Assessment of the Salcombe Estuary Scallop Fishery 1998-2020

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Contents

1. Introduction

There has been a small-scale scallop fishery in the Salcombe Estuary for a number of decades. This report presents a comprehensive analysis of the catch data collected over the period 1998 to 2020, first by the Devon Sea Fisheries Committee (DSFC) (1998 – 2010) and then by Devon and Severn Inshore Fisheries and Conservation Authority (D&SIFCA) (2011 onwards). This is the first time the data have been analysed in this way.

1.1 Site summary

Salcombe to Kingsbridge Estuary is located on the South Devon coast (Figure 1) and falls within the South Devon Area of Outstanding Natural Beauty (AONB). Th estuary was notified as a Site of Special Scientific Interest (SSSI) in 1987 and is also designated as a Local Nature Reserve (Northern *et al*, 2006). It is a sheltered marine inlet, characterised as a ria. It has a total area of 634.5ha and is 8.3km long with a maximum channel depth of 12.5m below chart datum. The SSSI encompasses the subtidal and intertidal zones of The Bar (a shallow sandbank just over 1km inside the mouth of the estuary), to the top of the estuary at Kingsbridge. There are numerous creeks that extend off from the main channel, all of which have very limited freshwater input (Critchley *et al*, 2015).

The conditions in which the seabed communities have developed remain predominantly marine. The upper estuary consists mainly of intertidal mudflats with some areas of eelgrass *Zostera noltii* and small patched of early-stage saltmarsh. The lower estuary consists of mostly sand and rocky reef. There are extensive areas of seagrass *Zostera marina* (Figure 2) at and below low water (Northern *et al*, 2006).

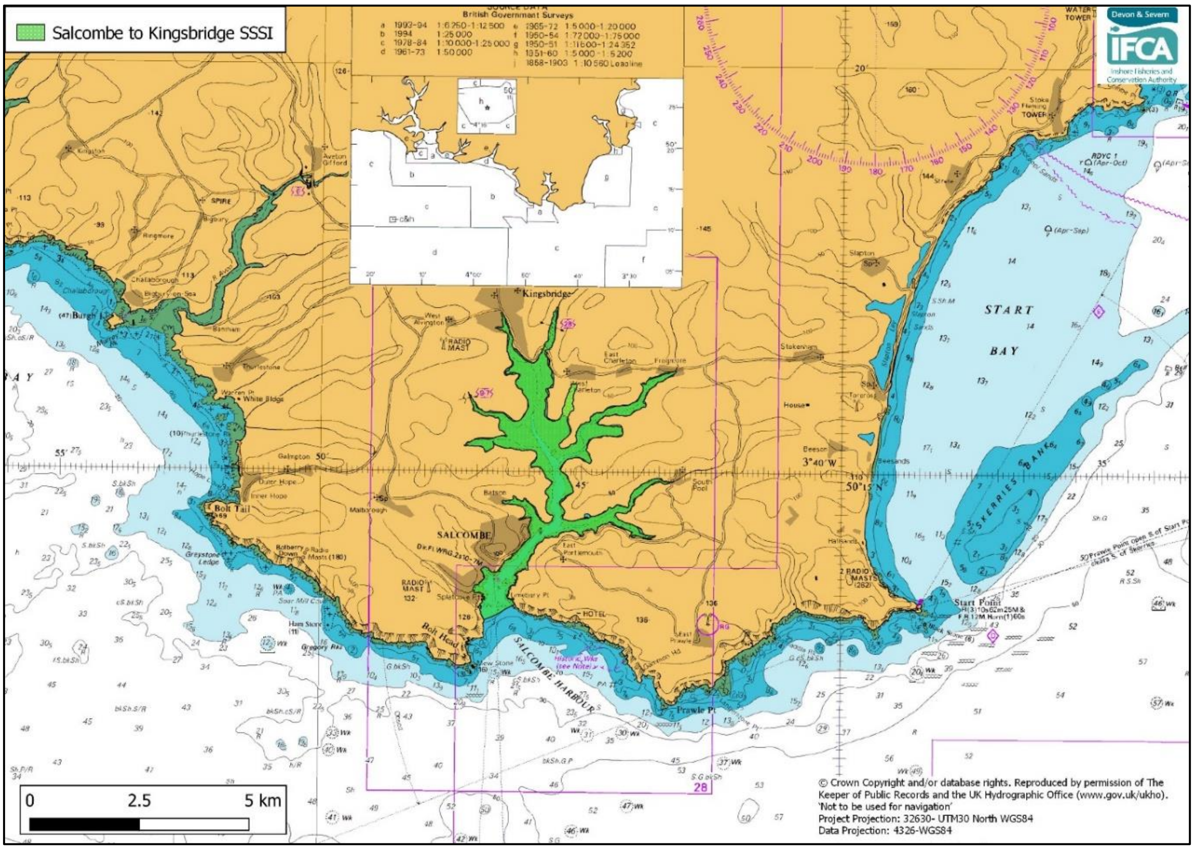

Figure 1 Location of Salcombe Estuary on south Devon coast. The Salcombe to Kingsbridge SSSI highlighted in green.

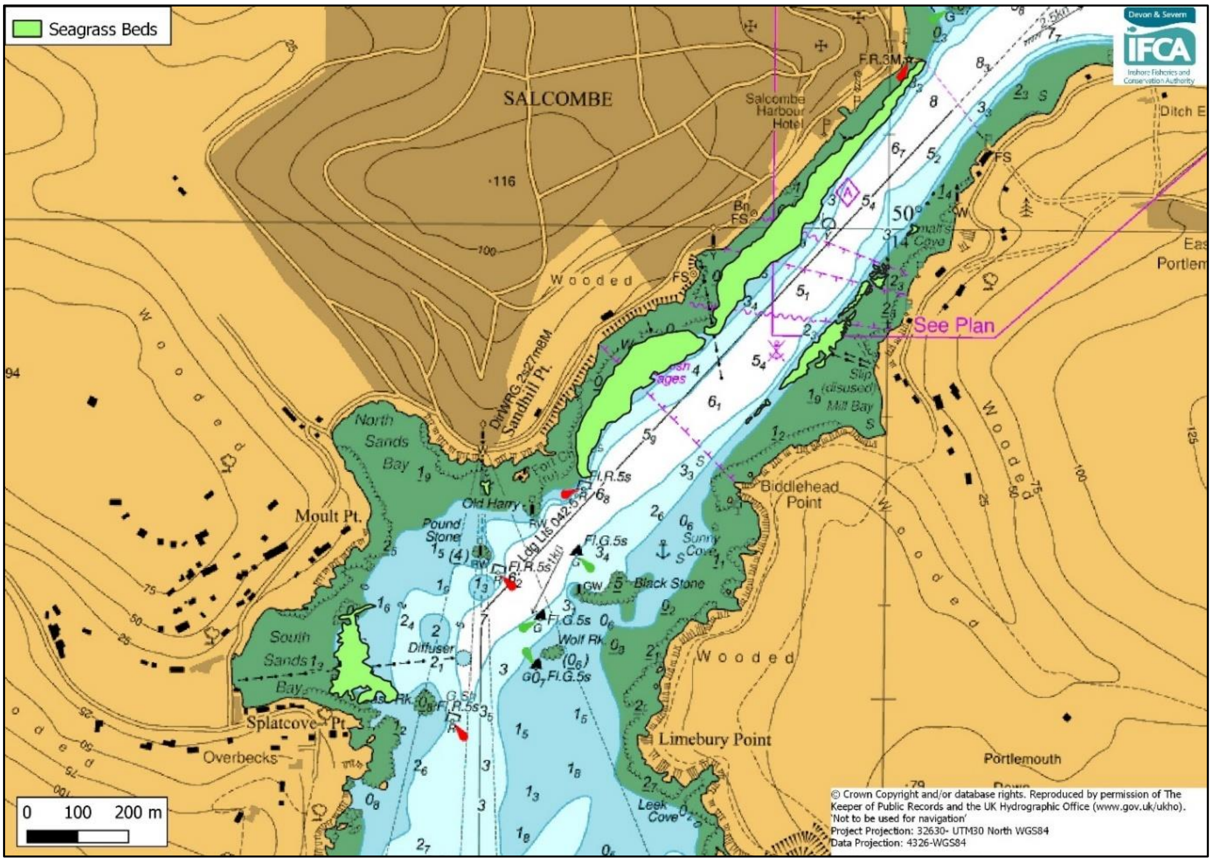

Figure 2 Chart of Zostera marina (seagrass) beds. Data from 2012.

