Centre for Environment Fisheries & Aquaculture Science

Cefas

Assessment of king scallop stock status for selected waters around the English coast 2021/2022 – Annexe

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1. Scallop biological sampling procedure

1.1. Methodology

The fishing industry proposed a methodology for the sampling procedure, which is a modification of an earlier scheme:

1. Cefas identifies sampling opportunities based on regular reports of the positions of participating vessels from the Vessel Monitoring Scheme (VMS) and requests a length or age sample from the processor.
2. The processor contacts the vessel operator by phone or internet-based messaging and requests a sample to be collected from the next haul.
3. The vessel crew collect a bag of scallops in a labelled and coloured bag (to aid identification at the processor) and land it along with the rest of the catch. Length

samples are retained in red bags, and those for age determination are retained in a blue bag.

4. At the processors, the industry staff measure the length samples (height of round shell perpendicular to hinge) and return the size distributions along with sample weight and sample details to Cefas. Age samples are processed at the factory as per the usual procedure, but flat shells are sent to Cefas for age determination.
5. A supplementary and opportunistic method was introduced, where samples are pre-ordered by the processor contacts in consideration of target shortfalls.

In the laboratory, low power microscopes are used to confirm age, as growth rings observed with the naked eye have shown to be unreliable in the English Channel. Initial ages are checked and, where discrepancies exist between readers, are determined by consensus.

1.2. Sampling targets

The spatial distribution of fishing effort and catches within each fishing season can be difficult to predict and appears to be influenced by irregular recruitment events. VMS data were used to define ICES statistical rectangles where fishing activity had occurred over the past 8 years and warranted sampling. Sampling targets in the first year (2017) were set at 5 length samples per rectangle per quarter year, where one of the length samples is retained for subsequent age determination to facilitate the construction of an age-length key for each rectangle. From 2018, sampling targets were revised to better reflect fishing patterns as defined by reported landings. One sample was requested for a threshold of 1 tonne of scallop landed per rectangle and then another for each subsequent 50 tonnes. To provide an improved estimation of age structure, two age samples were requested for every three length samples.

In a process parallel to that used by finfish stock assessments, estimates of the age composition of landings were obtained from length distributions through conversion to ages by means of an age-length key.

Given the limited mobility of scallops, together with pre-existing knowledge on the patchiness of scallop settlement and variability in growth rates, the sampling strata employed for scallops are much smaller than those for finfish.

The basic strata for the targeting of age and length are ICES statistical rectangles and reported landings. Samples are requested from a vessel when it is observed to be fishing in an area on a given day (using VMS data). The unit of sampling is therefore a combination of vessel, rectangle and day.

1.3. Data raising process

Age-length key (ALK)

1. From the age samples (blue-bag), 5 shells per 5-mm length class are retained for age-determination.
2. Within each 5-mm length class, the proportion of each age was determined to give an ALK for each rectangle-quarter stratum.
3. To fill any strata for which there were missing ALKs, all age (blue-bag) samples were pooled to the quarter - assessment area level to generate an ALK for each un-sampled rectangle within that assessment area.

Length distribution

4. Sample length distributions (LDs) were raised to the reported catch of the vessel within the day, using the ratio of reported sample weight to landings.
5. Sample LDs and weights from step 4 were aggregated to the level of rectangle and quarter.
6. The pooled LDs from step 5 were raised to the total UK landings for that rectangle and quarter using the ratio of the sampled weight to total landings.
7. Not all strata with landings records had length samples. Missing strata were assumed to come from the same length distribution as the aggregate quarter – assessment area. The LDs from step 6 were pooled and then raised to each missing stratum using the ratio of sampled weight to strata landings.
8. Numbers in each size class from step 7 were summed within each stock assessment area and sampling season (quarter 4 of the previous calendar year plus quarters 1-3 of the current year) to give total numbers in each size class per assessment area and sampling season.

Age distribution

9. For directly sampled strata, the raised rectangle-quarter numbers-at-length were multiplied by the corresponding ALK and then summed to give the total numbers-at-age per rectangle-quarter
10. For un-sampled strata, the in-fill LDs (step 7) were multiplied by the in-fill ALK (step 3) and summed to give numbers-at-age per un-sampled rectangle-quarter.
11. These numbers-at-age were summed over all quarters and rectangles within each stock assessment area and for each sampling season to give total removals-at-age per assessment area and sampling season.

2. Dredge survey design

2.1. Terminology

The following spatial areas were used during the survey design process:

- **Bed** – An irregular outline representing a fished scallop ground, identified using Vessel Monitoring System (VMS) data.
- **Block** – A regular coordinate grid of 0.1-by-0.1-degree rectangles, with an approximate area of 80 km^2.
- **Cell** – A regular coordinate grid of 0.025-by-0.025-degree rectangles, with an approximate area of 5 km^2 (2236-by-2236 metres, approximately twice the typical dredge tow length), and a maximum of 16 cells per block (4 by 4). This is the scale to which VMS data are aggregated as part of the survey design methodology. Mid-points of cells are used as potential sampling positions. This also forms the grid over which survey data are raised to calculate the bed biomass and size distribution in survey catches.

2.2. Identification of scallop beds

At the start of the scallop assessment project, in preparation for the first dredge survey in 2017, VMS data for fishing trips during the 2009-2016 period, by UK vessels deploying scallop dredges, were used to identify the location of scallop grounds targeted by the domestic scallop dredge fleet in the English Channel. Unfortunately, positioning data for international vessels is not available.

At the time, it was agreed with the Project Steering Board that, at the end of the first 5-year period, 2017 – 2021, the dredge bed outlines would be updated based on the most recent 10 years of VMS data. This is seen as a good compromise between year-to-year consistency on the one hand, and flexibility to allow the dredge surveys to adjust to shifting commercial exploitation patterns on the other. Until 2013, submission of VMS positioning data was only compulsory for vessels of at least 15-m length. Since 2014, all vessels with 12-m length and above are required to operate VMS tracking devices.

VMS data were processed as follows:

- Vessels were assumed to be fishing when the reported speed was between 1 and 4 knots. This speed range was used to remove records where vessels were likely to be transiting between grounds, or in harbour (see Figure 2.1).
- VMS data were aggregated within individual cells.

- Blocks with a combined average number of reported positions of fewer than 8 per year were omitted. This was necessary to remove a few transits at low speed.
- VMS data were linked to MMO landings records by vessel RSS number and day. Only positioning data from vessels deploying dredges and reporting landings of king scallops were retained.
- Total daily reported landings were divided equally between all VMS "fishing" locations.
- The total time fishing, as determined by VMS positioning data, was taken as a measure of fishing effort.

Using VMS-apportioned landings and effort data, bed boundary polygons were created using the R function `ashape` from the `alphahull` package, starting from the preliminary outlines shown in Figure 2.2. This function uses the algorithm defined by (Edelsbrunner, et al., 1983) to construct an α-shape around a set of points, in this case VMS points (cells), based upon the Delaunay triangulation. The resulting α-shape was converted to a polygon (bed outline) representing a scallop fishing ground. The final bed outlines are shown in Figure 2.3, Figure 2.4, and Figure 2.5.

Ideally, each block within bed outlines would be surveyed with one station, randomly positioned at the centre of any of the valid cells within that block. However, due to the large area that needs to be covered each year, this is not possible. Experience over the first 5 years of the project established that a combined number of 260 stations is the most that can be accomplished during the May and September surveys. We therefore specify this as our survey target and distribute these 260 stations according to the size of each dredge bed, with a minimum of one station (see Table 2.1). This results in approximately the same station density in the assessed beds. In each of the beds, blocks are ranked first by the number of contained cells that are inside the bed boundary, and second by the amount of fishing effort expended inside each block. The allotted number of stations in each bed is then selected from the top of the ranked list of blocks. This results in the final survey grids shown in Figure 2.6, Figure 2.7, and Figure 2.8.

Table 2.1: Number of stations and surveyed area in each of the dredge beds.

Bed	Number of Stations	Surveyed Area [km^2]	Part of Surveyed Area within UK EEZ
4.b.1	20	1382	100%
4.b.2	2	111	100%

4.b.3	5	262	100%
4.b.4	1	40	100%
4.b.5	1	27	100%
4.b.6	1	45	100%
4.b.7	1	32	100%
4.b.8	1	18	100%
4.b.9	1	41	100%
7.d.1	75	5878	62%
7.d.2	4	240	0%
7.e.1	32	2421	100%
7.e.2	34	2685	100%
7.e.4	24	1833	100%
7.e.5	19	1007	95%
7.e.7	6	365	19%
7.e.8	20	1523	0%
7.f.1	15	1110	100%

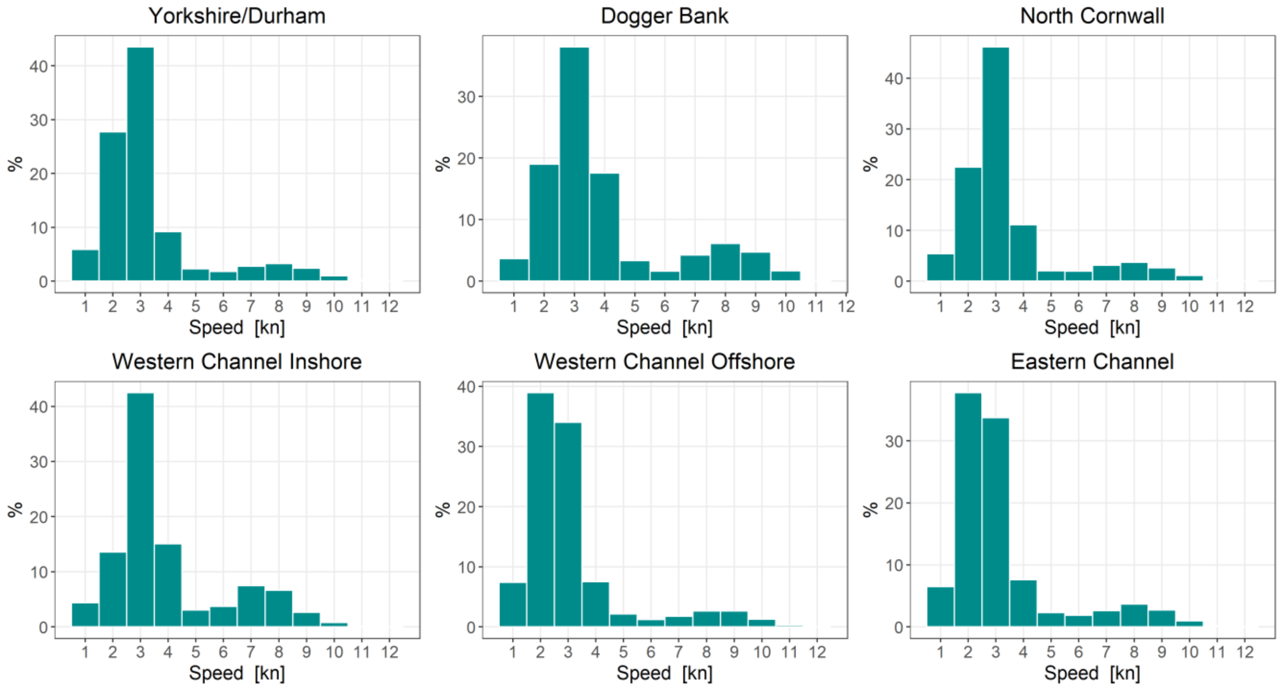

Figure 2.1: Speed histograms based on VMS positioning data from UK king scallop dredgers in different assessment areas. The Western Channel Inshore panel shows combined data for Areas 27.7.e.I and 27.7.e.L.

