Stock Annexe for King scallop in selected waters around the English coast

A Defra and Industry Funded Project

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Contents

1. King Scallop Biology

1.1 Range and Habitat

The king scallop (*Pecten maximus*) is a large bivalve mollusc (up to 175 mm shell length, or 153 mm shell height) that is resident on the continental shelf of Northwest Europe. It is common at depths of 5 – 200 m, on substrates ranging from muddy sand to coarse gravel. The species ranges from northern Norway to Morocco, the Canaries and the Azores. Scallops are common around the British Isles.

1.2 Reproduction and settlement

Scallops are permanent hermaphrodites and are very fecund. A large scallop may produce 2 million eggs per spawning event. Spawning times vary from spring to autumn with some populations exhibiting two peaks of spawning over that period. Larvae remain in the plankton for around 30 days and may thus be dispersed over long distances. At metamorphosis, the larvae settle onto a primary site (often erect Hydrozoans and Bryozoans) to which they attach by means of byssus threads. On reaching a size of approximately 1 – 5 mm, they detach and settle onto the seabed, where they take up their normal habit, recessed into the substrate.

1.3 Growth

Growth in scallops is continuous with new material laid down along the outside edge of the shell in very fine ridges (striae). There is considerable seasonal variation in growth rates, and a compression of the growth ridges indicates periods of slower growth, usually associated with winter conditions. Other causes of slower growth (“growth checks”) occur when animals are stressed (such as after damage caused by interaction with scallop dredges), or due to sudden climatic changes. Growth rates are extremely variable even between adjacent beds, with the time required to reach the local minimum landing size (MLS) varying from 2 to more than 5 years.

A review of historic growth estimates, based on an unpublished study by Cefas in the English Channel in 2001, provided von Bertalanffy growth parameters. Scallops were not individually weighed as part of this project, but parameters for a weight- length relationship for relevant ICES Divisions were obtained from IFREMER.

The relationship between live weight (W) estimated by round length (L), multiplied by *a* ($1.55x10^{-3}$) to the power *b* (2.45609),

$$W= aL^b$$

where *a* and *b* are area-specific positive constants, which are determined through regression analyses based on biological sampling data (IFREMER, Unpublished).

Animals larger than the area-specific MLS are almost exclusively found to be mature. Based on unpublished data, Cefas assumes maturity to be knife-edged at 90~m length (80 mm flat shell height) in all assessment areas.

1.4 Natural Mortality

Predation is the likely cause of most of the natural mortality (i.e., mortality not related to fishing activity), with brown crab and starfish being the most significant predators on scallops less than two years old. Scallops that reach sexual maturity are less vulnerable to predation due to the robustness of their shells.

Natural mortality is not precisely known. However, in common with other fish and shellfish stocks of similar longevity (up to 20 years), it is assumed to be 0.15 yr^{-1} for all ages and areas (Cook, et al., 1990).

Table 1. Biological parameters

Parameter	**Value**	**Source**
Round length to weight	$a = 1.55x10^{-3}$ $b = 2.45609$	IFREMER (unpublished); see Section 1.3 for functional relationship
Size at maturity	~90 mm length	Cefas (unpublished)
Natural mortality	0.15 for all ages	(Cook, et al., 1990)
Von Bertalanffy growth	$H_\infty = 119.3$ $k = 0.516$ $t_0 = 0.692$	Cefas (based on an unpublished fine-mesh dredge study in 2001)

2. King Scallop Fishery

2.1 Fisheries Management Overview

King scallops (Pecten maximus) around the English coast are one of the most commercially valuable marine species, and the most valuable of the wild-caught mollusc species in UK waters (MMO, 2022). In 2021 the MMO reported, to ICES, 13745 tonnes of international landings from the eastern English Channel (ICES Division 27.7.d) and 8929 tonnes from our three assessment areas in the western English Channel (ICES Division 27.7.e). An additional 2513 tonnes of international landings were reported from the area along the English east coast in the North Sea (ICES Division 27.4.b) and 85 tonnes from the Bristol Channel (Division 27.7.f).

The stocks are exploited principally by the UK and France, with additional activity from Ireland, the Netherlands and Belgium. Targeted fisheries predominantly use towed dredges, although some commercial dive fisheries exist, particularly around Lyme Bay. *Pecten maximus* fisheries lie outside the EU total allowable catch (TAC) and quota regime, and fishery management measures are largely under the control of individual states.

In UK waters, the minimum landing size (MLS) at which scallop may be retained is 100 mm round shell length, except for the Irish Sea (Division 27.7.a) and the Eastern Channel (Division 27.7.d), where it is 110 mm. These values originate from EU legislation but are now retained in the corresponding UK legislation.

The UK fleet comprises a mix of large (> 15 m) nomadic vessels, and smaller (10 – 15 m) vessels with a more localised range. EU legislation caps the effort that large vessels can utilise in ICES Subarea 27.7. This Western Waters effort regime places an upper limit on the number of kilowatt days fished by vessels with lengths > 15 m towing scallop dredges. Within the UK, this effort pool is administered by the Marine Management Organisation (MMO) in a system which sets a maximum number of days per quarter that any vessel with a scallop entitlement may fish. These limits are revised on a quarterly basis. The Scallop Fishing (England) Order 2012 applies to British vessels operating in English waters inside 12mn and places restrictions on the number of dredges that can be employed within this area at any one time. It also specifies technical measures defining the type of dredge that can be used.

In contrast, the French fishery is dominated by smaller vessels fishing much more inshore (on the French side of the Channel) and is concentrated in two zones: the Baie de Seine and the Baie de Saint Brieuc. The French management system is complex, with a range of quotas, and layers of temporal restrictions (annual, seasonal and daily hours), with access and quota being determined at a local level.

The UK left the EU on the 31st January 2020 and the transitional phase where the UK was still subject to EU laws expired 31st December 2020. The implications on fishery access, markets and management measures at the time of this report are still subject to further discussions. The Trade and Cooperation Agreements (TCA) between the EU and the UK includes conditions defining access of EU vessels to UK waters and UK vessels to EU waters. These are based on track record and are expected to replace existing arrangements. The TCA also sets the maximum tonnage of Non-Quota Species that the UK and EU can catch in each other's waters, this quota includes scallops. On 14 December 2023, a newly developed Fisheries Management Plan (FMP) for king scallops in English and Welsh waters was published by the UK Government (https://www.gov.uk/government/publications/king-scallop-fisheries-management-plan-fmp). It lays the foundation for improved data acquisition on the state of king scallop stocks to allow a transition of fisheries management away from a precautionary approach to more robust management strategy.

2.2 Fisheries Closures

Until 2024 the EU left scallop fishery management to its member states. The lack of agreements and coordination of fishery management measures at an official level has led to tension between fishers from the UK and France when some vessels were seen to be operating in places and at times that other fishers are prevented by their own national rules (i.e. UK vessels fishing during the French closed season). Since 2024, the EU has prohibited the fishing for king scallops in EU waters in the Channel from May 15th to October 15th.

A voluntary 2-month seasonal closure existed from 2013 to 2020 (with the exception of 2018) between the majority of the UK scalloping industry and the French industry. From 2021, mandatory seasonal closures in UK waters of Division 27.7.d have been in place, with changing closure periods from one year to the next. In 2023, the closure period ran from 1 July to 30 September, with a matching closure period in the Lyme Bay area of Division 27.7.e, to prevent effort displacement from the east. During that year, the EU introduced a seasonal closure for EU and UK scallop dredgers in EU (French) waters of Division 27.7.d and some parts of 27.7.e (North Finistère), during the period from 15 May to 30 September 2023 (with an extension until 15 October in the Baie de Seine area of 27.7.d). In 2024 the UK had an extended closure from the 15th May to the 20th September in 27.7.d and 27.7.e. The closure was administered by the Marine Management Organisation on behalf of the UK Fisheries Administrations with the purpose being to protect stocks during spawning (gov.uk, 2024).

2.3 Discards and bycatch

Discards are known to occur in the fishery. However, no quantitative estimates have been made, and therefore this assessment does not include discards. As almost all discards are due to minimum size restrictions, the lack of discard data does not affect the estimation of harvestable biomass. Scallops are assumed to have a high discard survival rate.

Prior to 2019, there was a limit on retained fish bycatch in scallop dredges of 5% of the total retained catch of otherwise bivalve molluscs. Since the complete phasing in of the EU Landing Obligation in 2019, scallop dredgers have been required to land all quota species (except skates and rays) regardless of catch component. However, for non-quota species the 5% bycatch rule applies as before.

3. Stock unit and assessment areas

There are four ICES Divisions included in the stock assessment (Figure 1), two of which, 27.7.e and 27.7.d, are divided into three and two sub-division respectively. Investigations into the transport and distribution of scallop larvae (Catherall, Hold, Murray, & Bell, 2014) indicate that scallops within ICES Divisions 27.7.d and 27.7.e are likely to compromise at least two biologically distinct populations, when viewed at the scale of multiple generations. This is due to the fact that a) larval interchange is considered to be only sporadic, b) there are distinct regional differences in growth rates and fishery management, and c) post-larval scallops exhibit largely sessile behaviour. Regional stock assessments are therefore appropriate. Stock assessment began in these areas in 2017. Additional stock areas in the Approaches to the Bristol Channel (27.7.f.I) and in the North Sea (27.4.b.S) were introduced in 2018.