1.2 *Pecten maximus*

Scallops are bivalve molluscs which belong to the family *Pectenidae.* There are two common species of scallops in British water; the king scallop *Pecten maximus,* which is the focus of this report, and the queen scallop *Aequipecten opercularis,* which is smaller in size. Maximum shell size varies with most being <150mm at the widest part of the shell. They reach reproductive maturity at a minimum size of 60mm and are fully mature at 3-5 years, living up to 20 years (Beukers-Stewart and Beukers-Stewart, 2009).

The king scallop is a simultaneous hermaphrodite. Spawning usually takes place during the spring and summer, although this can vary across the geographical range. Reproductive success and recruitment are influenced by a number of factors, including the amount of stock available at reproductive maturity, environmental conditions, and suitable settlement habitat availability (Franklin *et al*, 1980; Beukers-Stewart and Beukers-Stewart, 2009). Settlement occurs on sediment, usually made up of fine sand or gravel and sometimes mud.

Scallops are filter feeders, pumping water through a filter in a gill chamber to remove particulate organic matter and phytoplankton (Franklin *et al*, 1980). The recessed scallops orientate to water current which is thought to aid in efficient feeding and imposes rhythms of feeding and digestion phased with the tidal cycle (Brand, 2006).

The distribution range of king scallops is from Norway to the Atlantic coast of Spain, at depths of up to 100m.

1.3 Salcombe Scallop Fishery

D&S IFCA manages the highly restricted king scallop dredge fishery in Salcombe Estuary under the Mobile Fishing Permit Byelaw. The fishery falls under a Category 2 Mobile Fishing (Estuary) Permit.

Historically, a small boat scallop fishery has existed for many years in the Salcombe Estuary. In the past it was undertaken on an ad-hoc basis by a few of the local fishers using small dredges during periods of bad weather, when venturing out of the estuary over The Bar (a sandbar at the mouth of the estuary) was impossible to do safely. The fishery declined during the 1960s when stocks became depleted, possibly due to starfish scavenging the shellfish. The fishery gained traction again in the 1990s when some fishers found the stocks had recovered. This discovery led to a sudden increase in effort which included some larger vessels in Salcombe and from other Devon ports. Concerns were raised about the impact this effort could have on the stock and the fishery was closed for several years. In 1995 the fishers produced a signed petition requesting that the fishery be reopened. The fishery was opened under the Dredging in Salcombe Estuary Byelaw brought in by Devon Sea Fisheries Committee (DSFC) in 1998 with the development of gear restrictions, spatial and temporal restrictions, many of which were suggested by the fishers (Stephenson and Clark, 2016).

With the development of the of the D&S IFCA Mobile Fishing Permit Byelaw, which came into force on 1st January 2014, the conditions of the DSFC byelaw were transferred over to the permit conditions of the D&S IFCA Mobile Fishing Permit Byelaw. The conditions of the permit are as follows:

- The vessel must not exceed seven metres in overall length
- Dredging is permitted between 15th December to 15th March. The permit holder must inform the Authority prior to fishing for the first time during the fishing season
- The permit holder must submit to the Authority at the end of the period the number of scallops landed
- The maximum dredge width to be used shall be one metre (updated in 2020, see below)
- The maximum number of dredges to be used at any one time shall be two
- No toothed dredges shall be used
- Dredged shall be hauled by hand and no mechanical assistance is permitted
- Fishing shall only take place between 0900hrs (local time) and 1600hrs on weekdays, but not during public holidays.

There are also spatial restrictions as seen in Figure 3. The fishery operates in a restricted area between lines drawn from Woodville Rocks to Ager Point to the southern end, and Snapes Point to Scoble Point at the northern end. There are two zones, Zone A and Zone B, with no access to scallop dredging to protect the seagrass beds.

In 2020 there was a change to the dredge size which could be used. This was due to the provisions of The Scallop Fishing (England) Order 2012 which states that the width of the dredge frame must not exceed 85cm. The Order provisions take precedent over the permit conditions, and although permit conditions may be more restrictive, they cannot undermine the provisions in the Order. Therefore, for the 2020-2021 season and onwards, anyone wishing to take part in the fishery had to reduce the size of their dredges to a maximum width of 85cm.

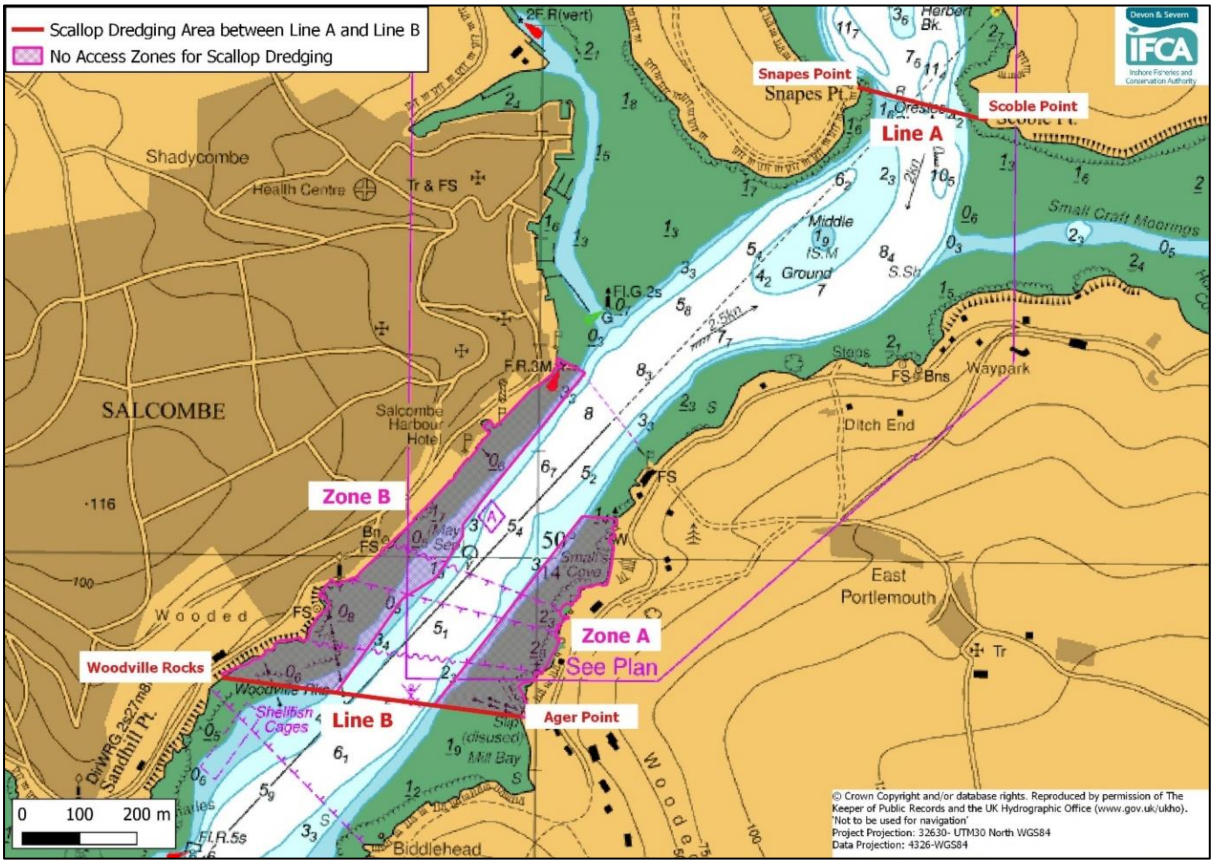

Figure 3 Salcombe Estuary scallop fishery area and no access areas for seagrass protection.