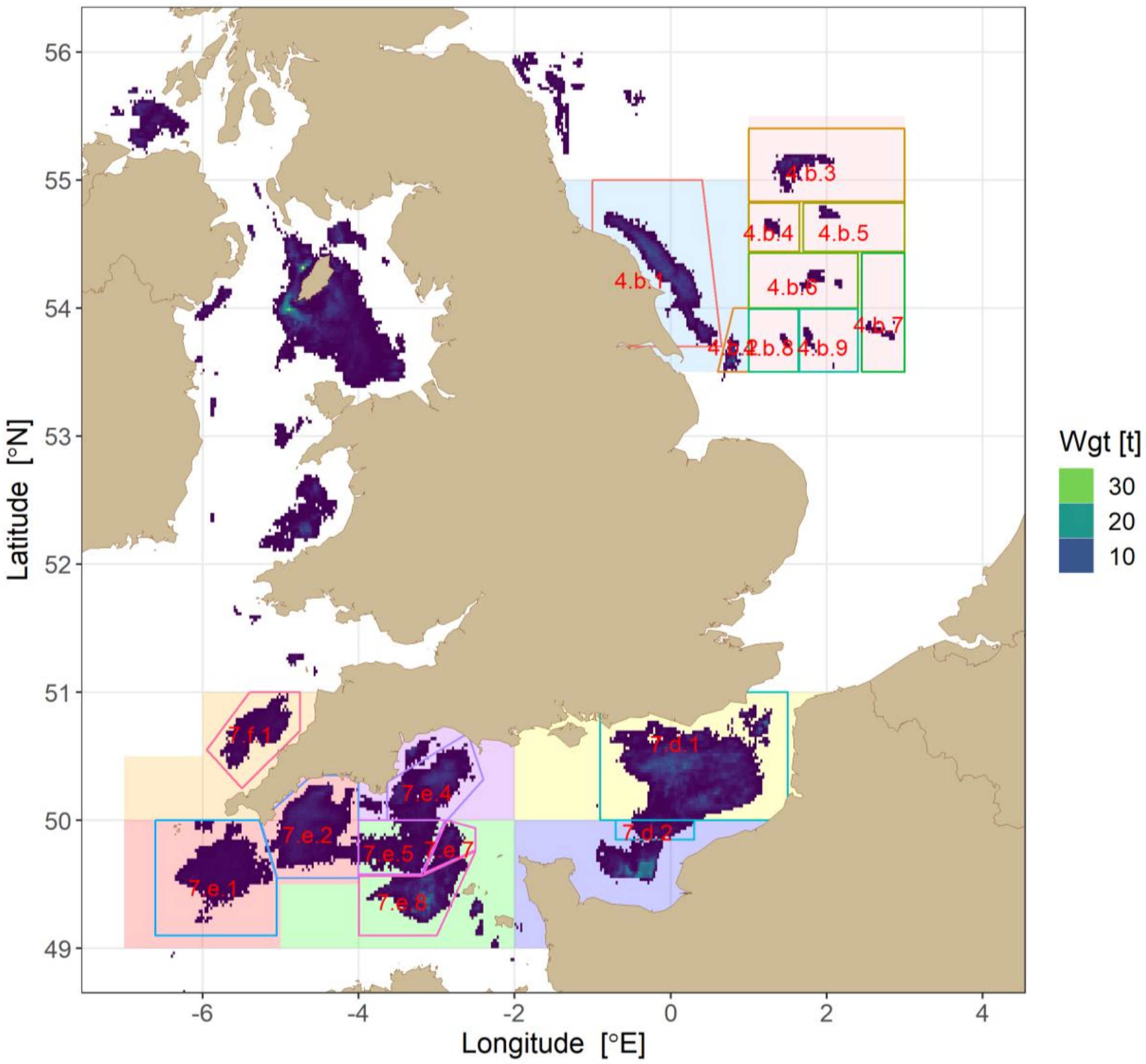

Figure 2.2: VMS positioning data from UK king scallop dredgers aggregated in the cell coordinate grid with associated distributed landings amounts. The labelled polygons are preliminary bed outlines which are refined using the R package `alphahull`.

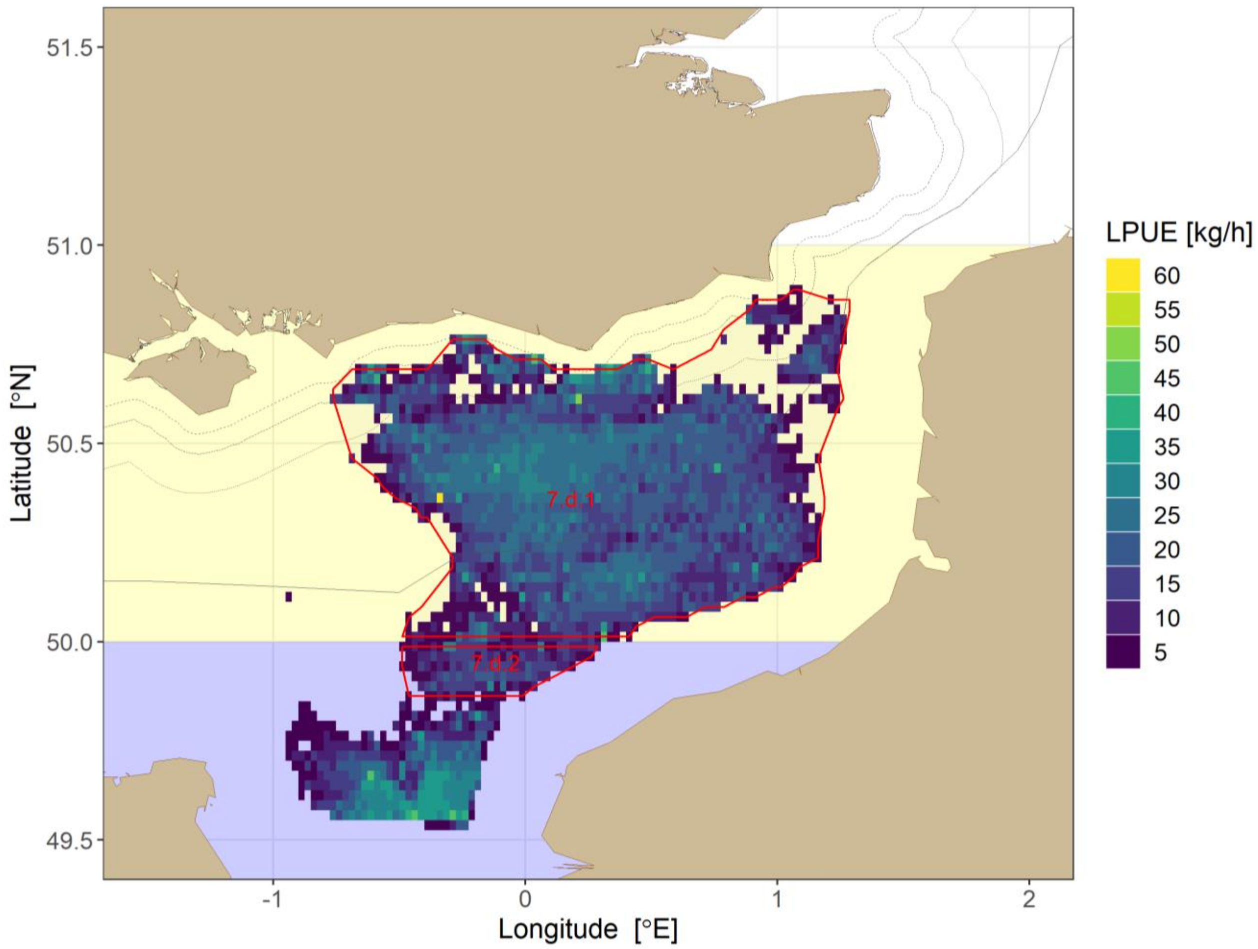

Figure 2.3: VMS-apportioned landings per unit effort (LPUE) within final bed outlines in the eastern English Channel.

