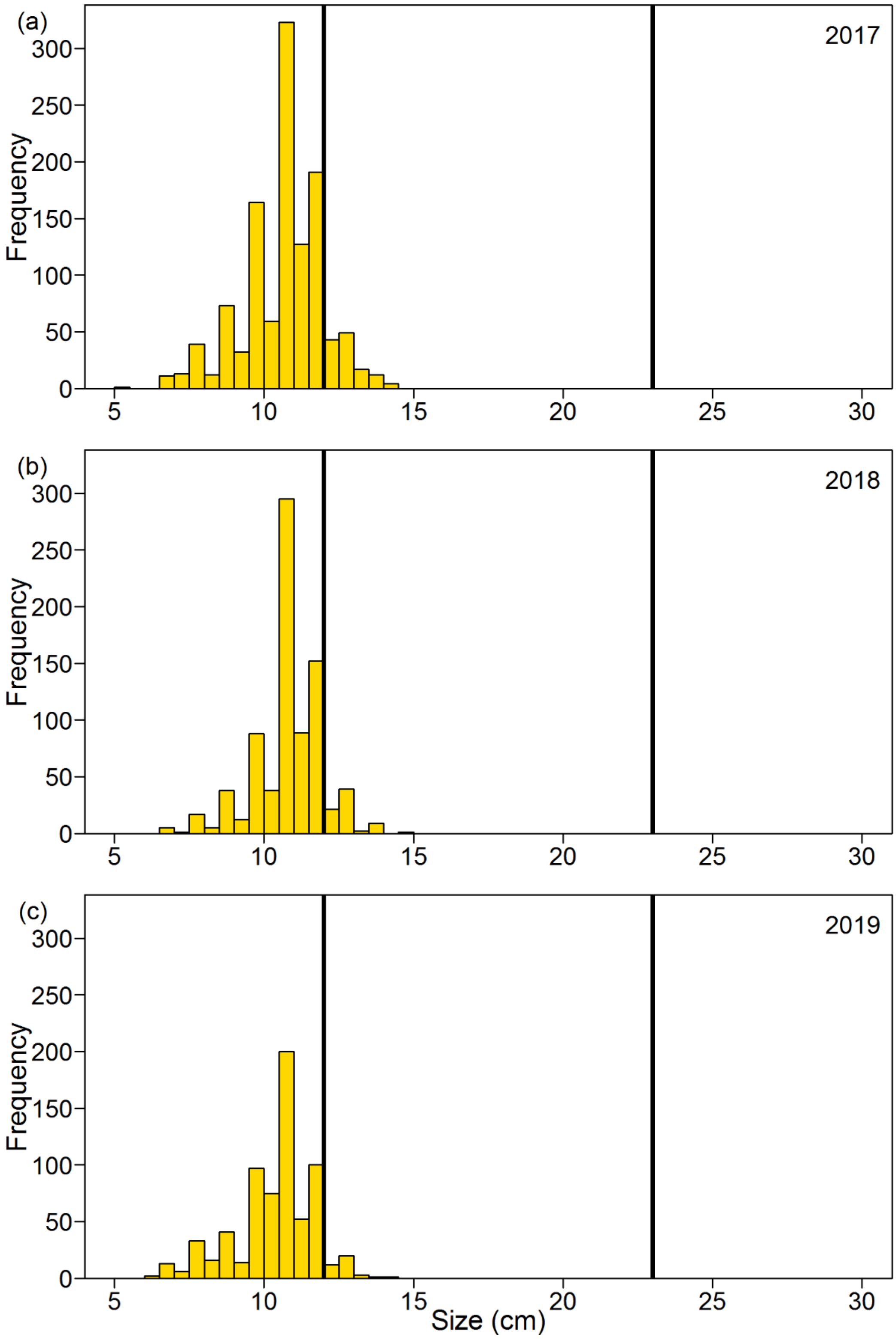

Figure 10. Size frequency histograms for goldsiny wrasse caught (regardless of whether they were retained or returned) during on-board observer surveys in (a) 2017, (b) 2018, and (c) 2019. Bold, vertical black lines indicate the minimum and maximum conservation reference sizes (CRS) for goldsinny wrasse.

3.4.3. *Rock Cook*

Mean $LPUE_{fc}$ for rock cook declined between 2017 and 2019 (Figure 11; Table 9), but appears not to have declined significantly between 2017 and 2018. However, the standard error associated with these effects (Table 9) suggest that these results should be treated with caution. CPUE declined consistently over the 2017–2019 period (Figure 12;Table 10).

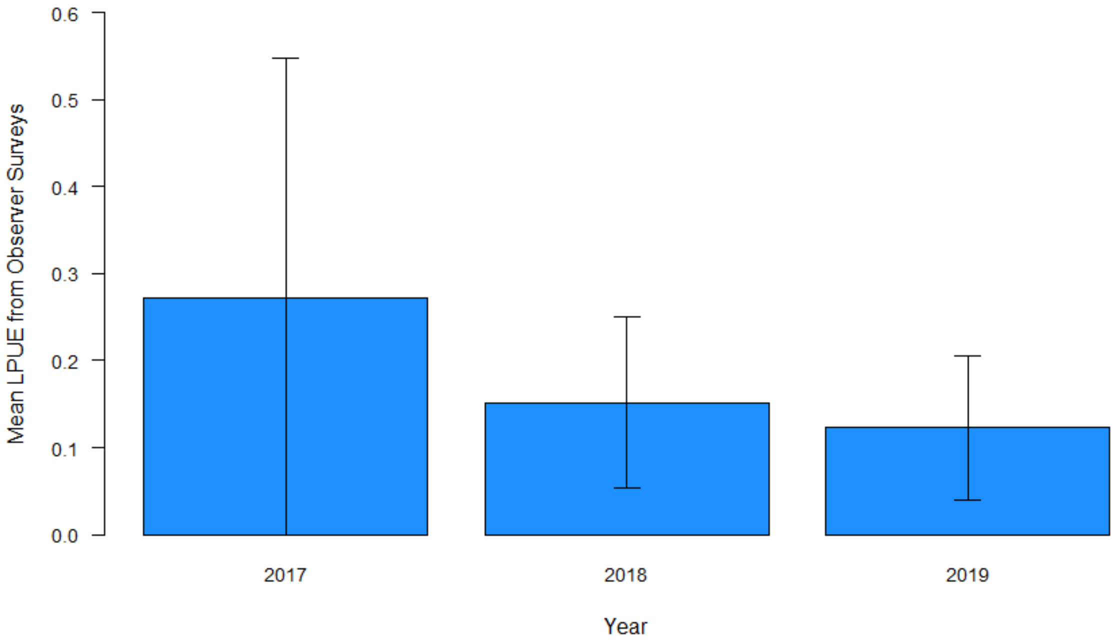

Figure 11. Landings Per Unit Effort ($LPUE_{fc}$), for rock cook wrasse caught during on-board observer surveys across all vessels during 2017, 2018 and 2019 (mean ± sd). Data taken from the on-board observer surveys.

Table 9. Summary of GLM results testing for differences in $LPUE_{fc}$ between years for rock cook wrasse, showing model coefficients and their standard errors; $p < 0.05$ indicates significance (i.e. whether LPUE is significantly different in the specified year relative to 2017). This table shows the results of the model that is most parsimonious with respect to the data (see Appendix 1 for full methods details and a summary of AIC analyses).

Coefficient	Parameter estimate	Standard error	*p*
Intercept	0.349	0.0491	<0.001
Year:2018	0.013	0.030	0.677
Year:2019	-0.048	0.022	0.030

Table 10. Summary of GLM results testing for differences in CPUE between years for rock cook wrasse, showing model coefficients and their standard errors; $p < 0.05$ indicates significance (i.e. whether CPUE is significantly different in the specified year relative to 2017). This table shows the results of the model that is most parsimonious with respect to the data (see Appendix 1 for full methods details and a summary of AIC analyses).

Coefficient	Parameter estimate	Standard error	*p*
Intercept	0.867	0.149	<0.001
Year:2018	-0.234	0.105	0.027
Year:2019	-0.303	0.098	0.002

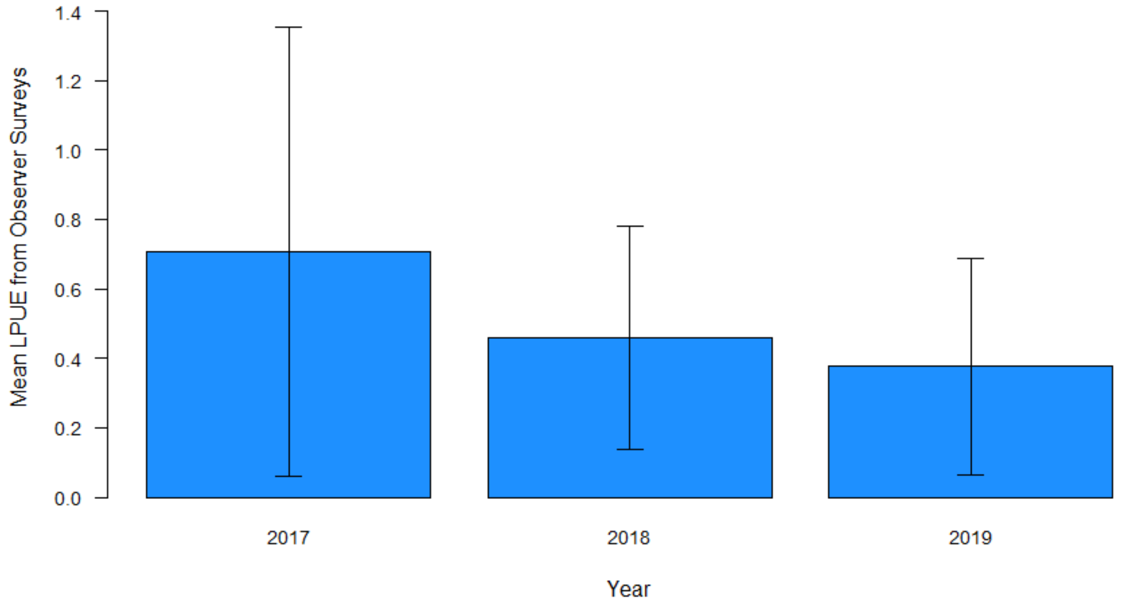

Figure 12. Catch Per Unit Effort (CPUE), for rock cook caught during on-board observer surveys across all vessels during 2017, 2018 and 2019 (mean ± sd). Data taken from the on-board observer surveys.

Figure 13 illustrates the size range of rock cook caught and recorded during the on-board observer surveys. The size of rock cook caught in 2019 ranged from 6 cm to 14 cm. 79% of rock cook caught were under the Min. CRS, resulting in the majority of catches of this species being returned to the sea. This is similar to 2018 (72% returned) and 2017 (74% returned) (Figure 13). The average size of rock cook caught has remained similar over the 2017–2019 period (10.6cm in 2017, 10.8cm in 2018 and 2019; Figure 13). The number of rock cook observed spawning during the on-board observer survey varied among years: 62 individuals in 2017, 29 in 2018 and none in 2019. The majority of spawning rock cook observed in 2018 were caught in June, suggesting that the first on-board observer surveys in 2019 may have occurred too late in the year to reliably detect signs of spawning.

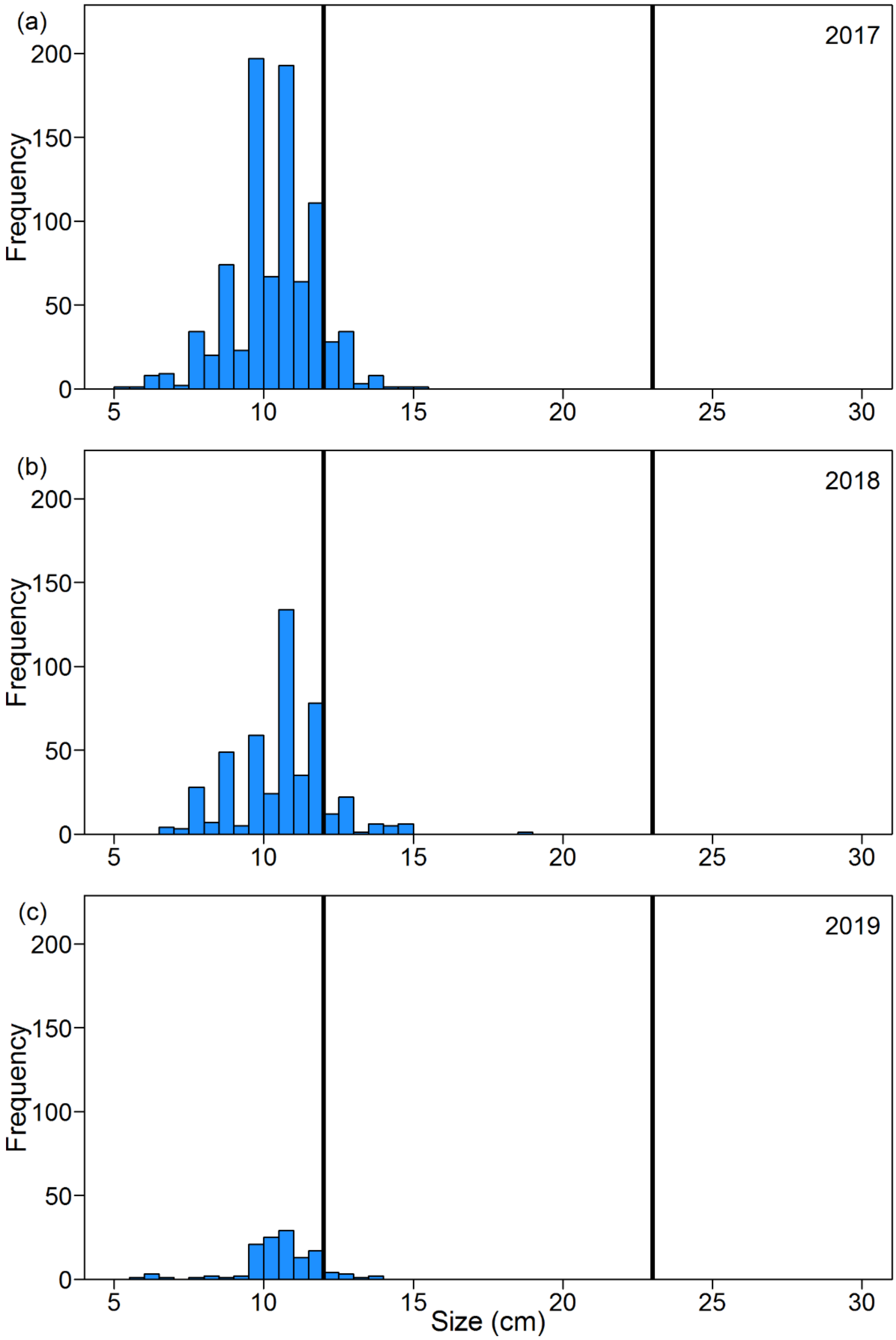

Figure 13. Size frequency histograms for rock cook caught (regardless of whether they were retained or returned) during on-board observer surveys in (a) 2017, (b) 2018, and (c) 2019. Bold, vertical black lines indicate the minimum and maximum conservation reference sizes (CRS) for rock cook.

