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Initial assessment of Scallop stock status for selected waters within the Channel 2016/2017

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Executive Summary

King scallop fisheries in the English Channel represent the most valuable single species in the region. The stocks are internationally exploited primarily by the UK and France using towed dredges. These stocks are not protected by EU or national TAC and as such have not been subject to routine monitoring or formal assessment.

This report describes the initial assessment of the status of some of these stocks undertaken in 2017 by the Centre for the Environment, Fisheries and Aquaculture Science (Cefas) during a collaborative project with the UK fishing industry, Defra and Seafish.

Five stock assessment areas have been identified as being of importance to UK fisheries, three in ICES subdivision 27.7.e (Inshore Cornwall, I; Offshore, O; Lyme Bay, L) and two in 27.7.d (North, N; South, S). These assignments are based on regional differences in growth and fishery exploitation patterns. Fisheries data are available at the spatial resolution of ICES Rectangle and their boundaries are used to describe the extent of the assessment areas. The fished stock in the Bay de Seine part of 27.7.d.S is assessed by France whose scientists carry out an assessment of biomass and exploitation rate on fished grounds in this region.

This report assesses the status of the dredged portion of stocks in 27.7.d.N, 27.7.e.I, 27.7.e.L and 27.7.e.O with additional estimates of unfished biomass in some parts of 27.7.e.L and 27.7.e.I. There is likely to be biomass of scallops outside those areas surveyed in this initial year but for which there are no data to make any estimates. This report does not cover scallop stock in area 27.7.d.S. The biomass and exploitation rate of the fished portion of stock in the Bay de Seine part of 27.d.S is routinely estimated by scientists from IFREMER in a robust process.

Three data streams were used for the assessments described in this report. Dredge surveys in the main fished beds of 27.7.d.N, 27.7.e.I, 27.7.e.L and 27.7.e.O were used to estimate harvestable biomass available to the dredge fishery (converting survey catch rates to absolute biomass via a gear-efficiency coefficient). The scallop biomass in some non-dredged regions of assessment areas 27.7.e.I and 27.7.e.L was estimated from underwater TV surveys; no underwater TV survey was undertaken in 27.7.d.N or 27.7.e.O. Estimates of harvestable biomass (i.e. biomass above minimum size and in areas in which dredgers can operate) and the exploitation rate experienced by those scallops are covered by this assessment, however the assessments presented here are not able to fully estimate the impact of the fishery on the wider stock as we were unable to estimate the scallop biomass in all un-dredged areas. Dredge surveys and catch sampling only cover the portions of stock found on the main fished grounds, as identified by density of VMS data. Harvest rate estimates from dredge surveys or commercial sampling therefore only apply to the fished portion of the stock. In situations where there are significant portions of non-dredged stock that are contributing offspring to the fished areas, the MSY harvest rate will, in future, need to be adjusted to compensate for this.

The potential harvest rates experienced by the surveyed portion of stocks were estimated by comparing the international landings to the available biomass estimates, either dredged area only or including the biomass from un-dredged areas from the available UWTV surveys. Finally, the age compositions of the landings were used in a cohort model to obtain alternative estimates of harvesting rates.

In order to put the estimates of biomass and harvest rate into context, candidate harvest rates for maximum sustainable yield have been estimated.

This is the first attempt at stock assessments undertaken for scallops in this region. Single points of data are always more uncertain than when a time series are available, so the results of this assessment should be viewed with some caution. The estimates of harvest rate from the different data streams are given below.

	Harvest Rate on dredged portion of stock (Dredge Survey Only)	Harvest Rate for wider stock where UWTV available (not 100% coverage)	Harvest Rate on dredged portion of stock (Cohort Model)	MSY Candidate
27.7.d.N.	35.5%	NA	48.0%	25.0%
27.7.e.I.	27.4%	17.3%	35.3%	24.5%
27.7.e.L.	36.5%	22.0%	32.5%	21.0%
27.7.e.O.	13.6%	NA	28.6%	32.8%

We consider this project to be the start of a long-term monitoring and assessment programme although there is likely to be some evolution of processes and methodologies. As the time series of data develops and increases in comprehensiveness, this will in turn contribute to a more robust determination of stock status of King scallop in this region.

Assessment caveats and assumption

- Dredge surveys and catch sampling only cover the portions of stock found on the main fished grounds. Harvest rate estimates from dredge surveys or commercial sampling only apply to the fished portion of the stock.
- The gear-efficiency factor used to convert dredge survey data to total harvestable biomass used unpublished Cefas data. These data came from depletion experiments which although broadly in line with some similar studies remain uncertain. Further refinement/data for this parameter is required including the testing of key assumptions. Revised efficiency factors could have a large influence on the estimates of stock statuses.
- UWTV surveys detected biomass of scallop on grounds not exploited by dredgers.
- Not all un-dredged grounds were surveyed with UWTV, so the total harvestable biomass of scallop in the assessment areas is unknown.
- The level of larval exchange between dredged and un-dredged areas is unknown. It is assumed that in order to support a fishery the main dredged areas must have a degree of larval retention (i.e. self-perpetuating).
- If all scallops within an assessment area contribute to the recruitment in the dredged areas then an appropriate measure of harvest rate for the stock uses the total harvestable stock biomass (not just the biomass on the dredged area).
- Such a "total harvestable stock" harvest rate would be lower than the "fished stock" harvest rate.

Contents

1 Introduction

1.1 Fishery Overview

The fishery for the scallop *Pecten maximus* in the Channel (ICES sub-divisions 27.7.d and 27.7.e) is the most valuable single species fishery in the region with around 35,000 tonnes of international landings reported in 2016. 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 TAC and quota regime and fishery management measures are largely under the control of the member states. EU regulations stipulate the minimum size of scallop that can be retained by vessels and also caps the level of effort that vessels ≥15m can utilise in area 27.7.

There is a distinct contrast between the UK and French fisheries, with the UK fisheries comprising a mix of large (≥15m) nomadic vessels and smaller (10-15m) vessels with a more localised range. Scallop fishery management for UK vessels consists of licence conditions (for vessels over 10m) and gear restrictions, with some spatial differentiation in vessel access in inshore (<6 nautical miles) areas. The French fishery is dominated by smaller vessels fishing much more inshore (on the French side of the Channel), and 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 (seasonal and daily hours), with access and quota being determined at a local level.

Although the EU leaves scallop fishery management to the member states, the fisheries are in fact quite international, with multiple member states fishing upon the same stock unit. 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 are 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). A voluntary seasonal closure harmonisation has existed since 2013 between the majority of the UK scalloping industry and the France industry.

1.2 Stock Unit Assessment Areas

Investigations into the transport and distribution of scallop larvae (ICES 2015, Catherall *et al.,* 2014) indicate that scallops within ICES subdivisions 27.7.d and 27.7.e are likely to compromise at least two biological populations, when viewed at the scale of multiple generations. However, given the fact that larval interchange appears only sporadic (rather than regular) and there are distinct regional differences in growth rates and fishery management, coupled to the largely sessile behaviour of post-larval scallops, more regional stock assessments are appropriate.

Two stock assessment areas have been designated for ICES subdivision 27.7.d split along the 50-degree North line termed 27.7.d.N and 27.7.d.S. Three stock assessment areas have been designated for ICES subdivision 27.7.e to reflect slow-growing inshore areas around Cornwall (27.7.e.I), faster growing areas around Lyme Bay (27.7.e.L), and offshore scallop beds (27.7.e.O) as indicated in Figure 1.1. The ICES rectangles that sit within the assessment areas are listed in Table 1.1.

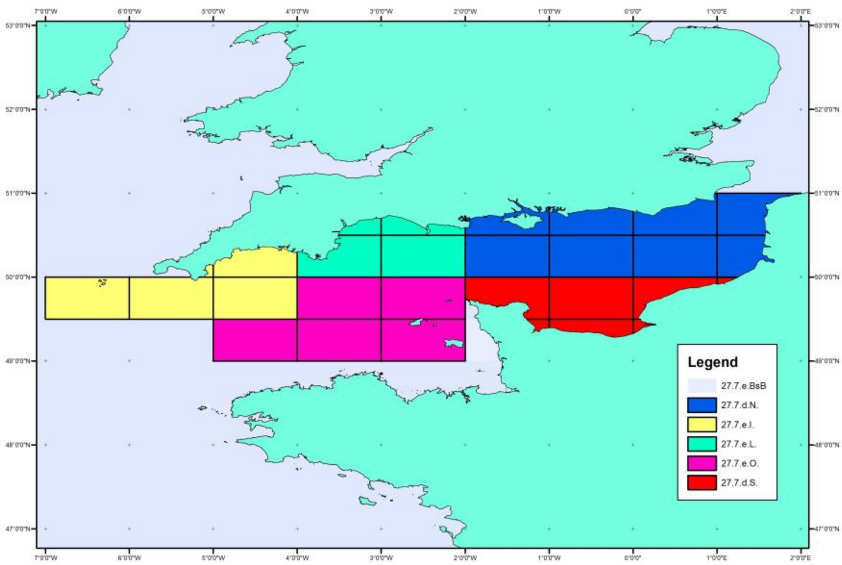


Figure 1.1. Stock unit assessment areas defined in the English Channel.

Table 1.1: Assessment areas by ICES rectangle.

27.7.d.N	29E8	29E9	29F0	29F1	30E8	30E9	30F0	30F1
27.7.e.I	28E3	28E4	28E5	29E5	29E4*			
27.7.e.L	29E6	29E7	30E6	30E7				
27.7.e.O	27E5	27E6	27E7	28E6	28E7			

*denotes area within boundaries of division 27.7.e

Scallop fisheries in the remaining ICES rectangles in 27.7.e are dominated by French coastal activity and therefore beyond the scope of this assessment. An area of 27.7.d.S (representing the majority of landings) is covered by a survey operated by IFREMER (France) and is also not covered by this assessment report.