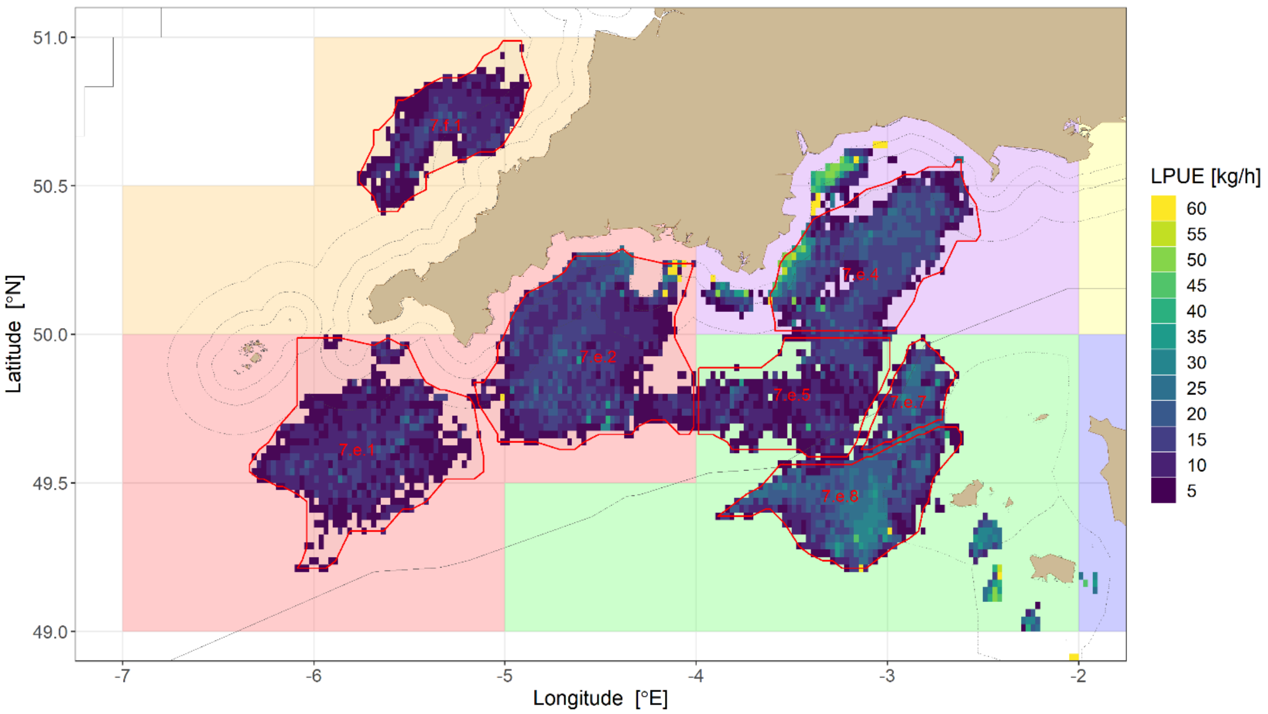

Figure 2.4: VMS-apportioned landings per unit effort (LPUE) within final bed outlines in the western English Channel and north of Cornwall.

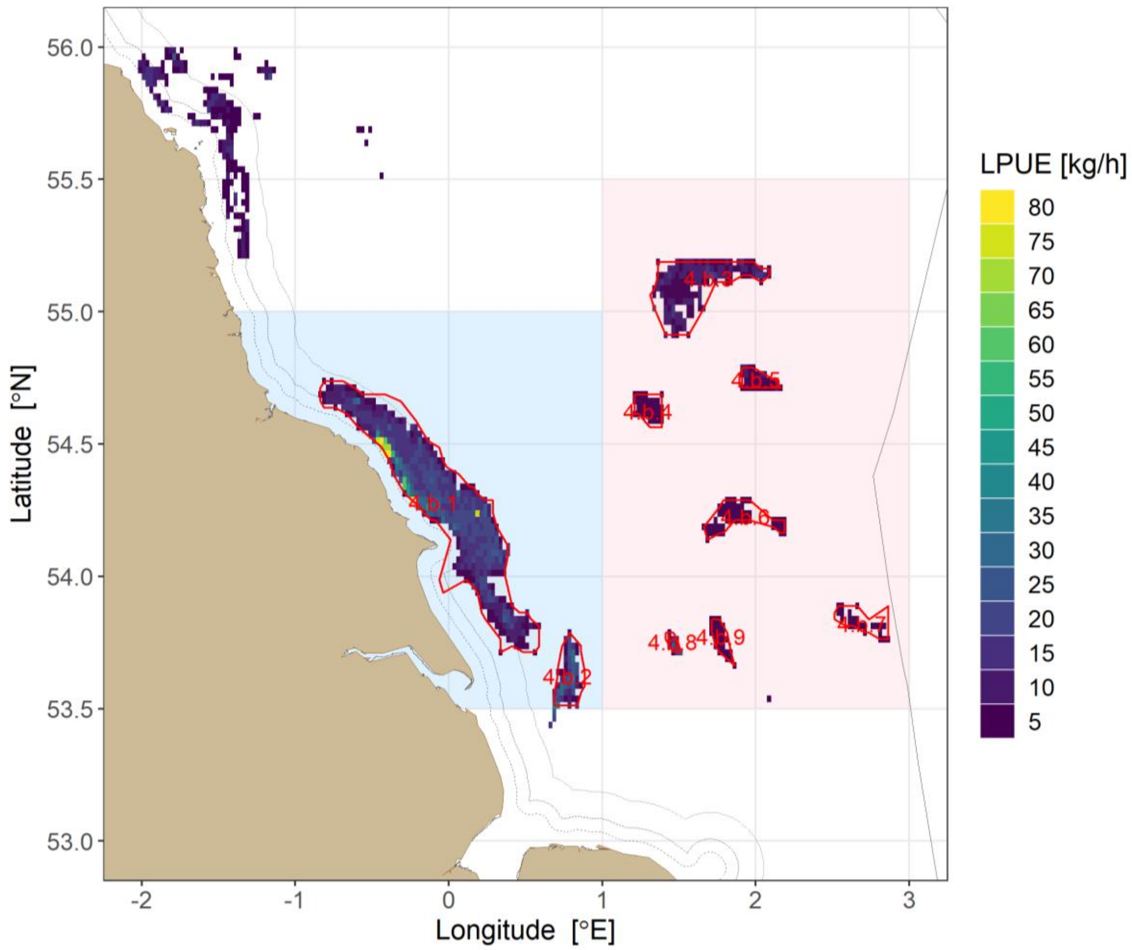

Figure 2.5: VMS-apportioned landings per unit effort (LPUE) within final bed outlines in the North Sea.

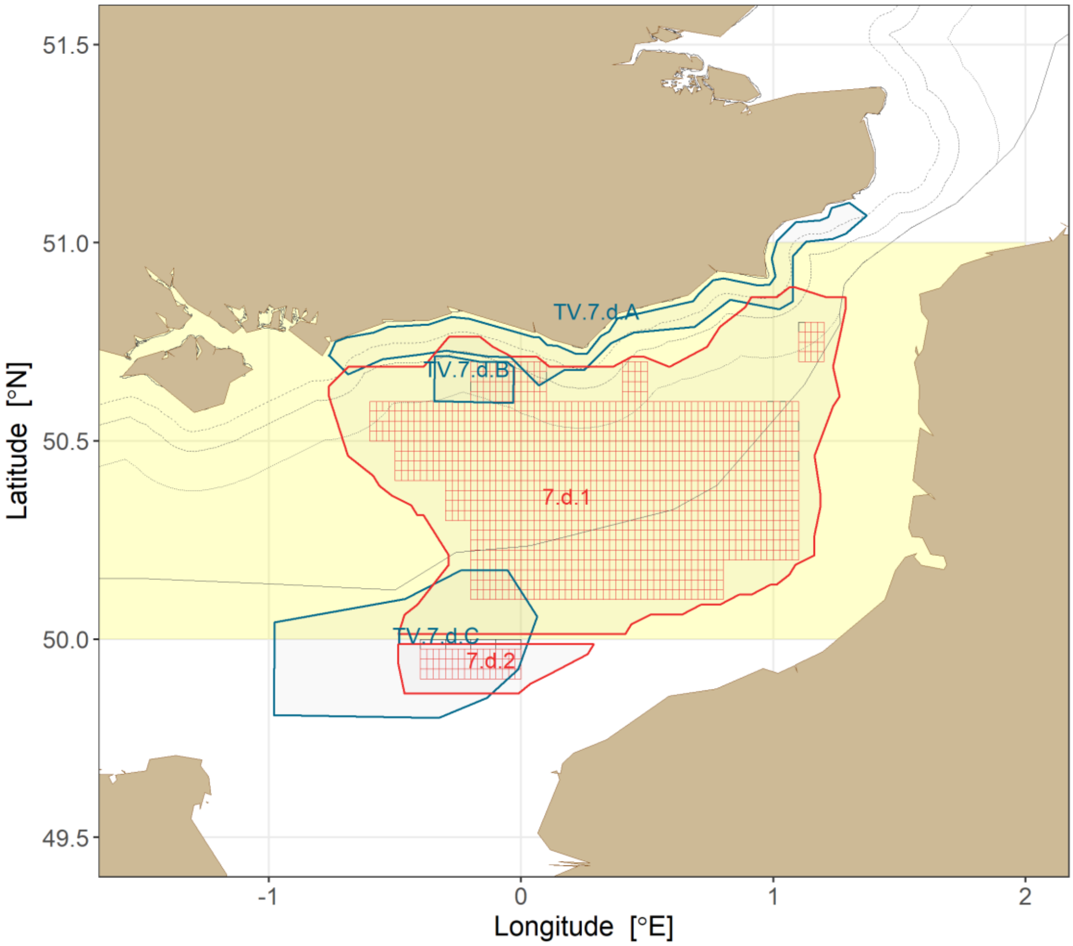

Figure 2.6: Survey grid in the eastern English Channel. The centre of each valid cell (red grid) is a potential station location. The blue lines indicate areas surveyed by underwater video system (see Section 4).

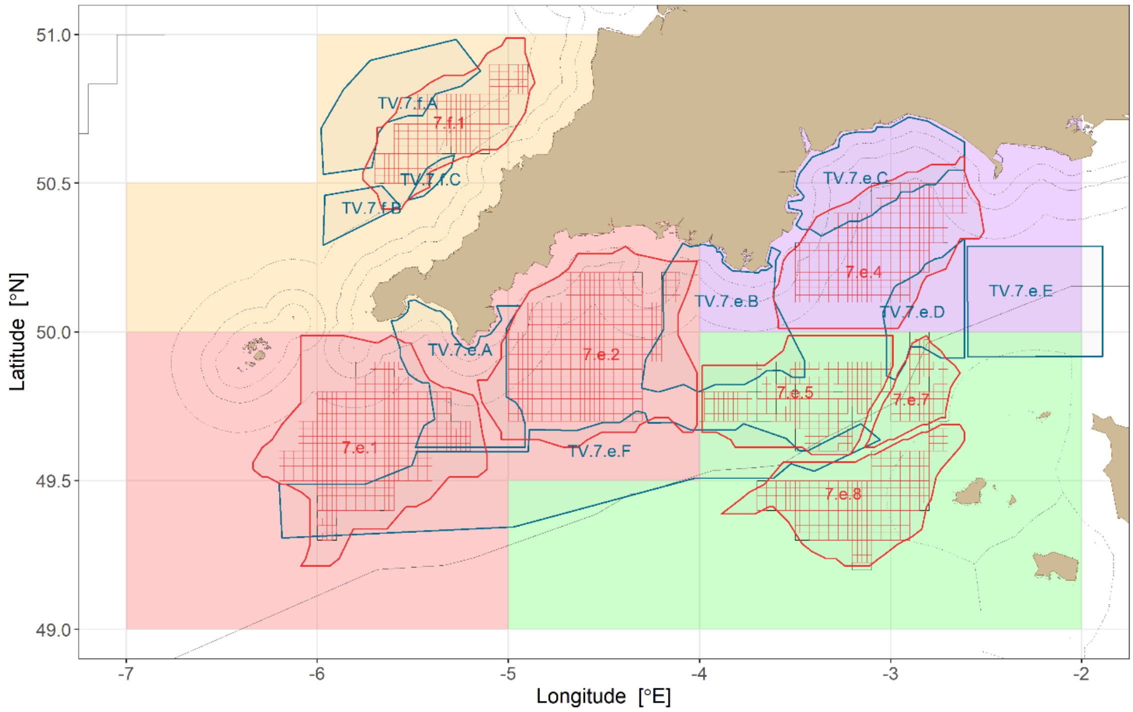

Figure 2.7: Survey grid in the western English Channel and north of Cornwall. The centre of each valid cell (red grid) is a potential station location. The blue lines indicate areas surveyed by underwater video system (see Section 4).