3.4.4. Corkwing

Mean $LPUE_{fc}$ has not changed significantly over the 2017–2019 period (Figure 14; Table 11). In contrast, CPUE increased significantly between 2017 and 2019 (Figure 15; Table 12).

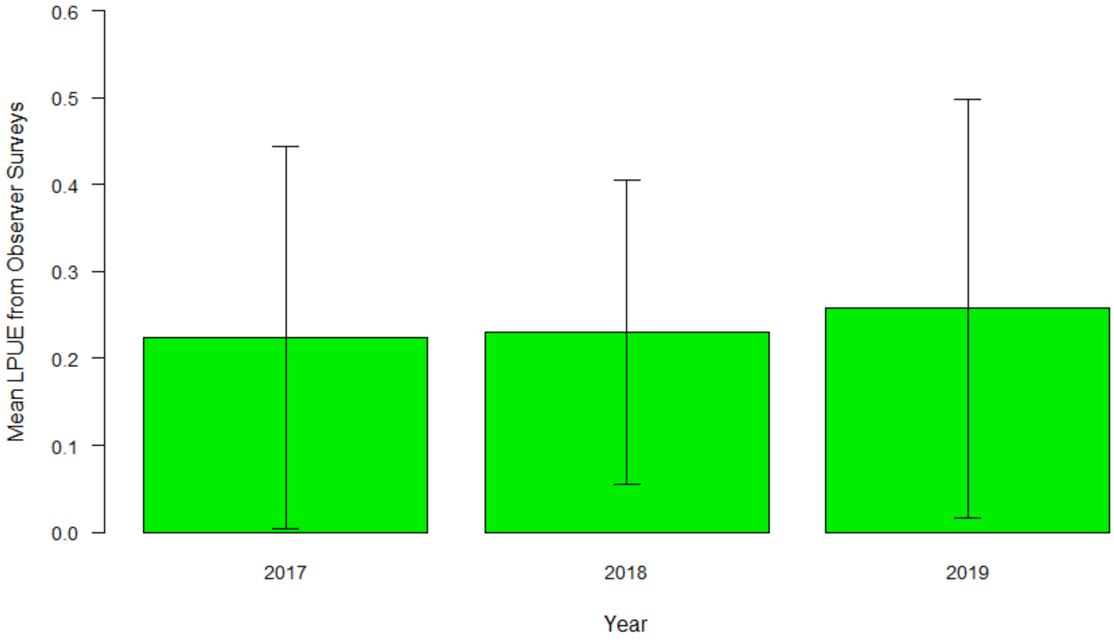

Figure 14. Landings Per Unit Effort ($LPUE_{fc}$), for corkwing wrasse caught during on-board observer surveys across all vessels during 2017, 2018 and 2019 (mean ± sd). Data taken from the on-board observer surveys.

Table 11. Summary of GLM results testing for differences in $LPUE_{fc}$ between years for corkwing wrasse, showing model coefficients and their standard errors; $p < 0.05$ indicates significance (i.e. whether LPUE is significantly different in the specified year relative to 2017). These results are derived from a GLM that did not outperform the equivalent null model, indicating that 'year' is not a suitable predictor of $LPUE_{fc}$ for corkwing ($LPUE_{fc}$ has not changed over 2017–2019). See Appendix 1 for full methods details and a summary of AIC analyses.

Coefficient	Parameter estimate	Standard error	*p*
Intercept	0.112	0.030	<0.001
Year:2018	-0.052	0.054	0.337
Year:2019	-0.003	0.062	0.956

Table 12. Summary of GLM results testing for differences in CPUE between years for corkwing wrasse, showing model coefficients and their standard errors; $p < 0.05$ indicates significance (i.e. whether CPUE is significantly different in the specified year relative to 2017). This table shows the results of the model that is most parsimonious with respect to the data (see Appendix 1 for full methods details and a summary of AIC analyses).

Coefficient	**Parameter estimate**	**Standard error**	***p***
Intercept	0.112	0.032	<0.001
Year:2018	0.001	0.061	0.990
Year:2019	0.308	0.132	0.022

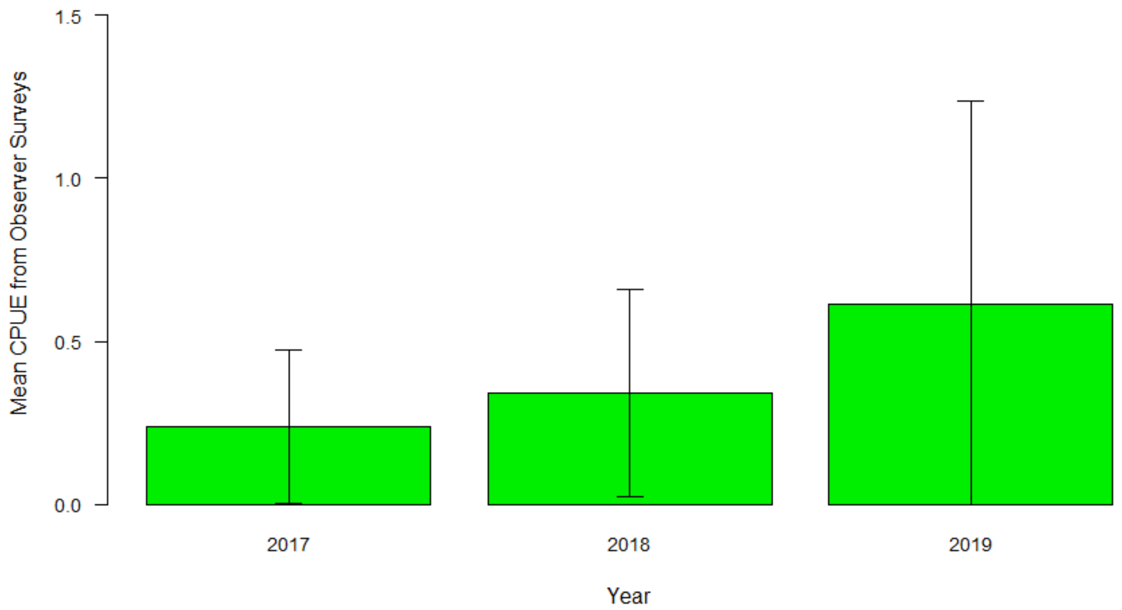

Figure 15. Catch Per Unit Effort (CPUE), for corkwing wrasse caught during on-board observer surveys across all vessels during 2017, 2018 and 2019 (mean ± sd). Data taken from the on-board observer surveys.

Figure 16 illustrates the size range of corkwing caught and recorded during the on-board observer surveys. The majority of corkwing caught (80%) were under the Min. CRS, resulting in a high proportion of these species being returned. This follows the same pattern as 2018 after the implementation of the new potting permit byelaw conditions. These conditions amended the Min. and Max. CRS to 14–18cm. The percentage of corkwing returned therefore increased from 19% in 2017 to 57% in 2018. The average size of corkwing caught appears to have declined from 15.5cm in 2017 to 13.9cm in 2019. However, the distribution of individuals among size classes appears to have remained fairly even across the three-year period (Figure 16). The number of corkwing wrasse observed spawning during the on-board observer surveys appears to have steadily increased from three in 2017, to 20 in 2018 and 32 in 2019.

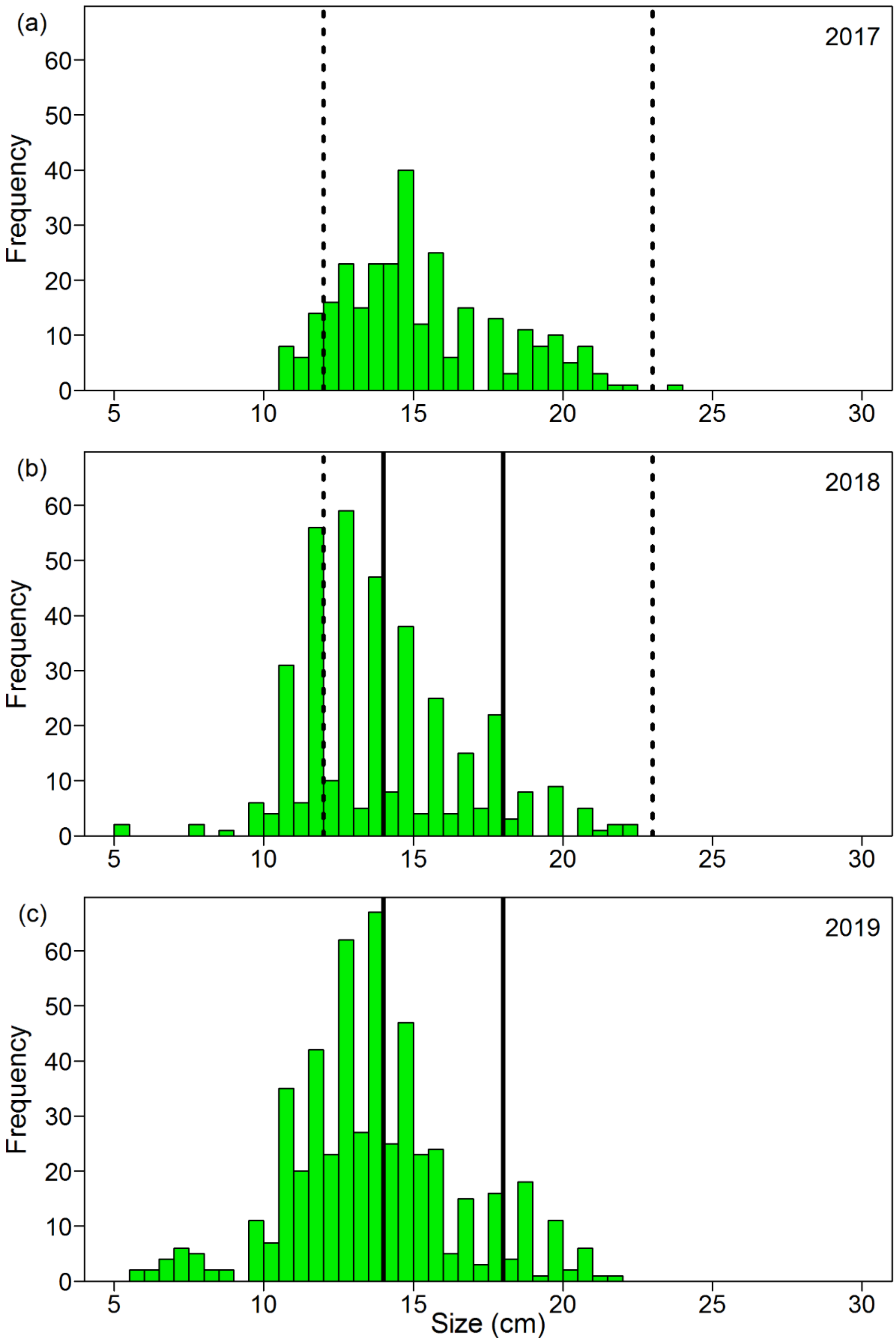

Figure 16. Size frequency histograms for corkwing caught (regardless of whether they were retained or returned) during on-board observer surveys in (a) 2017, (b) 2018, and (c) 2019. Bold, vertical black lines indicate the minimum and maximum conservation reference sizes (CRS) for corkwing after implementation of the new potting permit byelaw conditions on 13 August 2018. The dashed, black vertical lines indicate the minimum and maximum CRS for corkwing wrasse under the old potting permit byelaw conditions for the period before 13 August 2018.