2. Methods

2.1 Data Collection

Since 1998, fishers taking part in the Salcombe Scallop Fishery have been asked to return information on their catch; this became a permit condition under the Mobile Fishing Permit Byelaw in 2014. The categories of information gathered have differed over the seasons. From 1998 to 2011, when the DSFC was the relevant fisheries management authority, the total number of scallops caught, number of scallops returned, and total days fished in the season was recorded. D&S IFCA superseded DSFC in 2011. From 2011 onwards, the same information was collected for each date fished along with number of hours fished on each day and the number of tows conducted per day. Since 2013 the number of tows were also reported. The form issued to the fishers since the 2013-2014 season can be seen in Appendix 1 – Catch recording forms.

2.2 Data Analysis

The raw data were entered into Microsoft Excel at the end of each fishing season (by a Sea Fisheries Officer pre-2011 and an IFCA Officer thereafter). The quality of the data input varied over the years and mistakes were identified and corrected where possible when compiling the data in Excel for analysis in 2022. There were instances when the data issues could not be resolved, and data were omitted. Data for one vessel were removed from the 1998-1999 season and data from two vessels from the 2005-2006 season. Another vessel did not report number of tows during 2011 and 2012 and this vessel has also been excluded from analyses. In total, the excluded vessels accounted for less than 2.4% of catch and landings records, so their exclusion from analyses is unlikely to have affected the results presented here. The data were analysed in R v4.0.0 or later (R Core Team, 2021).

2.2.1 Calculation of CPUE and LPUE

Catch per unit effort (CPUE) was calculated differently for the full data set (1998-2020) and for 2011 onwards due to the difference in the types of data that were collected. For the full data set, CPUE was calculated as catch per days fished (CPDF) by dividing the catch by the number of days fished for each vessel in each season. This is because number of days fished was the highest-resolution measure of fishing effort available during that time period. For the full data set CPUE will be recorded as CPDF going forward in the report. Changes in CPDF between fishery seasons were visualised using a box plot, plotted using ggplot2 in R (Wickham, 2016).

The availability of additional effort measures in the data from the 2011-2012 season onwards allowed for more in-depth analysis. For the 2011-2012 season onwards, CPUE was calculated by dividing catch by both the number of hours and number of tows fished per catch report, in the following way: (CPUE=(catch/tows)/hours).

As scallop returns were recorded in the majority of instances from 2011 onwards, it was possible to calculate landings per unit effort (LPUE). This was done by subtracting the returns from the catch and then dividing this by the same combination of effort measures as with CPUE in the following way: (LPUE = ((catch-returns)/tows)/hours).

Returns per unit effort was calculated before LPUE was explored, however it was not possible to fit valid models to the returns data.

2.2.2 CPDF analysis

Firstly, a box plot was plotted in R using ggplot2 for CPDF to visualise changes between the fishery seasons.

The data were checked for normality using the Shapiro-Wilk test. The data were not normally distributed, with a p-value of 0.0089. CPDF was therefore square-root transformed towards normality, with normality confirmed with a Shapiro-Wilk test (p = 0.7144). Comparisons of square-root transformed CDPF values were conducted using a one-way ANOVA and post-hoc Tukey test.

2.2.3 Statistical modelling

Generalised linear models (GLMs) were used to identify which variables influenced CPUE and LPUE of scallops in the Salcombe Scallop Fishery for the period 2011–2020. Details of this method are presented in Appendix 2 – Generalised Linear Models methods. Within this GLM-based statistical approach, Catch to date (CTD), day of season (DoS), dredge size (DS), vessel length (VL), vessel identity (V) and year (Y) were considered as potential predictors. Year (Y) refers to fishing season and will be written as year from this point forward. Year 1998 is fishing season 1998-1999, and so forth. The interaction of day of season and year (DoS:Year) as a potential predictor was also considered. For example, in a GLM for CPUE, an interaction between day of season and year would indicate that CPUE changes with day of season, but that the change experienced is different between years.

In this GLM approach all plausible combinations of variables and the specified interaction were considered in individual models (GLMs) for CPUE and LPUE. Model selection techniques were then applied in order to determine which model (which combination of predictor variables) is the ‘best’ model given the data (Appendix 2 – Generalised Linear Models methods). This process led to the selection of a single best model for each of CPUE and LPUE. The modelling, model selection and model diagnostic approaches are outlined in Appendix 2 – Generalised Linear Models methods.

Tukey post-hoc tests, with *p*-values adjusted for multiple comparisons, were used to test for significant differences between levels of categorical predictors in the final models using the R package ‘multcomp’ (Hothorn *et al.*, 2020); for example, where a GLM identified Year as an important predictor, these Tukey tests were used to determine which years differed significantly from the other years.

Officers also attempted to model the returns data using GLMs, to identify whether the predictors outlined above also influenced the number or rate of scallops returned per unit of effort. However, it was not possible to fit a valid model despite attempts to use alternative methods (Appendix 2 – Generalised Linear Models methods). Therefore, it is only possible to infer information about changes in returns per unit effort by comparing the results from CPUE and LPUE models.

3. Results

3.1 Fishing Effort

Data collection for the fishery has taken place since the 1998-1999 season and data analysis runs until the 2020-2021 season. Different levels of data have been collected throughout this time however, number of vessels, number of days fished, and total catch has been consistent since recording began.

The number of vessels taking part in the fishery over the 23 seasons has ranged from two to twelve and the mean number of vessels is six. A total of 2,095 days of fishing have been carried out with a total of 342,877 scallops caught over the 23 seasons (Table 1).

Table 1 Summary of the vessel numbers in fishery, days fished, catch and CPDF since records of the fishery began in 1998.

Season	Total no. vessels	Total days fished	Total catch	CPDF
1998-1999	9	109	24624	225.91
1999-2000	9	104	11494	110.52
2000-2001	5	42	5556	132.29
2001-2002	8	106	19223	181.35
2002-2003	8	115	23992	208.63
2003-2004	5	80	12134	151.68
2004-2005	6	113	24433	216.22
2005-2006	6	117	20879	178.45
2006-2007	7	162	23958	147.89
2007-2008	11	156	17806	114.14
2008-2009	12	140	19979	142.71
2009-2010	12	80	11074	138.43
2010-2011	6	49	9266	189.10
2011-2012	7	108	14528	134.52
2012-2013	5	75	8838	117.84
2013-2014	5	77	11632	151.06
2014-2015	4	63	6844	108.63
2015-2016	2	21	3633	173.00
2016-2017	2	41	6816	166.24
2017-2018	2	51	14651	287.27
2018-2019	5	114	15017	131.73
2019-2020	5	122	22321	182.96
2020-2021	3	50	14179	283.58

3.2 CPUE results

3.2.1 CPDF

Figure 4 demonstrates that CPDF has fluctuated since recording began for the fishery in 1998. A one-way ANOVA [$F_{22,120}$=2.168, p=0.00426] indicated that there is a significant difference between years at a significance threshold of p <0.05. Post-hoc pairwise comparisons were carried out with 254 possible year combinations. Two combinations demonstrated a significant difference (Table 2), 2020-2014 and 2020-2007 with an increase in CPDF in 2020 on both occasions. Though there is apparent variation in CPDF between years (Figure 4), the high level of within-year variation means it is not possible to identify other significant differences in CPDF between years.

Only the year combinations which demonstrate significant differences are displayed in Table 2 due to the number of combinations the post-hoc test retuned.