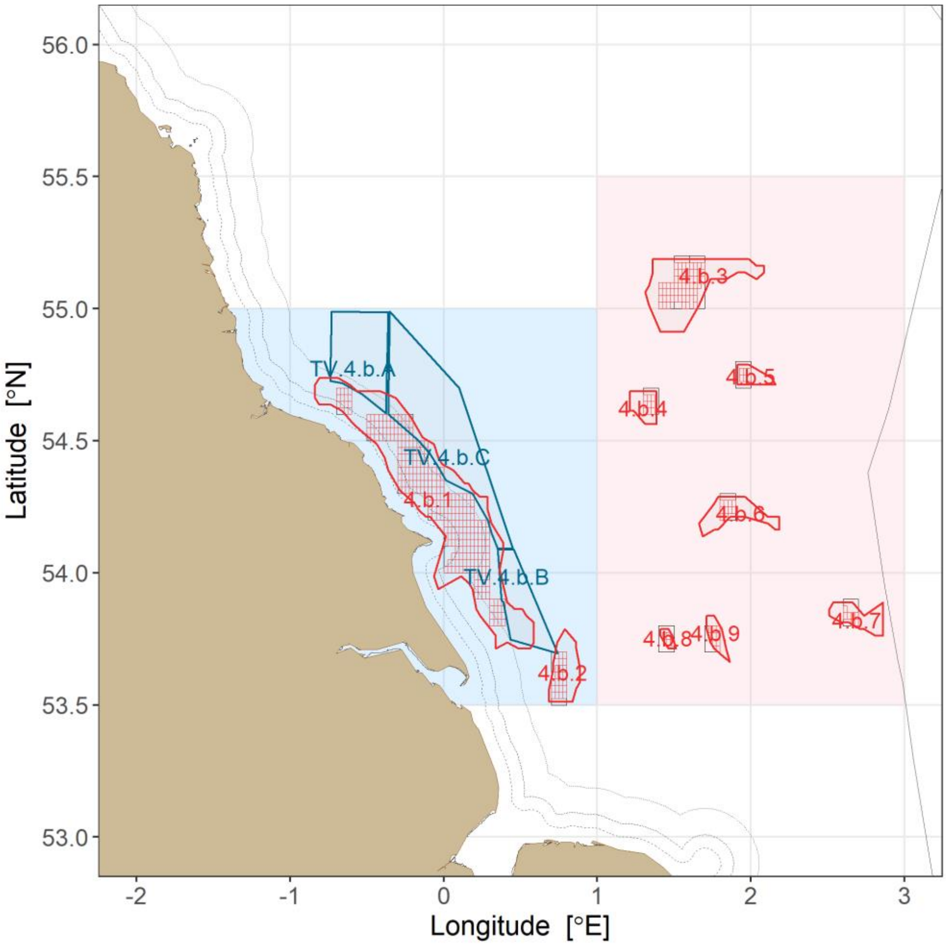

Figure 2.8: Survey grid in the North Sea. The centre of each valid cell (red grid) is a potential station location. The blue lines indicate areas surveyed by underwater video system (see Section 4).

3. Dredge survey data processing

3.1. Scallop density raising

The stratified random design dictated that the data were processed by block as the sampling strata. The density estimate from stations within a block were considered representative of the surface area of the block, and the block mean density was used if more than one station was in a single block. This would be the result of a misplaced tow position. The valid surface area of each block is the sum of the surface area of all valid cells. Total block abundance (in numbers) is then given by:

$$N = \sum_c \rho_c A_c \ ,$$

where c are the valid cells, ρ_c is the areal number density, and A_c is the surface area of each cell.

If, due to missed stations, there are un-sampled blocks, the density within the un-sampled blocks is estimated by applying the bed-averaged density.

3.2. Sample processing

Sampling was carried out from the dredges on only one side of the vessel, which provided adequate sampling levels throughout the surveys. As such, samples were raised only to the catches and area swept by sampled dredges, avoiding the need to consider any potential bias between starboard and port gears.

The following raising procedure was carried out on the survey data for the commercial dredge gear:

1. The sampled length distribution was raised to the total catch per station, using the raising factor calculated as caught weight over sampled weight for the two catch components, discards (below minimum landing size, MLS) and retained.
2. The catch components were aggregated to get total raised numbers at size by station.
3. The catch density (number m^{-2}) for each station was calculated by dividing the count by the swept area of the gear.
4. The scallop density on the seabed was estimated from the station catch density using the appropriate substrate-specific gear efficiency factor.
5. For blocks which had one or more sampled cells, the block mean density per length class was calculated.
6. Block mean densities were applied to all cells within blocks, where there was at least one sampled cell.
7. Bed mean densities were applied to all cells in un-sampled blocks.
8. Abundance in each cell was calculated by multiplying density with the cell area.

Harvestable biomass was calculated for each assessment area by using the length-weight conversion parameters to calculate weight-at-length for scallops larger than the MLS. For assessment areas in ICES Divisions 27.4.b, 27.7.e, and 27.7.f the MLS is 100 mm round shell length, whilst for ICES Division 27.7.d it is 110 mm.

3.3. Swept area estimation

Internally logging data storage tags (DST, Cefas G5) recording depth and time were attached to the bridles on the dredges to provide depth profiles and an accurate indication of the time of deployment. GPS receivers (RoyalTech MBT1100) recorded ship positions. These loggers provided the positions of the tow tracks with depth profiles of the gear and allowed the calculation of distance run on the ground at each tow position (see Figure 3.1). This integrated method is a more accurate measure of tow distance than calculating straight-line distances between start and end points.

For stations without combined track data, due to a failure of either the GPS or DST equipment, the median track length for the dredge bed is used (see Figure 3.2). This is typically less than 1250 metres, which corresponds to the distance run calculated as the product of mean tow speed (2.7 knots) and intended tow duration (15 min). This is partly due to the delay with the fishing gear reaching the seabed, but also due to deviations in tow speed and duration (e.g., due to tidal currents or sea state).

The swept area was then calculated as the sum of all individual dredge widths (75 cm times the number of sampled dredges, i.e., six standard king scallop dredges, and four queen scallop dredges), multiplied by the tow distance.

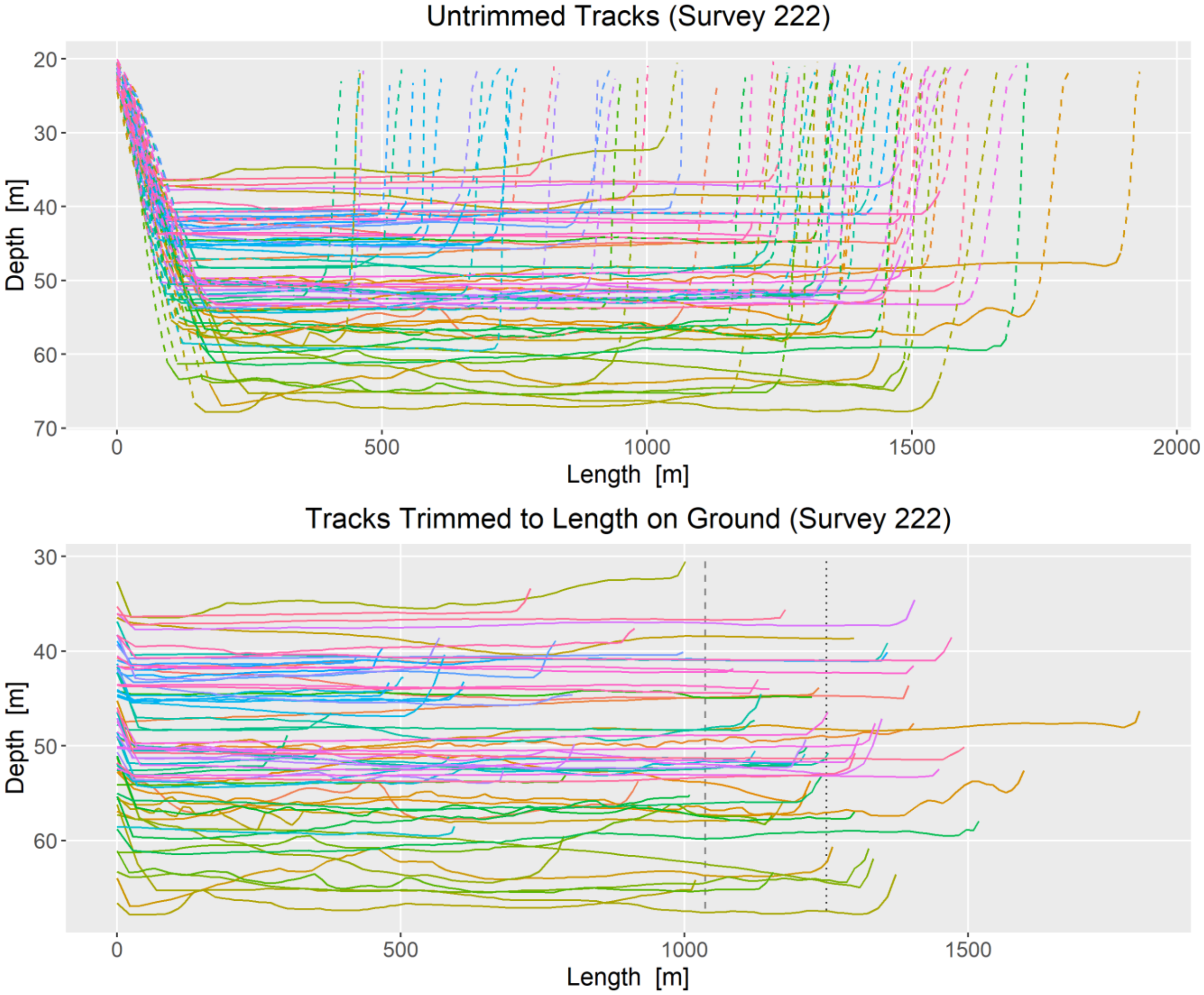

Figure 3.1: Tow tracks based on combined GPS and DST data (example from the September dredge survey in 2022). The dashed segments of the lines in the upper panel indicate descent and ascent of the fishing gear. The solid segments of the lines are the tracks of the fishing gear on the ground.