3.4.5. *Cuckoo*

Cuckoo wrasse are not targeted by the fishery and therefore all individuals caught are returned to sea. As a result, no $LPUE_{fc}$ figures were calculated for this species. Mean CPUE has not changed significantly over the 2017–2019 period (Figure 17; Table 13). However, it should also be noted that catches were very low for cuckoo in all years. The frequency of cuckoo wrasse observed during the on-board observer surveys has remained consistently low over the last three years, though the size range of these fish was relatively wide (Figure 18).The average size of cuckoo has declined since 2017 from 20.1cm to 19.9cm in 2019, though sample size was low in 2019, when only three individuals were caught (2019 data, therefore, have not been plotted here) (Figure 18). Only one individual has been observed spawning over the three-year period, perhaps as a result of the small sample size.

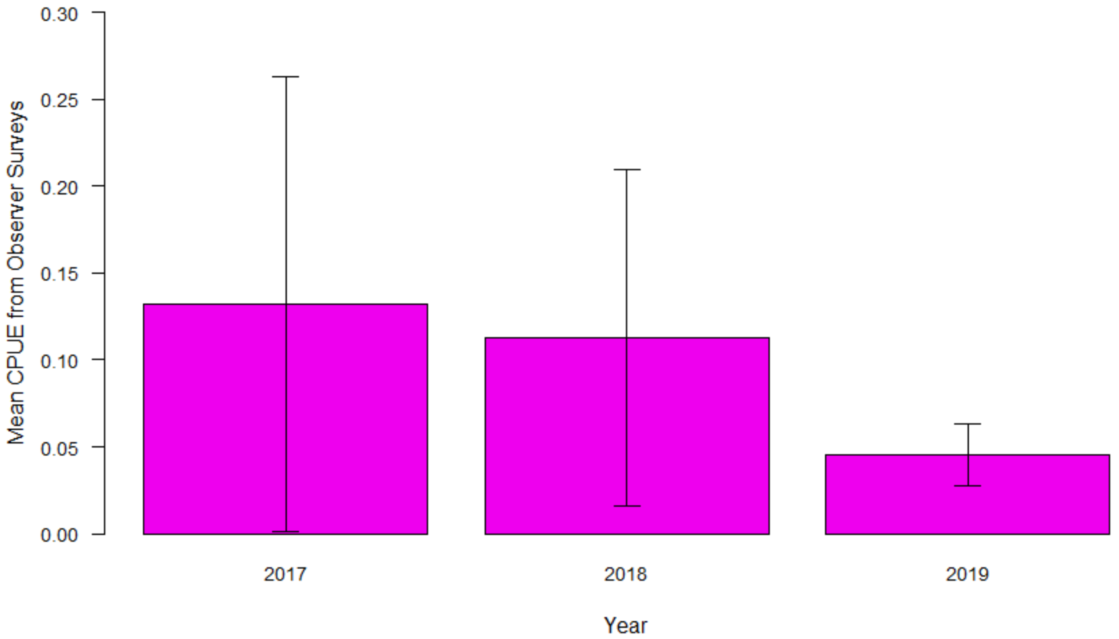

Figure 17. Catch Per Unit Effort (CPUE), for cuckoo wrasse caught during on-board observer surveys across all vessels during 2017, 2018 and 2019 (mean ± sd).

Table 13. Summary of GLM results testing for differences in CPUE between years for cuckoo wrasse, showing model coefficients and their standard errors; $p < 0.05$ indicates significance (i.e. whether CPUE is significantly different in the specified year relative to 2017). These results are derived from a GLM that did not outperform the equivalent null model, indicating that ‘year’ is not a suitable predictor of $LPUE_{fc}$ for cuckoo ($LPUE_{fc}$ has not changed over 2017–2019). See Appendix 1 for full methods details and a summary of AIC analyses. The GLM used an inverse link function so parameter estimates and standard errors are on the inverse scale.

Coefficient	**Parameter estimate**	**Standard error**	***p***
Intercept	6.002	1.176	<0.001
Year:2018	1.176	5.443	0.830
Year:2019	24.301	31.829	0.451

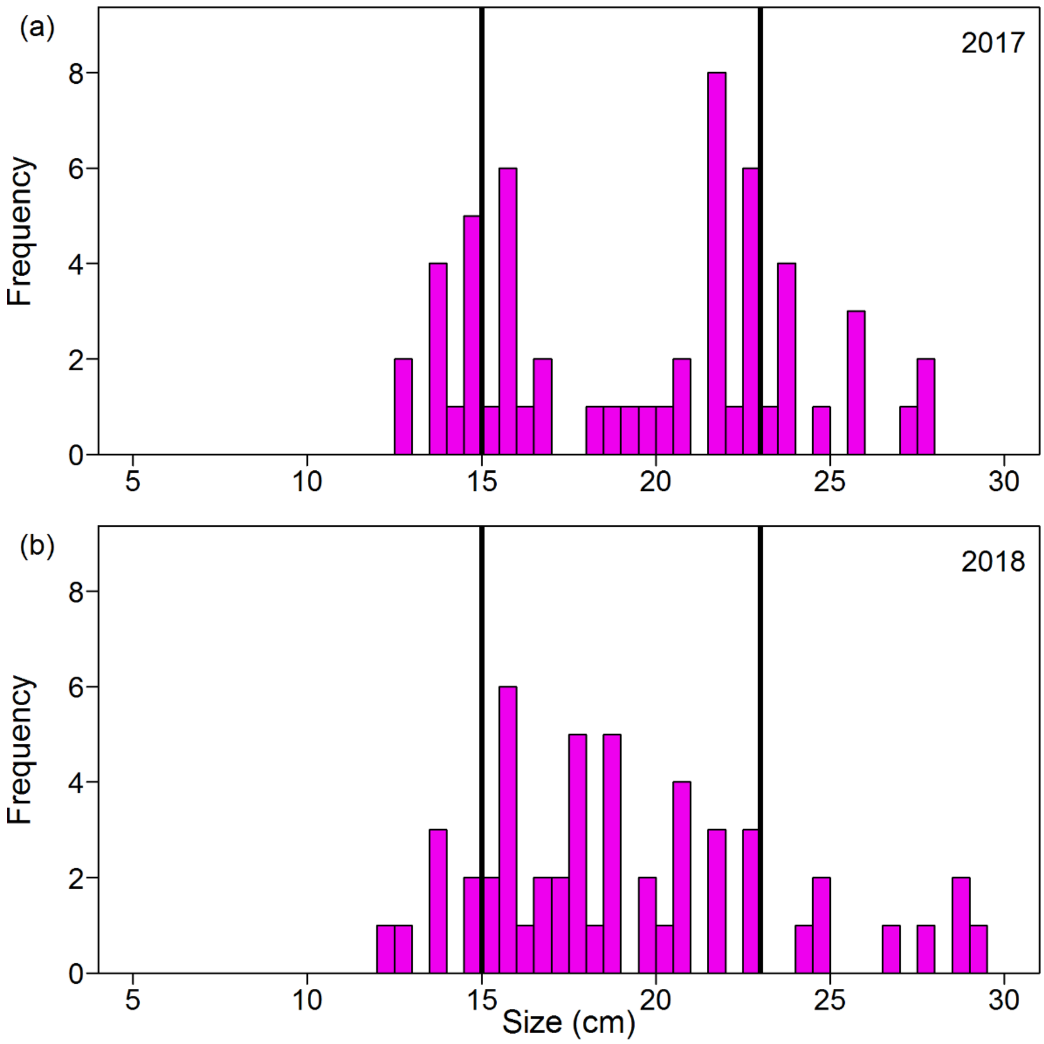

Figure 18. Size frequency histograms for cuckoo caught (regardless of whether they were retained or returned) during on-board observer surveys in (a) 2017, and (b) 2018. Bold, vertical black lines indicate the minimum and maximum conservation reference sizes (CRS) for cuckoo wrasse. Cuckoo wrasse are not routinely landed in the Plymouth Sound fishery.

3.5. Spatial Effort

Fishing largely took place outside of the voluntary closed areas (Figure 19), which were implemented in April 2018. However, in 2019, three strings overlapped with the voluntary closed area in grid cell M12 (Figure 30).

Overall effort per grid square in the D&S IFCA's District has reduced over the last three years (Figure 30), with the maximum total number of pot hauls per grid reducing from 4,322 in 2017 (Curtin and West, 2018) to 2,334 in 2019 (Figure 20). Overall fishing effort has primarily been concentrated around similar areas in 2018 and 2019: Drake's Island, the Mew Stone area and Fort Bovisand.

Vessel 2 and vessel 4 have fished similar areas in 2018 and 2019 (Figure 21 and Figure 22; Appendix 2). These vessels worked in both D&S IFCA's District and CIFCA's District, however only effort within the D&S IFCA's District is shown for vessel 2 as per the landings forms. The majority of fishing carried out by vessel 2 was around the Mew Stone and Renney Rocks, with some pots being moved closer to and inside Plymouth Sound breakwater due to weather conditions (Figure 21). Vessel 4 has predominantly fished around Drake's Island and Fort Bovisand (Figure 22). Vessel 6 entered the fishery this year and therefore there are no fishing effort maps for this vessel in 2017 or 2018 for comparison. Vessel 6 worked solely in the D&S IFCA's District with the majority of fishing taking place from Staddon Heights to Jennycliff and around the Mew Stone area (Figure 23).

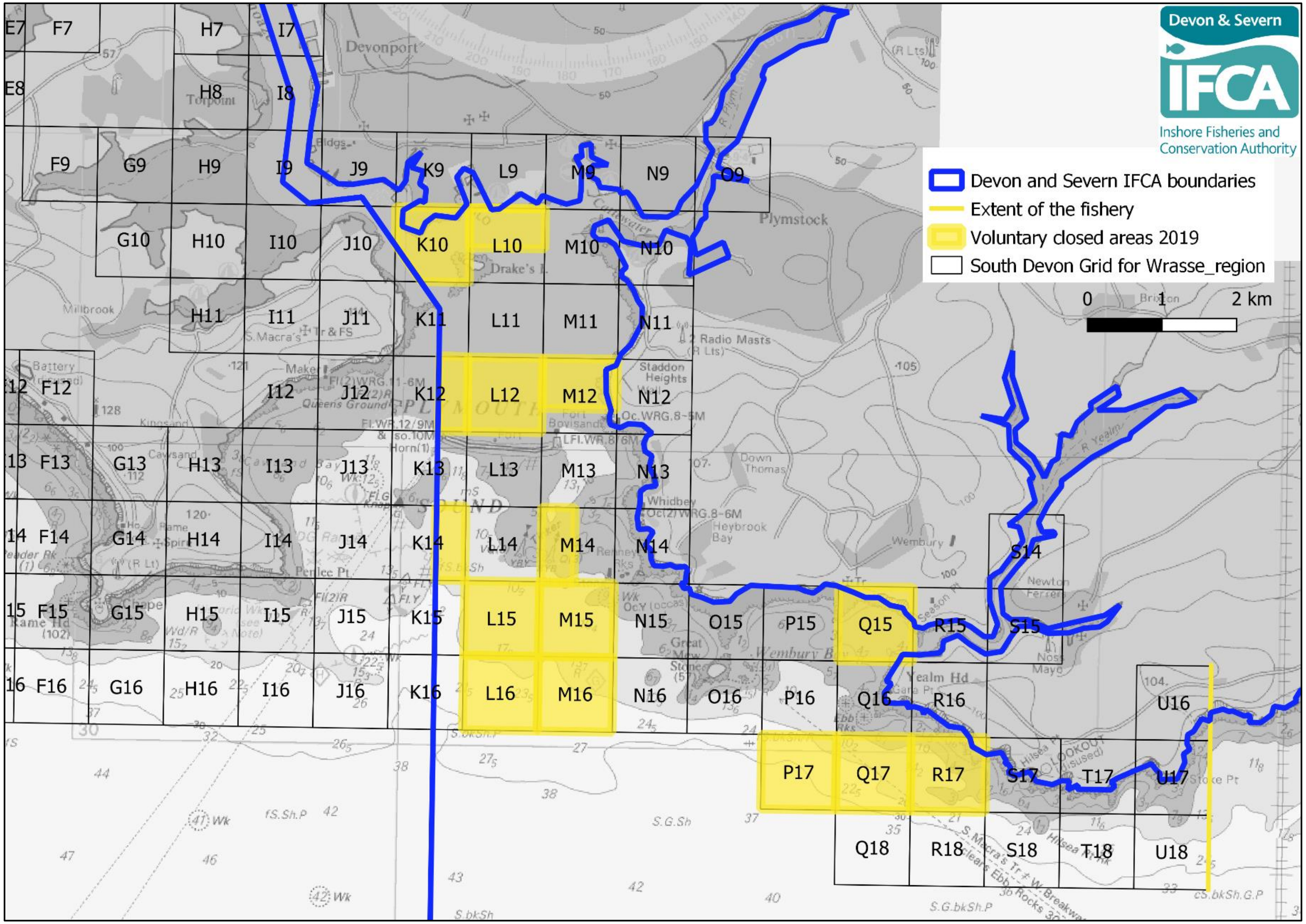

Figure 19. Chart of Voluntary Closed Areas 2019.