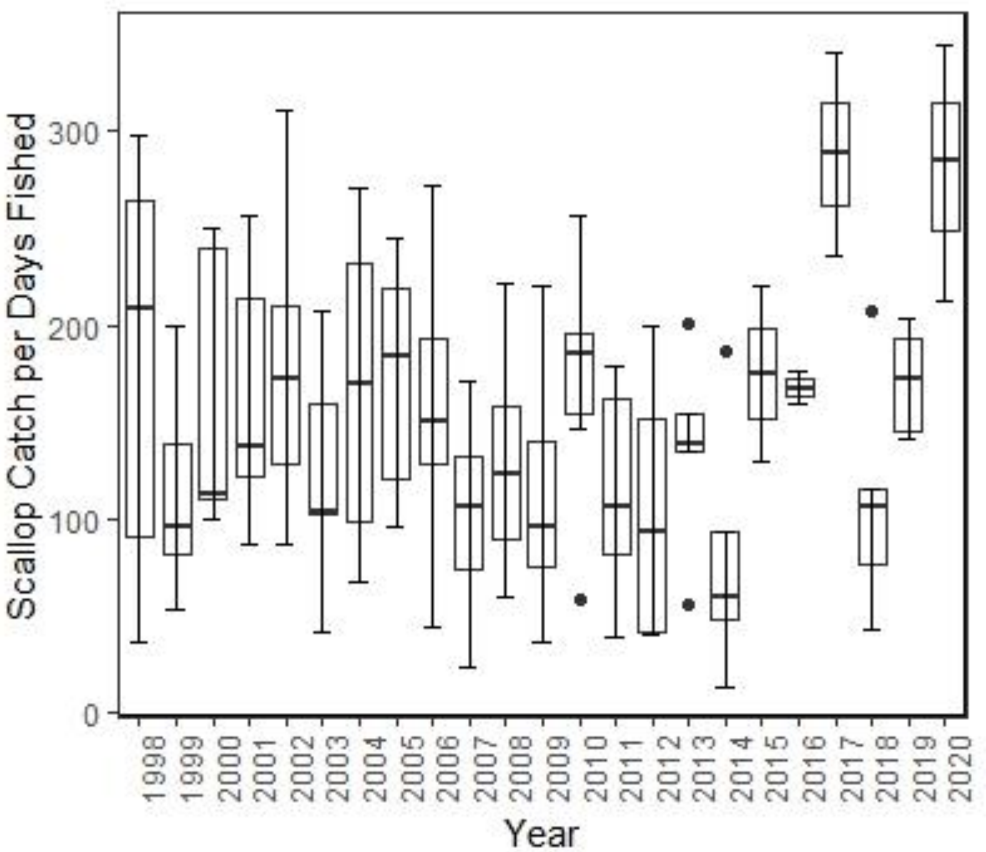

Figure 4 Box plot of Catch Per Days Fished (CPDF) across all vessels for all years showing the median (darker horizontal line), the lower and upper quartiles (25% and 75%) (top and bottom of the box), the minimum and maximum non-outlier values (the 'whiskers'), and the points indicate the outliers. The quartiles and 'whiskers' show the variation in CPDF between vessels in each year.

Table 2 Summary of post-hoc Tukey test for year combinations which had a significant difference in CPDF.

Comparison years	Difference	Lower confidence interval	Upper confidence interval	P-adj
2020-2014	8.451	0.564	16.337	0.022
2020-2007	6.816	0.090	13.542	0.043

3.2.2 CPUE

CPUE has fluctuated across the 2011-2020 period. The selected 'best' GLM for CPUE indicated that there were statistical differences between some of the years (Appendix 3 – Generalised Linear Model Results: CPUE). The post-hoc (Tukey) test results shown in Table 3 demonstrate which comparison years are significantly different from each other. 2020 was significantly different from all other years, which is also demonstrated in Figure 5. Figure 5, based on output of the selected CPUE model, shows this fluctuation of CPUE between years, with the post-hoc results shown with letters. Years sharing the same letter(s) are not significantly different from each other but years not sharing letters are significantly different from each other. The only year which had no similarities to any of the other years was 2020. A full summary of the post-hoc test can be seen in Appendix 4 – Post-hoc tests for the CPUE Generalised Linear Model

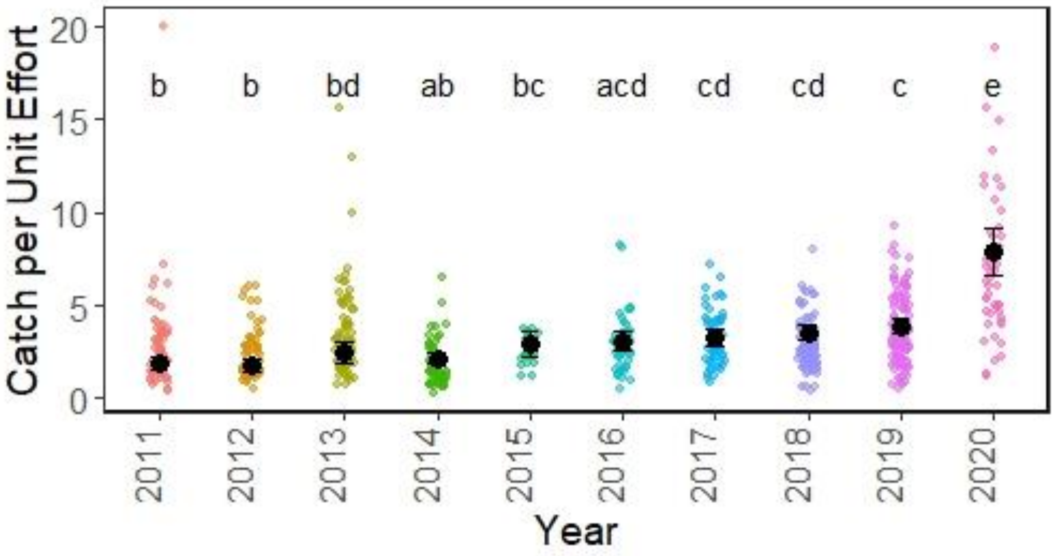

Figure 5 Predicted effects of year on CPUE as estimated by a generalised linear model. Error bars represent 95% confidence intervals around the predicted means. Coloured points represent the raw CPUE data. Letters represent groups from the pairwise comparison with the years that share letters not being significantly different from each other.

*Table 3 Summary of post-hoc (Tukey) test in CPUE between years which had significant difference. Significant difference codes: *** p<0.001, ** p<0.01, * p<0.05*

Comparison years	Estimate	Std.Error	z-value	p-value	Significance code
2016-2011	1.198	0.319	3.758	0.006	**
2017-2011	1.420	0.316	4.493	<0.001	***
2018-2011	1.689	0.284	5.956	<0.001	***
2019-2011	2.014	0.287	7.023	<0.001	***
2020-2011	6.041	0.681	8.866	<0.001	***
2016-2012	1.278	0.311	4.104	0.001	**
2017-2012	1.500	0.309	4.860	<0.001	***
2018-2012	1.769	0.275	6.427	<0.001	***
2019-2012	2.094	0.279	7.517	<0.001	***
2020-2012	6.121	0.678	9.028	<0.001	***
2019-2013	1.398	0.379	3.689	0.007	**
2020-2013	5.426	0.725	7.483	<0.001	***
2017-2014	1.128	0.292	3.869	0.004	**
2018-2014	1.397	0.241	5.804	<0.001	***
2019-2014	1.722	0.253	6.809	<0.001	***
2020-2014	5.750	0.679	8.471	<0.001	***
2020-2015	4.981	0.744	6.693	<0.001	***
2020-2016	4.843	0.706	6.859	<0.001	***
2020-2017	4.621	0.704	6.565	<0.001	***
2020-2018	4.352	0.676	6.436	<0.001	***
2020-2019	4.027	0.681	5.917	<0.001	***

The model results (Appendix 3 – Generalised Linear Model Results: CPUE) indicate that there is a significant difference in CPUE between some of the vessels, with CPUE being significantly higher in some vessels and significantly lower in others.

The effect of the day of the season was included in the GLM, primarily due to its interaction with year, which suggests that CPUE changes with day of season in a way that is dependent on other factors in particular years (Figure 6). The model indicates that CPUE declined over the course of the season in 2011. There was no clear evidence of an increase or decrease throughout the season in the other years (Figure 6; Table S3.2).