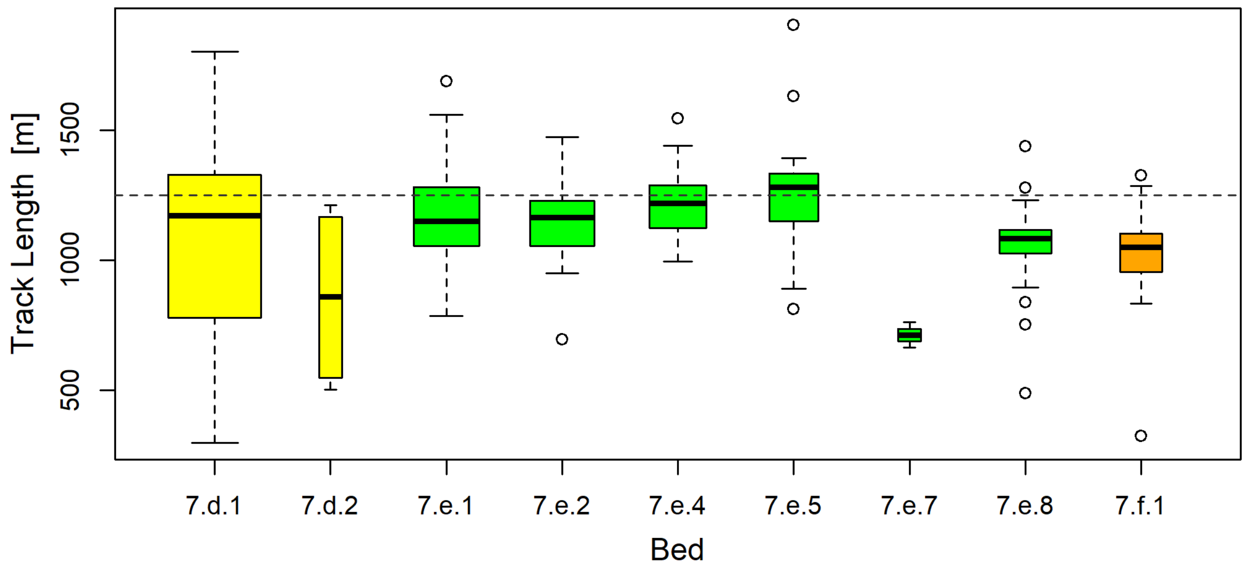

Figure 3.2: Range of tow track lengths in individual dredge beds (example from the surveys in 2022). The horizontal dashed line indicates 1250 metres, which corresponds to a tow duration of 15 min at 2.7 knots.

3.4. Substrate-specific dredge efficiency

The vessel skipper reports ground type at each survey tow location based on acoustic information in the wheelhouse and the contents of the dredges. The distribution of these ground types by bed and survey year is presented in Table 3.1. The skipper-reported ground types were related to two ground types described by historic depletion studies carried out by Cefas in the English Channel. These substrate-specific gear efficiencies are listed in the main part of the report, individually for each assessment area. The data were therefore adjusted for gear efficiency at each station based upon the skipper-determined ground type, prior to the raising procedure. The assumption of this method is that the ground types encountered at each tow position were representative of the wider area (block).

Table 3.1: Number of tows by ground type in each bed with proportion described by the survey vessel skipper as having significant amounts of flint or cobbles.

Bed	Year	Ground Type		Total	Tows with Flint Cobbles (%)
		Clean, Some Stones	Flint or Cobbles		
4.b.1	**2018**	8	15	23	65
	2019	19	3	22	14
	2020	22	0	22	0
	2021	17	0	17	0
	2022	17	2	19	11
4.b.2	**2018**	2	2	4	50
	2019	1	0	1	0
	2020	2	0	2	0
	2021	2	0	2	0
	2022	1	0	1	0
7.d.1	**2017**	49	14	63	22
	2018	38	28	66	42
	2019	50	17	67	25
	2020	49	2	51	4
	2021	35	12	47	26
	2022	58	6	64	9
7.d.2	**2018**	1	3	4	75
	2019	-	-	-	-
	2020	-	-	-	-
	2021	-	-	-	-
	2022	3	1	4	25
7.e.1	**2017**	20	1	21	5
	2018	18	2	20	10
	2019	20	0	20	0
	2020	19	0	19	0
	2021	23	0	23	0
	2022	32	0	32	0

Bed	Year	Ground Type		Total	Tows with Flint Cobbles (%)
		Clean, Some Stones	Flint or Cobbles		
7.e.2	**2017**	32	3	35	9
	2018	29	3	32	9
	2019	32	0	32	0
	2020	33	0	33	0
	2021	33	0	33	0
	2022	31	0	31	0
7.e.4	**2017**	31	0	31	0
	2018	31	0	31	0
	2019	29	0	29	0
	2020	31	0	31	0
	2021	31	0	31	0
	2022	24	0	24	0
7.e.5	**2017**	16	8	24	33
	2018	18	2	20	10
	2019	18	0	18	0
	2020	20	0	20	0
	2021	16	0	16	0
	2022	18	0	18	0
7.e.7	**2017**	7	2	9	22
	2018	6	2	8	25
	2019	4	0	4	0
	2020	4	0	4	0
	2021	7	0	7	0
	2022	2	2	4	50
7.e.8	**2017**	13	8	21	38
	2018	9	10	19	53
	2019	5	3	8	38
	2020	8	0	8	0
	2021	20	1	21	5

Bed	Year	Ground Type		Total	Tows with Flint Cobbles (%)
		Clean, Some Stones	Flint or Cobbles		
	2022	18	2	20	10
7.f.1	**2018**	8	6	14	43
	2019	12	0	12	0
	2020	13	0	13	0
	2021	-	-	-	-
	2022	13	0	13	0

4. Underwater video system survey

4.1. Methodology

4.1.1. Survey design

Beds where scallop fishing takes place had already been defined for the scallop dredge surveys. For the underwater video system (UVS) survey areas, boundaries were defined around likely scallop ground (from habitat modelling), as well as around areas that are considered by industry to contain scallop populations but cannot be fished due to unsuitable ground type, conservation management, or gear conflict issues. Four zones adjacent to current fishing grounds that are typically not fished by scallop dredgers were defined in 2017 (TV.7.e.A-D). Ten further un-dredged zones were defined in 2019, and another zone in the North Sea was defined in 2021. The outlines of all UVS survey areas, in relation to the dredge survey areas, are shown in Figure 2.6, Figure 2.7, and Figure 2.8.

Once the un-dredged zones had been determined, random positions were selected using the same procedure as for the dredge surveys.

Limited survey vessel time necessitated prioritisation of the survey areas. Three zones were surveyed in 2017 (TV.7.e.A, C and D). In 2019, two un-dredged zones were surveyed in the western English Channel (TV.7.e.B and E), and another in the eastern English Channel (TV.7.d.A). In 2021, zones TV.4.b.A-C were surveyed. In 2022, zone TV.7.d.C was surveyed.

The research vessel (RV) Cefas Endeavour was used to survey a grid of randomly selected positions in the identified un-dredged zones. During the 2017 survey, at each position, an STR High Definition (HD) video camera and an SLR stills camera were deployed on an STR drop frame system for an 11-min track. Tow direction and speed were with the tide at 0.3 knots, controlled by the ships dynamic positioning system and equated to a distance run typically of just over 100 m. From the 2nd UVS survey in 2019 onwards, the tow speed of the drop frame was increased to 0.4 knots, and track duration was increased to 20 minutes to increase the distance covered to just under 250 m. An altimeter on the drop frame enabled it to be maintained at a relatively consistent height of 0.5 m above the seabed. Field of view was determined by the view within the drop frame (about 1.35 m), and determination of scale was facilitated by point lasers fitted to the camera mounts to mark a consistent distance on the seabed.

Video images were viewed live on board the RV and all observed scallops were counted. Digital stills were manually taken when scallops or indications of scallops were observed to provide more detailed images for subsequent count confirmation.

As is standard practice for other UVS surveys, video footage was reviewed later by trained staff for additional verification, and the median count per transect standardised to area. For the Cefas Nephrops UVS survey, Lin’s Concordance Correlation Coefficient (CCC) methodology is used to measure inter-observer reliability, i.e., the agreement between burrow counts by different scientists. However, this is not considered to be suitable for the scallop survey footage due to the very low counts and resulting integer artefacts (~ 1 per minute, compared to ~ 30 for Nephrops). When Nephrops stations get to similarly low densities, the CCC criterion is waived.

4.1.2. Video processing

Arithmetic methods were used to raise observed counts to survey areas using a similar methodology as that used for the dredge surveys. As with the dredge survey, the conversion of the relative density of scallops to absolute abundance indices requires an assumption about the relative efficiency of the camera gear, in this case the proportion of observed scallops. Again, this is likely to be dependent upon the ground type, with scallops on softer ground being more difficult to identify when they are partially buried. At present there are no data available for the specific gear configuration being used, and a coefficient of 1.0 (i.e., 100% efficiency) is used. There is, as yet, no information on the size range of animals observed. It is assumed that scallops become detectable on UVS footage at 80 mm shell height, which is at the low end of the range of mature sizes.

4.2. Results

A summary of the range of scallop number densities along the transects within different UVS survey zones is presented in Table 4.1. This includes those parts of UVS survey zones that overlap with the revised dredge survey beds.

Table 4.1: Summary of UVS survey results. Densities are given as numbers per 100 m^2.