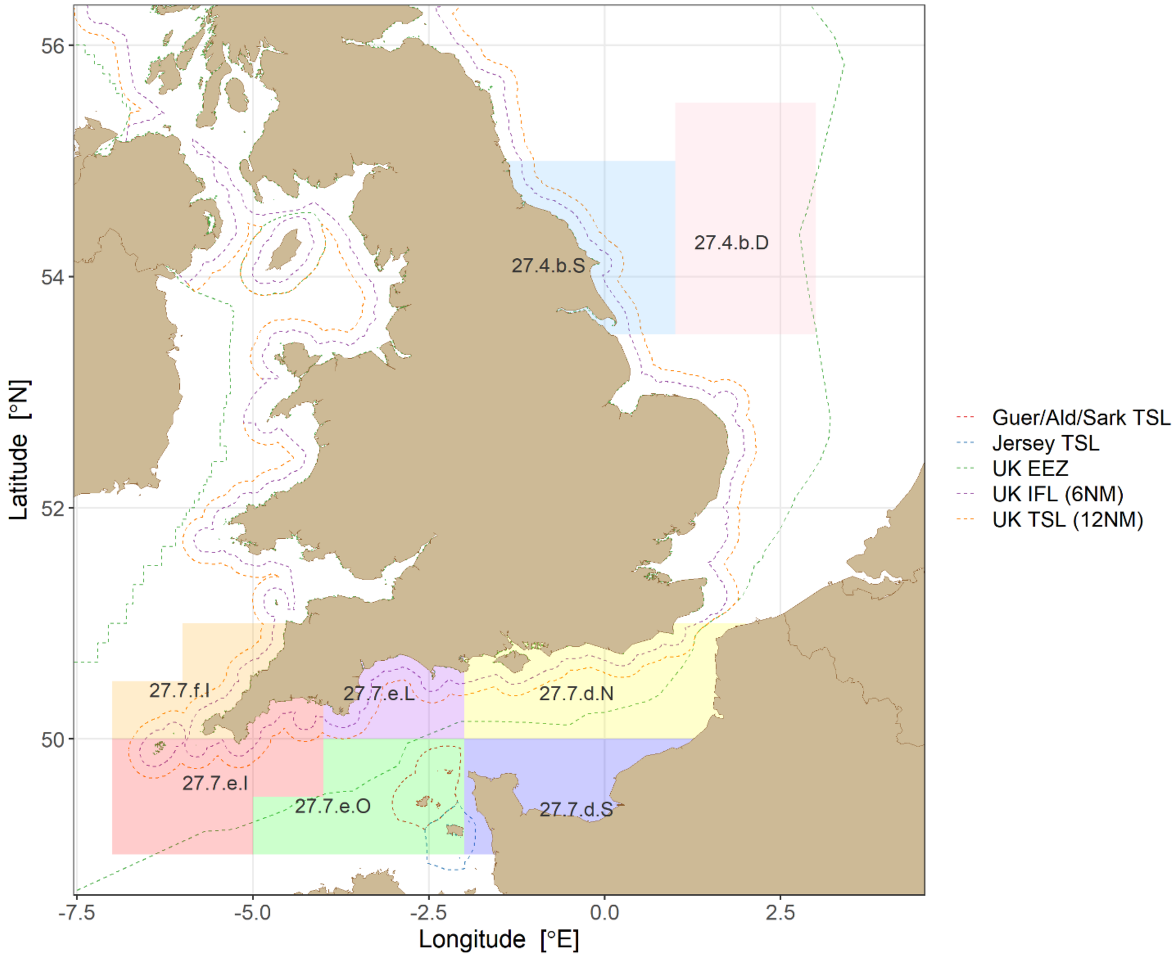

Figure 1 King scallop stock unit assessment areas defined in the English Channel, the Celtic and North Sea. The dashed lines indicate the Territorial Sea Limits (TSLs) of the UK and the Channel Islands, the UK Economic Exclusion Zone (EEZ), and the UK Inshore Fisheries Limit (IFL).

ICES Division 27.7.d in the eastern English Channel, has been divided into two stock assessment areas - 27.7.d.N and 27.7.d.S, which are split along the 50ºN line (Figure 1). This split, dictated by the resolution of landings data, allows a separation of the faster growing Baie de Seine stock from the rest of the eastern Channel, and is considered appropriate for stock assessment purposes.

Three stock assessment areas have been designated for ICES Division 27.7.e to reflect slow-growing inshore areas south of Cornwall (27.7.e.I), faster growing areas within Lyme Bay (27.7.e.L), and offshore scallop beds further to the south (27.7.e.O). Scallop fisheries in the remaining ICES rectangles in Division 27.7.e are dominated by French coastal activity and are therefore beyond the scope of this report.

In 2021, a new assessment area covering the Dogger Bank (27.4.b.D) was established, in response to the increase in fishing activity in that area during the previous year. However, with the introduction of a dredge ban inside the Dogger Bank MPA, the area was dropped from the routine survey in 2022.

The ICES statistical rectangles that define all our assessment areas are listed in Table 2. Two finer grids than statistical rectangles are defined for more detailed spatial analyses: a grid of 0.1-by-0.1 degree blocks, and a grid of 0.025-by-0.025 degree cells.

Table 2. Assessment areas by ICES statistical rectangle

ICES Division	ICES Statistical Rectangles							
27.4.b.D	36F1	36F2	37F1	37F2	38F1	38F2	39F1	39F2
27.4.b.S	36E9	36F0	37E9	37F0	38E8	38E9	38F0	
27.7.d.N	29E8	29E9	29F0	29F1	30E8	30E9	30F0	30F1
27.7.d.S	27E8	27E9	27F0	28E8	28E9	28F0	28F1	
27.7.e.I	27E3	27E4	28E3	28E4	28E5	29E5	29E4*	
27.7.e.L	29E6	29E7	30E6	30E7				
27.7.e.O	27E5	27E6	27E7	28E6	28E7			
27.7.f.I	29E3	29E4+	30E4	30E5				

* Small area within boundaries of Division 27.7.e.

+ Main area within boundaries of Division 27.7.f.

4. Assessment methodology overview

The assessment model is survey-based, using both a dredge survey in fished beds, and video survey in non-fished beds. The essence of the approach is to determine the stock unit harvestable biomass of scallops, as derived from fished and non-fished beds. To do so, the catch and observed densities of scallops at or above MLS are raised by the gear efficiency parameter appropriate for the particular survey gear and ground type, and raised to the area covered by the stock unit. Harvest rates are then calculated for each stock unit using landing data. Harvest rate is a measure of the fishing mortality within a given area. Ideally it is calculated from the harvestable biomass immediately prior to the start of a particular fishing season, in relation to the total removals during that season. The UK and international landings of scallops are combined to provide a total harvest of scallop biomass per stock unit. Harvest rates are presented in relation to proxy reference points that were determined to establish exploitation levels consistent with maximum sustainable yield (MSY).

5. Survey design – identification of fished and unfished scallop beds

5.1.1 Terminology

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

Bed – An irregular outline representing a scallop ground.

Block – A regular coordinate grid of 0.1-by-0.1-degree rectangles, with an approximate area of 80 km2.

Cell – A regular coordinate grid of 0.025-by-0.025-degree rectangles, with an approximate area of 5 km2 (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.

5.1.2 Identification of fished scallop beds

The outline of fished beds to be included in the survey was developed as part of a survey strategy with the Project Steering Board (PSB) at the start of the king 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. This survey strategy agrees to a revision of the survey bed outlines, based on the most recent 10 years of Vessel Monitoring System (VMS) data, every 5 years (Figure 2). The first 5-year period was 2017 – 2021, and the second has been 2022 – 2027 (this Annex presents the latest survey design, updated for 2022). This update only affects the surveyed regions within the established assessment areas (Figure 3) rather than the assessment areas themselves. Updating the survey design every 5 years is seen as a good compromise between year-to-year consistency and flexibility, to allow the dredge surveys to adjust to shifting commercial exploitation patterns.

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 (Figure 2).

- 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. This function uses the algorithm defined by (Edelsbrunner, Kirkpatrick, & Seidel, 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 Figures 3-6.