1.3 Biology

1.3.1 Range and habitat

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

1.3.2 Reproduction

Scallops are permanent hermaphrodites and are very fecund; a large scallop may produce 2 million eggs. 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 1-5mm they then detach and settle onto the sea-bed where they take up their normal habit, recessed into the substrate.

1.3.3 Growth

Growth in scallops is continuous with new material laid down along the outside edge of the shell in very fine ridges (striaie). 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 (so called ‘growth checks’) occur when animals are stressed (such as after damage caused by interaction with scallop dredges) or sudden climactic changes. Age determination of scallops is performed by reading the annual growth rings on the upper (flat) shell, however care must be taken not to confuse stress induced growth checks with annual patterns. Growth rates are extremely variable between areas and even between adjacent beds with the time required to reach the local Minimum Landing Size (MLS) varying between 2 to more than 5 years.

1.4 General comments on LPUE

Landings per unit of effort (LPUE) are sometimes used as fishery dependent indices of stock abundance, often being the only data available. The principle behind such use is that as a stock increases in abundance, the average distance between individual animals decreases and provided that the probability of fishing gear encountering an individual remains a random event, then the number of individuals caught in a fixed fishing effort unit will increase (and vice versa). In order for this relationship to hold, the key assumptions of individuals redistributing, and random encounters must be met and as situations deviate from this ideal then the resulting LPUE index may suffer from bias. This is particularly the case where animals are shoaling whereby it is possible to maintain a high catch rate even as stocks decline, although this is not assumed to be the case with a relatively sedentary animal like *Pecten maximus*. This sedentary nature does, however, create a second possibility in that it could be possible to sequentially deplete areas thereby maintaining an artificially high LPUE in relation to the total remaining stock size. The key to deriving indices which may reflect stock status in this case rely upon identifying the appropriate spatial and temporal scale of data.

UK Landing statistics were examined to explore whether LPUE at the level of Stock assessment area or rectangle conform to the statistical assumptions required for LPUE to be considered a robust index of stock abundance. In this analysis, we have plotted the reported catch rates against the cumulative landings for each season. The expectation of such analyses is that within a fishing season as the total removals increase, the stock must decrease and therefore the LPUE should also decrease. Key assumptions here are that there is no large-scale immigration or emigration from the area and that recruits are fully recruited to the fishery at the start of the season. Scientific studies of scallop movements indicate that movements are fairly restricted (<2 miles) when measured over several years, so large-scale migration at the ICES division or rectangle level is considered to be highly unlikely. Within season growth may however, influence catch rates as recruits grow into the fishery.

For each area, landings were grouped into fishing seasons based upon general effort patterns, with the season in 27.7.d commencing in July and running to the end of June the following year. For 27.7.e the season started on January 1st. The total cumulative landings were calculated for each reported day through the season, along with the catch rate (tonnes per KW day) for the fleet, split into 2 size categories (10-15m and ≥15m overall length). Catch rate data for the <10m fleet were not analysed as there are relatively few records making the analysis very noisy. Reported daily catch rates for the other two fleets also contained considerable noise, so the analysis presented here uses catch rates calculated over 2-day periods. These analyses assume that the cumulative landings represent 100% of the landings from the area and for 27.7.d this assumption is heavily violated (UK landings typically being between 19%-58% of international landings over the period 2009-2016) therefore it is inappropriate to analyse the data for this area. For the remaining stock assessment areas in 27.7.e, the catch rates were plotted against cumulative landings, with the expectation that if LPUE is related to stock size then as the total catch for the season increases the catch rate should decline. Figures 1.2 show the results at the division level and Figure 1.3 at the stock assessment level.

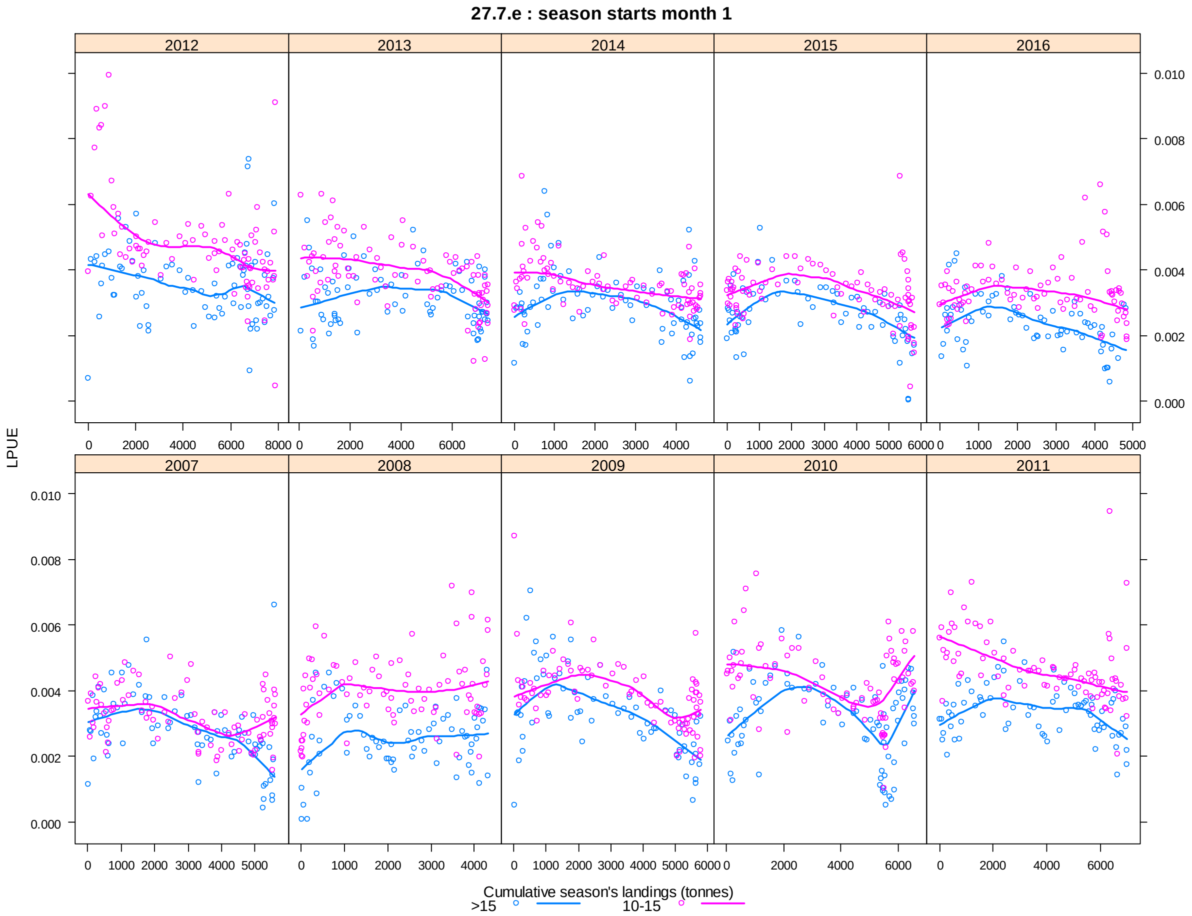


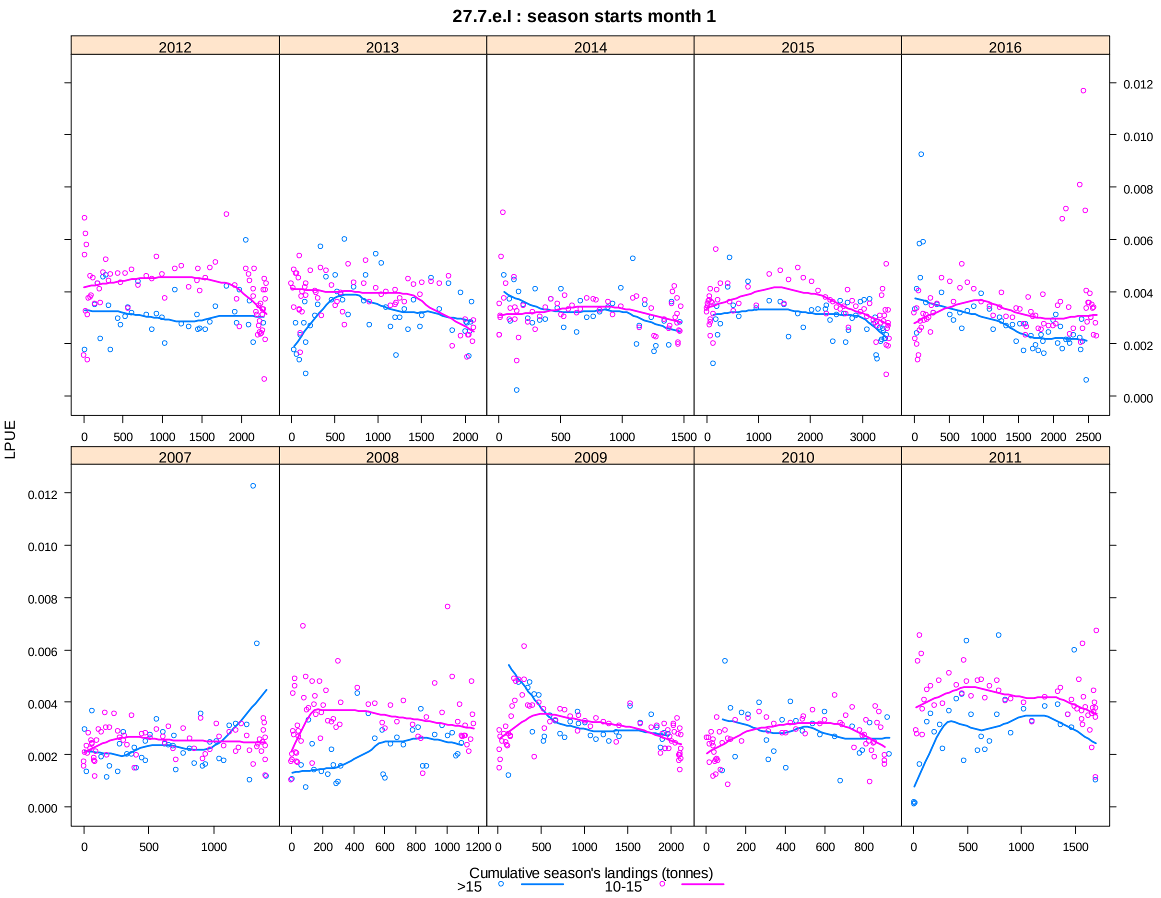
Figure 1.2 Cumulative season's landings (tonnes) against LPUE (tonnes KW Days) for ≥15m (blue) and 10-15m vessels (red) in ICES Sub Division 27.7.e. Lines fitted using Loess smoother to demonstrate trends.