Un-Dredged Zone	Number of Transects	Mean Density	Min Density	Max Density	Number of Zero Counts
TV.7.e.A (2017)	25	1.71	0	7.01	9
TV.7.e.C (2017)	26	0.53	0	3.71	19
TV.7.e.D (2017)	12	0.43	0	2.42	7
TV.7.e.B (2019)	21	0.17	0	0.94	14
TV.7.e.E (2019)	11	0.05	0	0.30	9
TV.7.d.A (2019)	15	0	0	0	15
TV.4.b.A (2021)	16	0.13	0	1.80	14
TV.4.b.B (2021)	10	0.27	0	1.14	7
TV.4.b.C (2021)	31	0.44	0	6.78	24
TV.7.d.C (2022)	17	3.20	0	18.41	2

Zone abundances in un-dredged areas, estimated based on the results from UVS surveys, are presented in Table 4.2, together with estimates of harvestable biomass and spawning stock biomass. The survey estimate is obtained by using all survey tracks. Median and inter-quartile range are obtained from random resampling with replacement (“bootstrapping”, 5000 iterations), following the same procedure as for the dredge surveys. The spawning stock biomass is estimated from the area-aggregated length distributions by assuming a logistic maturity curve, with L25 = 75 mm, and L50 = 80 mm.

The values listed in Table 4.2 differ from previously published results, as they were recalculated following the revision of dredge survey beds in 2022. Since the dredge survey beds expanded to adjust to more widespread commercial fishing activity, the UVS-surveyed areas outside the dredged areas shrank, which is reflected in reduced abundances compared to the previously published values.

Table 4.2: Abundance of scallops in un-dredged zones surveyed by UVS (2017, 2019, 2021), together with estimates of harvestable biomass and spawning stock biomass.

Area	UWTV Zone	25th Perc. (mil)	Median Abund. (mil)	Survey Estimate (mil)	75th Perc. (mil)	Harv. Biomass (tonnes)	Spawn. Stock Biomass (tonnes)
27.7.d.N	TV.7.d.A	0	0	0	0	0	0
27.7.d.N	TV.7.e.E	0.05	0.1	0.1	0.15	29	28
27.7.d.N	TV.7.d.C	6.1	7.9	7.9	8.8	966	965
27.7.e.I	TV.7.e.A	12.6	19.6	19.5	27.8	2826	2817
27.7.e.I	TV.7.e.B	0	0	0	0	0	0
27.7.e.L	TV.7.e.B	0.9	1.1	1.1	1.4	245	229
27.7.e.L	TV.7.e.C	6.2	8.0	7.3	9.8	1610	1506
27.7.e.L	TV.7.e.D	0.5	0.6	1.0	1.1	169	168
27.7.e.L	TV.7.e.E	0.2	0.2	0.4	0.5	127	127
27.7.e.O	TV.7.e.B	0	0.2	0.2	0.2	32	31
27.7.e.O	TV.7.e.D	0	0	0	0	0	0
27.7.e.O	TV.7.e.E	0.2	0.3	0.3	0.4	54	50
27.7.f.I	TV.7.e.A	1.7	2.3	1.7	3.1	375	351
27.4.b.S	TV.4.b.A	0	1.0	1.1	1.1	194	194
27.4.b.S	TV.4.b.B	0	0.6	0.6	0.6	130	130
27.4.b.S	TV.4.b.C	1.2	1.9	2.3	2.5	532	531

5. Supporting research and development

Additional research would enable refinement of our current stock assessment methodology. Some of our main priorities are discussed below.

5.1. Dredge efficiency estimates

These are required to relate dredge survey catch rates to absolute abundance. Biomass estimates are generated using substrate-specific estimates of dredge efficiency derived from earlier work by Palmer and others at Cefas (2001; unpublished). Although these efficiency estimates are in line with some other work, a method to determine the dredge efficiency, in particular on the dredge survey vessel, is required to further refine the efficiency estimates we use. Historically, depletion studies or diver surveys have been used to estimate dredge efficiency, but results can be inconsistent or logistically problematic. In 2017, a Defra funded R&D project was started to determine if novel technology (Radio Frequency Identification, RFID) could provide a solution.

This project was designed to derive a method that could generate vessel specific efficiency rates. The ultimate aim is to design a method that can be replicated on a commercial scallop dredging vessel to provide robust efficiency coefficients of direct relevance to the vessel and ground types surveyed. The equipment counts the number of uniquely tagged scallops in the path of a dredge using an antenna mounted in front of the scallop dredge. This total is then compared to the actual number of tagged scallops caught by the dredge.

The initial phases included land, aquaria and beach trials of the technology. The resulting rig was then mounted to scallop dredging gear and tested at sea on the RV *Cefas Endeavour* in the Western Channel in June 2018. These at-sea trials aimed to determine several factors: a) how to achieve a dispersal pattern that was dense enough to re-locate tags, yet sufficiently dispersed to avoid “tag-clash” (detection errors when tags are too close together); b) the time required for tagged scallops to reacclimatise and behave “normally” on release; c) how the antennae performed at depth; and d) how the antenna mount performed in front of the dredge.

A satisfactory dispersal pattern was achieved by hand-releasing scallops from the deck (as opposed to cage-borne releases in mid-water). The released scallops typically took longer than 24 hours to commence “normal” behaviour, although the length of time between initial capture and final release is considered to have been highly influential. The antennae worked at depth although with a reduced range compared to that experienced on land. The prototype electronics also require further development to be sufficiently robust. The antennae mounting mechanism (a wooden trolley in front of the dredge) appeared to work well in the water but was prone to damage (principally on retrieval).

A first inshore survey was carried out in April 2021 on board the Cornwall Inshore Fisheries and Conservation Authority (IFCA) research vessel *Tiger Lily* to trial the equipment on a drop frame using UVS. Feedback from this survey was used to modify the equipment which was then re-tested on land. The range and consistency of the logger was successfully trialled at sea during a second survey on the same vessel using UVS in February 2022. During this survey, the UVS drop frame was deployed and suspended no higher than 1m off the seabed and an altimeter was used to verify the altitude and thereby the detection range of the RFID equipment. UV paint was used on the marked scallops to enhance their visibility. Results showed the maximum altitude at which the antenna could detect an RFID tag on the seabed with 100% certainty was 50cm. Above this was a band at which some tags were detected, and some were not, and the maximum altitude at which a tagged scallop was recorded was 84cm. This range was considered sufficient for use on scallop dredges, which operate on the seabed, as well as for further UVS work, assuming reasonably calm weather conditions and limited vessel motion. Further development to the electronics has occurred to provide additional reliability and practicality.

Knowing the RFID tag detection was completely reliable within a specified range meant the RFID equipment was viable and could be tested on a commercial scallop vessel. The use of this equipment is therefore not limited to seabed conditions with good visibility as is the case with underwater cameras. A bespoke trolley designed to house the antenna and logger, and fit across the width of four dredges, was fabricated and deployed on board the fishing vessel *Evening Star*, which is used to carry out Cefas' bi-annual dredge surveys.

The RFID equipment was trialled in the Eastern Channel in May 2022. The RFID trolley was attached to the fishing gear for the first time and deployed in the harbour before leaving port, as teething problems with deployment and recovery were anticipated. Recovery of the gear resulted in damage to the trolley which was repaired in situ. The trolley was subsequently reinforced to avoid further damage by the fishing gear.

The trial site chosen was mid-Channel to the west of the Bassurelle Marine Protected Area with a sandy shingle substrate around 30m deep. A scallop bed with soft substrate type was chosen to ensure scallops were able to recess after tagging and release, and rocks could have damaged the RFID trolley during towing. Sandy shingle is also the most common type of substrate targeted by the fishery as scallops are typically found here and gear is less likely to get caught on rocks or other obstacles. The tow bars on both sides of the vessel were configured with four dredges in the middle, a one-dredge gap either side, then two dredges on either end of the tow bar. The RFID equipment was positioned ahead of the middle four dredges deployed from the starboard side of the vessel, with the one-dredge gap to ensure scallops caught in dredges with the RFID antenna in front did not overlap with non-RFID dredges. Early camera work showed it was necessary to put more warp out than usual when towing to ensure the trolley was in contact with the seabed and any tagged scallops would be in the detection range of the antennae. As such the usual fishing practice was altered.

Catchability of dredges on both sides were compared for seven tows when the RFID trolley was deployed. Length distributions of scallops caught in the port-side dredges were not significantly different to the starboard (RFID) side. Mean shell length was 124.4mm and 123.9mm for port and starboard dredges respectively. However, total numbers of scallops caught were significantly higher on the RFID side, both from dredges directly behind the RFID trolley and those either side. One of seven tows caught 21% fewer scallops on the RFID side compared to the port side dredges, and the remaining six tows caught between 5-97% more scallops in the RFID side dredges compared to port. Overall, the starboard side dredges with the RFID trolley attached caught 50% more scallops than the port side. A comparison of catches on the same vessel during a standard dredge survey in September 2021 showed a difference in catch numbers of scallops between port and starboard side commercial scallop dredges in individual tows, but with high variability and an overall difference of 2.5% in catch between both sides. It is therefore likely the presence of the RFID trolley, potentially combined with the warp length, affected the efficiency of the starboard dredges. This would require further investigation and potentially mitigation if this efficiency factor was to be applied to the port dredges samples, or to different tows.

To verify the consistency of the RFID equipment, two GoPro Hero 5 cameras in 60 metre rated underwater housings with two Suptig 84 LED lights rated to 50 metres were attached to the tow bar looking forward towards the RFID trolley. This was the first time the cameras

had been fitted to this commercial gear and it was noted the field of view of the GoPros did not cover the outer edges of the trolley. The field of view was limited by the mounting possibilities of the camera on the tow bar and therefore the camera footage would have underestimated the number of tagged scallops the RFID antenna went over, it is thought by as much as 30% judged by the amount of the RFID trolley seen in the field of view. Some tows had clear bright footage, but during the morning and evening when the sun was below a critical angle, the edges of the footage were too dark to distinguish tagged scallops on the seabed. This single survey highlighted the need for further refinement of the UW camera system to verify the RFID equipment on dredges.

5.2. Biomass estimates from UVS

UVS surveys are used to determine abundance of scallop populations in un-dredged areas. This is important as we would expect populations in some of these areas to contribute to recruitment to adjacent exploited populations by larval dispersal.

5.2.1. Camera system

A non-contact camera system is used, as ground types may not be suitable for camera platforms that are towed along the seabed (sledges). Such towed systems may not be appropriate for sensitive habitats. However, the non-contact system currently used from the Cefas research vessel (STR SeaSpyder drop frame with HD video and stills) is limited to low tow speed deployment. This system does not cover much ground and there is a risk of under-sampling scallops which are distributed at relatively low densities. In addition, scallops can be cryptic by recessing into the substrate and covering themselves with a fine layer of sediment. Alternative camera platforms have been investigated and some trialled for suitability.