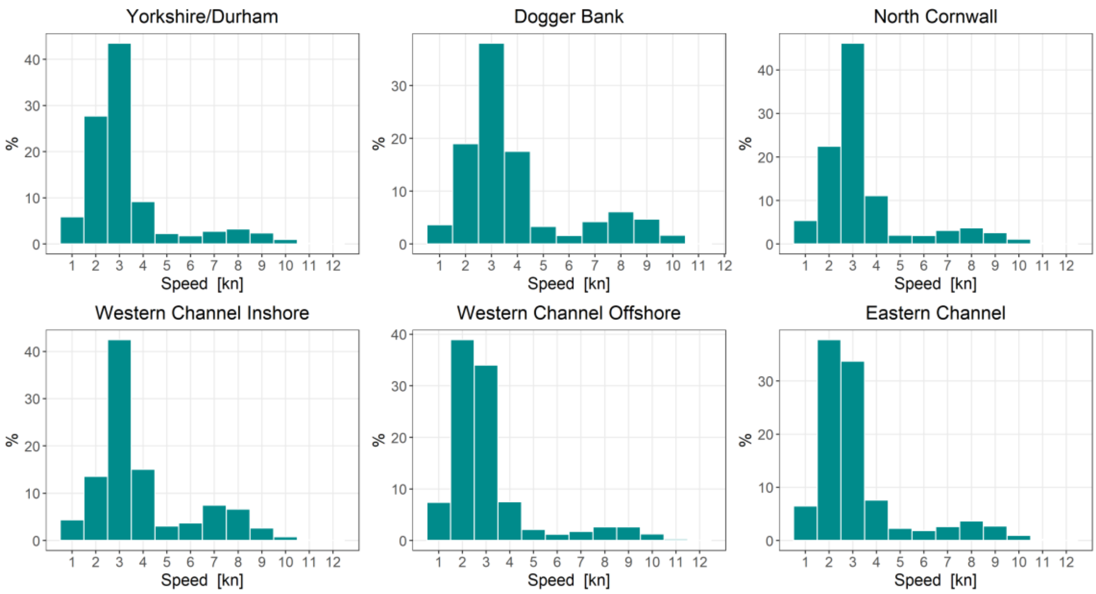

Figure 2. Speed histograms based on VMS positioning data (2012 – 2021) from UK king scallop dredgers in different assessment areas. The Western Channel Inshore panel shows combined data for Areas 27.7.e.I and 27.7.e.L.

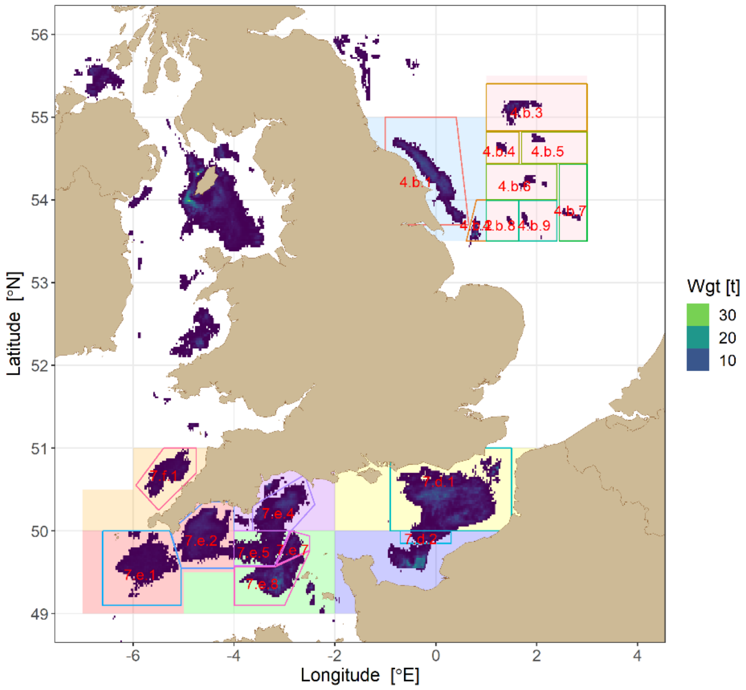

Figure 3. VMS positioning data (2012 – 2021) from UK king scallop dredgers aggregated in the cell coordinate grid with associated distributed landings amounts. The labelled polygons are preliminary bed outlines which are refined using the R package alphahull.

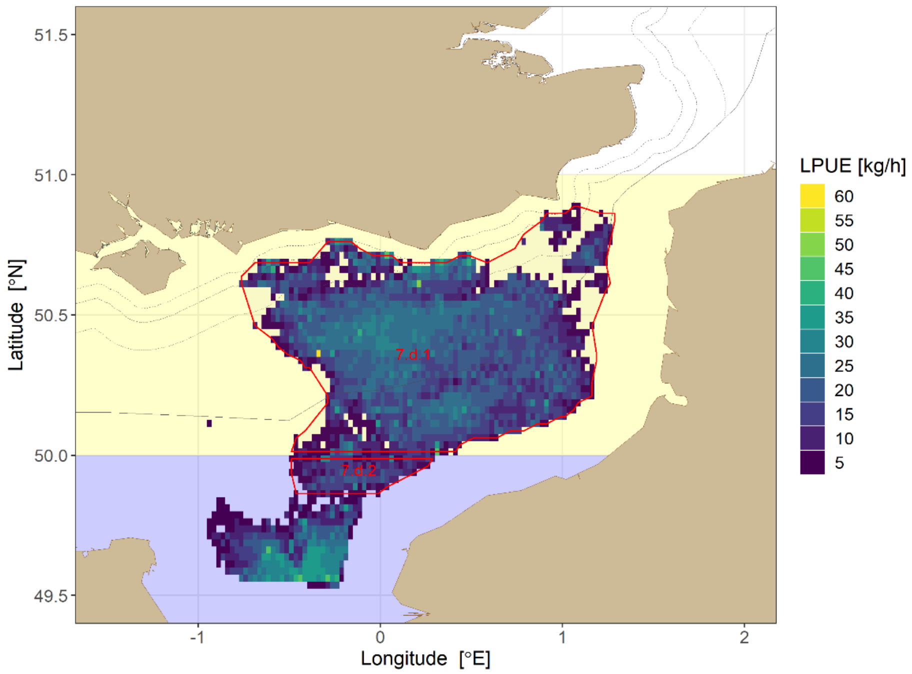

Figure 4. VMS-apportioned landings per unit effort (LPUE) within final bed outlines in the eastern English Channel (2012 – 2021).

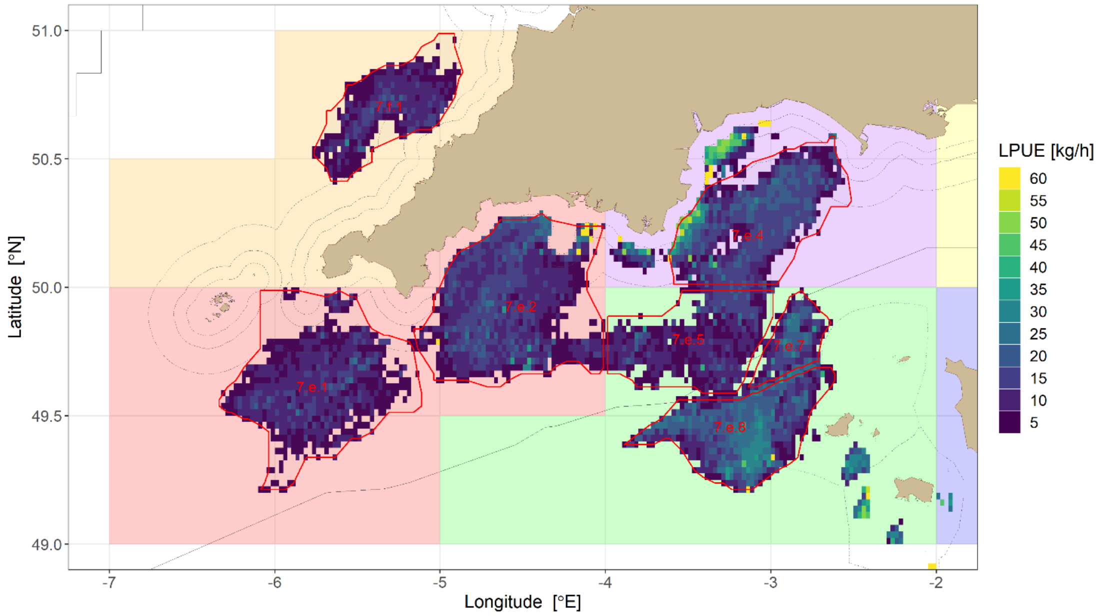

Figure 5 VMS-apportioned landings per unit effort (LPUE) within final bed outlines in the western English Channel and north of Cornwall (2012 – 2021).