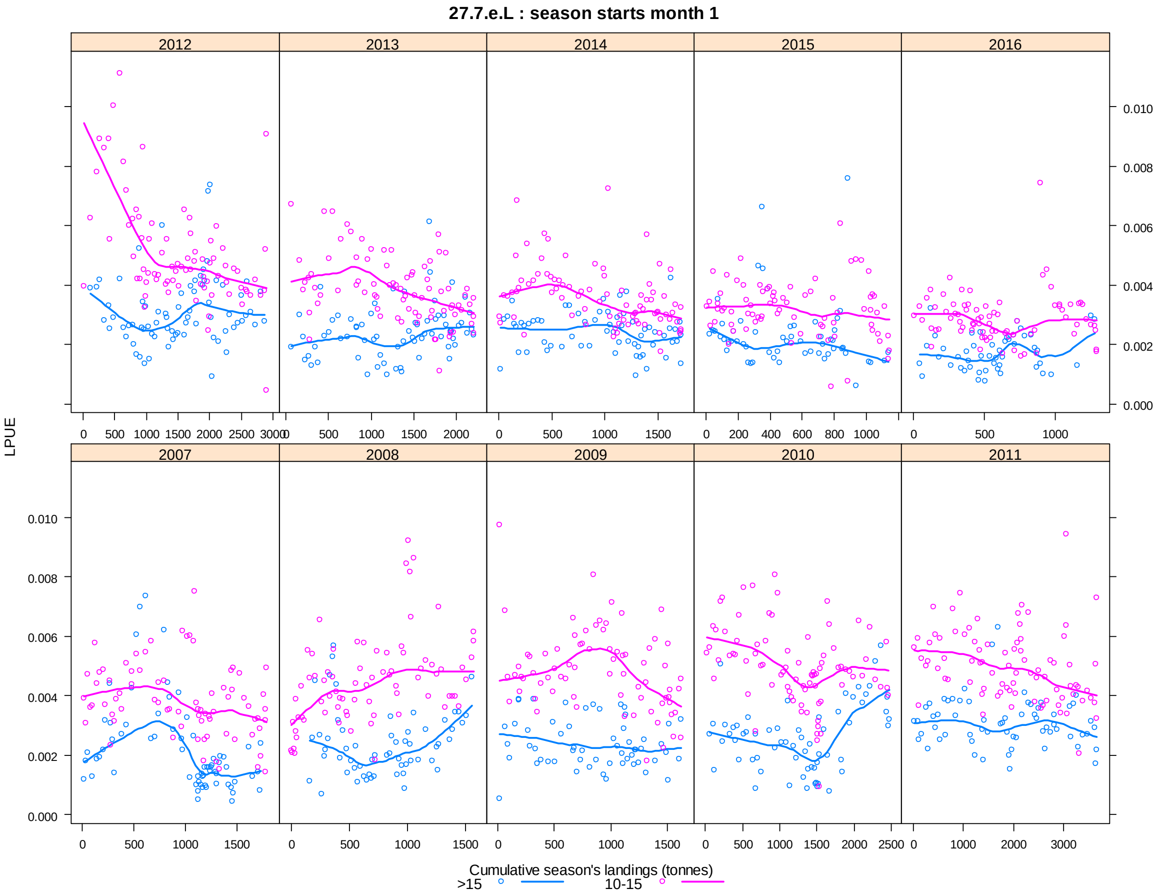
At the division level there is some indication of a decline in LPUE with increasing catch, however this pattern is not consistent either within years or between fleet sectors. Increases in catch rates with increasing removals at the start of the season are observed in most years with the ≥15m sector being more affected possibly due to spatial restriction in the sector's access to the more productive scallop grounds. The early-season increases in catch rate may also be an artefact of in-year scallop growth and/or fishers taking time to find the most productive grounds (highlighting the difficulty in using LPUE indices for patchily distributed and sessile animals). The plot for 2008 is particularly odd as both fleet sectors show a higher catch rate at the end of the year compared to the start of the year despite removing 4000 tonnes from the stock, which contrasts to 2007 which saw a decline (at least to the 4000-tonne level). The LPUE for the 10-15m fleet in 2016 started and ended the season at the same level which if LPUE is related to stock biomass would suggest that removing 5000t had no effect on the stock whilst the ≥15m sector experienced a decline in catch rates. This contrast suggests that the two fleet sectors are fishing different portions of the stock and therefore there is likely to be spatial detail at the stock level which could be better served by finer scale investigations.

Looking at the finer scale actually increases the contrast between the two fleet sectors, possibly suggesting that the large-scale analysis masks localised catch-optimisation behaviour. The increased contrast between fleets, along with the more variable shape of the LPUE vs landing plots at this spatial scale suggests that any relationship between LPUE and stock size may be operating at even finer scale than the assessment unit.

Given the general lack of relationship between LPUE and removals at the scales examined here there are clearly issues in using LPUE as a linear index of stock size at these scales. There are, however, some general features which warrant further research. The general shape of the LPUE for the 10-15m sector in 27.7.e.L shows an increase from 2007-2010 after which the rates have sequentially declined. Whilst it is unlikely to be statistically appropriate to use the proportional change in LPUE as a direct proxy for stock level changes, it does not seem unreasonable to assume that the stock has experienced an increase and decrease over that time period. What is less certain is whether short term changes (or stability for that matter) in LPUE is a true reflection of stock status.

It is proposed that further analyses of LPUE, incorporating VMS linked landings is continued and the results will be reported in the next stock assessment.


27.7.e.l : season starts month 1
2012
2013
2014
2015
2016
2007
2008
2009
2010
2011
LPUE
Cumulative season's landings (tonnes)
>15
10-15


27.7.e.L : season starts month 1
2012
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LPUE
Cumulative season's landings (tonnes)
>15
10-15

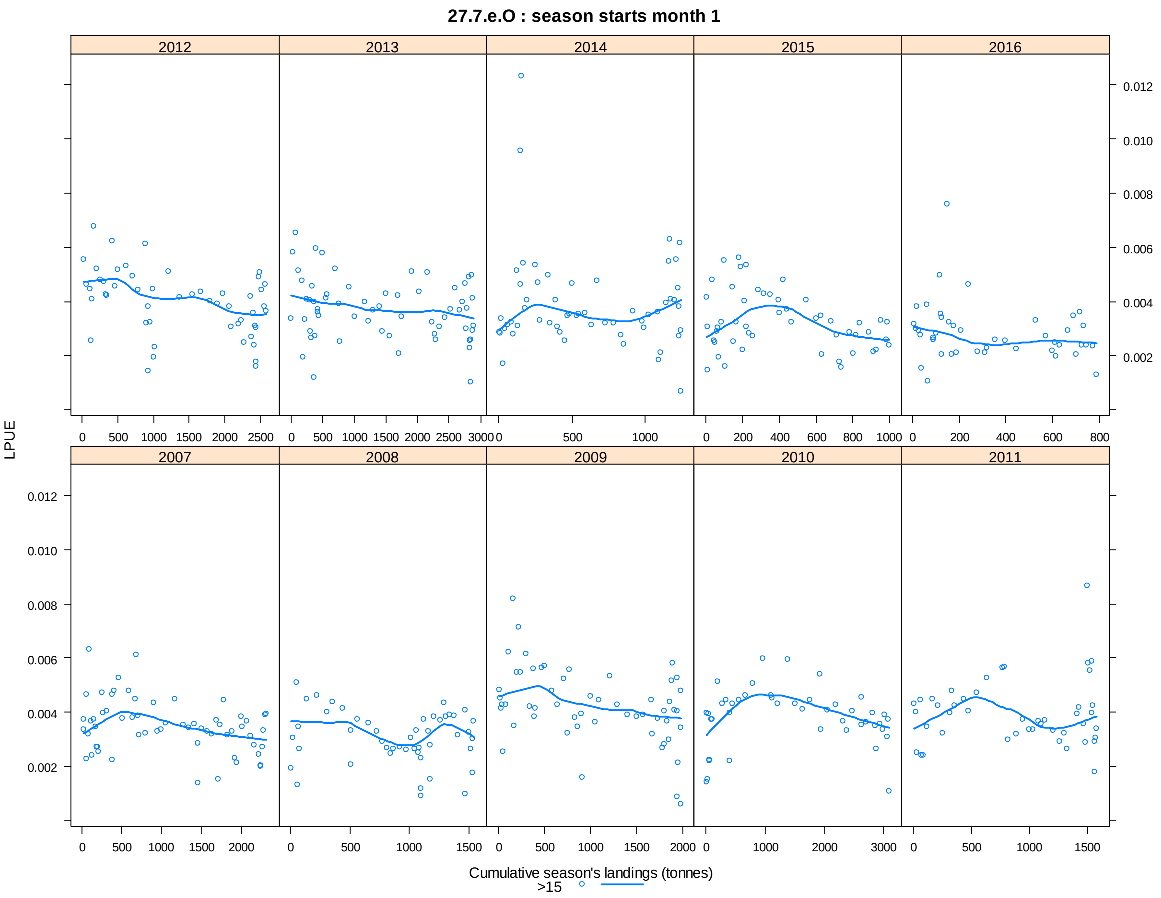

Figure 1.3 Cumulative season's landings (tonnes) against LPUE (tonnes KW Days) for ≥15m (blue) and 10-15m vessels (red) by assessment areas, 27.7.e.I (top panel), 27.7.e.L (mid panel) and 27.7.e.O (lower panel). Lines fitted using Loess smoother.