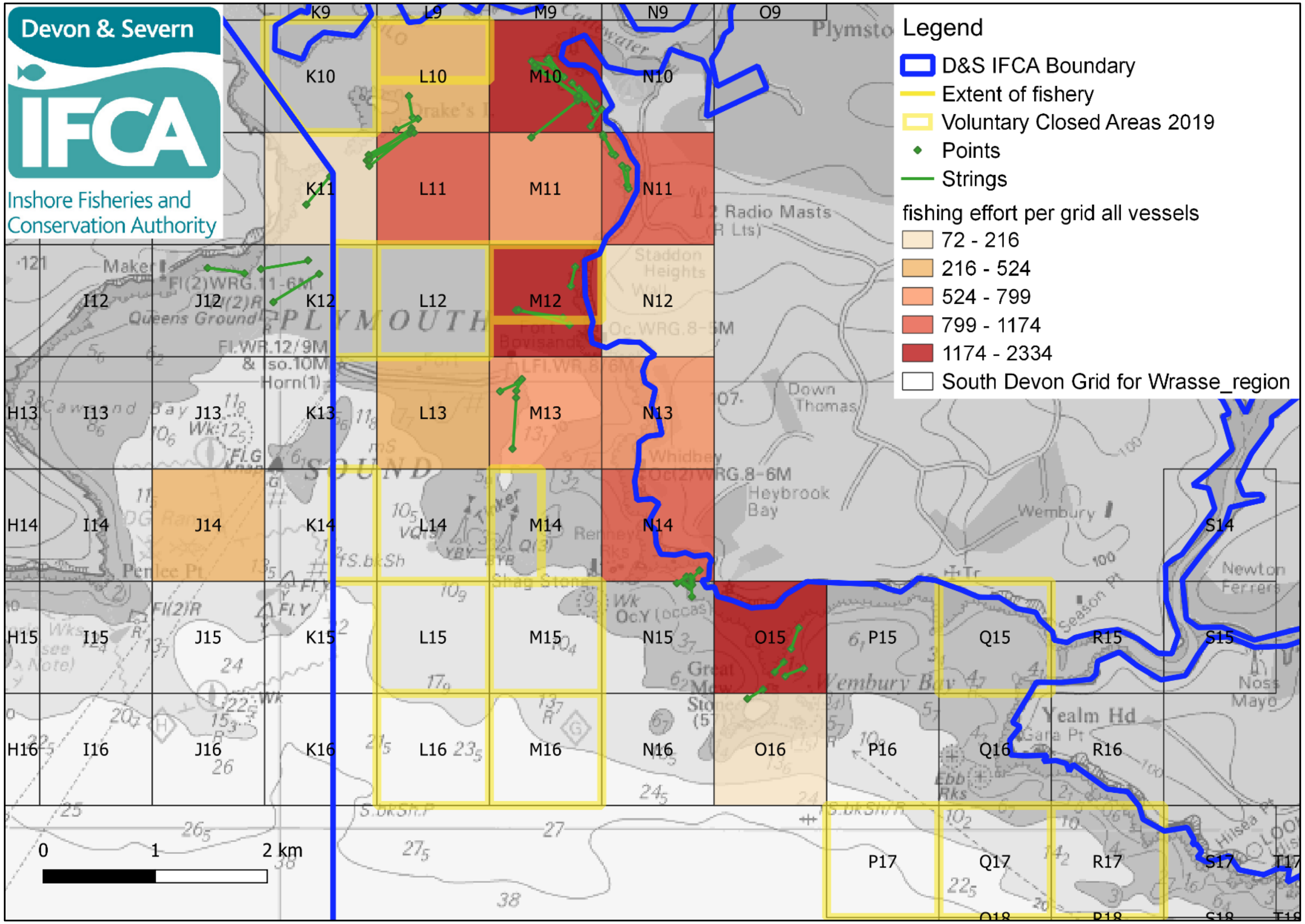

Figure 20. Chart of Plymouth Sound showing location of strings for all vessels from observer surveys and fishing effort per grid (number of pots hauled) during March to December 2019 from fishers' landings forms.

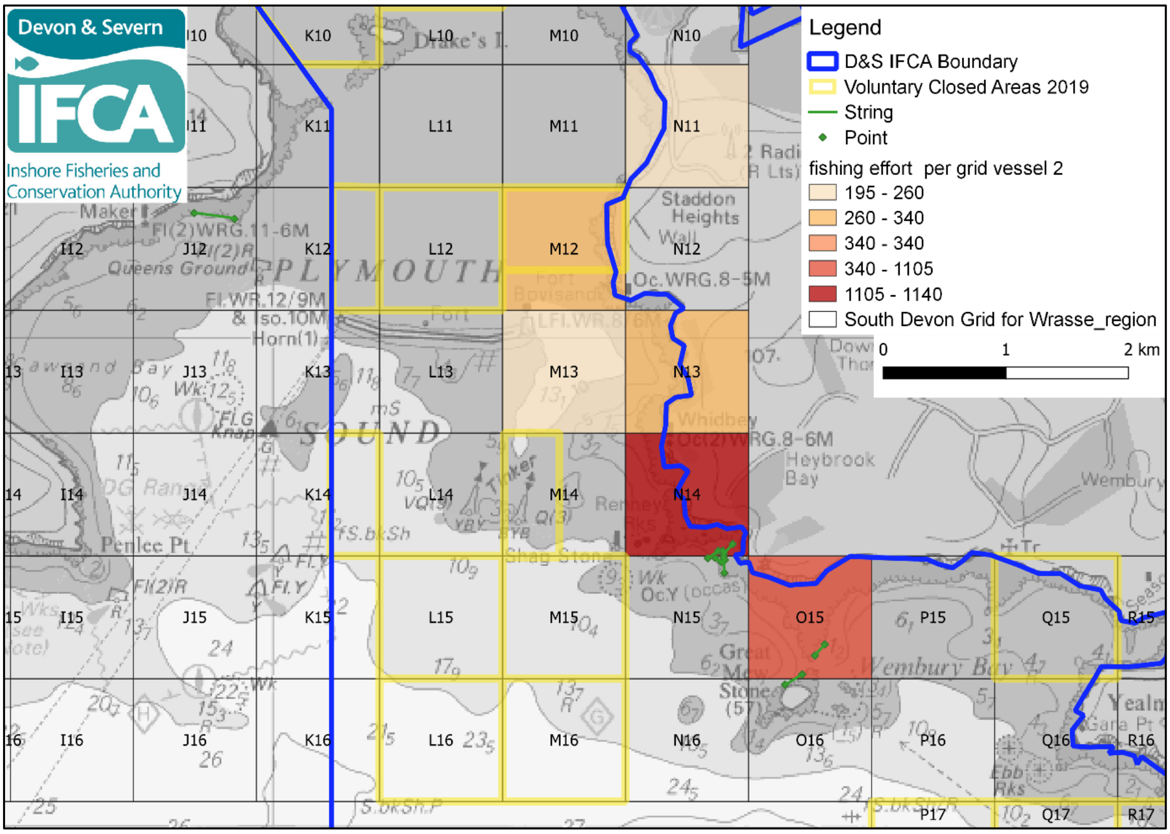

Figure 21. Chart of Plymouth Sound showing location of strings from the observer surveys and fishing effort (number of pots hauled) from landings forms of vessel 2 during 2019.

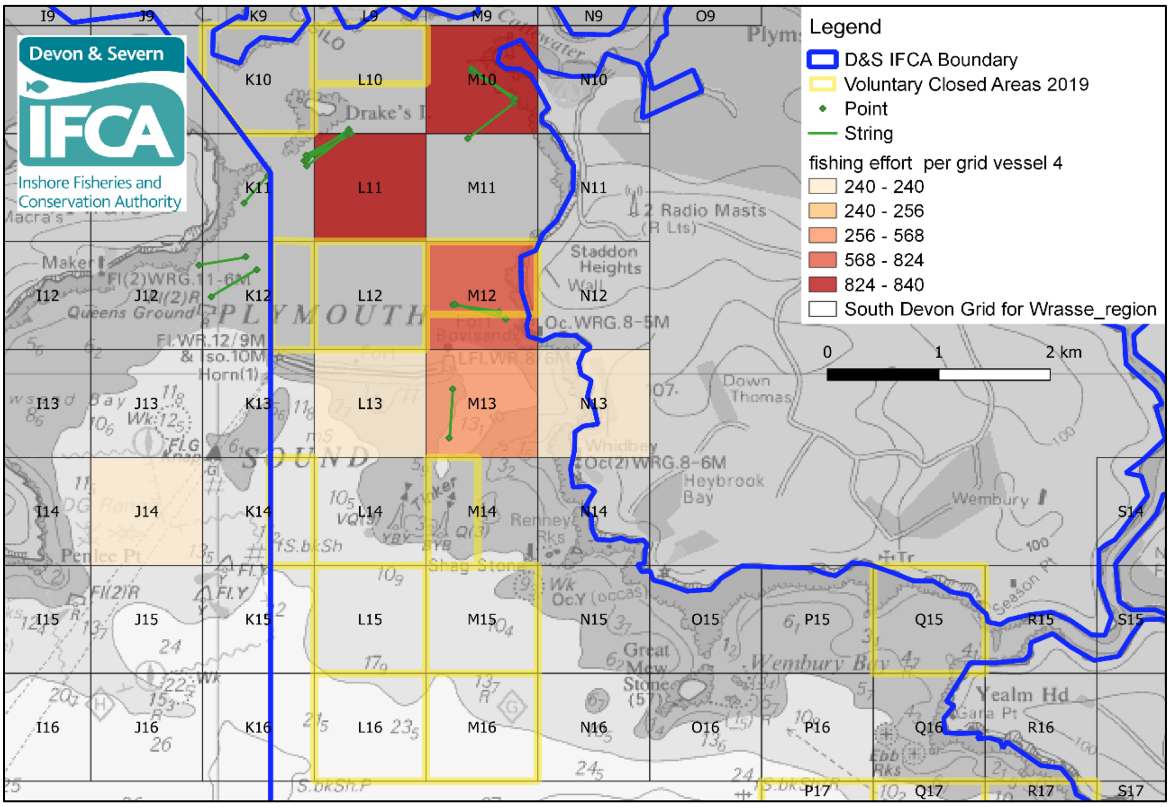

Figure 22. Chart of Plymouth Sound showing location of strings from the observer surveys and fishing effort (number of pots hauled) from landings forms of vessel 4 during 2019.

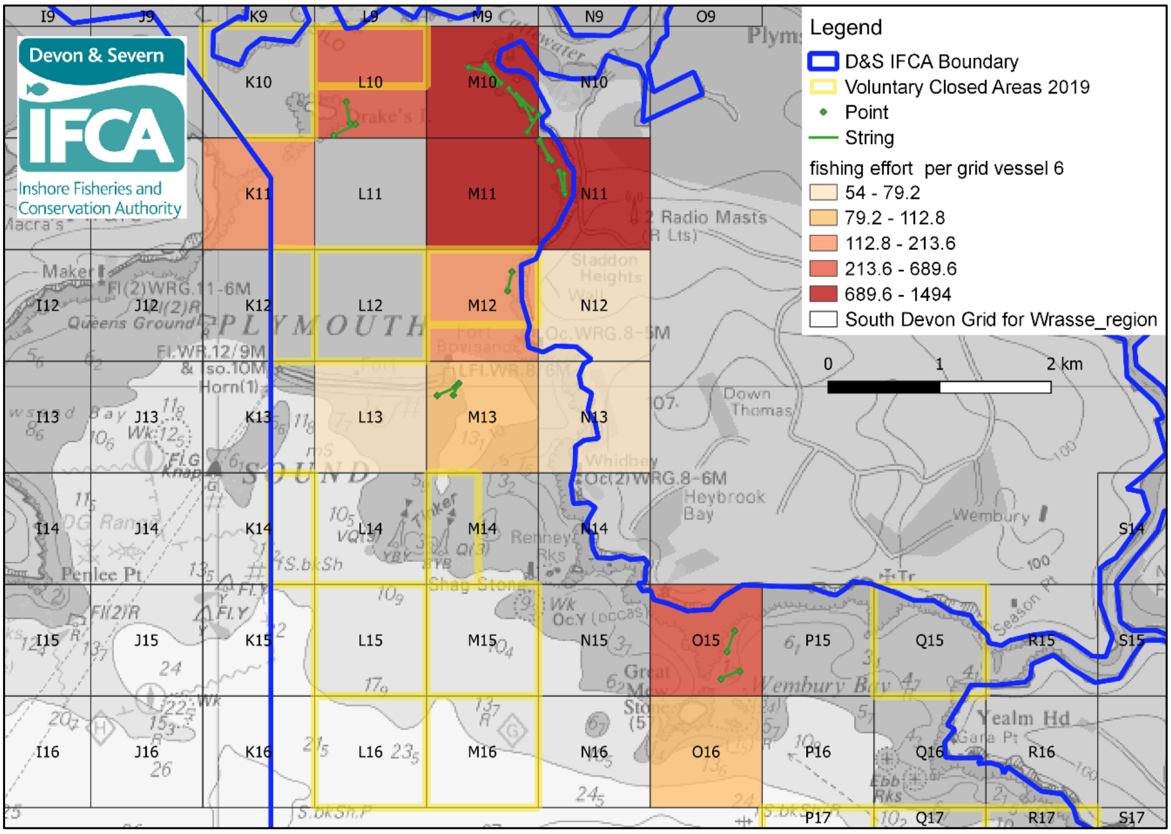

Figure 23. Chart of Plymouth Sound showing location of strings from the observer surveys and fishing effort (number of pots hauled) from landings forms of vessel 6 during 2019.

3.6. Catch Composition

The composition of wrasse caught and recorded for the 2017–2019 period during the on-board observer surveys is shown in Figure 24. Goldsinny dominates the catch in all years, consistently comprising between 40.9% and 45.1% of the catch. The proportion of rock cook within catches has declined over the three-year period from 27.6% of the 2017 catch to just 9.9% of the 2019 catch. In contrast, the proportion of corkwing has increased over the three year period, from 19.3% of the catch in 2017 to 37.5% of the catch in 2019. The proportions of ballan and cuckoo within catches were consistently low across the 2017–2019 period (10.8%, 5.0% and 7.2% for ballan and 1.3%, 2.9% and 0.2% for cuckoo in 2017, 2018 and 2019, respectively).