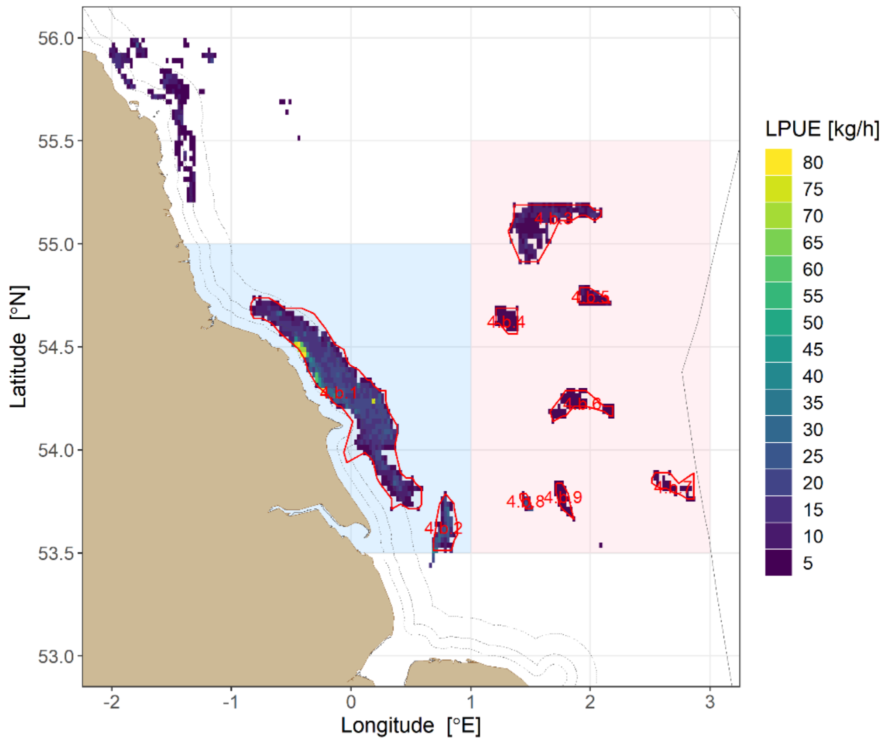

Figure 6. VMS-apportioned landings per unit effort (LPUE) within final bed outlines in the North Sea (2012 – 2021).

5.1.3 Summary of stock assessment areas and fished scallop beds

Within the stock assessment areas spanning the western channel, 27.7.e.I (inshore Cornwall), 27.7.e.L (Lyme Bay) and 27.7.e.O (offshore), eight scallop beds have been identified (figure 5). Two beds within 27.7.e.I, two entirely within 27.7.e.L, and two entirely within 27.7.e.O. Two beds (7.e.4 and 7.e.5) straddle two of the assessment areas. Bed 7.e.3 is within a Marine Protected Area and bed 7.e.6 is positioned in a sensitive area within 6 nm of the coast. These two beds are no longer accessible to larger vessels, including our survey vessel. They are therefore not part of the dredge survey anymore but have been surveyed using UVS in 2017 and 2019. Beds 7.e.7 and 7.e.8 lie predominantly in the French EEZ, with a small part of Bed 7.e.8 lying in the territorial waters of Guernsey, and a small part of Bed 7.e.7 lying in the UK EEZ.

In 2018, a new bed, 7.f.1, was defined and surveyed in Area 27.7.f.I (Inshore). This area is within ICES Division 27.7.f, off the North Cornish coast.

Within Area 27.4.b.S, two scallop beds were first defined in 2018, and revised in 2022. Due to the intense fishing activity in the Dogger Bank area during spring and early summer of 2020, five beds were defined within Area 27.4.b.D, which were surveyed once in 2021. All beds in Division 27.4.b are within the UK EEZ. However, there are now restrictions imposed on towed gear within Area 27.4.b.D, as it is within the Dogger Bank SAC, which is partly proposed to protect seabed features. Dredge surveys have therefore not been carried out in that area since 2021.

The main fishery in 27.7.d.N covers a large bed which stretches across the mid-eastern part of the Channel, straddling the border between UK and France, and extending into Area 27.7.d.S (Figure 7). As VMS data was used the define the bed, the bed represents only those grounds fished by vessels ≥ 12 m, however as these large vessels land more than 90% of scallops from Division 27.7.d, VMS recorded activity captures the vast majority of landings.

The majority of Area 27.7.d.S is covered by a survey conducted by IFREMER (France) and is therefore not included in this assessment. From 2022 onwards, only a small bed, 7.d.2, was routinely surveyed at the northern edge of Eastern Channel South (7.d.S). This bed is too small to be representative of the entire Eastern Channel South (7.d.S) stock unit. The bed is surveyed as an extension to the bed in 7.d.N, and results are presented in Figure 5, but no assessment is run in 7.d.S by the UK.

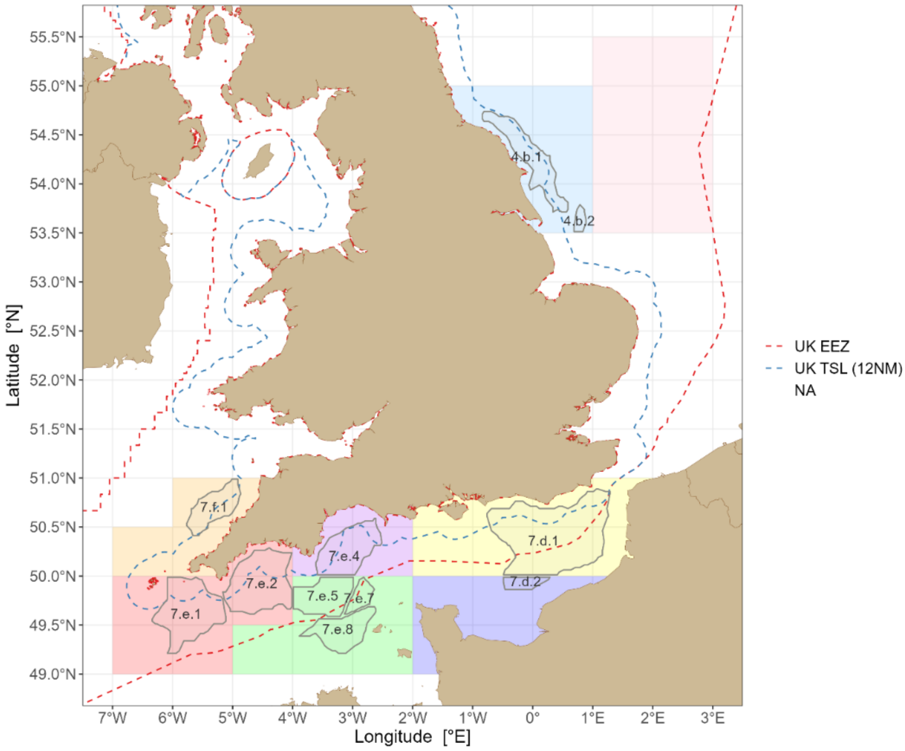

Figure 7. King scallop stock unit assessment beds defined within the stock unit assessment areas. The dashed lines indicate the UK Economic Exclusion Zone (EEZ), and the UK Territorial Seas Limit (12nm).

5.1.4 Identification of non-fished scallop beds

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 Figures 8-10. Note that these areas currently overlap with the fished beds as the outline of those were updated in 2021 but the video survey bed boundaries were maintained until all had been surveyed once. The dredge survey data takes precedent, any overlap in surveyed area is accounted for in the raising of the data to ensure that there is no double counting when assessing the biomass at the assessment unit level.

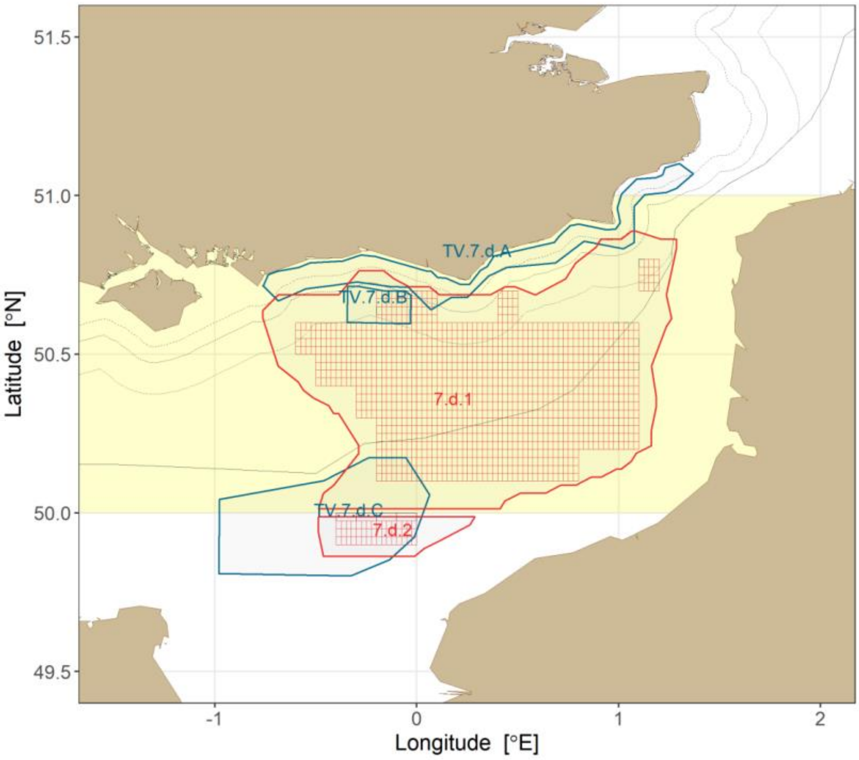

Figure 8. Survey grid in the eastern English Channel. The centre of each valid cell (red grid) is a potential station location. The blue lines indicate areas surveyed by underwater video system.