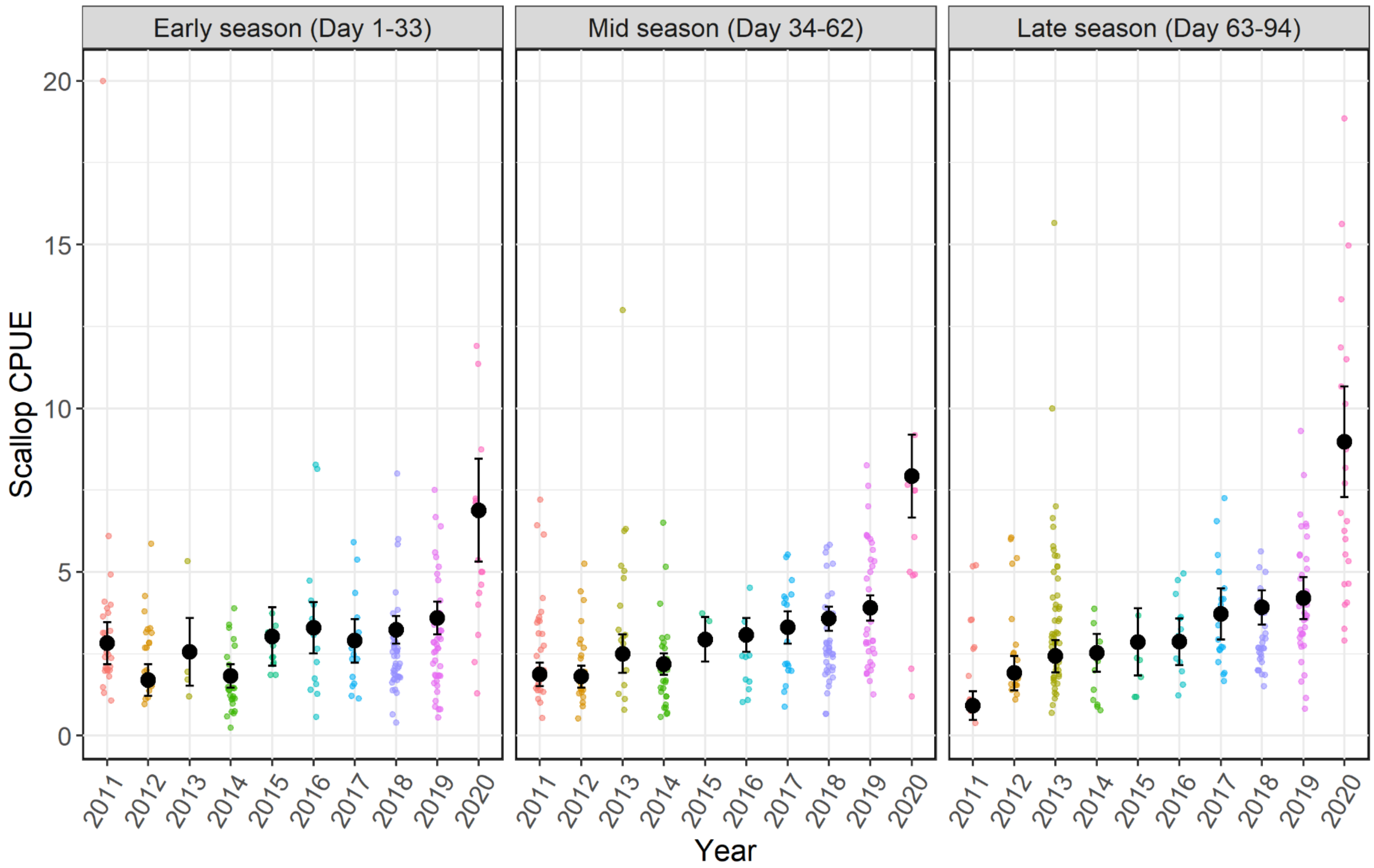

Figure 6 Representation of the day of season:year interaction effect from the GLM for Catch Per Unit Effort, in which the change in CPUE across the season varies between years. Black points and standard errors represent model-derived estimates of CPUE for early, mid- and late-season time periods (days 17, 48 and 74 respectively, chosen as example sampling points). Coloured points represent observed data for days 1-33, 34-62 and 63-94, respectively.

3.2.3 LPUE

LPUE has also varied significantly across the 2011-2020 period (Figure 7 and Appendix 5 – Generalised Linear Model Results: LPUE). The selected 'best' GLM indicated that there were statistical differences between some of the years, with Tukey post-hoc tests demonstrating which years were significantly different to one another (Figure 7 Table 4). In Figure 7, each year has been assigned a grouping letter; LPUE does not differ significantly between years under the same grouping letter(s) but does differ significantly from LPUE in years with a different grouping letter. A full summary of the post-hoc test can be seen in Appendix 6 – .

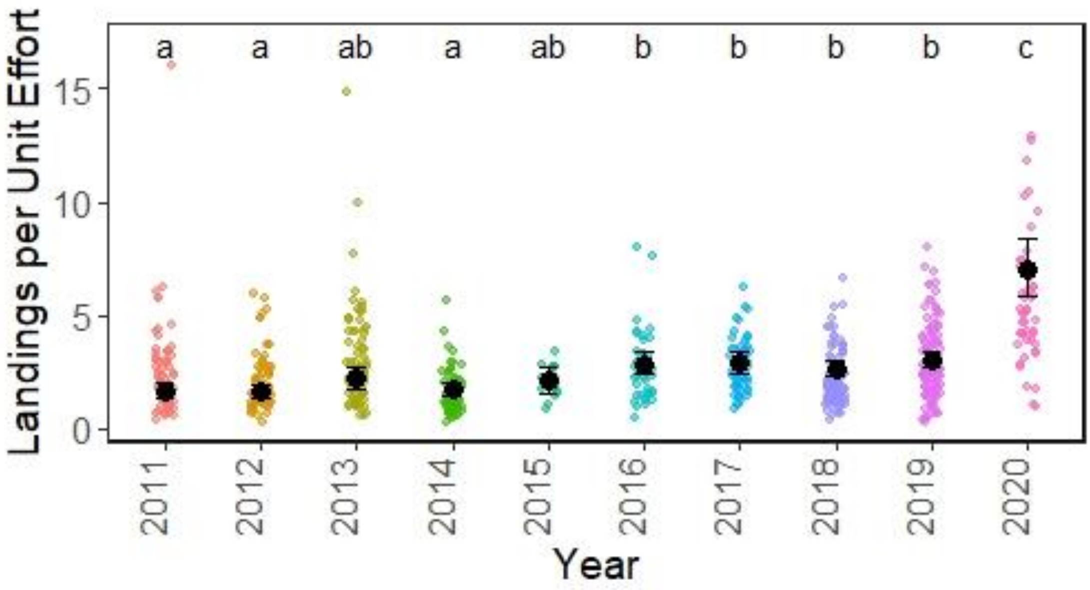

Figure 7 Predicted effects of year on LPUE as estimated by a generalised linear model. Error bars represent 95% confidence intervals around the predicted means. Coloured points represent the raw LPUE data. Letters represent groups from the pairwise comparison, with the years that share letters not being significantly different from each other.

*Table 4 Summary of post-hoc (Tukey) test in LPUE between years which had significant difference. Significant difference codes: *** p<0.001, ** p<0.01, * p<0.05*

Comparison years	Estimate	Std.Error	z-value	p-value	Significance code
2016-2011	0.527	0.135	3.905	0.004	**
2017-2011	0.547	0.131	4.173	0.001	**
2018-2011	0.457	0.122	3.735	0.006	**
2019-2011	0.597	0.119	5.004	<0.001	***
2020-2011	1.430	0.136	10.486	<0.001	***
2016-2012	0.569	0.129	4.431	<0.001	***
2017-2012	0.589	0.124	4.739	<0.001	***
2018-2012	0.499	0.115	4.336	0.001	***
2019-2012	0.639	0.112	5.714	<0.001	***
2020-2012	1.472	0.130	11.334	<0.001	***
2020-2013	1.155	0.149	7.748	<0.001	***
2016-2014	0.505	0.118	4.287	0.001	***
2017-2014	0.524	0.111	4.719	<0.001	***
2018-2014	0.435	0.096	4.517	<0.001	***
2019-2014	0.575	0.096	5.999	<0.001	***
2020-2014	1.407	0.124	11.347	<0.001	***
2020-2015	1.211	0.171	7.068	<0.001	***
2020-2016	0.902	0.130	6.945	<0.001	***
2020-2017	0.883	0.125	7.056	<0.001	***
2020-2018	0.973	0.110	8.815	<0.001	***
2020-2019	0.832	0.109	7.662	<0.001	***

The model results (Appendix 5 – Generalised Linear Model Results: LPUE) indicate that there is a significant difference in LPUE between some of the vessels, with LPUE being significantly higher for some vessels and significantly lower in others.