1.5 Fishery Management

EU legislation sets a MLS of 100mm shell length except for Irish Sea (107A) and Eastern Channel (107D) where it is 110mm. There is a limit on retained fish by-catch to 5% of the total quantity of bivalve molluscs. The Western Waters effort regime has the potential to cap the number of KWdays fished by vessels ≥15m towing dredges for scallops. Within the UK this pool of effort is administered by the Marine Management Organisation in a system which sets a maximum number of days (per quarter) that any vessel with a scallop entitlement may fish, these limits being revised on a quarterly basis. In recent years this effort cap has been limiting, however the French fishery limits are not considered to be restrictive on their activity.

National legislation limits the number of licenses for scallop vessels >10m. The English Scallop Order places spatial restrictions on number of dredges that can be employed at any one time and specifies technical measures defining the type of dredge that can be used.

2 Stock Assessment for surveyed areas of 27.7.d.N

2.1 Area Definition

As described in Section 1.2, the stock area for 27.7.d.N covers the northern half of ICES subdivision 27.7.d with the main fishery covering a large bed which stretches across the mid-Eastern part of the channel, straddling the midline between UK and France. The perimeter of the bed was defined using VMS data (see Annex 2). Using VMS data does mean that the bed represents only those grounds used by vessels >12m, however as vessels >12m land 93% of scallops from 27.7.d.N this designation captures the vast majority of landings.

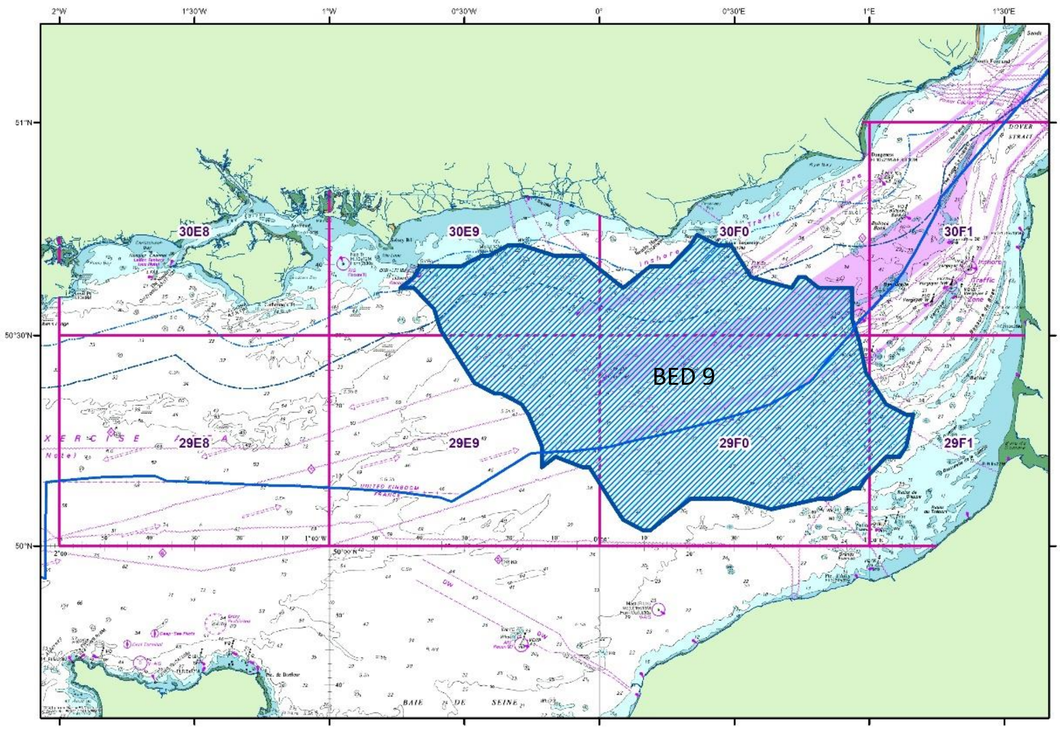

Figure 2.1 – Surveyed dredge area (Bed 9) within Assessment Area 27.7.d.N.

2.2 Data Available 27.7.d.N

2.2.1 Catch, effort and survey data

Landings by country as reported to STECF for the rectangles in assessment area 27.7.d.N are given in Table 2.1. Note that Belgian data are likely to be missing prior to 2012 although the tonnages are small.

Table 2.1 Landings (tonne) by country (STECF) in assessment area 27.7.d.N.

	BEL	FRA	NLD	IRL	GBG	GBJ	IOM	UK	International Total
2009	-	7375	299	-	-	-	15	5888	13577
2010	-	6701	148	-	-	-	-	9509	16359
2011	-	6792	-	5	-	-	-	8077	14874
2012	214	5747	-	-	-	-	-	3061	9023
2013	271	13190	-	14	-	-	-	3178	16653
2014	576	4190	-	232	-	-	-	4163	9160
2015	354	2983	-	7	-	-	-	1590	4935
2016	354	4323	-	86	-	-	-	1896	6659

The proportion of international landings, by quarter, that are generated by the UK fleet are given in Table 2.2. The landings (tonne) by country and by quarter are shown below (Figure 2.2) with grouped UK data. Winter seasons tend to show the greatest activity with the least landings occurring in the summer months (during which there is a voluntary closure by part of the UK fleet).

Table 2.2 UK fleet proportion of international landings by quarter

	Q1	Q2	Q3	Q4
2012	38.6%	16.3%	97.5%	23.1%
2013	36.4%	53.4%	67.6%	12.8%
2014	45.4%	43.5%	59.1%	44.5%
2015	24.8%	27.1%	82.8%	51.2%
2016	11.8%	8.5%	44.0%	38.1%
mean	31.4%	29.7%	70.2%	33.9%

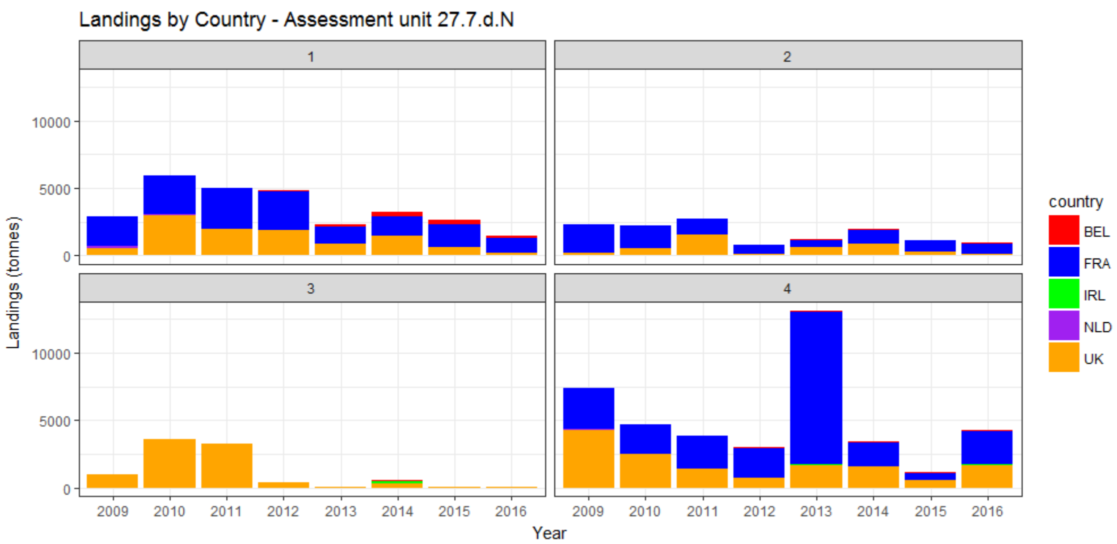

Figure 2.2 Assessment Area 27.7.d.N. Landings by country and by quarter (NB. Isle of Man, Guernsey and Jersey landings <1t per annum. Belgian landings only recorded since 2012).

International landings data for 2017 are not yet available. There is also a lag interval in the collation of landings data within the UK; at the time of report writing (December 2017), landings data to the end of September (Q3, 2017) are considered reliable.

The fishery tends to be more active during the autumn and winter, therefore an appropriate way of viewing the landings data is by season, in which a season comprises Q3 and Q4 of the preceding year. UK landings data for area 27.7.d.N by quarter are summarised in Table 2.3 and indicate a large increase in 2009 compared to earlier in the time series, peaking in 2010, followed by a decline in recent years back to more typical values. This sudden increase in landings appears to have resulted from an increase in catch rates which drew in additional effort from the nomadic fleet at a time when access to other waters was becoming limited.