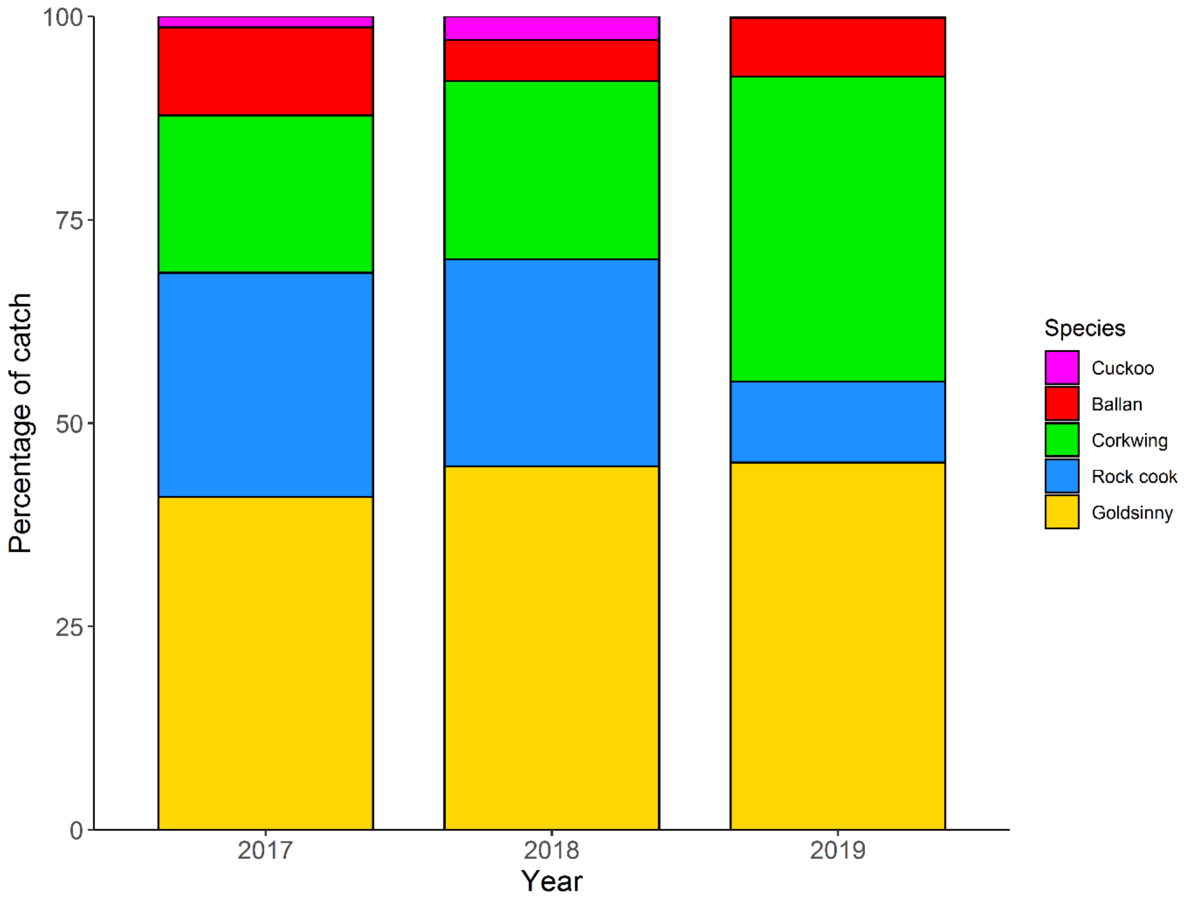

Figure 24. Composition of wrasse catches for the 2017-2019 period. Taken from data obtained during the on-board observer surveys for the D&S IFCA District only. Only the months of July to October were included in the data as on-board observer surveys were conducted across these months for all three years.

Figure 25 illustrates geographic variation in wrasse species composition across Plymouth Sound. Goldsinny catches were highest around Bovisand and to the north of Plymouth Sound around Drake's Island. This area, Renney Rocks and the Mew Stone appear to be hotspots for corkwing. The Mew Stone also appears to be a preferred area for rock cook, while the highest catches of ballan occur north of Plymouth Sound around Drake's Island.

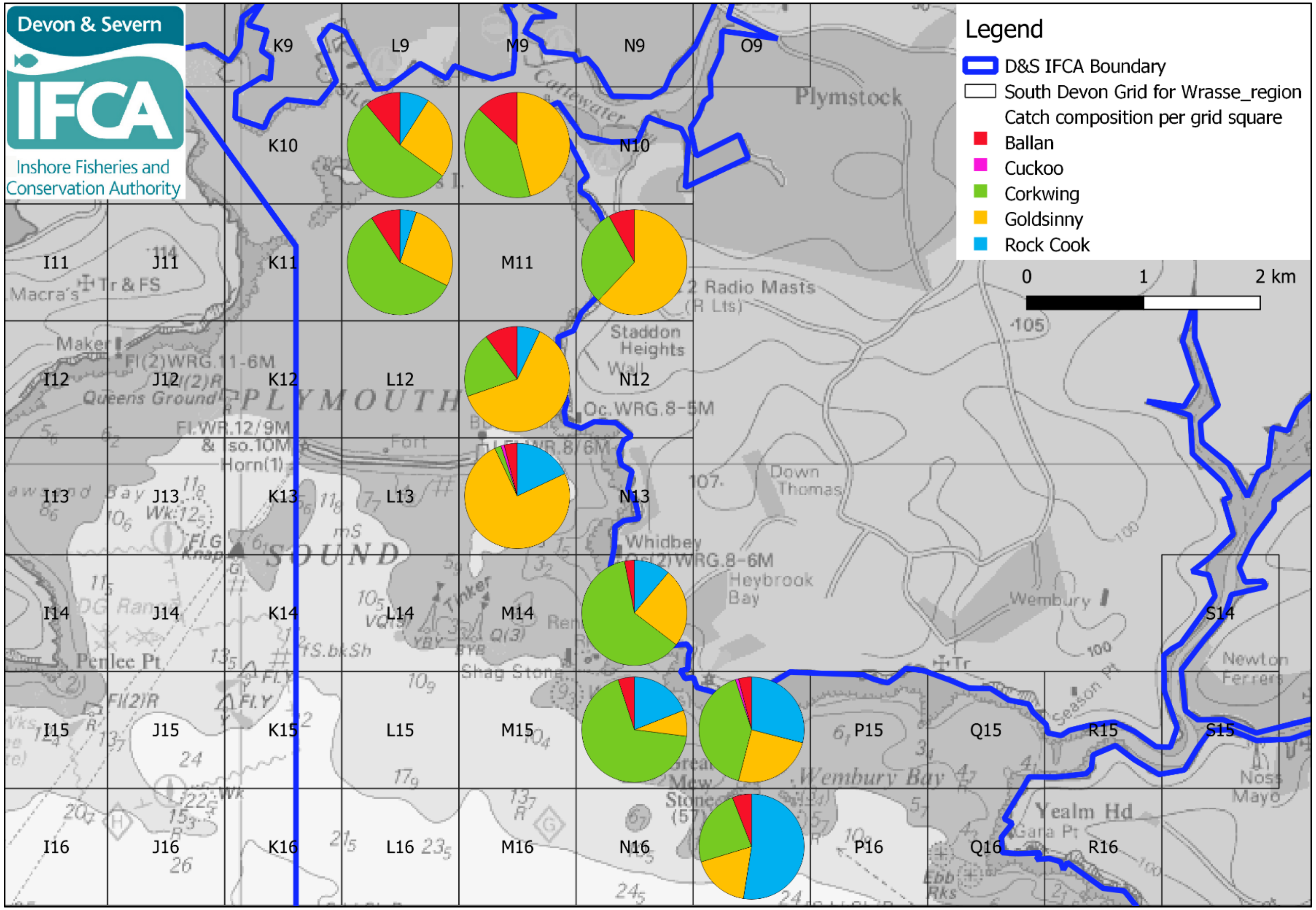

Figure 25. Assemblage composition of wrasse catches per grid square in Plymouth Sound during 2019. Data taken from the on-board observer surveys.

4. Discussion

4.1. Trends in LPUE and CPUE and Indications of Sustainability

Fishery-level $LPUE_{fc}$ and CPUE have remained stable across the last three years of the fully documented wrasse fishery (2017–2019), and indicate that current levels of catch and landings are sustainable for most species. However, patterns at an individual species level raise concerns about the status of rock cook wrasse, which is the only species to have experienced consistent declines in LPUE and CPUE since 2017. Here, patterns in LPUE and CPUE, their potential drivers, and their implications for the understanding of sustainability in the live wrasse fishery are discussed. Also highlighted is the value of on-board observer surveys in discerning important indicators of sustainability at the species level, which would not be possible using fishers' landings data alone.

As stated, fishery-level LPUE and CPUE have remained stable across the 2017–2019 period. This pattern is mirrored by stable trends in $LPUE_{fc}$ for ballan and corkwing and stable trends in CPUE for ballan, goldsinny and cuckoo. However, the fishery-level patterns mask declines in $LPUE_{fc}$ and CPUE for rock cook between 2017–2019. In contrast, CPUE for corkwing has increased between 2017–2019 while LPUE has remained stable; this suggests that current fishery effort is sustainable and has not impacted wider population growth.

The majority of rock cook that are caught are subsequently returned to the sea, as they are below the minimum CRS. Therefore, the cause of reductions in rock cook $LPUE_{fc}$ and CPUE is currently unclear. The mortality of wrasse caught but returned to sea is not yet known, though mark-release-recapture surveys may aid the understanding of this. However, this is beyond the current operational capacity of D&S IFCA. As the landed wrasse are retained alive, transported to Scotland and released into salmon farms, it appears unlikely that simple catch and release would be associated with high mortality.

However, the catching process may interfere with wrasse swim bladder function in the short-term, briefly limiting their mobility upon being returned to the sea and increasing mortality due to predation. It may therefore be useful to promote a new code of conduct for wrasse fishers. Under this code, wrasse to be returned to sea should first be retained in seawater on board the vessel for a short period while their swim bladder function equilibrates with ambient pressure (allowing them to swim more effectively upon release). Initial observations of wrasse swimming behaviour while retained and initially returned to sea, during the first on-board observer surveys in early 2020, may inform the details of this code of conduct (for example, in determining the length of the recovery period).

Understanding how CPUE and LPUE relate to abundance is extremely difficult in this fishery both overall and on a species-by-species basis, in part because the association of wrasse with reef habitat may result in a complex relationship between fisher behaviour and stock dynamics (Ross 2016). It may, therefore, be difficult to identify unsustainable fishing practices underlying apparently stable CPUE patterns. For example, the CPUE may remain high despite an overall reduction in the wrasse population, because fishers move from reef to reef to maintain catch levels. This is known as hyperstability, and contrasts with an alternative scenario known as hyperdepletion. Under hyperdepletion, early reduction in CPUE occurs because of local depletions on individual reefs, but overall stock abundance remains stable as other reef remain unfished (Hilborn and Walters, 1992). However, the exact nature of the interaction depend on fisher behaviour and the source-sink ecological dynamics of wrasse populations, how these relationships differ between reefs of different physical characteristics (depth, exposure, size, habitat complexity) and, if the fishery moves into new areas, between different habitats (e.g. reefs vs seagrass).

In the case of wrasse in the D&S IFCA's District, hyperstability initially seems unlikely because fishers have maintained their effort over similar areas (grid cells) during the 2017–2019 period, rather than moving between sites following local depletions. However, previous studies have reported that movement of wrasse occurs over relatively short distances (less than 592 meters at a site in Norway) (Aasen, 2019). Therefore, hyperstability may be occurring at a spatial scale smaller than an individual grid cell ($1km^2$). As a result, the $1km^2$ grid cell would not be a fine enough resolution to detect changes in abundance based on LPUE or CPUE data.

The relationships between fishing pressure, CPUE and species abundance may also be masked by the effects of drivers not measured here. For example, CPUE of wrasse has been found to be positively correlated to water temperature, and tends to increase from June to September (Darwall *et al.* 1992, Gjøsæter 2002). Similar patterns have been observed in D&S IFCA over the 2017–2019 period. The mechanisms behind this pattern are unknown but could include increased activity driven by the warmer environment, or increased feeding rates post-spawning (resulting in increased catchability). Modelling of fine-scale weather, sea temperature and catch data would be required to more fully understand the seasonal trends in CPUE, including the summer CPUE peak. These analyses are currently being undertaken by a PhD student at the University of Exeter.

4.2. Spatial Effort and Catch Composition

Species-specific spatial structures can be seen in Plymouth Sound within and between years. Variation in spatial catch composition can be a result of interactions between the ecology of individual species, habitat and diet preferences as well as life history traits (Aasen, 2017, Skiftesvik *et al.,* 2014). For example, goldsinny can be found in areas exhibiting turbulent water movement with a rocky reef habitat (Darwall *et al.,* 1992, Skiftesvik *et al.,* 2014). As this species remains in hiding for long periods, the availability of complex refuge appears to be a factor limiting goldsinny distribution (Skiftesvik *et al.,* 2014). In contrast corkwing are more specialised and prefer sheltered shallower water within kelp forests and have been shown to move longer distances compared to goldsinny. These differences in space use and movement may be attributed to differences in growth rate, body size and territory sizes (Aasen, 2019, Skiftesvik *et al*., 2014). Changes in spatial fishing effort can also impact spatial catch composition. Although the fishers appear to be targeting the same locations each year (at the 1 km^2 grid square scale), they may be fishing in slightly different areas within the same grid square. As species composition differences have been recorded over distances as small as a few meters, with individuals possibly changing territories as they grow (Skiftesvik *et al.,* 2014), this may give rise to within-grid cell variation in catch composition. Apparent spatial differences in catch composition could also relate to differences in the number and timing of surveys within and between years.