The effect of the day of the season was included in the GLM, primarily due to its interaction with year, which suggests that LPUE changes with day of season in a way that is dependent on other factors in particular years (Figure 8). The model indicates that LPUE declined over the course of the season in 2011 but increased over the course of the season in both 2018 and 2020 (Figure 8; Appendix 5 – Generalised Linear Model Results: (Table S5.2)). There was no clear evidence of an increase of decrease throughout the season in the other years.

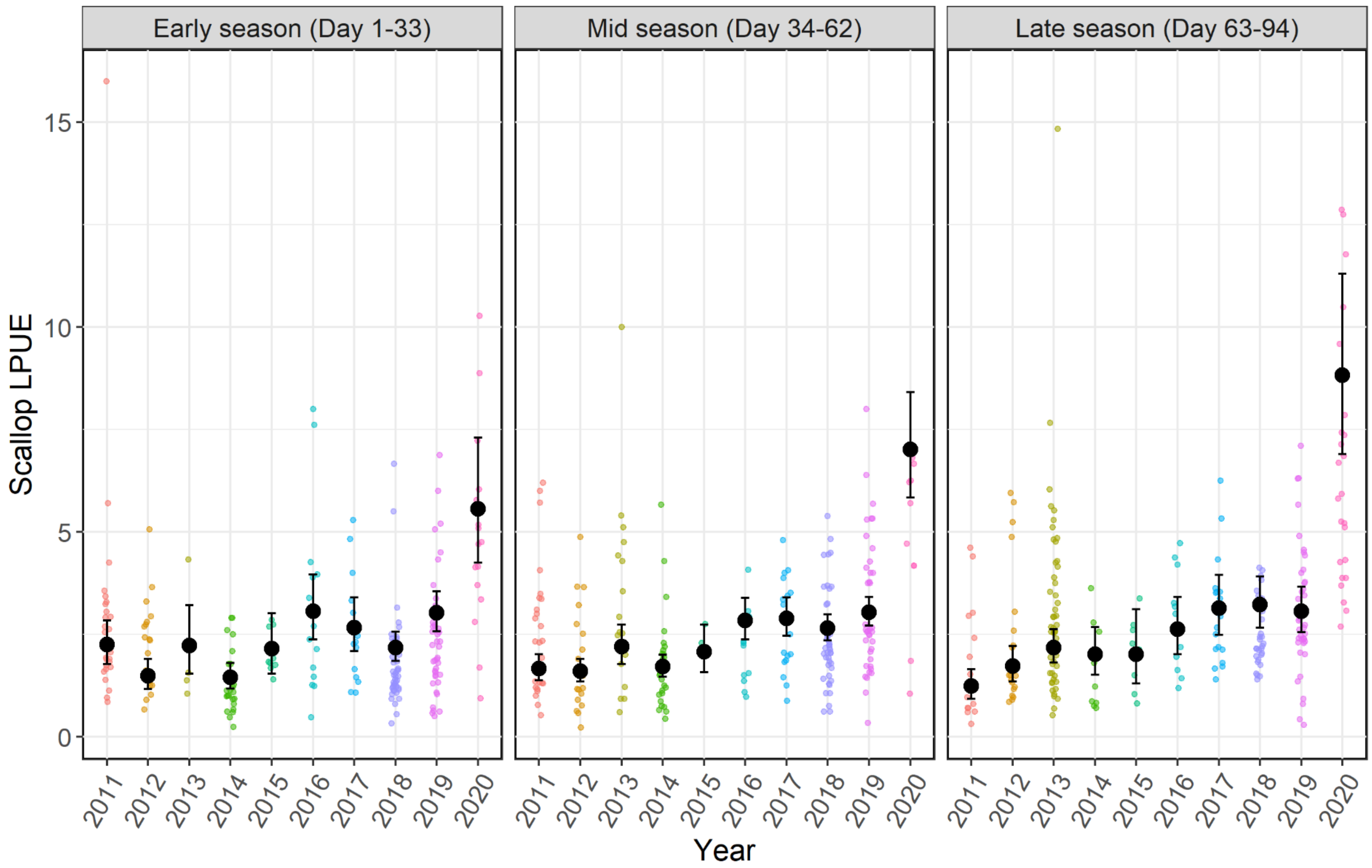

Figure 8 Representation of the day of season:year interaction effect from the GLM for Landings Per Unit Effort, in which the change in LPUE across the season varies between years. Black points and standard errors represent model-derived estimates of LPUE for early, mid- and late-season time periods (days 17, 48 and 74 respectively, chosen as example sampling points). Coloured points represent observed data for days 1-33, 34-62 and 63-94, respectively.

4. Discussion

The results of the GLMs indicate that CPUE and LPUE in this fishery have fluctuated since 2011. The analysis of CPDF since 1998 also shows this variation. There was a significant increase in both catch and landings per unit effort in 2020, however it is not clear what has caused this increase. There are no sustained declines in CPUE, LPUE or CPDF, which may suggest that the current fishery is not having a long-term negative impact on the harvestable scallop stocks in the estuary.

There was a significant difference detected between some vessels for both the CPUE and LPUE models, suggesting that some vessels are more efficient than others. It is not clear from the data available what drives these differences. Vessel length was included in the model selection process, but the analysis demonstrated that vessel length is not an important predictor of vessel success, at least for the range of vessel lengths used in this fishery (4 – 6.2 m). There could be several reasons for these differences such as location of typical fishing within the estuary or fishing technique, however these cannot be established in this work.

Due to the dredge size changing for the 2020 season from a maximum of one metre to a maximum of 85cm, dredge size was included in the model selection process however was not used in the final model. Although the model did not detect an effect of dredge size, this does not mean it will not make a difference, but there are not enough years data with the use of the 85cm dredge to determine that at this stage.

There appeared to be a decrease in both CPUE and LPUE over the season in 2011, however this did not occur in any other season and there appeared to be an increase in LPUE over the season in 2018 and 2020. A survey was carried out by D&S IFCA before and after the 2011-2012 and 2012-2013 fishing seasons to investigate any changes to scallop stock levels and size distribution of scallops. This was only a small-scale survey with the post season survey not taking place for the 2011-2012 season (Gray, 2013). The results indicated there was little variation between stock levels and size distribution across the surveys, which is supported by the results of the CPUE and LPUE models for the stock levels. The results presented here and by Gray (2013) indicate that scallop stock levels, CPUE and LPUE were at least as high at the start of the 2012-13 season as they were at the start of the 2011-12 season. This provides further confidence that the levels of harvest do not have a substantial negative impact on the local scallop populations, despite an apparent decline in CPUE and LPUE over the course of the 2011-2012 season.

There was a difference between the results of the CPUE and LPUE models in one of the years. For this year, the CPUE was lower than the average for the 2011-2020 period, however the LPUE was the same as the average LPUE for the 2011-2020 period; this suggests that in this year more scallops were of a landable size (returns were lower).

CPDF and CPUE produced different results in 2017, this can be seen by comparing Figure 4 and Figure 5. The average CPDF for 2017 was one of the highest in the 1998-2020 time series and was at least as high as the CPDF for 2020. However, the CPUE for 2017 was similar to the average CPUE, and substantially lower than that of 2020. This suggests that in 2017, a lot more effort had to be expended per day fished in order to catch the same number of scallops as in 2020. The reasons for this are unclear from this study, and could relate, for example, to real differences in the catchability of scallops during these years or could results from discrepancies in reporting the number of days, tows or hours fished between 2017 and 2020.

The difference in CPDF and CPUE in 2017 highlighted that using CPDF as a measure of catch per unit effort likely does not show the true scale of the fishery and potentially underestimates the effort in the fishery. When recorded by day, the amount of effort expended is not fully established. On some occasions vessels were only fishing for an hour and others may have been fishing for five hours but both are recorded as a day fished. This was confirmed when looking at the raw data: on some occasions a vessel appeared to have a target amount to catch which was often small numbers. This would be recorded as a day's fishing, but the vessel would have only been fishing for a short time. CPDF was only available for 1998-2011 and was therefore the best available data for this timeframe, however from the results it has been established that this is not a true reflection of the fishery. Finer levels of effort such as number of tows and hours which were used in CPUE from 2011 onwards are more appropriate for this analysis.