1. Devon and Severn IFCA "flying array" (a device originally developed by Plymouth Marine Laboratory) which was deployed from both an inshore vessel (D&SIFCA) and the Cefas RV with dynamic positioning.
2. Cornwall IFCA STR SeaSpyder drop frame system (more compact than the Cefas system and suitable for small vessel deployments) deployed from CIFCA RV.
3. Videoray Pro4 mini ROV deployed from CIFCA RV.
4. The Marine Scotland "Sea Chariot" was investigated but not deployed.

Further optimisations of the current Cefas STR SeaSpyder drop frame system has been carried out to provide more ground coverage without compromising scallop visibility, and to maximise the potential of the captured imagery.

Development of a high-speed, non-contact camera platform with a camera system optimised for scallop surveys is ongoing, as resources allow.

A new video camera (Rayfin by SubC Imaging) which provides high-definition video imagery and facilitates capture of multiple high resolution stills images was trialled in May 2021. These images are taken at high frequency by means of strobe lighting. The stills images compliment the video footage by enabling digital enhancement and zooming in on scallop shells that may require confirmation that they are alive or for finding the more cryptic animals. Multiple stills images may lend themselves to automated image analysis in the future, although many problems of using machine learning algorithms to achieve this require resolution.

5.2.2. Camera efficiency

The cryptic behaviour of scallop means that in some circumstances not all of the scallops in the field of view of the video camera will be observed. The video camera and human observer combination has an efficiency that, analogous to the scallop dredges, is likely dependent on substrate type. As yet, there are no data available for the specific gear configuration used. Therefore, a coefficient of 1.0 is used, assuming that all scallops in the camera field of view are identified. The same RFID technology used to determine dredge efficiency is currently also being developed to determine camera/human observer efficiency on various substrates (see Section 5.1 above).

5.2.3. Population structure

Relating video observations of scallops in the un-dredged areas directly to the harvestable biomass of the population is not straightforward. In our assessment we have assumed that the camera has a knife edge selection at 80 mm shell height, which is at the low end of the range of mature sizes. Automated image analysis software has been considered as an alternative to manual methods of determining scallop size from video and stills images. However, application of this technology to scallop species is relatively new and in the early stages of development. The potential application of any new developments in video or still image analysis and machine learning, both at Cefas and at external agencies, will be considered as resources allow.

5.2.4. Connectivity between dredged and un-dredged areas

To enable appropriate incorporation of biomass estimates from un-dredged beds into the assessment process, we need to determine the level of linkage between scallop populations in un-dredged zones and fished beds. This might best be achieved by calculating harvest ratios that incorporate a proportion of the biomass estimated in un-dredged areas derived from UVS, with biomass estimated in the dredged beds derived from the dredge surveys. These proportions could be defined by the levels of recruitment to the dredged beds which are derived from those un-dredged beds.

Recent work by (Nicolle, et al., 2017) used particle dispersal modelling in the English Channel to provide some answers as to the level of linkage between fished areas but does not describe the specific connectivity between most of the un-dredged beds with the dredged beds defined for Cefas scallop stock assessments. Further oceanographic modelling was carried out by colleagues at Cefas in 2021 to determine levels of connectivity. Results from North Sea modelling show no connectivity to the inshore exploited beds. For the Channel region, the modelling data are presently being analysed.

6. Maximum sustainable yield estimation

The proxy reference points used in this assessment to establish exploitation levels consistent with maximum sustainable yield (MSY) for individual assessment areas are determined by a yield and spawner per recruit model. In data-limited situations, this type of model is more appropriate than a full dynamical stock assessment model, as it requires less input data.

The required biological parameters are natural mortality, growth, and maturity at age (or size). Natural mortality is difficult to determine for a heavily exploited species. The best estimates for the different assessment areas are listed in the main part of the report. Growth parameters (for the von Bertalanffy model) are based on a subset of shells from dredge surveys that have been aged. The currently used values are listed in the main part of the report. Maturity stages have not been assessed by Cefas in recent years. Based on previous sampling studies, we are using a logistic function for maturity at size that is 25% at 75 mm and 50% at 80 mm flat shell height.

In addition to the biological parameters, the model requires parameters that describe gear efficiency. Gear efficiency depends on many factors, including gear type, gear deployment, substrate type, as well as the size of scallops.

For the king scallop assessments, catch sampling data are provided by the annual dredge surveys. For these surveys we are using standard commercial Newhaven-type spring-loaded dredges with 75-mm belly rings, which are deployed from a commercial scallop dredger. We therefore assume that survey gear type and deployment are representative of commercial fishing operations. Substrate-specific parameters describing overall gear efficiency for commercial sizes were determined based on depletion studies and are listed in the main part of the report.

To take into account size-dependency, we determine two parameters, L_{25} and L_{50}, for the gear selectivity function that scales fishing mortality for different sizes, based on scaled length distributions in dredge survey catches. For four of the assessed areas, this is shown in Figure 6.1. Gear selectivity depends on the upward slope of the catch size distribution, where L_{25} is the size at which gear selectivity is 25% of its maximum value, and L_{50} is the size at which gear selectivity is 50%. The corresponding logistic gear selectivity functions are shown in Figure 6.2.

Using these parameters, and starting with an initial number of animals at age one – a group of recruits – the model calculates the evolution of this cohort over time in annual time-steps (see Figure 6.3 for a schematic representation). The initial number of animals is immaterial, as the model outputs are given on a per-recruit basis. For each age (and corresponding size class determined based on von Bertalanffy growth parameters), the cohort model determines the remaining number of animals and their combined biomass.

Number abundance steadily declines over the lifetime of the cohort, first by natural mortality alone, until the animals have reached commercial size (MLS). From then on, their number also decreases due to size-dependent fishing mortality, as determined by the gear selectivity function.

Total biomass at each age is determined by the number abundance (steadily decreasing with age) and the individual weights of animals (steadily increasing with age). Early on during the lifetime of the cohort, individual growth typically outweighs losses due to natural mortality, and possibly even fishing mortality. Cohort biomass can therefore increase over the first few years.

Fishing mortality, or yield, at each age is determined by the total number of animals caught and by the individual weights of caught animals. The total number of animals caught depends on gear selectivity (steadily increasing with age or size) and the number of animals remaining in the cohort (steadily decreasing with age). Together with the steadily increasing individual weights of caught animals, yield at age typically first increases, until the reduced number abundance outweighs gains due to increased gear selectivity and individual weights.

Yield per recruit is calculated as the combined yield at all ages over the lifetime of the cohort, divided by the initial cohort size (number of recruits).

Using the logistic maturity at size function, the number of mature animals (spawners) at each age can be calculated, as well as the average annual number and biomass of all spawners over the lifetime of the cohort. Spawners per recruit is then calculated as the average annual number of spawners divided by the initial cohort size.

These calculations are done for a range of terminal fishing mortalities (i.e., that fishing mortality experienced by the largest size class), starting from zero (for an unfished or “virgin” cohort). Based on that ensemble of calculations, for one of the assessed areas, yield and spawners per recruit, as functions of average fishing mortality experienced over the lifetime of the cohort, are shown in Figure 6.4. Starting from zero average fishing mortality, yield per recruit first increases until it reaches its maximum, beyond which it decreases again with increasing fishing mortality. This is due to the fact that past the average fishing mortality at maximum yield per recruit the cohort becomes overfished in the sense that animals are caught at increasingly young ages (small sizes), before they can significantly increase cohort biomass through individual growth.

A commonly used MSY-proxy reference point, and the one chosen for the king scallop assessment, is that fishing mortality that results in 35% of spawners per recruit relative to an unfished cohort. The connection between that fishing mortality and yield per recruit is illustrated in Figure 6.4. For the scenario resulting in 35% virgin spawners per recruit, the harvest rate consistent with MSY can be calculated as the ratio of total yield over total harvestable biomass over the lifetime of the cohort.

To be able to relate abundance at age throughout the lifetime of the cohort to the cross-section of population abundance at age in any given year, the population has to be in equilibrium, i.e., recruitment and fishing activity have to be constant. In reality, this is not the case. We therefore intend to update the MSY calculations on the same five-year cycle on which the dredge survey design is being updated, as described in Section 2.2, using the survey sampling data from the most recent five-year cycle.

The revised harvest rates consistent with the chosen MSY-proxy that were calculated in 2022, based on 2017 – 2021 dredge survey sampling data, were higher than those estimated at the start of the stock assessment project in all four areas that had sufficient sampling data at that time (which excluded the areas outside the English Channel, i.e., 27.4.b.S and 27.7.f.I). The reason for the increased MSY-proxy harvest rates is a shift in the gear selectivity pattern to higher sizes. With an increasing proportion of large animals being caught, yield increases with the same overall number of caught animals. Alternatively, yield can be maintained with a reduced number of caught animals. A given harvest rate by weight, which is used as reference point, is therefore associated with a reduced harvest rate by number, which indicates the actual losses to the population. The currently used values for MSY-proxy harvest rates in different assessment areas are listed in the main part of the report.