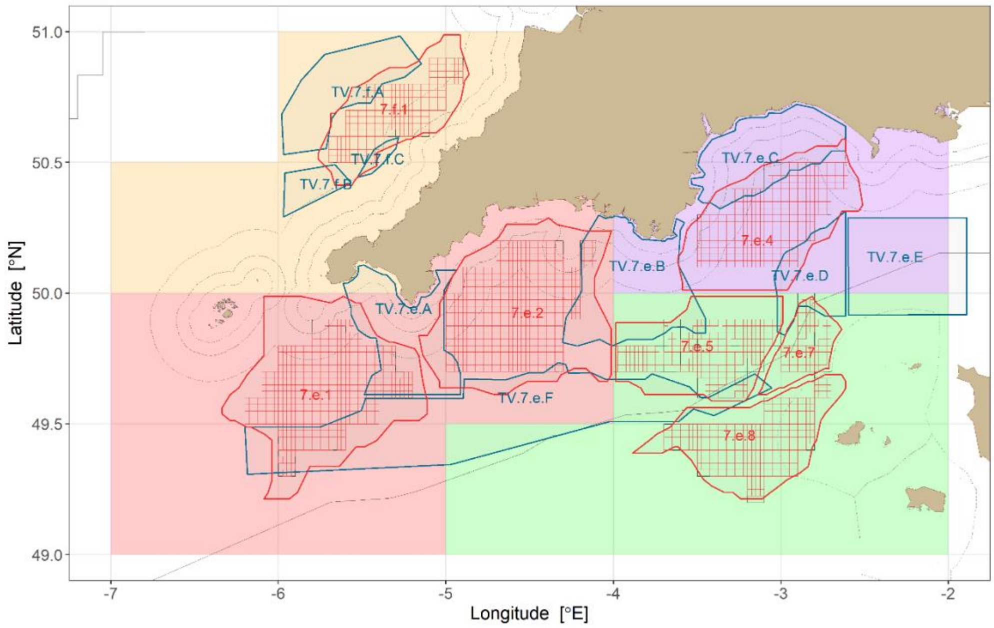

Figure 9. Survey grid in the western English Channel and north of Cornwall. The centre of each valid cell (red grid) is a potential station location. The blue lines indicate areas surveyed by underwater video system.

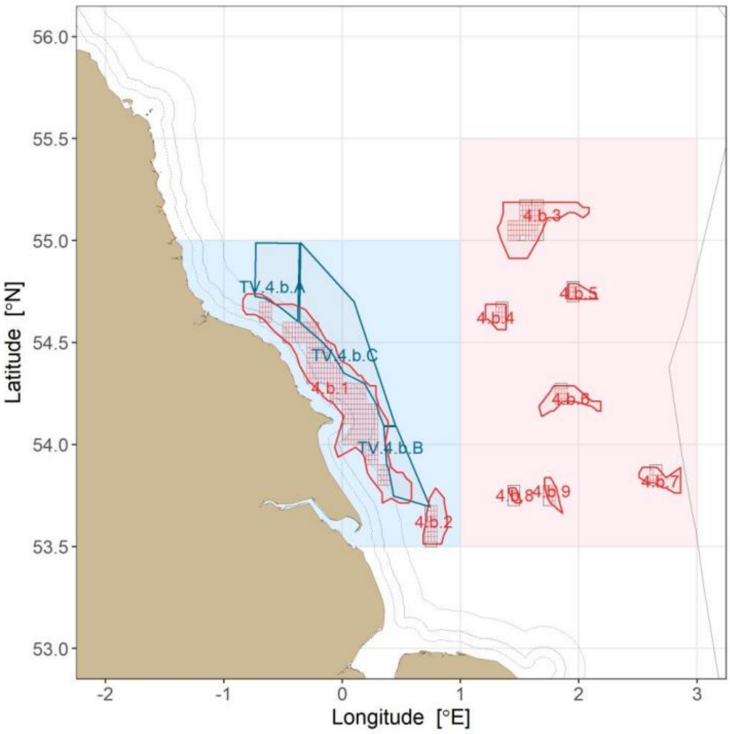

Figure 10.Survey grid in the North Sea. The centre of each valid cell (red grid) is a potential station location. The blue lines indicate areas surveyed by underwater video system.

6. Dredge Survey

6.1 Vessel and dredge gear specifications

A chartered commercial fishing vessel was used to survey a grid of fishing stations as defined in the survey design (Section 6.2). The commercial fishing vessel used for the surveys since 2018 has been a 24-m scallop dredger. A larger vessel was used for the 2017 survey (Bell, et al., 2018). During the survey, ten “Newhaven” type dredges were deployed on each side (Figure 11). On the sampling (starboard) side, six standard king scallop dredges and four queen scallop dredges with smaller ring diameters were deployed, with ten standard dredges on the non-sampling side for compensation. A conveyor system takes catch down from the main deck to the factory deck for sorting, and a wooden marker was used to keep the catch from the two different gear types separate on the conveyor belt. The two beams were deployed synchronously for 15 minutes at a speed of approximately 2.5 – 3.0 knots. Where the commercial dredges were observed to have filled (with biota and substrate) on recovery, the tow was rejected, and a further 5-minute tow was carried out at the same site. This was to avoid underestimation of scallop biomass at sites where dredges may have stopped fishing during the course of the tow.

The standard gears (Newhaven type dredges) were 75 cm wide and fitted with 85-mm ring bellies and 8-teeth swords (tooth bars). The queen scallop dredges were 75 cm wide with 55-mm rings in the belly, nylon mesh backs and 13-teeth swords. Dredge spring tension was manually tested regularly by the crew throughout the survey, and the vessel’s usual schedule of gear refurbishment was carried out to maintain efficiency.

At each tow position, catches of scallops were processed and measured as follows.

- Starboard side – scallop catch sorted into retained and discarded component for each of the two gear types (all dredges within gear type pooled). Numbers of each component was recorded, if necessary, components were then subsampled.
- Five individuals per 5-mm size bin were retained for age determination at selected sites within each bed.

The inclusion of the four modified dredges was to allow for sampling of smaller size (pre-recruitment) scallops that would otherwise be under-sampled using the standard commercial gear.

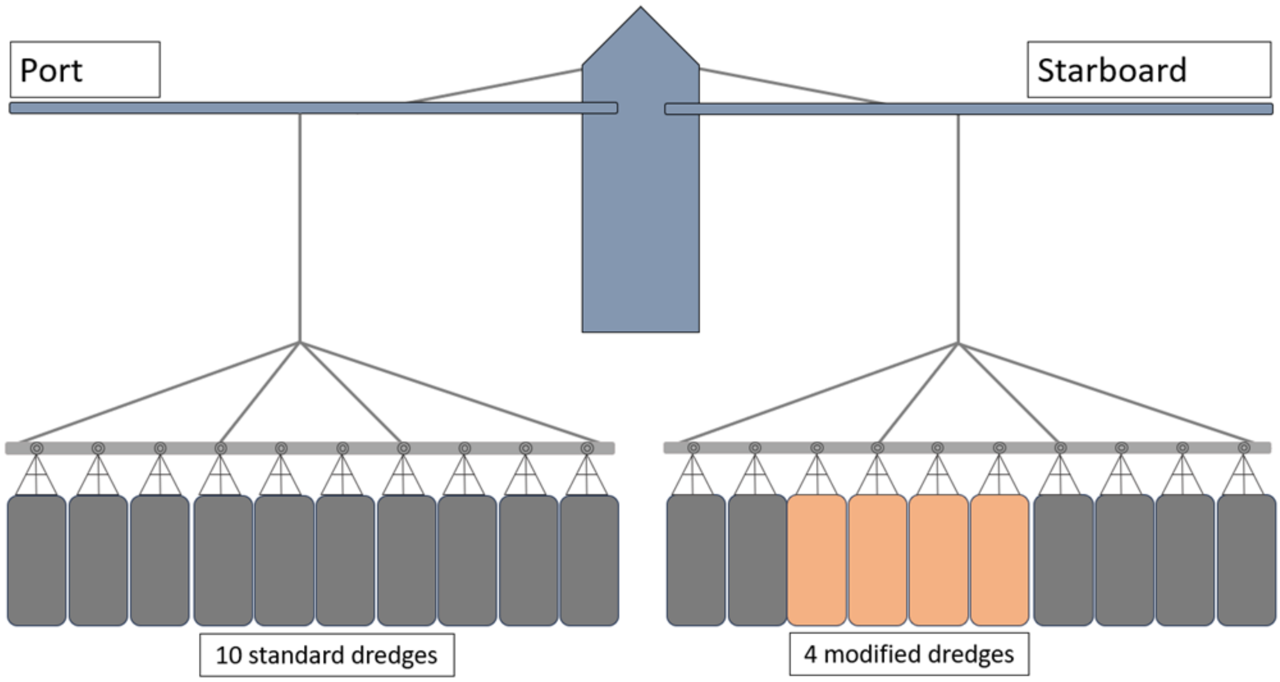

Figure 11. Gear configuration on the survey vessel

6.2 Dredge survey design

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 (Table 3). 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 the assessment report.