5. Conclusions and Recommendations

Although there has been variation over the years, there have been no sustained declines in CPUE or LPUE. This suggests the fishery, at its current and recent historical level, is not having a detrimental impact on the harvestable scallop stocks of the estuary and that the current management measures provide an effective way to manage the fishery.

It is recommended that catch reporting is continued for the fishery using the catch recording forms shown in Appendix 1. It is necessary to continue recording the number of tows and hours fished per trip as this level of effort is more appropriate for analysis than days fished.

As the GLM method has now been established for these data, the analysis should be run at the end of each season to establish any changes which could potentially lead to a review of the management. Further seasons of data collection may also detect any changes to CPUE and LPUE due to the change in dredge size.

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Appendix 1 – Catch recording forms

Devon & Severn IFCA - Scallop Returns				
Name of Fishing Vessel				
PLN				
Permit Number				
Dates *	Fishing Hours	Number Of Tows	Total Catch (*Number*)**	Undersize Returned *(Number)***
* Please indicate the actual date of fishing rather than a period (e.g. 29th December rather than 27th-30th December)				
** Please indicate whether the catch number is in dozens or individual numbers				

Appendix 2 – Generalised Linear Models methods

Generalised Linear Models (GLMs) are essentially a flexible form of ‘linear regression,’ which is a statistical method that describes change in one variable (the response) as a function of change in one or more predictors.

GLMs were used to assess changes in LPUE and CPUE over the 2011–2020 period, and to investigate the drivers of change. This approach also permits identification of the variables that influence LPUE and CPUE, which can help to inform management decisions (e.g. Henly *et al.*, 2021).

Within this GLM-based statistical approach, Catch to date (CTD), day of season (DoS), dredge size (DS), vessel length (VL), vessel identity (V) and year (Y) were considered as potential predictor. Year (Y) refers to fishing season and will be written as year from this point forward. Year 1998 is fishing season 1998-1999, and so forth. We also considered the interaction of day of season and year (DoS:Year) as a potential predictor.

In this GLM approach all plausible combinations of variables and the specified interaction were considered in individual models (GLMs) for each response variable (LPUE and CPUE). Models were excluded from consideration if they contained two or more variables that were highly correlated with one another, as this affects the validity of the model itself and the interpretation of model results; all other combinations of variables were tested, so this rule has not unduly affected full consideration of any potential predictors. Model selection techniques were then applied in order to determine which model (which combination of predictor variables) is the ‘best’ model given the data. Tukey tests, with p-values adjusted for multiple comparisons, were used to test for significant differences between levels of categorical predictors in the final models using the R package ‘multcomp’ (Hothorn *et al.*, 2020).

Detailed modelling and model selection approach

For each response variable (CPUE and LPUE), a candidate set of models was sought that were consistent with the data, in addition to a ‘null model’ (which contained no predictor variables). When created, each model has an associated “AIC value” (Akaike’s Information Criterion), which is an estimate of the relative quality of a model for a given set of data. AIC was used as the model selection criterion to select the most appropriate model from this set of candidate models.

Though the model with the lowest AIC is likely to be the most parsimonious (accounts for the observed data with the simplest effective explanation), AIC is only an estimate of parsimony. Therefore, following Richards (2008), certain other models were considered as well. First, models that generated AIC values with $\Delta AIC \leq 6$ (within 6 units of the model with the lowest AIC) were determined and then, to prevent unsupported, overly-complex models being selected, models from the candidate set that were more complex versions of other selected models were removed (Richards, 2008). This approach allowed all good candidate models to be compared, and permitted consideration of other important variables that would be excluded using methods such as stepwise selection (Mundry and Nunn, 2009). Then, comparing the final model to the 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).

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 2011–2020 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 and statistical assessment of scaled model residuals, using the 'DHARMa' R package (Hartig and Lohse, 2020).

Detailed AIC analyses and model results

Appendix 3 and Appendix 5 report comparisons (based on AIC) of the GLMs for each response variable.

References for Appendix 2

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Appendix 3 – Generalised Linear Model Results: CPUE

Table S3.1: Drivers of variation in catch per unit effort (CPUE), for the Salcombe scallop fishery 2011–2020, summarising AIC analyses for all candidate GLMs with ΔAIC ≤ 6. M_{AIC} denotes the best AIC model and M_{final} denotes the selected, most parsimonious model (M_{final} is used if the best AIC model was selected as the final model). Also presented for comparison is the null model (M_{null}). Parameter estimates (with standard errors) are shown for the intercept (β_0), day of season (DoS), vessel identity (V) and year (Y), as well as an interaction term for DoS:Y. k is the number of parameters and LL is the log-likelihood of the model. The variables catch to date, vessel length and dredge size were also tested but were not included in the candidate set of models. All models fitted with gamma error distribution and identity link function. A log link function was tested but did not improve the model AIC. Due to the large number of years and vessels, individual estimates are not presented for each level of these predictors in this table; instead, ● is used to denote the inclusion of these predictors in the models. Full parameter estimates are presented in S3.2.

Model	**β_0**	**DoS**	**V**	**Y**	**DoS:Y**	**k**	**LL**	**ΔAIC**
M_{final}	3.167 (0.160)	0.105 (0.075)	●	●	●	33	-1137.32	0
M_{null}	3.296 (0.089)	–	–	–	–	2	-1325.47	314.30

Table S3.2 Summary of Generalised Linear Model output for the CPUE model M_{final} presented in Table S3.1, including parameter estimates, standard errors and significance values.

Parameter	**Estimate**	**Std.Error**	**t-value**	***p*-value**	**Significance**
(Intercept)	3.167	0.160	19.829	<0.001	***
Scale(DoSeason)	0.105	0.075	1.386	0.166	
2011	-1.425	0.196	-7.266	<0.001	***
2012	-1.505	0.186	-8.099	<0.001	***
2013	-0.809	0.295	-2.743	0.006	**
2014	-1.133	0.171	-6.610	<0.001	***
2015	-0.365	0.321	-1.135	0.257	
2016	-0.227	0.249	-0.909	0.364	
2017	-0.005	0.243	-0.021	0.983	
2018	0.264	0.192	1.373	0.170	
2019	0.589	0.201	2.930	0.004	**
2020	4.616	0.594	7.765	<0.001	***
Vessel no.14	-0.951	0.249	-3.818	<0.001	***
Vessel no.19	1.992	0.633	3.147	0.002	**
Vessel no.20	-0.388	0.238	-1.626	0.105	
Vessel no.21	-3.815	0.926	-4.122	<0.001	***
Vessel no.22	0.290	0.321	0.905	0.366	
Vessel no.24	-0.966	0.327	-2.956	0.003	**
Vessel no.27	1.112	0.518	2.148	0.032	*
Vessel no.31	0.750	0.702	1.068	0.286	
Vessel no.32	-2.476	0.276	-8.974	<0.001	***
Vessel no.36	2.045	0.457	4.478	<0.001	***
Vessel no.37	1.914	0.384	4.989	<0.001	***
Vessel no.6	0.079	0.188	0.424	0.672	
(DoSeason):2011	-0.905	0.177	-5.129	<0.001	***
(DoSeason):2012	-0.016	0.161	-0.099	0.922	
(DoSeason):2013	-0.160	0.225	-0.708	0.479	
(DoSeason):2014	0.194	0.153	1.262	0.207	
(DoSeason):2015	-0.173	0.272	-0.637	0.525	
(DoSeason):2016	-0.282	0.221	-1.273	0.203	
(DoSeason):2017	0.235	0.216	1.090	0.276	
(DoSeason):2018	0.180	0.137	1.312	0.190	
(DoSeason):2019	0.154	0.178	0.864	0.388	
(DoSeason):2020	0.773	0.399	1.937	0.053	.