Assemblage composition over the three-year period (2017–2019) appears to have changed, and the apparent reduction in rock cook catches is in line with anecdotal information on rock cook abundance received from a SCUBA diver local to the area. Catches (CPUE) of both goldsinny and ballan have remained stable over this period, while catches of corkwing have increased.

4.3. Size Distribution and Spawning

During the last three years of the fishery, the landed rock cook and goldsinny comprised the largest size classes of these species in the catch (Figure 10 and Figure 13). Male goldsinny and rock cook have been reported to mature at 9cm, while female maturation occurs at 8 cm in goldsinny and 8.5 cm in rock cook (Matland, 2015). Therefore, the current Min. CRS of 12cm for these species is thought to be protecting individuals that have the potential to spawn and restock the population. However, in the context of recent reductions in rock cook CPUE, the removal of the largest individuals of this species may be problematic in terms of maintaining stable population structures with mature individuals (Lauren Henly, *pers. comm.*), and may have contributed to the observed CPUE declines. However, the current data do not permit full analysis of this.

The number of goldsinny observed spawning in 2019 has reduced by more than half compared to 2018, and no rock cook were observed spawning in 2019. Previous studies have indicated that the spawning period for goldsinny is from May to mid-June, possibly till the end of July (Halvorsen *et al*., 2016, Matland ,2015, Skiftesvik *et al*., 2015) and from May to August for rock cook (Matland, 2015). Therefore, the majority of individuals would have spawned prior to surveys commencing. The reduction in the number of individuals observed spawning may indicate that the temporal closure from 1st May to 15th July is protecting the majority of spawning individuals. Ballan have been reported to spawn synchronously (Darwell *et al*., 1992); synchronous spawning just outside of D&S IFCA's period of observation may explain why only one ballan was observed spawning during the 2019 surveys. There have been conflicting results from previous reports looking at the spawning period of ballan wrasse. In Norway spawning took place from April to July (Matland 2015), whereas in Spain it was observed from January to April (Villegas-Rios *et al*., 2013). Additional surveys would need to be carried out throughout the year in order to determine whether the temporal closure is protecting spawning individuals. The number of corkwing observed spawning has steadily increased over the last three years with 32 individuals spawning in 2019. The spawning season has been reported to be from April to September (Darwall et al., 1992, Skiftesvik *et al*., 2014) which coincides with the majority of individuals observed during the on-board observer surveys. In order to better quantify spawning states for all species, and investigate whether the temporal closure is protecting the majority of spawning individuals, additional surveys would need to be conducted throughout the year, as it appears that the timing of D&S IFCA's on-board observer surveys has not been optimal for detecting signs of spawning. However, these additional surveys are currently beyond the resource capabilities of D&S IFCA

The size class distribution of ballan wrasse appears to have remained stable from 2017–2019. Female ballan mature at 16–18cm and males at 28cm (Darwall et al., 1992). Ballan wrasse are protogynous hermaphrodites: they start life as female and later change to male. It has been reported that this sex change can be associated with body size and social cues (the absence of functional males). This is an important consideration within the fishery, particularly if a rod and line fishery emerges within the D&S IFCA's District, as the disproportionate removal of one particular sex could result in a shift in sex ratio and have consequences for future recruitment and breeding (Muncaster et al., 2013). As stated in the 2018 report (Curtin and West, 2018), the current Min. and Max. CRS appear to be protecting juvenile females and larger dominant mature males, reducing the risk of disproportionate male loss.

The size frequency histograms for corkwing illustrate that a large proportion of individuals are being returned, particularly after the adoption of a new Min. and Max. CRS in 2018. The Min. CRS of 14cm protects nesting mature males, females and sneaker males, which have been reported to have average lengths of 12–14cm, 13cm and 10–12cm respectively (Halvorsen *et al*., 2016). The Max. CRS of 18cm ensures that the larger dominant males are returned to the population, potentially avoiding destabilization in social structures (Darwall et al., 1992, Halvorsen *et al*., 2016). In order to determine whether the fishery is being sex selective, further analysis of the data is required which is beyond the scope of this report.

4.4. Compliance with the Fully Documented Fishery

In the 2018 report (Curtin and West, 2018) it was suggested that the same level of observer coverage be attained in 2019. Fewer on-board observer surveys were possible in 2019, and 9% observer coverage was achieved across all vessels (excluding March and April) which is the same as 2018. This was mainly driven by a reduction in the amount of days fished in 2019 compared to 2018.

The fishery requires a large allocation of resources, from a limited resource pool, to obtain survey data. Over the last three years there have been difficulties in arranging on-board observer surveys due to fishers' vessels being out of the water for extended, interruptions to fishing activity by inclement weather, and difficulty aligning limited officer time with sporadic fishing activities. Furthermore, vessel 3 has not co-operated with D&S IFCA officers over the last three years, making on-board surveys difficult to achieve. In 2017 no on-board observer surveys were conducted on vessel 3 due to space constraints, in 2018 only one survey was conducted despite numerous attempts to arrange surveys, and in 2019 it was deemed unsafe for officers to conduct surveys on-board the vessel. Other vessels co-operated with officers, who were allowed on-board the vessels.

Since 2017 there have been recurring issues with the fishers' landings forms not being completed and returned on a weekly basis. Repeated requests by IFCA officers as well as letters reminding fishers of their obligations were required to obtain the forms, which requires allocation of a considerable amount of Officer time. However, vessel 3 did not return any landings forms, despite several reminders throughout the 2019 season. Without these forms LPUE cannot be calculated for the vessel in question, and data are missing from the analyses. Greater consideration should be given to improving compliance, including via strict enforcement of the Potting Permit Byelaw, under which fishers are required to 'provide any relevant fisheries information required by the Authority for the discharge of its functions'. This would allow D&S IFCA to enforce any issues of non-compliance and reduce time spent requesting forms and reminding fishers of their obligations.

The voluntary closed areas are likely important for maintaining natural population sizes and size structure (Halvorsen *et al*., 2017). During the period March to December 2019 only three strings slightly overlapped into a closed area (Figure 22 and Figure 23). Fishers should be reminded of the voluntary closed areas and compliance should be monitored throughout the fishing season.

5. Conclusions

The overall stability of fishery-level LPUE and CPUE during the 2017–2019 period suggests that the fishery is sustainable at the current level of effort, and that the current management measures provide an effective way to manage the fishery. However, the fishery-level measures of LPUE and CPUE mask other patterns at the species level. LPUE has remained steady for ballan, goldsinny and corkwing (suggesting no detrimental effects of fishing effort), but declined for rock cook. CPUE has also remained stable for ballan and goldsinny, and has increased for corkwing (again suggesting no detrimental effects of fishing effort), but has declined for rock cook. This report highlights that the declines in both LPUE and CPUE for rock cook give cause for concern, particularly as the fishery to date has been targeting larger size classes of this species.

D&S IFCA's close monitoring of this fishery has been imperative for being able to discern these trends. However, this monitoring is at risk due to repeated non-compliance issues, which relate primarily to a single fisher. This non-compliance also absorbs a lot of Officer time in chasing catch returns forms. Under Paragraph 17 of the Potting Permit Byelaw 'the permit holder shall provide any relevant fisheries information required by the Authority for the discharge of its functions.' This has been repeatedly communicated to the fishers and the salmon farm agent who deals with the fishers. This needs to be reiterated and enforced to ensure compliance with this Byelaw condition.

Overall, the fishery is showing promising signs of sustainability and productive management. Given the evidence outlined in this report, the following actions are recommended in order to maintain the environmentally, economically and socially sustainable nature of the live wrasse fishery in D&S IFCA's District:

(i) Continue to manage the fishery as outlined in the D&S IFCA's Policy Statement and Potting Permit Conditions for the Live Wrasse Fishery (1st August 2018), except in the case of rock cook (ii, below)

(ii) In the case of rock cook, all catch taken from within the D&S IFCA's District must be returned to the sea immediately. No rock cook can be retained on board while fishing in the D&S IFCA's District.

(iii) Continue with at least the current level of on-board observer effort for this fishery, and

(iv) To use Paragraph 17 of the Potting Permit Byelaw to formally require relevant fisheries information from fishers.

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Appendix 1 – Methods of LPUE, $LPUE_{fc}$ and CPUE analyses using Generalised Linear Models

Generalised linear models (GLMs) were used to assess changes in species-level $LPUE_{fc}$ and CPUE over the 2017–2019 period. Generalised linear models are essentially a flexible form of 'linear regression'. Linear regression is a statistical method that describes change in one variable (the response) as a function of change in one or more predictors. In this approach, the response variable (e.g. LPUE) is normally distributed (the plotted data look like a bell-shaped curve) and has a linear relationship with the predictors (i.e. there is a straight-line relationship between the response and predictors). Generalised linear models are a more flexible extension of this approach, which allow for the modelling of non-normal response variables (whose plots do not look like a bell-shaped curve), and allow for non-linear relationships between the response and predictors. Here, generalised linear models with a 'gamma error structure' were used because the gamma distribution is a good approximation for the $LPUE_{fc}$ and CPUE data (when plotted, they all look like a bell-shaped curve leaning to the left). To assess changes in $LPUE_{fc}$ and CPUE over the 2017–2019 period, these GLMs were fitted with year and vessel ID as categorical predictors, allowing for identification of changes in (for example) CPUE that occur between years, whilst accounting for changes that occur due to differences in the response variables between vessels.

Detailed modelling and model selection approach

For each response variable ($LPUE_{fc}$ for each species and CPUE for each species), two models were constructed: a 'test model' (including Year and vessel ID as predictors), and a null model (which contained no predictor variables). Comparing the test model to this null model essentially allows for assessment of whether the models are performing better than random (i.e. whether the predictor terms are useful in predicting the response variable). The 'test' and 'null' models were compared using an 'information theoretic approach', based on their Akaike's Information Criterion (AIC) value: the model having the lowest AIC is likely the most parsimonious. However, as AIC is only an estimate of parsimony, other models were also considered, in line with Richards (2008): any model within 6 AIC units of the model with the lowest AIC were deemed to perform equally well. Therefore, if the 'test' model for each response variable was within 6 AIC units of the corresponding null model, it was deemed to have failed to outperform the null, implying that the tested predictor variables are not associated with change in the response variable.

Biological inference based on selected models

Following selection of the most parsimonious model for each response variable, the GLM output was used to identify changes in the response variable over the 2017–2019 period. For cases in which a model outperforms the associated null model (based on AIC), this is widely considered to be sufficient evidence that the predictor variables are useful in predicting change in the response variable. However, *p*-values associated with individual model terms are presented, as these may be more familiar to readers of this report. *P*-values < 0.05 essentially indicate that the model terms are significant predictors of change in the response.

Model assessment

Model diagnostics were checked based on visual assessment of model residuals. Where model diagnostics were deemed to be unsatisfactory, alternative GLM error structures and link functions were attempted. These approaches are common and in widespread scientific use (see e.g. Crawley, 2007). If model diagnostics were still unsatisfactory, non-parametric analysis of variance tests (Kruskal-Wallis tests with pairwise *post hoc* comparisons) were used instead.

Detailed AIC analyses and model results

This section reports comparisons (based on AIC) of the GLMs for each response variable ($LPUE_{fc}$ for each species and CPUE for each species). In all cases, both the 'test' GLM and the 'null' GLM are reported for comparison.

Table A1.1 Summary of AIC analysis of all GLMs (gamma error structure) used to assess changes in Landings Per Unit Effort (from catch; $LPUE_{fc}$). • indicates the presence of each predictor in the model, *LL* is the log-likelihood of the model, *k* is the number of parameters, and AIC denotes the AIC value of the model. The null model is denoted '$_{null}$', and the model used to test the effect of year (accounting for vessel ID) is denoted 'test'. RC = rock cook, CW = corkwing.

Model	Model parameters			*LL*	*k*	AIC
	Intercept	Year	Vessel			
RC_{test}	•	•	•	81.89	9	-145.79
RC_{null}	•			57.39	2	-110.77
CW_{test}	•	•	•	56.05	9	-94.10
CW_{null}	•			48.76	2	-93.51

Table A1.2 Summary of AIC analysis of all GLMs (gamma error structure) used to assess changes in Catches Per Unit Effort (CPUE). • indicates the presence of each predictor in the model, *LL* is the log-likelihood of the model, *k* is the number of parameters, and AIC denotes the AIC value of the model. The null model is denoted '$_{null}$', and the model used to test the effect of year (accounting for vessel ID) is denoted 'test'. BA = ballan, RC = rock cook, CW = corkwing, CU = cuckoo.