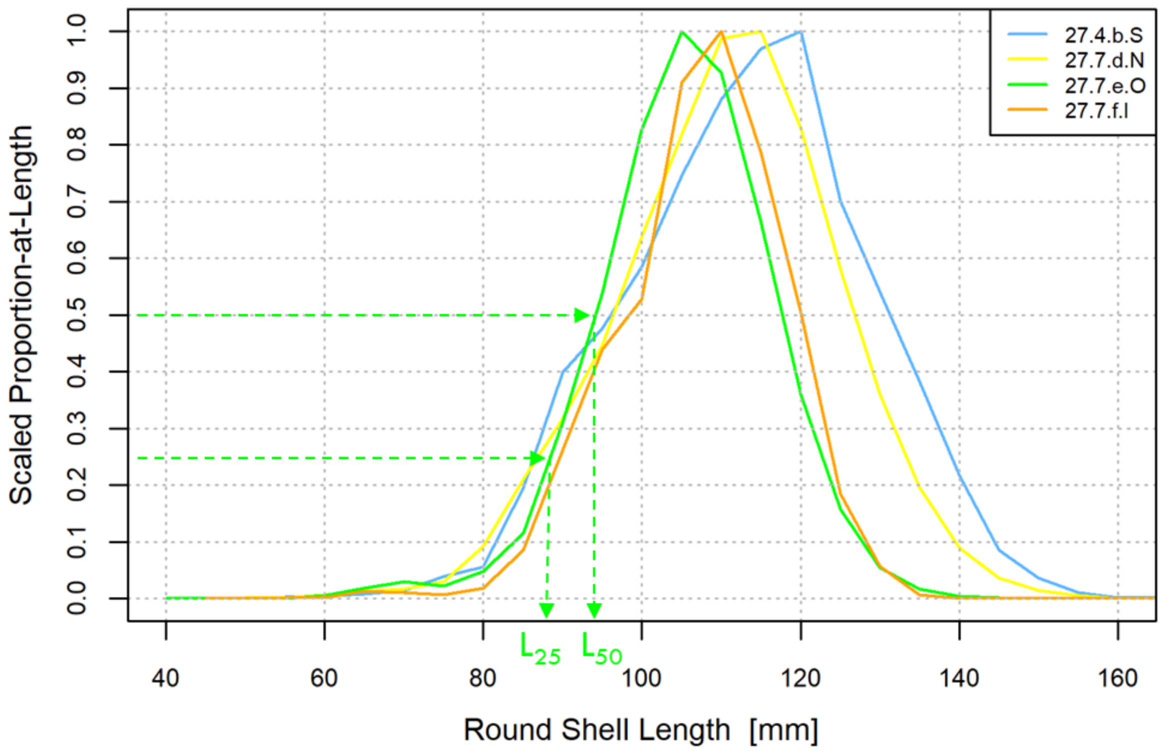

Figure 6.1: Scaled size distributions (in units of the maximum value of the original distribution) of dredge survey catches (2017 – 2021), using standard commercial Newhaven-type spring-loaded dredges with 75-mm belly rings, for four of the assessment areas. The determination of gear selectivity parameters, L_{25} and L_{50}, is shown for Area 27.7.e.O (green line).

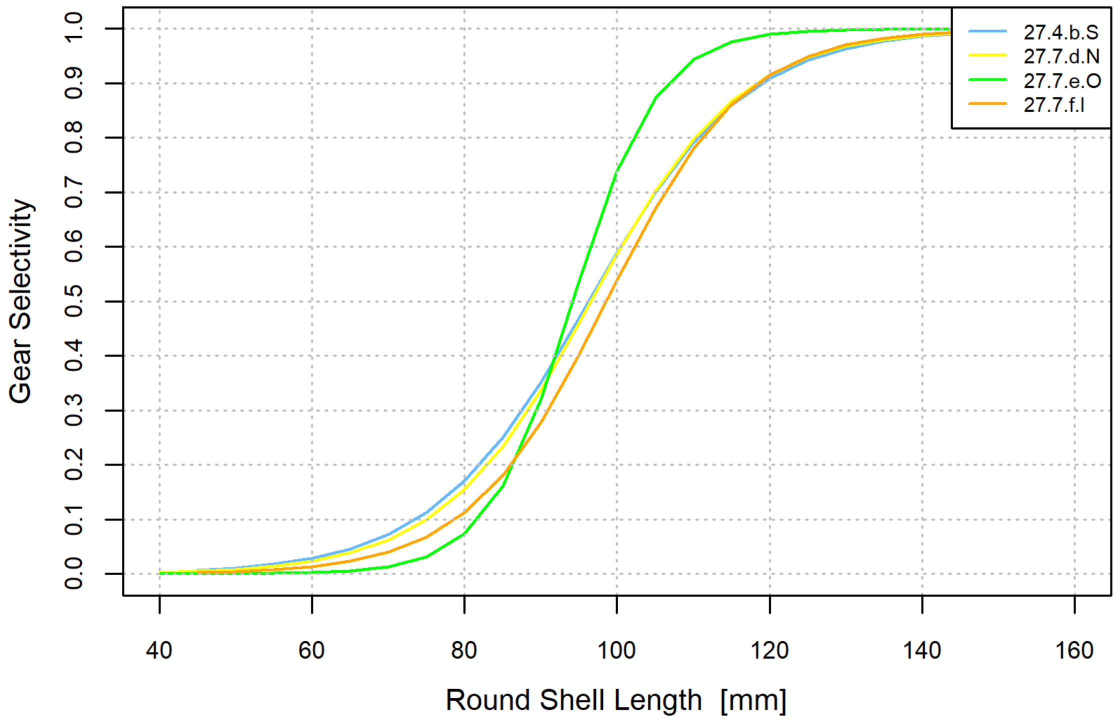

Figure 6.2: Gear selectivity curves (logistic functions) for four of the assessment areas, with gear selectivity parameters, L_{25} and L_{50}, determined based on scaled size distributions of dredge survey catches (2017 – 2021), using standard commercial Newhaven-type spring-loaded dredges with 75-mm belly rings.

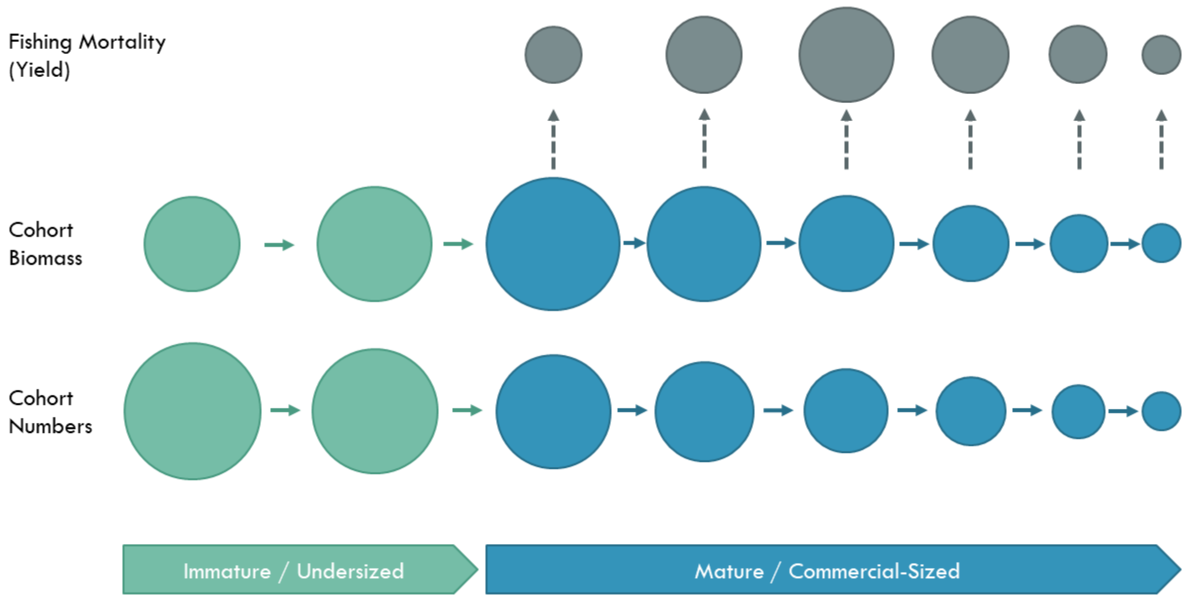

Figure 6.3: Schematic depiction of the evolution of a cohort of king scallops. Each circle represents a life stage defined by either age or a size class.

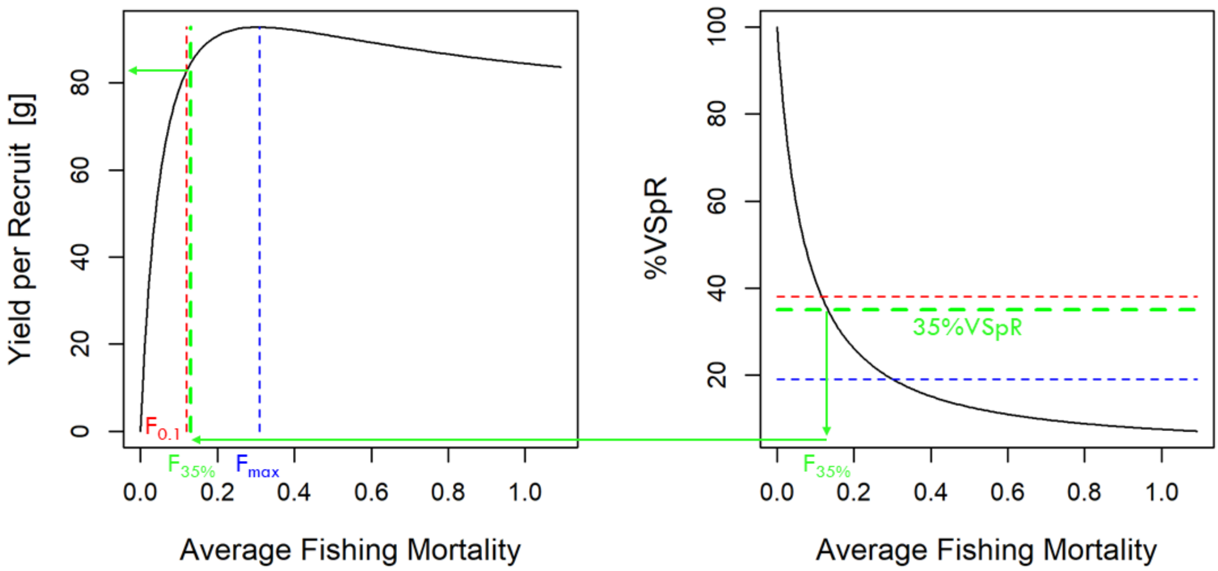

Figure 6.4: Simulated yield per recruit (left) and percent virgin spawner per recruit (right) as functions of average fishing mortality for the Yorkshire/Durham assessment area (27.4.b.S). The green dashed lines and arrows indicate the average fishing mortality, $F_{35\%}$, that results in 35% of spawners per recruit relative to an unfished cohort (virgin spawners per recruit, VSpR), and the associated yield per recruit. The red dashed lines indicate the yield per recruit and percentage of virgin spawners per recruit that correspond to that average fishing mortality, $F_{0.1}$, at which the slope of the yield per recruit curve is 10% of the slope at very small fishing mortalities (< 0.05). The blue dashed lines indicate the yield per recruit and percentage of virgin spawners per recruit that correspond to that average fishing mortality, F_{max}, at which yield per recruit is maximised. $F_{0.1}$ and F_{max} are sometimes used as MSY-proxy reference points and are shown here for comparison with $F_{35\%}$, which is the chosen MSY-proxy reference point for the king scallop assessments.

7. References

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