Significant difference codes: *** p<0.001, ** p<0.01, * p<0.05

Appendix 4 – Post-hoc tests for the CPUE Generalised Linear Model

Table S4.1 Summary table of Tukey post-hoc tests for the year effect in the selected Generalised Linear Model for Catch Per Unit Effort, showing p-values corrected for multiple comparisons. p-values < 0.05 indicate a significant difference in CPUE between the indicated years

Comparison years	Estimate	*p*-value	Significance code
2012-2011	-0.080	1.000	
2013-2011	0.615	0.703	
2014-2011	0.291	0.979	
2015-2011	1.060	0.189	
2016-2011	1.198	0.006	**
2017-2011	1.420	<0.001	***
2018-2011	1.689	<0.001	***
2019-2011	2.014	<0.001	***
2020-2011	6.041	<0.001	***
2013-2012	0.695	0.492	
2014-2012	0.371	0.882	
2015-2012	1.140	0.106	
2016-2012	1.278	0.001	**
2017-2012	1.500	<0.001	***
2018-2012	1.769	<0.001	***
2019-2012	2.094	<0.001	***
2020-2012	6.121	<0.001	***
2014-2013	-0.324	0.996	
2015-2013	0.445	0.994	
2016-2013	0.583	0.901	
2017-2013	0.804	0.565	
2018-2013	1.073	0.106	
2019-2013	1.398	0.007	**
2020-2013	5.426	<0.001	***
2015-2014	0.769	0.429	
2016-2014	0.907	0.068	.
2017-2014	1.128	0.004	**
2018-2014	1.397	<0.001	***
2019-2014	1.722	<0.001	***
2020-2014	5.750	<0.001	***
2016-2015	0.138	1.000	
2017-2015	0.360	0.997	
2018-2015	0.629	0.788	
2019-2015	0.954	0.264	
2020-2015	4.981	<0.001	***
2017-2016	0.222	1.000	

2018-2016	0.491	0.864	
2019-2016	0.816	0.246	
2020-2016	4.843	<0.001	***
2018-2017	0.269	0.997	
2019-2017	0.594	0.667	
2020-2017	4.621	<0.001	***
2019-2018	0.325	0.936	
2020-2018	4.352	<0.001	***
2020-2019	4.027	<0.001	***

Significant difference codes: *** p<0.001, ** p<0.01, * p<0.05

Appendix 5 – Generalised Linear Model Results: LPUE

Table S5.1: Drivers of variation in landings per unit effort (LPUE), for the Salcombe scallop fishery 2011–2020, summarising AIC analyses for all candidate GLMs with ΔAIC ≤ 6. M_{AIC} denotes the best AIC model and M_{final} denotes the selected, most parsimonious model (M_{final} is used if the best AIC model was selected as the final model). Also presented for comparison is the null model (M_{null}). Parameter estimates (with standard errors) are shown for the intercept (β_0), day of season (DoS), vessel identity (V) and year (Y), as well as an interaction term for DoS:Y. k is the number of parameters and LL is the log-likelihood of the model. The variables catch to date, vessel length and dredge size were also tested but were not included in the candidate set of models. All models fitted with gamma error distribution and log link function. An identity link function was tested but did not improve the model AIC. Due to the large number of years and vessels, individual estimates are not presented for each level of these predictors in this table; instead, ● is used to denote the inclusion of these predictors in the models. Full parameter estimates are presented in S5.2.

Model	**β_0**	**DoS**	**V**	**Y**	**DoS:Y**	**k**	**LL**	**ΔAIC**
M_{final}	0.907 (0.056)	0.028 (0.025)	●	●	●	33	-1031.42	0
M_{null}	1.001 (0.027)	–	–	–	–	2	-1209.43	294.01

Table S5.2. Summary of Generalised Linear Model output for the LPUE model M_{final} presented in Table S5.1, including parameter estimates, standard errors and significance values.

Parameter	Estimate	Std.Error	t-value	*p*-value	Significance
(Intercept)	0.907	0.056	16.347	<0.001	***
Scale(DoSeason)	0.028	0.025	1.092	0.275	
2011	-0.403	0.094	-4.286	<0.001	***
2012	-0.445	0.085	-5.213	<0.001	***
2013	-0.128	0.107	-1.200	0.231	
2014	-0.381	0.076	-5.035	<0.001	***
2015	-0.185	0.129	-1.429	0.153	
2016	0.124	0.085	1.454	0.146	
2017	0.143	0.079	1.818	0.070	
2018	0.054	0.062	0.866	0.387	
2019	0.194	0.060	3.243	0.001	**
2020	1.026	0.089	11.478	<0.001	***
Vessel no.14	-0.388	0.087	-4.441	<0.001	***
Vessel no.19	0.562	0.172	3.277	0.001	**
Vessel no.20	0.048	0.105	0.457	0.648	
Vessel no.21	-0.698	0.202	-3.446	<0.001	***
Vessel no.22	-0.240	0.157	-1.523	0.128	
Vessel no.24	-0.816	0.420	-1.944	0.052	
Vessel no.27	0.260	0.172	1.507	0.132	
Vessel no.31	0.224	0.167	1.342	0.180	
Vessel no.32	-1.149	0.240	-4.782	<0.001	***
Vessel no.36	0.652	0.159	4.102	<0.001	***
Vessel no.37	0.639	0.131	4.881	<0.001	***
Vessel no.6	-0.044	0.067	-0.659	0.510	
(DoSeason):2011	-0.277	0.074	-3.737	<0.001	***
(DoSeason):2012	0.034	0.071	0.476	0.634	
(DoSeason):2013	-0.036	0.078	-0.461	0.645	
(DoSeason):2014	0.108	0.079	1.372	0.171	
(DoSeason):2015	-0.056	0.108	-0.519	0.604	
(DoSeason):2016	-0.093	0.077	-1.217	0.224	
(DoSeason):2017	0.041	0.071	0.572	0.568	
(DoSeason):2018	0.138	0.056	2.485	0.013	*
(DoSeason):2019	-0.023	0.055	-0.422	0.673	
(DoSeason):2020	0.165	0.074	2.219	0.026	*

Significant difference codes: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Appendix 6 – Post-hoc tests for the LPUE Generalised Linear Model

Table S6.1 Summary table of Tukey post-hoc tests for the year effect in the selected Generalised Linear Model for Landings Per Unit Effort, showing p-values corrected for multiple comparisons. p-values < 0.05 indicate a significant difference in LPUE between the indicated years.

Comparison years	Estimate	*p*-value	Significance code
2012-2011	-0.042	1.000	
2013-2011	0.275	0.614	
2014-2011	0.023	1.000	
2015-2011	0.219	0.964	
2016-2011	0.527	0.004	**
2017-2011	0.547	0.001	**
2018-2011	0.457	0.006	**
2019-2011	0.597	<0.001	***
2020-2011	1.430	<0.001	***
2013-2012	0.317	0.266	
2014-2012	0.065	1.000	
2015-2012	0.261	0.880	
2016-2012	0.569	<0.001	***
2017-2012	0.589	<0.001	***
2018-2012	0.499	<0.001	***
2019-2012	0.639	<0.001	***
2020-2012	1.472	<0.001	***
2014-2013	-0.252	0.748	
2015-2013	-0.056	1.000	
2016-2013	0.253	0.777	
2017-2013	0.272	0.662	
2018-2013	0.182	0.940	
2019-2013	0.322	0.303	
2020-2013	1.155	<0.001	***
2015-2014	0.196	0.952	
2016-2014	0.505	<0.001	***
2017-2014	0.524	<0.001	***
2018-2014	0.435	<0.001	***
2019-2014	0.575	<0.001	***
2020-2014	1.407	<0.001	***
2016-2015	0.309	0.678	
2017-2015	0.328	0.550	
2018-2015	0.238	0.822	
2019-2015	0.379	0.225	
2020-2015	1.211	<0.001	***
2017-2016	0.019	1.000	

2018-2016	-0.070	1.000	
2019-2016	0.070	1.000	
2020-2016	0.902	<0.001	***
2018-2017	-0.089	0.996	
2019-2017	0.051	1.000	
2020-2017	0.883	<0.001	***
2019-2018	0.140	0.723	
2020-2018	0.973	<0.001	***
2020-2019	0.832	<0.001	***

Significant difference codes: *** p<0.001, ** p<0.01, * p<0.05