Model	Model parameters			*LL*	*k*	AIC
	Intercept	Year	Vessel			
BA_{test}	•	•	•	136.26	9	-254.51
BA_{null}	•			123.02	2	-242.03
RC_{test}	•	•	•	-37.55	9	93.10
RC_{null}	•			-49.19	2	102.38
CW_{test}	•	•	•	15.22	9	-12.43
CW_{null}	•			-6.29	2	16.58
CU_{test}	•	•	•	54.73	8	-93.45
CU_{null}	•			47.41	2	-90.81

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Appendix 2 – Fishing Effort Charts 2018

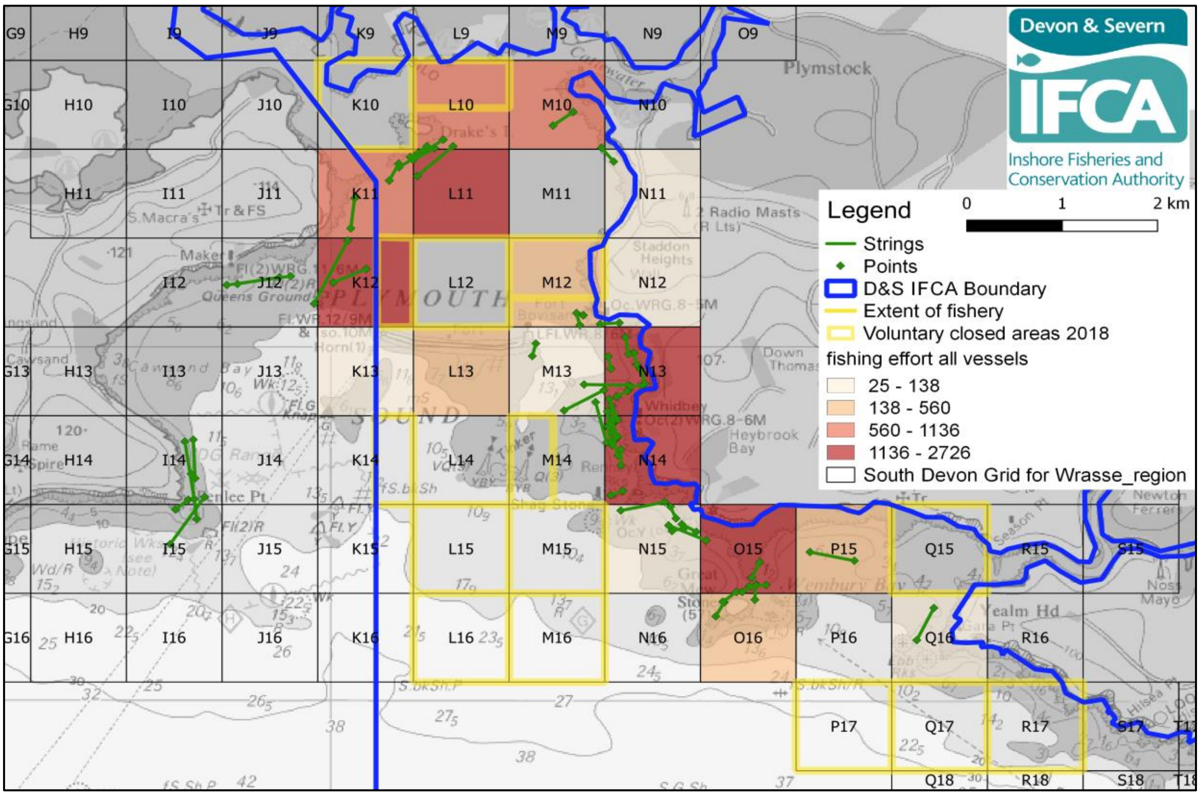

Figure 26. Chart of Plymouth Sound showing areas worked by all vessels during 2018. Data taken from the landing's forms.

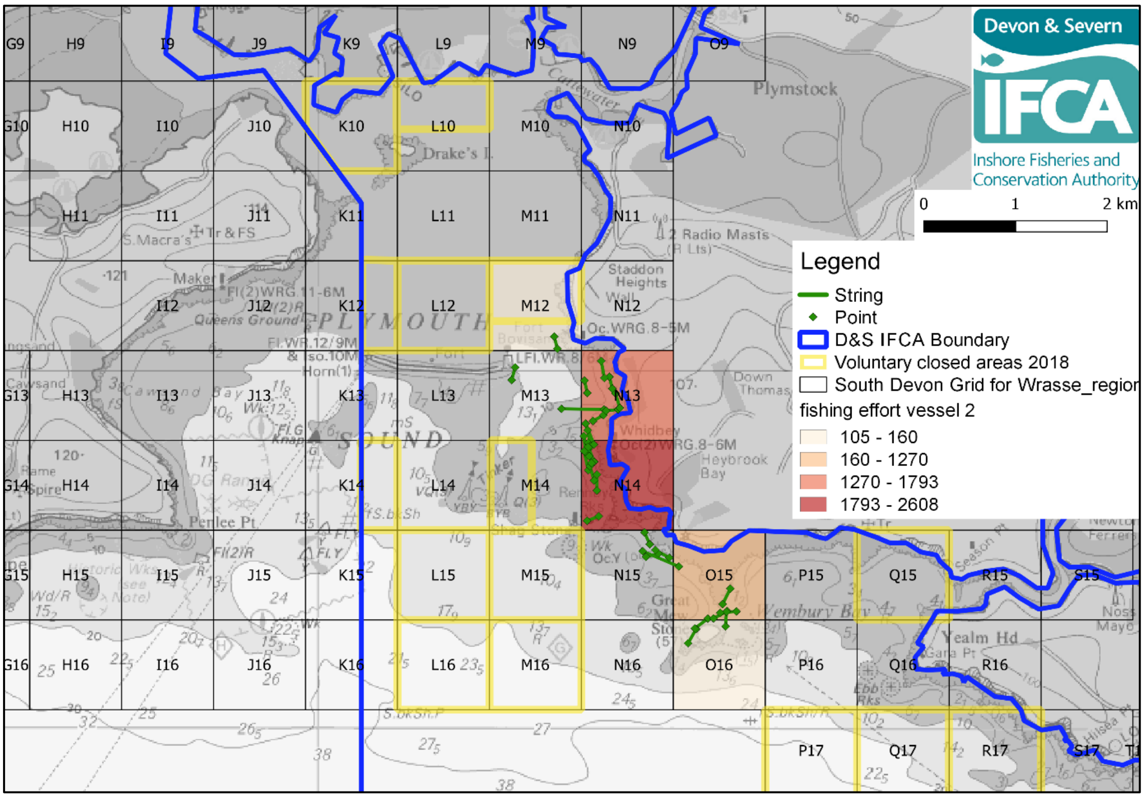

Figure 27. Chart of Plymouth Sound showing areas worked by all vessel 2 during 2018. Data taken from the landing's forms.

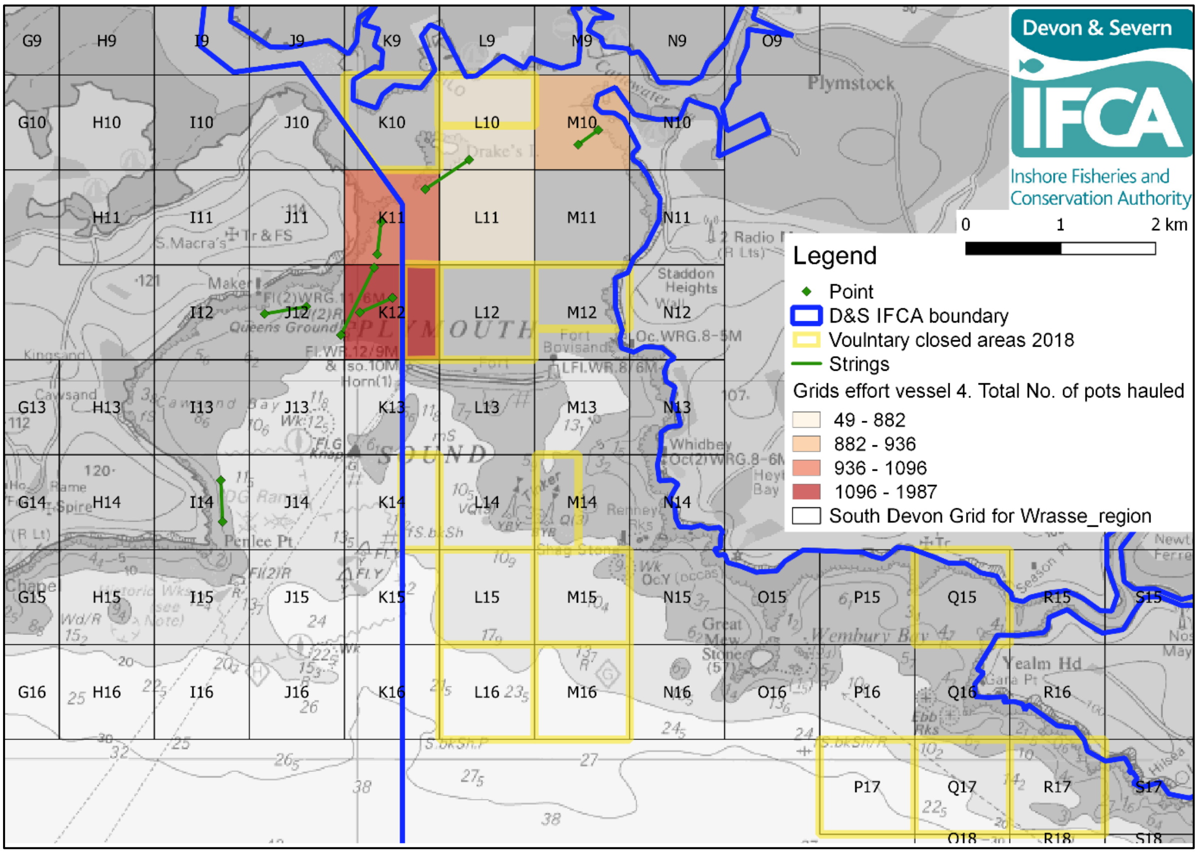

Figure 28. Chart of Plymouth Sound showing areas vessel 4 during 2018. Data taken from the landing's forms

Appendix 3 – Catch Composition 2017–2018

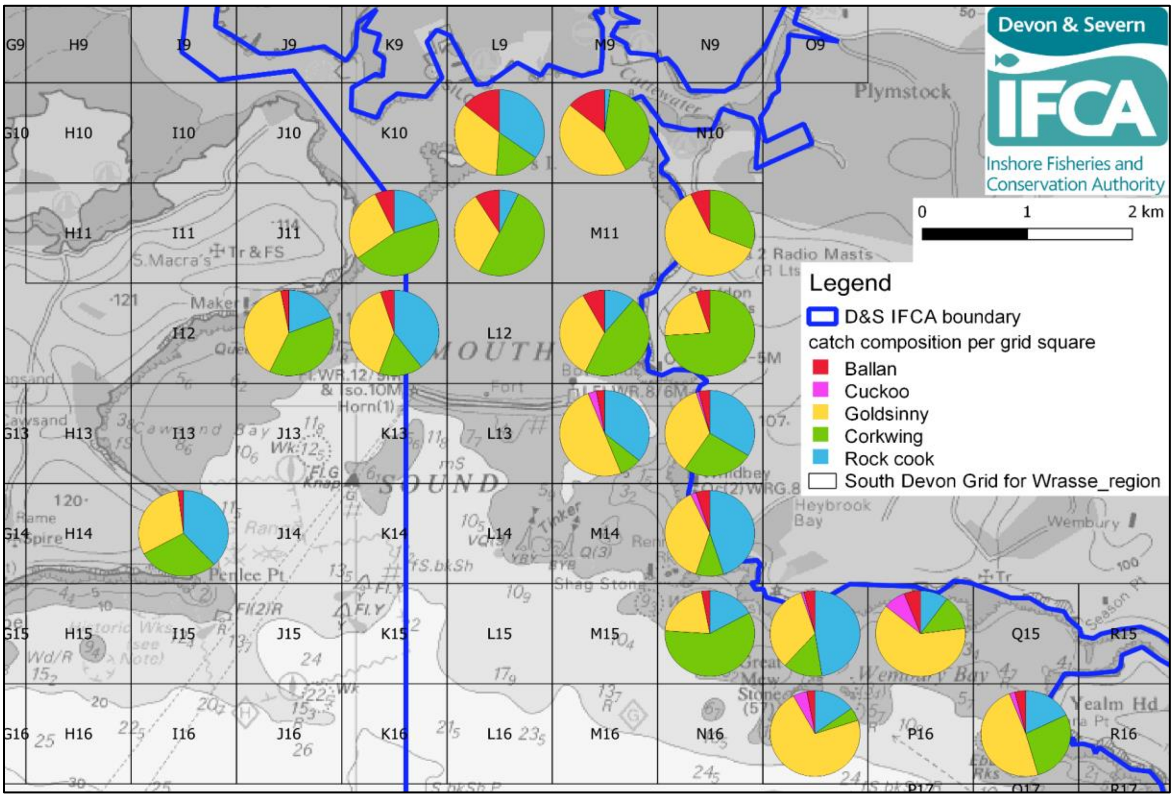

Figure 29. Assemblage composition of wrasse catches in Plymouth Sound during 2018. Data taken from the on-board observer surveys.