Table 3: 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%

6.3 Raising to harvestable biomass

Sampling is carried out from the dredges on only one side of the vessel, which provides adequate sampling levels throughout the surveys. As such, samples are 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 is carried out on the survey data for the commercial dredge gear:

1) The sampled length distribution is 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 are aggregated to get total raised numbers at size by station.
3) The catch density (number m^{-2}) for each station is calculated by dividing the count by the swept area of the gear (described in section 6.4).
4) The scallop density on the seabed is estimated from the station catch density using the appropriate substrate-specific gear efficiency factor (described in section 6.5).
5) For blocks which have one or more sampled cells, the block mean density per length class is calculated.
6) Block mean densities are applied to all cells within blocks, where there is at least one sampled cell.
7) Bed mean densities are applied to all cells in un-sampled blocks.
8) Total block abundance (in numbers) is then given by:

   $N = \sum_c \rho_c A_c$, where c are the cells, ρ_c is the scallop density in the cell, and A_c is the cell surface area
9) Total block abundance estimates are added up within each bed

Harvestable biomass is 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.

To establish a measure of uncertainty around the harvestable biomass based on all survey stations ("survey estimate"), the values for individual stations within the same bed are randomly resampled with replacement ("bootstrapped") 5000 times. For each iteration, the same analysis procedure as described above is applied.

6.4 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 (Figure 12). 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 (Figure 13). 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.

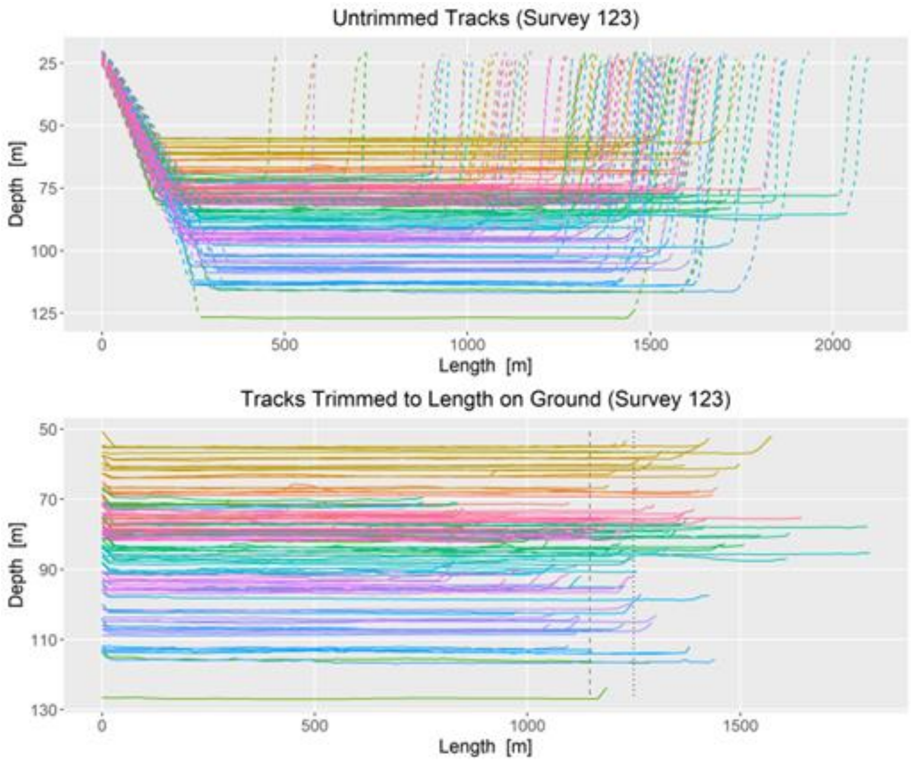

Figure 12. Tow tracks based on combined GPS and DST data (example from the May dredge survey in 2023). The colours indicate different scallop beds, using the same association as in Figure 7. The dashed segments of the lines in the upper panel indicate descent and ascent of the fishing gear. The solid segments of the lines are the tracks of the fishing gear on the ground.

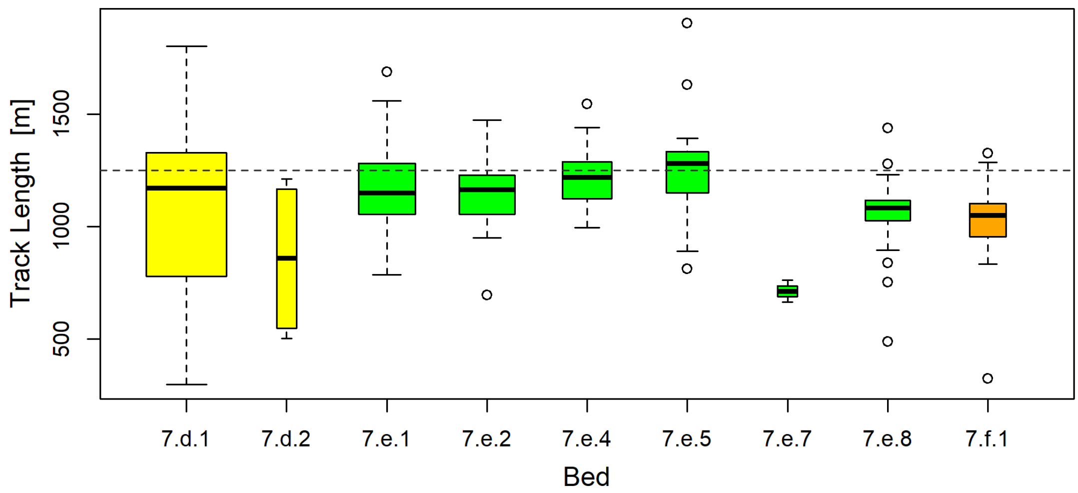

Figure 13. Range of tow track lengths in individual dredge beds (example from the surveys in 2022). The horizontal dashed line indicates 1250 metres, which corresponds to a tow duration of 15 min at 2.7 knots.

6.5 Dredge efficiency estimates

Pecten maximus inhabits substrates from fine sand through to coarse sand and gravel, in which it lies recessed into the seabed. However, such substrates may exist among varying amounts of rocks, stones, outcrops of bedrock and associated benthos, all of which will affect the efficiency of dredges. Gear efficiency is defined as the percentage of captured scallops in the path of the dredge. In order to assess the spatial distribution of the stock, whether from commercial catch per unit effort (CPUE) data, or from research surveys, it is important to be able to account for variations in gear performance. Any biomass estimates presented in this assessment are sensitive to the choice of substrate-specific efficiency parameters. The efficiency of spring-loaded dredges has been studied using diver observations, mark recapture methods and depletion studies (Chapman, Mason, & Kinnear, 1977; Dare, Key, Darby, & Connor, 1993; Dare, Palmer, Howell, & Darby, 1994; Jenkins, Beukers-Stewart, & Brand, 2001). However, for these stock assessments, we are currently using unpublished results from a depletion study carried out by Cefas in the English Channel in 2001.

The efficiencies currently utilised for the two assessment strata are 0.30 for sand and small stones, and 0.43 for flint and cobbles. These parameters are within and in other cases very close to the ranges estimated across published literature THAT ARE DERIVED FROM a range of methods including divers, seed recapture, Leslie-Davis depletion, towed camera system and Patch Model depletion. It's of note that substrate time / habitat has been reported using differing criteria and categories across publications (Table 4).

Table 4: Published efficiency parameters for capturing the King scallop (*Pecten maximus*) with Newhaven spring-loaded dredges, summary extracted from Delargy *et al*. 2022. SH is shell height and SW is shell width.

Demographic group	Habitat	Catch efficiency estimates
80–89 mm SH	Smooth	0.269
> 90 mm SW	Smooth	0.406–0.580
> 90 mm SW	Sand	0.246
90–109 mm SW	-	0.243–0.380
> 109 mm SW	-	0.260–0.620

Recent work at Cefas to determine a methodology for estimating dredge efficiency using Radio Frequency Identification (RFID) and Underwater Video Systems (UVS) has made some progress but has not yet provided alternative efficiency coefficients to those used in previous years. Research efforts are expected to continue with a focus on UVS, rather than RFID. For RFID, the system has proven to be too fragile for deployment from a commercial scallop dredger.

The vessel skipper reports the 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 the main report. The skipper-reported ground types are related to one of two ground types and attributed an efficiency coefficient accordingly (Table 5). The assumption of this method is that the ground types encountered at each tow position are representative of the wider area (block).