Table 2.3 UK Landings (tonne) for 27.7.d.N by quarter.

	1	2	3	4	ANNUAL TOTAL	SEASON TOTAL (Q3, Q4, Q1, Q2)
2001	653	96	24	201	974	
2002	380	220	63	647	1310	825
2003	1228	111	6	487	1832	2049
2004	889	107	6	383	1385	1489
2005	553	133	18	529	1234	1075
2006	749	305	30	475	1559	1602
2007	653	152	51	1559	2414	1310
2008	686	479	51	606	1823	2775
2009	533	174	962	4242	5911	1365
2010	2947	514	3591	2458	9509	8665
2011	1922	1509	3256	1397	8083	9479
2012	1872	131	368	690	3061	6656
2013	831	620	40	1688	3179	2510
2014	1463	850	310	1541	4163	4040
2015	644	306	59	584	1594	2801
2016	168	78	21	1629	1897	889
2017	426	174	410			2250

2.2.2 Discards

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 omission of discard data does not affect the estimation of fishable biomass. Scallops are assumed to have a high survival rate and therefore discard induced mortality is considered to be low.

2.2.3 Size & age composition

An extensive biological sampling program was set up in 2016 and is described in Annex 1. The program collected both length and age samples with a higher sample collection rate on lengths than ages as is standard for fishery data collection programs. Age determination for scallops age older than 8 is problematic and so all animals age 8 or older are classified into an 8+ group.

Length samples were raised to UK landings for 2017 on a quarterly basis and then converted to age using age-length keys (ALKs).

The number of samples collected is shown (Table 2.4) below along with the number of age samples collected during the dredge survey.

Table 2.4 Sampling programme summary

Stock assessment area	Length samples	Animals measured	Age samples	Shells aged	Age samples from dredge survey	Shells aged from dredge survey
27.7.d.N	17	2825	1	24	9	335

Due to the low numbers of age samples taken in 27.7.d.N it was necessary to pool the age-length data from the dredge and biological sampling schemes and construct an annual ALK which was applied to the quarterly length distributions.

The landed numbers at age, raised to the landings data from January – September 2017 are show in Figure 2.3.

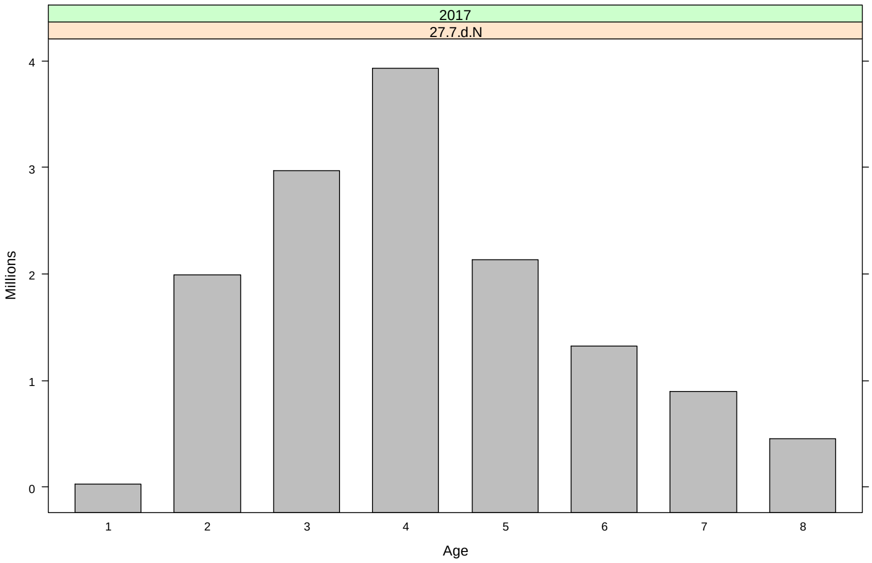

Figure 2.3. Numbers at age landed from dredge areas in 27.7.d.N. during the period 01/01/2017 – 30/09/2017

2.3 Biological Parameters and Dredge Efficiency

2.3.1 Natural mortality

Predation is the likely cause of most of the natural mortality, with brown crab and starfish being the most significant predator 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 but 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).

2.3.2 Size of maturity

Animals above Minimum Landing Size (MLS, 110 mm shell length) are almost exclusively found to be mature. Maturity is assumed to be knife-edged at 80mm shell height (based on Cefas data, unpublished).

2.3.3 Growth

Methodology for ageing at Cefas is based on work carried out by Dare and Deith (1989). Oxygen isotope assay was used to validate traditional ring counting methods and to produce von Bertalanffy growth parameters. A review of historic growth estimates including different grounds in the English Channel by Dare and Palmer provided von Bertalanffy growth parameters for assessment area 27.7.d.N (Cefas unpublished review).

The von Bertalanffy model was used to estimate size at age:

$$\boldsymbol{Shell\ ht} = \boldsymbol{H}\infty\ (\mathbf{1} - \boldsymbol{exp}(-\boldsymbol{k}(\boldsymbol{age} - \boldsymbol{t0})))$$

where $\boldsymbol{H}\infty$ = shell height of an infinitely old scallop, $\boldsymbol{k}$ =growth rate and $\boldsymbol{t0}$ is the time at zero size.

2.3.4 Shell metric conversions

The growing edge of scallop shells is the most fragile part of the shell and prone to damage. Scientific shell measurements are therefore generally taken on shell height (perpendicular to the hinge) as this axis has the least potential for damage. The minimum landing size for scallop is, however, determined using the shell length (parallel to the hinge across the widest point). As one purpose of the stock assessment is to estimate fishable biomass it is desirable to present results in length equivalents. Consequently, parameters for converting shell metrics to the equivalent length of the round shell have been determined.

The linear relationships between round shell length and both flat shell height and round shell height was investigated using an Analysis of Covariance. In this report we specifically state which size metric is used.

2.3.5 Weight – length relationship

Scallops were not individually weighed as part of this project but parameters for a weight-length relationship for 27.7.d was obtained from IFREMER.

The relationship between live weight and shell length is defined by:

$$\boldsymbol{Live\ wt} = \boldsymbol{a}.\boldsymbol{Shell\ length}^{\mathrm{b}}$$

2.3.6 Dredge efficiency

Pecten maximus inhabits substrates from fine sand through to coarse sand and gravels 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 the fishing gear. 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 such variations in gear performance. Any biomass estimates resulting from the dredge surveys used for this assessment are sensitive to the choice of substrate specific efficiency parameters. The efficiency of spring loaded dredges have been studied using diver observations, mark recapture methods and depletion studies (Chapman *et al*, 1977, Jenkins *et al* 2001 and Dare *et al* 1993 and 1994). However, it is a subset of results from a more recent depletion study carried out in the English Channel by Palmer *et al* (Cefas, unpublished data) that have been used for the basis of the stock abundance estimates presented here. The efficiency is defined as the percentage of scallops in the path of the dredge that are captured.

The biological and dredge efficiency parameters used in this assessment are presented in Table 2.5.

Table 2.5 Assessment parameters

PARAMETER	DESCRIPTION	GROUND TYPE	SOURCE
30%	Gear efficiency	Clean or clean becoming stony	Cefas (Palmer: 2001, unpublished data)
43%	Gear efficiency	Flint cobbles	Cefas (Palmer: 2001, unpublished data)
a= $6.11707X10^{-4}$ b=2.65415	Weight – shell length	NA	IFREMER (unpublished data)
a=1.208916 b=-5.386429	Shell metric conversion - Flat height to round length	NA	Eastern Channel dredge survey 2017
80mm shell hgt (~90 length)	Size of maturity	NA	Cefas (unpublished data)
0.15 all ages	Natural mortality	NA	Cook *et al*., 1990
$H\infty$=119.3, k=0.516, t0=0.692	von Bertalanffy Growth	NA	Cefas (unpublished review)

2.4 Dredge Surveys

2.4.1 Survey design description

The dredge survey design and station selection are described in Annex 2.

2.4.2 2017 survey

A chartered commercial fishing vessel was used to survey a grid of fishing stations as defined in the survey design (Annex 2) and shown in Figure 2.4. The commercial fishing vessel chartered for the survey was a 36m scallop dredger which usually fishes 17 “Newhaven” type dredges each side, and which facilitates short tow durations for effective sampling as determined in scoping work carried out in 2016. The vessel deploys a conveyor system to take catch down from the main deck to the factory deck for sorting.