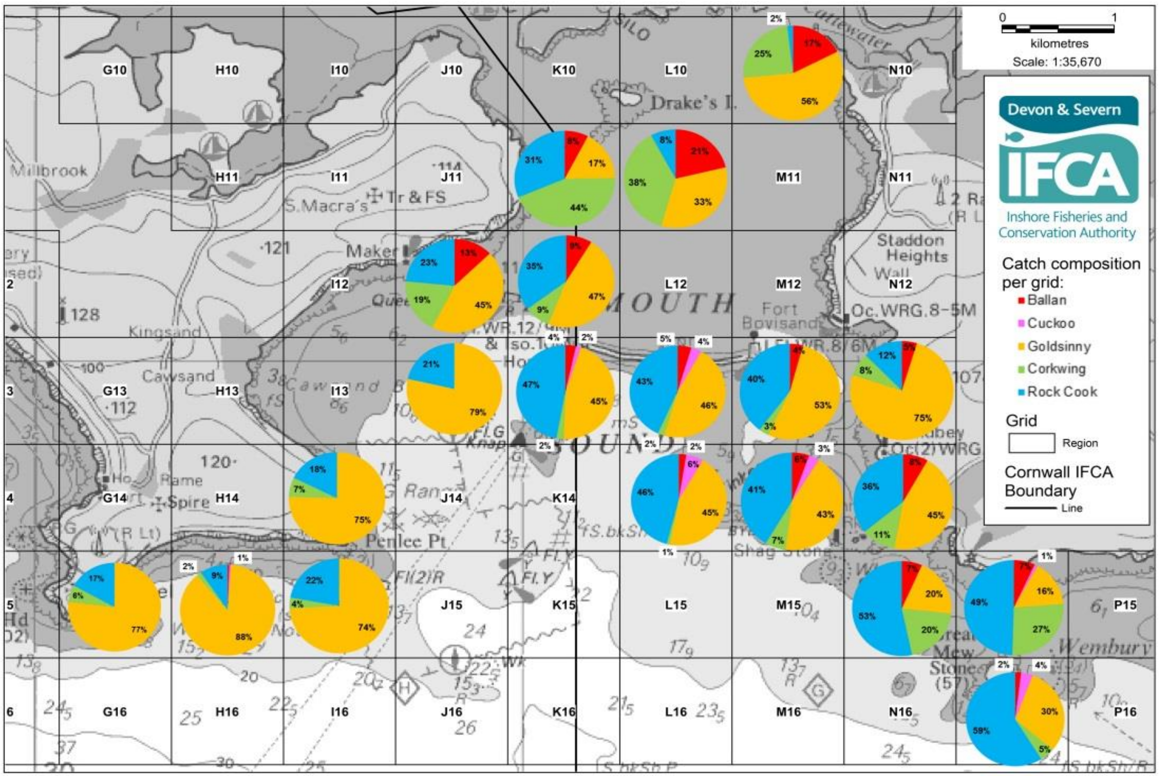

Figure 30. Assemblage composition of wrasse catches in Plymouth Sound during 2017. Data taken from the on-board observer surveys.

Appendix 4 – Summary of Resource Allocation

This summary provides information on the amount of resource allocated to the Live Wrasse Fishery in 2019 and compares this to the value of the fishery. This summary should be read in conjunction with the main text of the February 2020 Three Year Comprehensive Review of the Live Wrasse Fishery in Devon & Severn IFCA's District.

The total value of the fishery for the whole of the Plymouth Sound was £33,284 in 2019. This is based on payable fish (amount landed less any damaged, undersized, or dead). It should be noted that data are taken from the sales notes supplied by the MMO and only include data up to 13th October 2019.

The following table illustrates the amount of resource in days it takes to collect, compile, analyse and produce a report on the Live Wrasse Fishery. This is based just on the 2019 season and includes patrols that have been undertaken by the enforcement team as a result of compliance issues with one of the fishers.

Description of resource	Time spent (days)
Carrying out on-board observer surveys	10 days
Analysing data and producing report	30 days (based on a part-time officer working 3 days a week)
Enforcement patrols	6 days (3 in April; 2 in August; 1 in September).

IFCA charge rates for officer time and use of David Rowe, based on previous working agreements, are set out below

Charging item	Basis of Charging	Charge Rate	Additional information
(Crew) Master	Day 6hrs / Hourly	£180 / £30	
(Crew) EO	Day 6hrs / Hourly	£180 / £30	
RIB Hire	Day 6hrs / Hourly	£270 / £45	
Fuel	Per litre / Per hour	£1.50 / £63	Average of 42 litres P/H
Mooring	Actual cost	Actual cost	
Towing of RIB	Per hour	£60.00	Excluding officer time

The estimated charge for the David Rowe for a 6-hour day operating at cursing speed, with engines at idle during boarding

Charging Item	Basis of Charging	Charge
Vessel Hire	Per day	£270
Fuel	Per day	£378
Crew (based on 2)	Per day	£360
Total Cost (excl. VAT)		**1,008**

The cost of monitoring the Live Wrasse Fishery for the 2019 period was £15,708, which is just under half the value of the fishery. A more detailed breakdown of the costs can be seen in the table below;

Charging Item	**Charge rate**	**Total**
Use of David Rowe (incl. 2 crew)	£1,008 x 6 days	£6,048
Additional Enforcement officer time	£180 x 9 additional officers over the 6-day period	£1,620
Conducting on-board observer surveys	£180 x 10 days	£1,800
Analysing data and report writing	£240 (based on 8hr days) x 26 days	£6,240
Total		**15,708**

In addition to the above costs incurred, time has been spent by D&S IFCA officers contacting fishers and various agencies to complete and return documentation required in order to compile the report. A detailed communication log can be seen in the table below;

Vessel/ Contact	**Date**	**Comments**
2 and 4	17/04/2019	Letters sent with new pot tags, requesting old ones be returned and reminding fishers to complete landings forms and return them to MMO office
6	10/07/2019	Letter sent with new pot tags, landings forms for completion and asking them to be completed on a weekly basis. Copy of the potting permit conditions specific to the live wrasse fishery included and map of voluntary closed areas
3	23/07/2019	Letter sent with new tags as fisher did renew permit prior to this date and reminding him of obligation to complete and return landings forms.
2	29/07/2019	Chased landings on 13/08 as not received any since fishery opened on 15/7. Handing them in on 16/08
3	29/07/2019	Cannot get hold of fisher
4	29/07/2019	Vessel out of the water
2	12/08/2019	Awaiting landing forms. Has dropped them off
3	12/08/2019	Called on 13/08 cannot get hold of. Went to voicemail so left a message
4	12/08/2019	Called to arrange survey but Vessel out of the water
6	12/08/2019	Chased landings forms but not landed any wrasse yet
6	14/08/2019	Chased landings forms but not landed any wrasse yet
3	19/08/2019	Tried to contact to chase landings but got voicemail
MMO	19/08/2019	DPA request sent to MMO for transport documents
4	19/08/2019	Spoke to vessel 4 and should be back in water today, inspection due 20/08/19
4	02/09/2019	Spoke to vessel 4 and only has one string out in the District ATM. Should have full set of pots out this week
3	04/09/2019	Letter sent to vessel 3 reminding of obligations to complete landings forms, asking for contact no and advising D&S IFCA Officers will be using the RIB to survey his vessel
2 & 6	09/09/2019	Chased landings forms for vessel 2 and 6

MMO	30/09/2019	Sent email to MMO to ask whether they received any landings forms as none been received by me
2	01/10/2019	Letter sent to vessel 2 with additional tags
3	02/10/2019	Phoned vessel 3 to chase landings forms
3	14/10/2019	Phoned vessel 3 to chase landings forms
6	14/10/2019	Phoned vessel 6 to see if fishing but not going out on 15/10.
MMO	16/10/2019	Emailed MMO to ask whether they have any landings forms and chase sales documents after submitting DPA request
3, 4 and 6	16/10/2019	chased landings forms
3	05/11/2019	Phoned vessel 3 to chase landings forms
4	06/11/2019	Chased landings forms and advised one string is within the voluntary closed area and asked to move it
3	25/11/2019	called vessel 3 to chase landings forms but no answer
3	26/11/2019	called vessel 3 to chase landings forms, advised he would speak to the skipper and get him to send them in or contact us
2,4,6,3	10/12/2019	called to chase landings forms from all fishers, vessel 2, 6 and 4 dropping them to MMO at the weekend, vessel 3 has had paperwork stolen as truck got broken into
3	17/12/2019	Called vessel 3 to request crime reference number re stolen paperwork (landings) but no answer

The Deputy Chief Officer has corresponded with the salmon farm company on numerous occasions and a summary is shown in the table below. This work, time and resources used in contacting the fishers and chasing for information is not costed in this report.

Date	**Type of correspondence**	**Summary of information**
11/03/2019	e-mail from SFA	Informed IFCA that only 3 vessels would be operating in 2019 and wanted to share the remaining 120 pots out between the 3 fishers.
14/03/2019	e-mail to Salmon Farm Agent (SFA)	Explained that the permit condition only allows 120 pots per permit holder. Reiterated that Paragraph 17 of the Potting Permit Byelaw allows D&S IFCA to request relevant information to discharge its duties. The Agent was asked to ensure the fully documented fishery was achieved through supplying data and allowing officers on board. Also explained that if this was not achieved a review of the fishery would take place. Provide copies of the Byelaw and Permit conditions.
14/03/2019	e-mail from SFA	Response to D&S IFCA e-mail of 14th March 2020
15/03/2019	e-mail to SFA	Provided clarity on the process to change permit conditions and reiterated the importance of working with the fishers and gathering on-board survey data.

09/07/2019	e-mail to SFA	Explained that old tags need to be replaced by new tags for 2019. Reiterated the importance of good evidence for the review of the fishery. Explained the difficulty for D&S IFCA officers being able to contact the fishermen and get on board for surveys. Explained about Paragraph 17 of D&S IFCA's Potting Permit Byelaw which details the requirement to provide relevant fisheries information as required, which is not happening with all fishermen operating in the Wrasse fishery. Asked about the position on rearing of wrasse and the rod and line effort on Ballan.
11/07/2019	e-mail from SFA	He explained that he had reiterated to the fishermen the importance of allowing D&S IFCA to board vessels to collect data
23/09/2019	several e-mails between SFA and DCO	Discussed the wrasse pots that D&SIFCA had seized during an enforcement patrol and whether he could verify they were his and therefore could be released. SFA explained that one of his past fishermen had sold some of the Agent's wrasse pots without his permission and potentially were the ones that were seized.
04/12/2019	e-mail / letters to fishers	Regarding GDPR and sharing data with CIFCA
06/12/2019	e-mail to SFA	Requested the sales information for the wrasse fishery. DCO explained that D&S IFCA had the data up to September 2019 but no more up-to-date data. Reiterated the importance of having all the up to date data for the 2020 review of the fishery and as a part of the fully documented fishery. Also explained that D&S IFCA had not received all the landings data from the fishers. Asked for information on the intention of the fishery for 2020.
18/12/2019	e-mail from SFA	SFA explained he had updated the sales notes on the MMO electronic system and they should be available to all. Explained that the intention for 2020 will be finalised in February 2020. Likely to be no more than 4 boats with three existing fishers and potentially an additional one.
05/01/2020	e-mail from SFA	Update on plans for 2020 fishery. Increasing Min CRS for all species (excluding Ballan) to 14cm.

The wrasse fishery requires a lot of resource to monitor in order to establish whether it is sustainable. Moving forward in 2020, this level of resource may not be achievable due to new fisheries emerging in the D&S IFCA's District that also require monitoring over the same period. The non-compliance of some fishers to complete landings forms on a weekly basis is a drain on D&S IFCA resources as a large proportion of officer time is spent requesting the data repeatedly on several occasions. The research report includes recommendations for maintaining the current level of monitoring of the fishery, in addition to making it a formal requirement for fishers to complete and return detailed and accurate landings forms, as detailed under Paragraph 17 of the Potting Permit Byelaw. This would allow better enforcement of these requirements, and reduce the time spent by D&S IFCA's Officers on pursuing fishers for their un-returned landings forms.

Appendix 5 – Gaps in Research and Knowledge

This appendix provides information on evidence gaps and areas of research that D&S IFCA was unable to carry out to limitations on resources. Being able to obtain these additional data would improve D&S IFCA's knowledge of the wrasse populations and fishery and provide some clarification for any trends seen within the dataset. Some potential avenues for initial work to fill these data gaps are highlighted below, but these are currently beyond the resource capabilities of D&S IFCA.

- Mortality rates of returned wrasse. This may be assessed by, for example, mark-release-recapture experiments.
- Impacts of environmental drivers on local wrasse abundance (modelling of fine scale weather sea temperature and catch data to understand seasonal trends) – this is being looked at by L. Henly at the University of Exeter.
- Location-specific spawning seasons for all species; this could be based on laboratory-based analysis of gonads, or more regularly spaced observer surveys to identify signs of spawning throughout the year.
- Size of wrasse home ranges and territories, and how this relates to their population structure. The genetic population structure of Ballan wrasse on the south coast is currently being investigated by L. Henly at the University of Exeter.
- Wider ecological impacts of wrasse removal – is there an increase in sea lice within Plymouth Sound, either on wrasse or other species? However, this would require several years of spatially-structured repeat observation/sampling to accurately determine.
- Wider ecological impacts of wrasse removal – the ecological niches of these wrasse species are unknown, so it is not possible to state what wider ecological impacts may occur if wrasse removal were to be unsustainable. This is being assessed by L. Henly at the University of Exeter.
- Sex selectivity regarding Corkwing and Ballan wrasse. This may be investigated by, for example, simple genetic tests on live-caught wrasse.
- Anglers catch compared to commercial catch in Plymouth Sound and the effect of the fishery on the Angling community. Work by L. Henly at the University of Exeter is beginning to highlight the importance of the wrasse fishery to anglers and identify things like who fishes for wrasse, as well as where, when and why they do it. This may highlight the most important areas of overlap with the commercial fishery.
- Catches of wrasse by other means and for other purposes (e.g. pot bait) are as yet unquantified.