Table 5. Dredge efficiency parameters

Parameter	Value	Source
Gear efficiency – ground type clean or clean becoming stony	30%	Cefas (based on an unpublished depletion study in 2001)
Gear efficiency – ground type flint cobbles	43%	Cefas (based on an unpublished depletion study in 2001)

7. Underwater video system survey

7.1 Specifics of the 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). non-contact systems are more appropriate for sensitive habitats. The STR SeaSpyder drop frame with HD video and stills system currently used from the Cefas research vessel (is towed at low speed flown over the seabed to ensure clear video and stills image capture. High-definition feed to the ship is via fibre optic cable in real time. As with many towed camera systems, the low speed means the ground covered (area swept) is low and with scallops distributed at relatively low and patchy densities, there is a risk of under-sampling. Scallops can be cryptic by recessing into the substrate and covering themselves with a fine layer of sediment, so visibility may be different in softer sediments, however high-definition stills improve the detection rate of these scallops. Alternative camera platforms have been investigated 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. Rayfin imaging system (SubC Imaging)
5. Aris sonar imaging camera system
6. The Marine Scotland “Sea Chariot” was investigated but not deployed.

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

Further development of 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 and machine learning algorithm development in the future.

7.2 Survey design

Random positions within the unfished zones are selected using the same procedure as for the dredge surveys.

The research vessel (RV) Cefas Endeavour is used to survey a grid of randomly selected positions in the identified un-dredged zones. 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 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 enables it to be maintained at a relatively consistent height of 0.5 m above the seabed. The field of view is determined by the view within the drop frame (about 1.35 m), and determination of scale is facilitated by both line and point lasers fitted to the camera mounts to mark a consistent distance on the seabed. Further development of extended laser mounts have allowed a wider field of view (approx. 1.80m since 2023).

Video images are viewed live on board the RV and all observed scallops are counted. Digital stills are manually taken at regular intervals (every 10-30 seconds depending on flash refresh) and when scallops or indications of scallops are observed to provide more detailed images for subsequent count confirmation. The video footage is later viewed twice for recounts before those are validated by a trained staff to obtain a single final count per transect.

7.3 Video processing

Arithmetic methods are 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. Until 2022, scallops were recorded in the detectable size range at and above 80 mm shell height, which is at the low end of the range of mature sizes. Since 2023, measurement of scallops allows quantification of scallops equal or greater than MLS (100mm W. Channel and 110mm E.Channel) within a tolerance range of +/-0.2. Work is underway to develop image analysis software to be able to detect and measure scallops 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

8. 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.

Estimation of the fishing mortality that generates maximum sustainable yield (MSY) requires a full analytical assessment, including an estimate of the stock-recruitment relationship. Most fully analytical fish stock assessments use a time series of age composition of the landings (along with other data such as total landings or catches and a survey series) to estimate the rate at which the fishery is exploiting the stock. As is the case with many stocks assessed by ICES, this is not yet possible for king scallops. For these stocks, ICES scientists use proxy reference points that have been found to be reasonable approximations to MSY reference points. The fishing mortality which generates 35% of the virgin spawning potential (F35%VSpR) is a commonly used reference point within ICES advisory areas (ICES, 2022).

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, L25 and L50, 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 14. Gear selectivity depends on the upward slope of the catch size distribution, where L25 is the size at which gear selectivity is 25% of its maximum value, and L50 is the size at which gear selectivity is 50%. The corresponding logistic gear selectivity functions are shown in Figure 15.

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 16 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 17. 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 17. 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 5, 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. MSY proxy reference points for each stock unit are presented in Table 6.

Table 6. MSY proxy reference points (as % of stock exploited) for all stock assessment unit areas for 2017 - 2024

MSY Proxy						
	Eastern Channel North (7.d.N) (Bed 7.d.1)	**Western Channel Inshore (7.e.I)**	**Lyme Bay Area (7.e.L)**	**Western Channel Offshore (7.e.O)**	**Bristol Channel (7.f.I) (Bed 7.f.1)**	**Yorkshire and Durham Coast 4.b.S (Bed 4.b.1)**
2017	21.5	19.5	21.0	20.9	-	-
2018	21.5	19.5	21.0	20.9	-	-
2019	21.5	19.5	21.0	20.9	-	-
2020	21.5	19.5	21.0	20.9	-	-
2021	21.5	19.5	21.0	20.9	-	-
2022	23.4	24.2	24.4	26.5	23.4	23
2023	23.4	24.2	24.4	26.5	23.4	23
2024	23.4	24.2	24.4	26.5	23.4	23

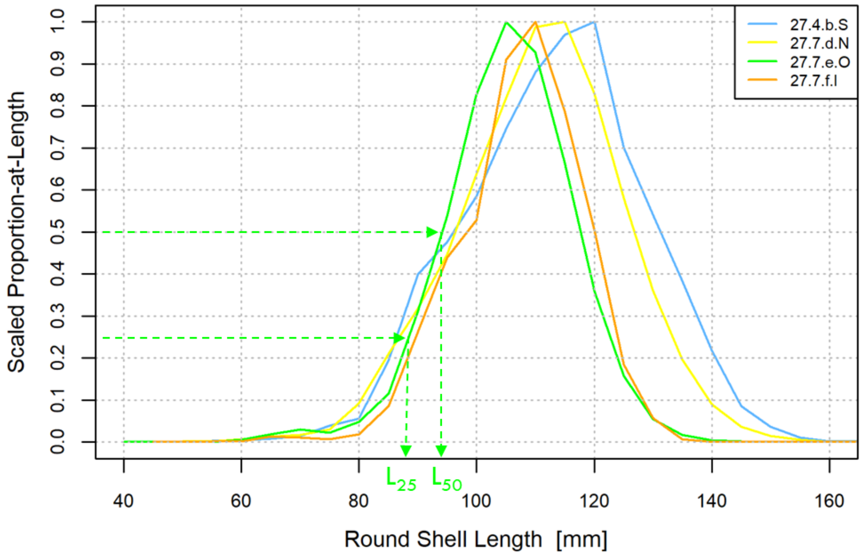

Figure 14. Scaled size distributions (in units of the maximum value of the original distribution) of dredge survey catches (2017 – 2021), using standard commercial Newhaven-type spring-loaded dredges with 75-mm belly rings, for four of the assessment areas. The determination of gear selectivity parameters, L25 and L50, is shown for Area 27.7.e.O (green line).

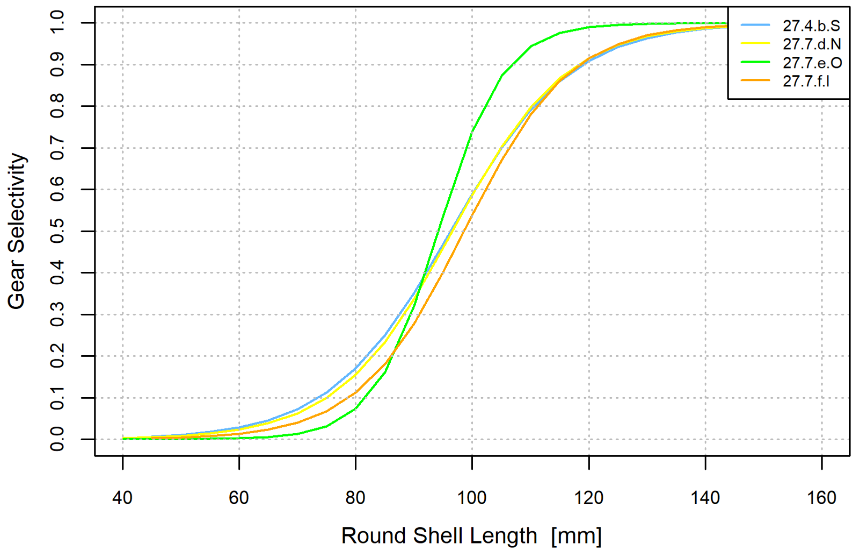

Figure 15. Gear selectivity curves (logistic functions) for four of the assessment areas, with gear selectivity parameters, L25 and L50, determined based on scaled size distributions of dredge survey catches (2017 – 2021), using standard commercial Newhaven-type spring-loaded dredges with 75-mm belly rings.

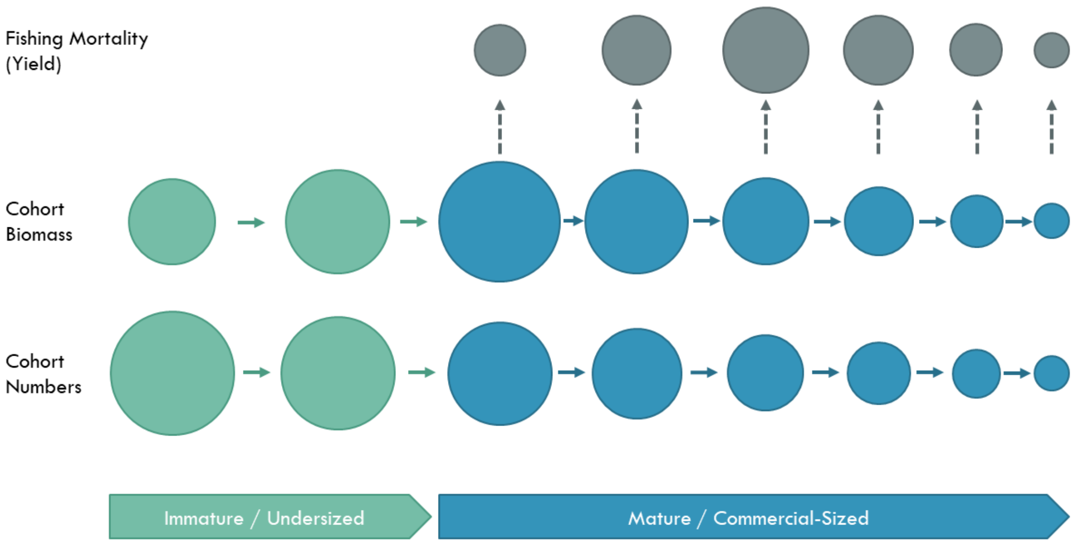

Figure 16. Schematic depiction of the evolution of a cohort of king scallops. Each circle represents a life stage defined by either age or a size class.