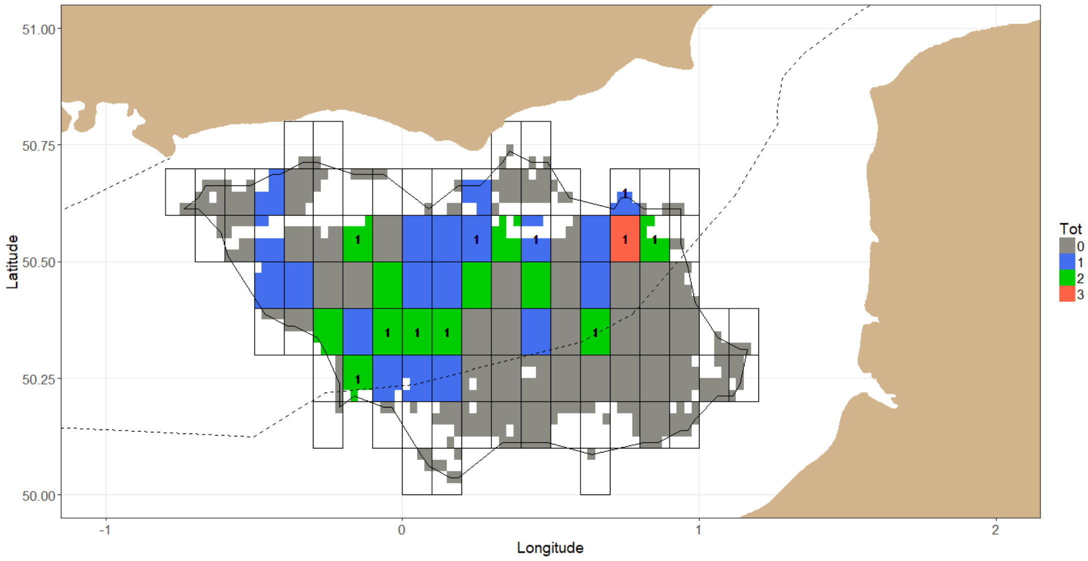

Figure 2.4. Sampled blocks in Bed 9, 27.7.d.N. Block shading indicates the total number of stations within each block 0 =grey, 1=blue, 2=green and 3=red. The number of industry selected tows comprising the total within each block is given as a numeric. N.B. the area in the French EEZ was not surveyed this year but was included in the analysis by extrapolation using the survey median.

Thirty-five randomly selected stations and 12 industry selected stations were surveyed in the English EEZ (47 stations) between 25-29th September 2017 and operating from the West Sussex port of Shoreham-by-Sea. Permission to survey on the French side of the median line was not available at time of survey. Three positions were not viable due to the presence of static gear.

The starboard side used 4 modified dredges and 11 standard dredges with a gap separating the two gear types to avoid catch merging on the conveyor belt (see Figure 2.5). The port side beam used a standard 17 commercial dredge configuration. The beams were deployed synchronously for 15 minutes at approximately 3 knots. The inclusion of the modified dredges was to allow for sampling of smaller size scallops that would otherwise be under-sampled using the standard commercial gear. N.B. In this first year, the length distributions from the 4 modified dredges have been used for exploratory purposes only and are not included in this assessment.

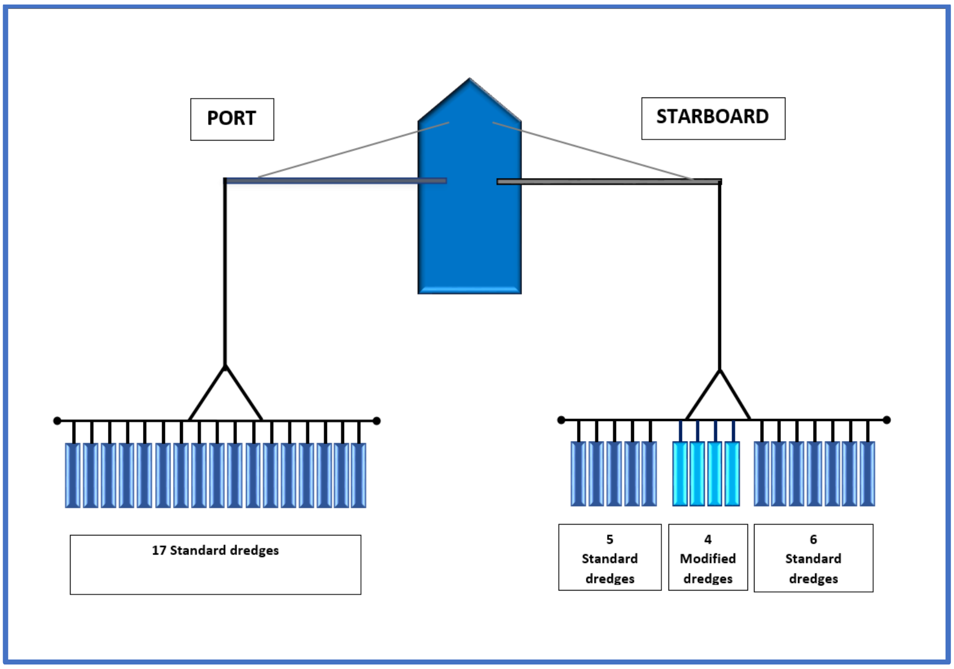

Figure 2.5 Gear configuration on survey vessel.

The standard gear ("Newhaven dredges") were 75cm wide and fitted with 85mm ring bellies and 8 teeth swords (tooth bars). The modified dredges were 75cm wide with 55mm rings in the belly, nylon mesh backs and 9 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). Weight of each component was recorded, and components were then subsampled for length purposes, shell length measured to the nearest mm. The weight of each length sample was recorded to provide a raising factor.
- Five individuals per 5mm size bin were retained for age determination at selected sites within each bed. To ensure sufficient numbers of animals in the extreme length sizes, samples for age determination were pooled over up to three adjacent tow sites.

2.5 Survey Processing

The processing of the dredge survey data is detailed in Annex 3. The essence of the approach is to determine the swept area of the gear and then determine the relative biomass density of caught scallops above MLS from the swept area and catch of scallop >MLS. These densities are then converted to absolute densities using the gear efficiency parameter appropriate to the ground type (Table 2.5). Geostatistical approaches to raising the survey estimate were investigated, but no reliable variogram could be established for the sampling density used. This is partly because there appears to be relatively little regular structuring within each bed and also because there were instances of non-stationary distributions (i.e. high densities along an edge), both of which will cause difficulties in utilising geostatistical approaches. As no reliable geostatistical method could be found to raise the observed scallop densities, an arithmetic approach was taken, with the observed cells of randomly selected stations first being raised to the valid surface area of the block the cell was in. Cells within unsampled blocks were assumed to have the same density as the median sample density from randomly selected stations; the median density was taken to account for the skewed distribution of the station densities. This also applies to all Blocks in the French EEZ, which weren't sampled during the 2017 dredge survey. Finally, the cells with industry selected stations were replaced with their observed values. This last step was required to retain the statistical integrity of the sampling design.

2.5.1 Age-length key – dredge survey

Age-Length keys were generated for the Assessment Area (Figure 2.6). In order to rationalise the number of age-readings required, age-length keys within each bed were generated from pooled stations (i.e. ~3 stations went into the production of each ALK, some beds therefore having multiple ALKs). Nine age samples were taken with a total of 417 scallops aged. Size stratified samples were taken for aging in an attempt to ensure that the full-length distribution was sampled. However, one length class was unaged (160-165mm length) and therefore the age distribution for the length class below (155-160mm) was assigned to this length class.

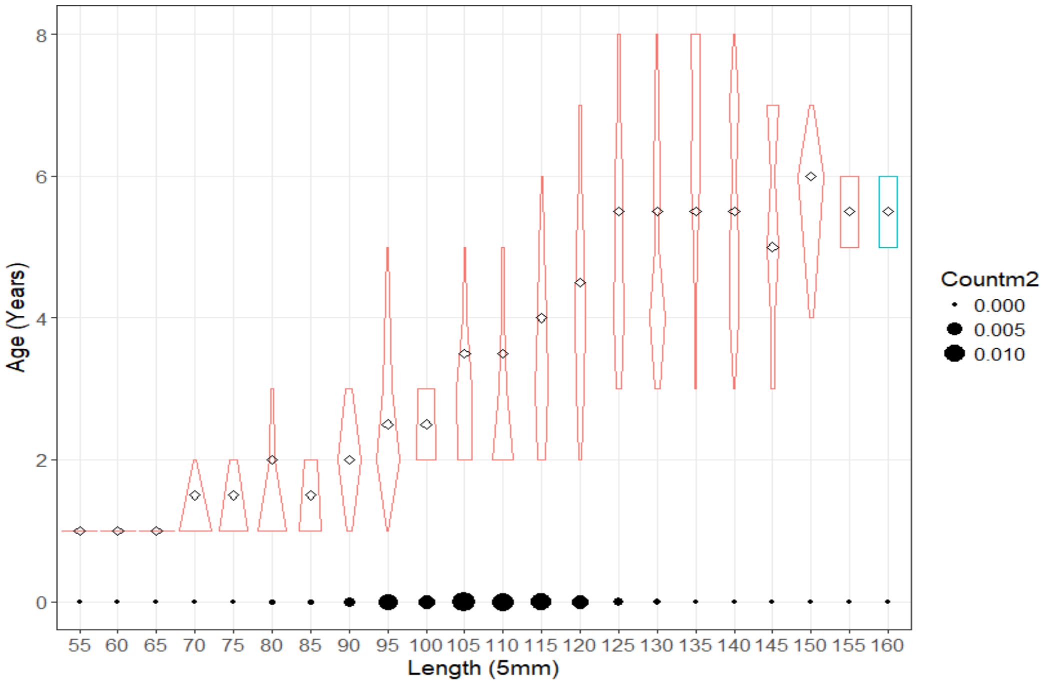

Figure 2.6 - Age-Length key for Bed 9, Assessment Area 27.7.d.N.

One length class (blue) was unsampled and was assigned the age distribution from the length class below. Hollow triangles give the mean age at length. Filled circles represent the length distribution from the dredge survey, sized proportionally to the number of scallops at length per m^2.

2.5.2 Raised biomass estimates and uncertainty

The estimated biomass of harvestable scallop (>110mm) raised to each block is presented in Figure 2.7.