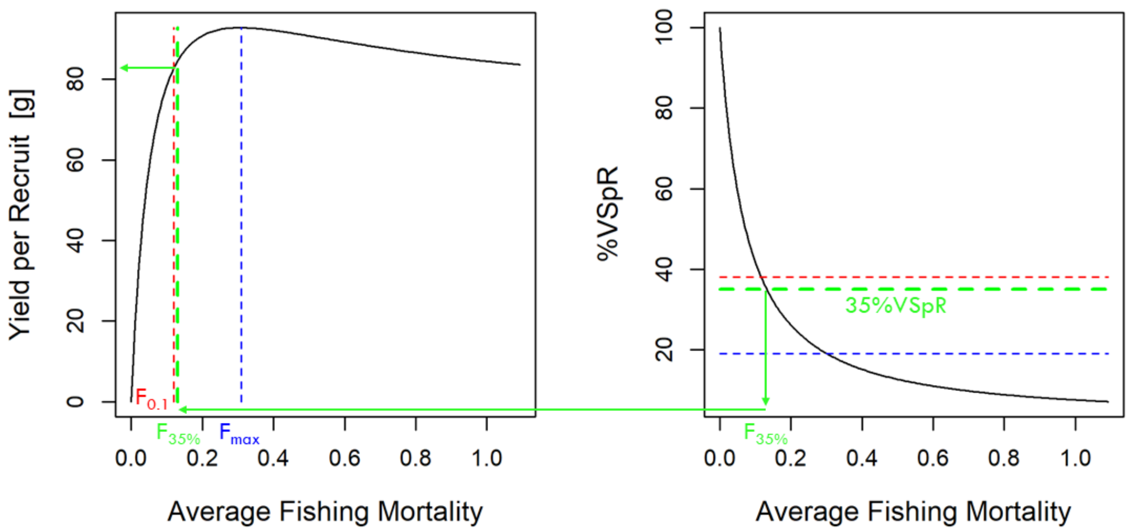

Figure 17. Simulated yield per recruit (left) and percent virgin spawner per recruit (right) as functions of average fishing mortality for the Yorkshire/Durham assessment area (27.4.b.S). The green dashed lines and arrows indicate the average fishing mortality, F35%, that results in 35% of spawners per 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, F0.1, 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, Fmax, at which yield per recruit is maximised. F0.1 and Fmax are sometimes used as MSY-proxy reference points and are shown here for comparison with F35%, which is the chosen MSY-proxy reference point for the king scallop assessments.

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Supplementary information. Dredge efficiency experiment

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 50 cm. 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 84 cm. 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 30 m 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 124.4 mm and 123.9 mm 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.

The RFID equipment was again deployed in the Bassurelle Area of the Eastern Channel in September 2023. Refinements were made to the trolley housing the RFID equipment through reinforcements and in addition to the previously used GoPro Hero 5 camera, a 360° camera and new mount was trialled. Additional Suptig 84 LED lights rated to 50 metres and lasers to mark out the field of view were also incorporated.

A scallop bed with soft substrate type was chosen first (with the intention of surveying harder ground upon completion) to minimize possible damage to the trolley. The gear was configured as previously with the RFID equipment 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.

24 hours after the capture, marking and tagging of scallops, re-capture tows were conducted in the soft substrate area. Six tows were completed before both trolleys were damaged irreplaceably. A further two tows were carried out on the same substrate type with cameras only in attempt to obtain efficiencies but due to the loss of other key equipment, the footage captured was not sufficient.

For the six successful re-capture tows when the RFID trolley was deployed, the catchability of tagged and wild scallops on port side and starboard side (RFID) were compared. There appeared to be no significant differences in the catch for the six tows combined (Figure SI1).

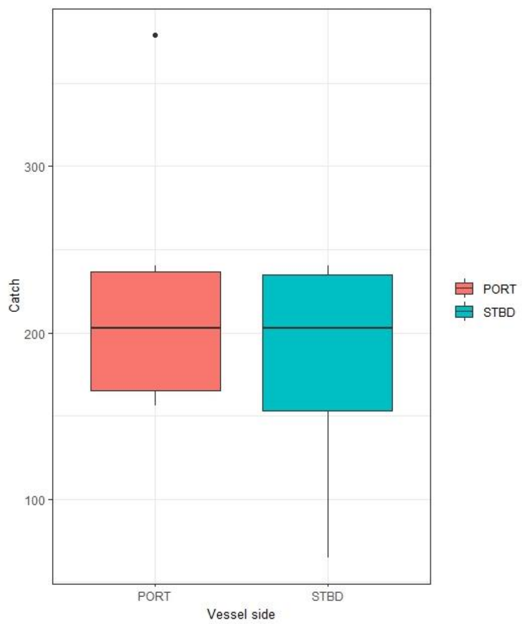

Figure SI1. Catch of scallops caught on port and starboard side (RFID) for all six tows combined, conducted in the Bassurelle area in 2023.

Of the six tows conducted at site A, four of six tows caught fewer scallops on the starboard side (RFID) compared to the port side dredges. Two of the six tows caught fewer scallops on the port side compared to the starboard side (RFID) dredges. Overall, for the six tows combined, the number of scallops caught on the port side was 20.38% greater than that of the starboard side (Table SI1.).

Table SI1. The individual number of scallops caught on port and starboard side (RFID) for all six tows, and the total for all tows combined, conducted in the Bassurelle area in 2023.

Site / Tow	**Port side**	**Starboard side**	**Catch difference (percent)**
A1	226	225	0.44
A2	240	65	114.75
A3	156	181	14.84
A4	379	238	45.71
A5	160	144	10.53
A6	180	240	28.57
Total	1341	1093	20.38

For the six successful re-capture tows when the RFID trolley was deployed, the length distributions of tagged and wild scallops on port side and starboard side (RFID) were compared. There appeared to be no significant differences in the length distributions for the six tows combined (Figure SI2).

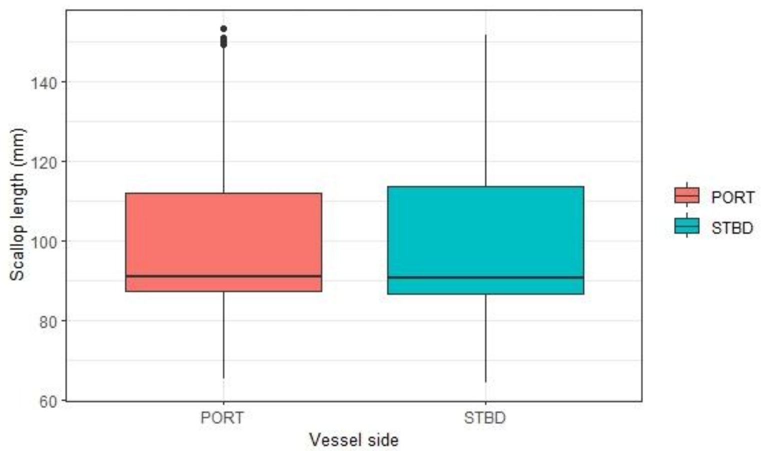

Figure SI2. Length distributions of scallops caught on port and starboard side (RFID) for all six tows combined, conducted in the Bassurelle area in 2023.

Shell lengths ranged between 64.24 - 151.8mm on the starboard side (RFID) and 65.17 – 153.37 mm on port side. Mean shell length was 99.26mm and 98.32mm for port and starboard (RFID) dredges respectively.

Despite the use of a 360° camera, the field of view was again limited by the mount on the tow bar and therefore the footage would have underestimated the number of tagged scallops the RFID antenna went over. In addition, the camera mounts obstructed some of the field of view and the footage clarity was not as expected. Day light operation provided good conditions for maximum visibility and despite additional lights, visibility of footage remained poor late evening. Footage was reviewed but the poor level of tag detection with the RFID antenna meant estimation of gear efficiency estimates relied solely on the DMC footage. It was not possible to calculate gear efficiency estimates due to lighting conditions and the configuration of the DMC equipment mounted to dredges. Moving forwards, the DMC equipment is the most viable means of obtaining gear efficiencies and preparation work towards refining this method is ongoing.

Previous surveys have shown the RFID technology is a viable method of establishing efficiencies, although cameras are still required to verify outcomes, and the technology could not be used in isolation. It is however less feasible for use on a fishing vessel due to the high risk of equipment damage. This survey showed that the UW camera system will be the most promising means of establishing efficiencies.

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