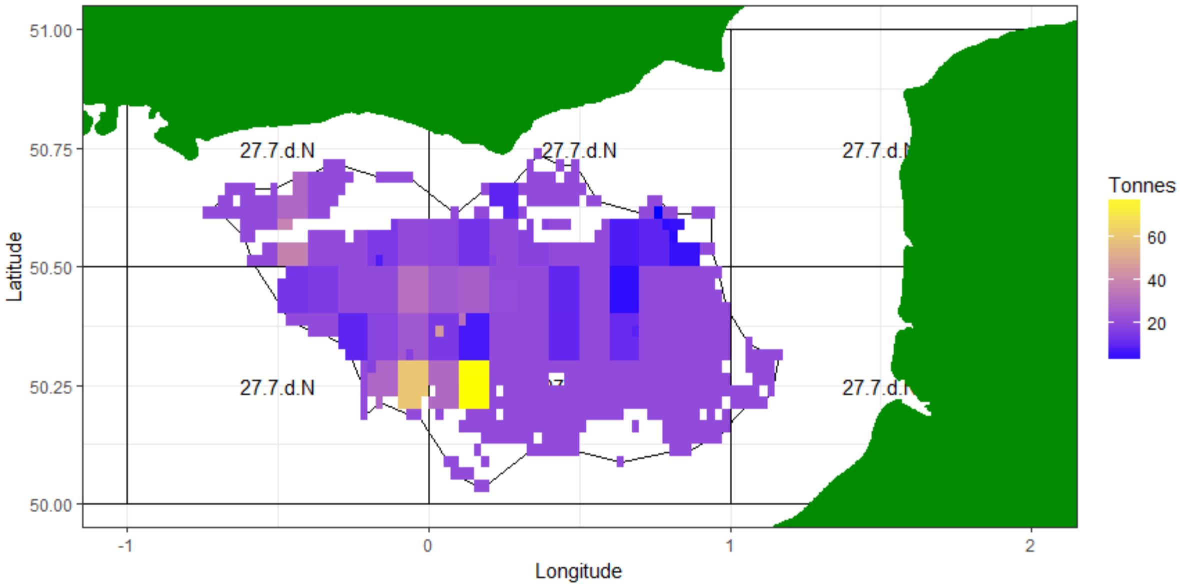

Figure 2.7 – Biomass (Tonnes) of harvestable (above 110mm length) scallops in Bed 9, Assessment Area 27.7.d.N.

In order to estimate the uncertainty around the estimate of harvestable biomass, the samples for each bed were bootstrapped 1000 times with replacement (Figure 2.8). For each iteration, the same raising procedure was used as for the main biomass estimation routine. The point estimate along with median, 25th and 75th percentiles are given in Table 2.6. The point estimate is different from the median estimate due to the skewness of the distribution. As the point estimate utilises all available data it is considered the most appropriate value for the biomass estimate for 2017.

The biomass estimates from the bootstrap exercise show that although the majority of biomass estimates fall within a fairly narrow window around 18000 tonnes, there are 2 further modes around 21000 and 26000 tonnes although these have much lower probabilities (particularly the higher value).

Table 2.6 Median biomass, point estimate and percentiles dredged areas of 27.7.d.N

Gear	Assessment area (dredged area only)	25th centile (tonnes)	Median biomass (tonnes)	Point estimate (tonnes)	75th Centile (tonnes)
Commercial	27.7.d.N.	17196	17982	18726	18876

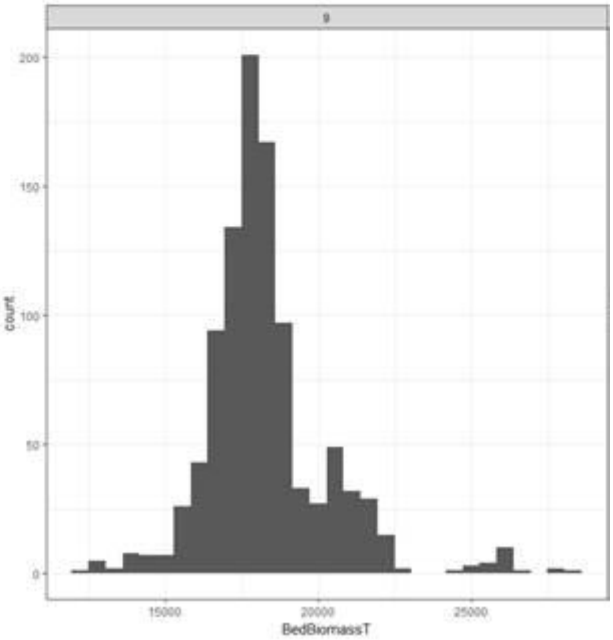

Figure 2.8 Distribution of biomass estimates for bed 9 from bootstrapping procedure

2.5.3 Size and age composition from dredge survey

From the size frequencies taken at each station, a total length frequency was derived and raised to the total population estimate. Age samples were used to construct a single age-length key for the bed (binned in 5mm groups) and this was applied to the total length distribution to derive the age composition observed during the survey (Figure 2.9). A significant portion (36%) of the catch in bed 9 was below the MLS.

The age distribution of the survey catches is similar to that from the commercial landings, although there are a higher proportion of 2-year olds in the survey catches. This is understandable given the large proportion of catch that was below the minimum landing size in the surveys. The proportions of older age scallops are very similar between the two datasets, but this is most likely an artefact of having to use the same age-length key for both series, and there being little contrast in the length frequencies at the larger/older sizes.

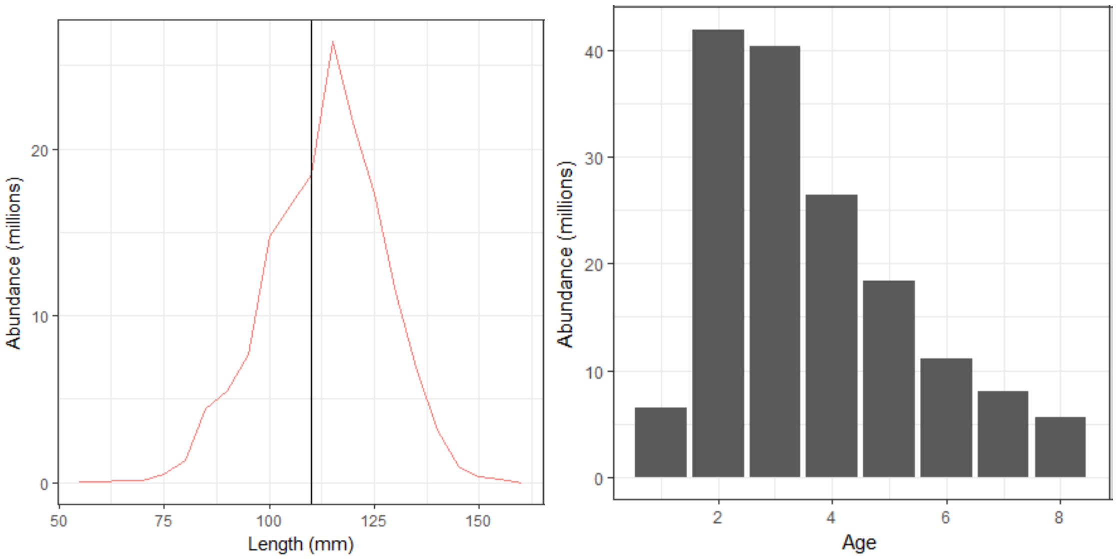

Figure 2.9 – Age and length distributions of the scallop catch from the dredge survey in Assessment Area 27.7.d.N

2.6 Harvest Rate Estimation

The harvest rate (i.e. the ratio of landings to total harvestable biomass) is proposed to give a proxy for the fishing mortality experienced by this stock area. Ideally this will be constructed from the biomass immediately prior to the fishery and then compared to the removals from the observed biomass, however as the survey was undertaken prior to the main fishery in 2017, clearly this is not possible in this first instance. Instead we used the international landings from 2016 for those rectangles which intersect bed 9 (Table 2.7).

The best estimate of harvest rate uses the point estimate from all data, the range uses the 25th and 75th centile from the bootstraps. Note that the 75th centile from the bootstraps is very close to the point estimate due to the skewed nature of the bootstrap runs (which itself is a product of the skewed distribution of survey catches).

Biomass estimates for non-dredged areas of 27.7.d.N were not assessed using video survey in this, the initial assessment year, and as such harvest rate estimates only covers the fished part of the stock. There is additional stock outside the area surveyed with dredges but for which there are currently no data on either their biomass or ability to contribute recruitment to the main areas of fished stock.

Table 2.7 Biomass and Harvest rate estimate for dredged areas of 27.7.d.N

Assessment area	International landings (tonnes)	Harvestable biomass estimate of dredged area (tonnes)	**Harvest Rate on dredged portion of stock (Dredge Survey Only)**	Harvest rate range
27.7.d.N	6379	18726	34.0%	33.7% - 37.1%

2.6.1 Fishing mortality estimates from the landings age composition

Most fully analytical fish stock assessments use a time series of age composition of the landings (along with other data such as total landings/catch and a survey series) to estimate the rate at which the fishery is exploiting the stock. Attempting to glean information regarding fishing mortality from a single year of age composition is fraught with uncertainty and the estimate of fishing pressure arising from the dredge survey is considered to be more robust at this stage.

An investigation into the use of the age composition to estimate fishing mortality was made using a cohort model assumption. This assumes that for the time-span of the ages observed (8 years in this case), the population has been in equilibrium – that is that fishing effort, recruitment and growth have all been constant. Deviations from this assumption will cause the model to give unreliable answers.

The model requires growth and natural mortality parameters (as listed in Table 2.5). Selection at age was estimated using the growth parameters and an assumption that the fishery has knife-edge selection at the minimum landing size. The model estimates the size of recruitment and the fishing pressure required to generate the observed catch numbers at age and the results of the model are shown in Figure 2.10. The model has reasonable fits to the older ages but is unable to produce the catch numbers at ages 2 and 3. There are a number of potential reasons for this discrepancy at younger ages. Growth rates at younger ages may be under-estimated and perhaps in reality more age 2 scallops have grown to commercial size by the time the bulk of the fishery occurs. A more potentially important explanation is that the lack of age samples from the commercial fishery meant the age composition from the dredge fishery was used. As this survey occurred at what is effectively the end of the growth period of the year, the survey is likely to over-represent fast growing 2-year olds compared to the annual fishery.

The fishing mortality rate estimated by the model is 0.65 which equates to a harvest rate of 48%. This is considerably higher than the harvest rate estimated by the survey approach (Table 2.8)

Table 2.8 Harvest rates estimate for dredged areas of 27.7.d.N

Assessment area	**Harvest Rate on dredged portion of stock (Dredge Survey Only)**	**Harvest Rate on dredged portion of stock (Cohort Model)**	**MSY Candidate**
27.7.d.N	34.0%	48%	25%

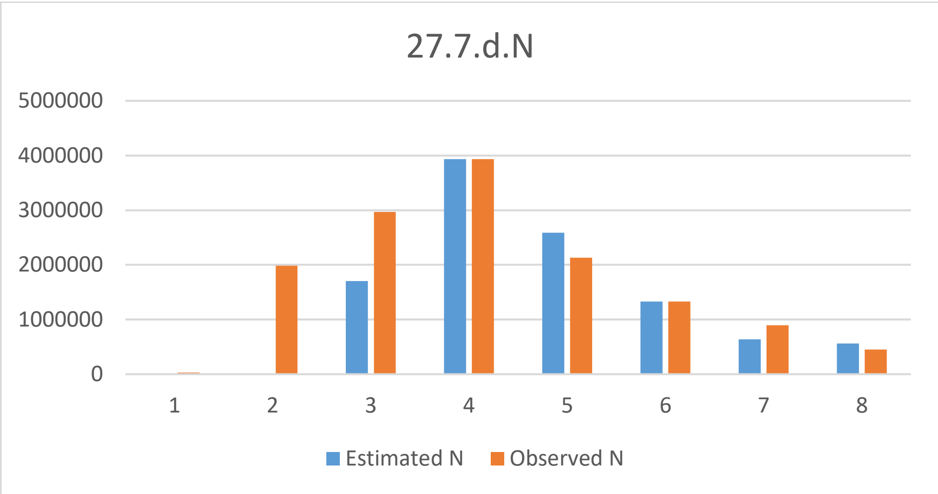

Figure 2.10. Estimated size of recruitment and the fishing pressure required to generate the observed catch numbers at age.

2.7 MSY Reference Point Estimation

Full estimation of the fishing mortality that generates maximum sustainable yield (MSY) requires a full analytical assessment and an estimate of the stock-recruitment relationship. Clearly this is not yet possible as is the case with many stocks assessed by ICES. In such cases, ICES 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%SpR) is a commonly used reference point, both within ICES and more widely around the globe. Fmax, the fishing mortality which gets the maximum yield from each recruited individual is also sometimes used as a proxy for Fmsy, but is unlinked to spawning potential, is more uncertain in its estimation and in some circumstances, suggests fishing rates which are highly risky for the stock size.

A simple yield -per recruit model was constructed using the selection-at-age and maturity-at-age parameters estimated in this assessment. This model estimates that in order to achieve F35%SpR, a harvest rate in the vicinity of 25% would be required. The Fmax estimate for this stock is very high (because there is relatively little growth potential after the MLS has been reached compared to expected losses through natural mortality). Following the Fmax estimate for this stock would remove all spawning stock in one year and is therefore highly risky. The recommended FMSY reference point for this stock is therefore F35%SpR.

2.8 Conclusions

This is the initial stock assessment undertaken for scallops in this region. Single points of data are always more uncertain than when a time series are available, so the results of this assessment should be viewed with some caution.

A presentation of the assessment approach to the ICES Scallop Working Group highlighted that there are several key areas of uncertainty that require further work to better understand their impact and influence. With the swept area biomass assessment, the key parameter is the gear-efficiency estimate, and even relatively small changes to this estimate would have a significant impact upon the estimated harvestable biomass and harvest rate.

The estimates of a provisional harvest rate arising from both the dredge survey and the age determination are above the initial estimate of an MSY harvest rate. It should be noted that these estimates are for the fished portion of the stock only, unfished portions of stock were not surveyed in this area. The estimate of moderately high fishing pressure arising from the age-structure of landings is driven by the relatively low numbers of scallops age ~6 and older. For a species which is capable of living to >20 years old, the scarcity of such animals points to a fairly high mortality rate, however as previously mentioned caution should be used over interpretation of single years of age data. A age structure truncated to this degree is not uncommon in exploited scallop populations with some fisheries showing very few animals aged older than three.

We would hope that in future assessments we will be able to see weak and strong year-classes moving through the population structure to give confidence that the sampling scheme is able to adequately follow the population development.

The assessment of scallops in 27.7.d.N only covers the fished part of the stock and there is known to be additional stock outside the area surveyed but for which there are currently no data on either their biomass or ability to contribute recruitment to the fished stock. Future surveys of un-dredged areas are planned and are likely to revise the estimates of realised harvest rate down, provided that un-dredged areas are considered to contribute to the recruitment in the dredged areas. The preliminary estimates of harvesting rates on the fished stock are both above the preliminary estimate of MSY, however these estimates are also subject to high uncertainty due to the limited data available so far. As the time series of data develops and increases in comprehensiveness, this will in turn contribute to a more robust determination of stock status of King scallop in this region.

3 Stock Assessment in surveyed areas of 27.7.e

3.1 Area Definitions

As described in Section 1.2, three scallop assessment areas which encompass the majority of areas fished by UK vessels have been defined within ICES division 27.7.e; 27.7.e.I (Inshore Cornwall), 27.7.e.L (Lyme Bay) and 27.7.e.O (Offshore). Within these there are 8 scallop beds; two scallop beds are within 27.7.e.I, three within 27.e.L, and three within 27.7.e.O. Two of the beds (4 and 5) straddle two of the assessment areas; these beds have been assigned to the assessment area into which the majority of it lies (Figure 3.1). Beds 7 and 8 lie predominantly in the EEZ of Guernsey with a small part of bed 8 lying over the median line with France.

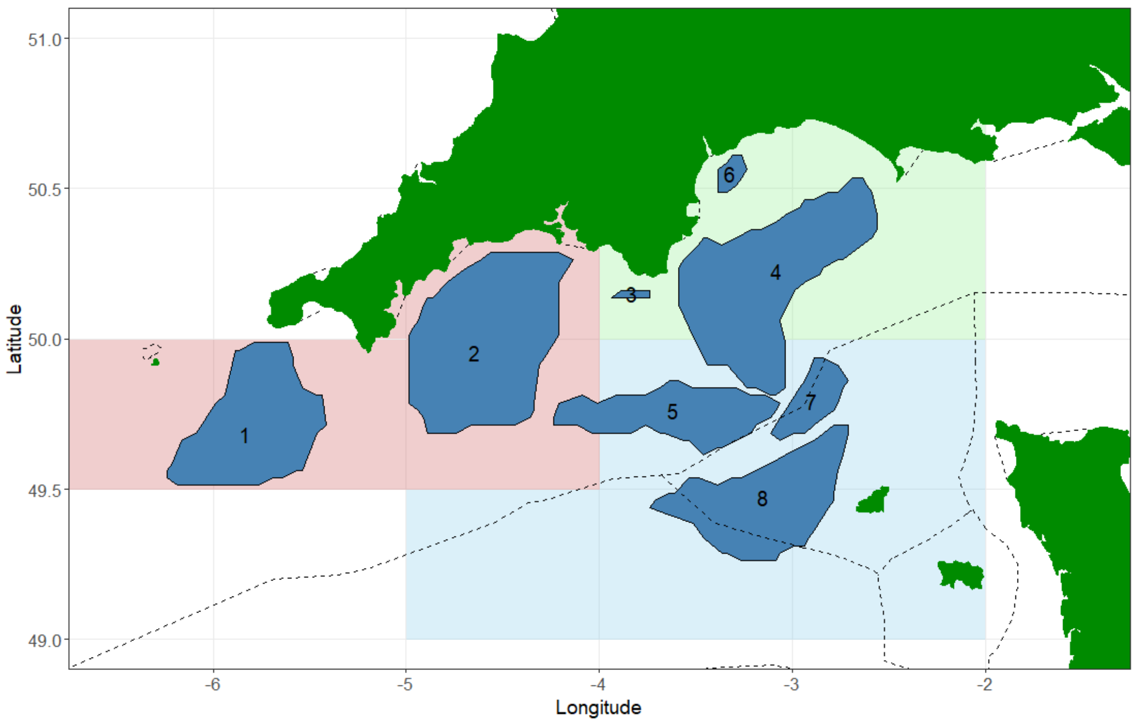

Figure 3.1– Beds 1 and 2 within Assessment Area 27.7.e.I (red), Beds 3, 4 and 6 in 27.7.e.L (green), and Beds 5,7 and 8 in 27.7.e.O (blue).

3.2 Data Available 27.7.e

3.2.1 Catch, effort and survey data

Landings by country as reported to STECF for the three assessment areas in 27.7.e are given in Table 3.1. Note that Belgian data are likely to be missing prior to 2012 although the tonnages are generally small. Rectangle 29E4 contains waters in both 27.7.E and 27.7.F. It is assumed that non-UK landings from 29E4 are from the 27.7.F area because all the 27.7.E waters lie inside 6 nautical miles where non-UK vessels are not entitled to fish.

Table 3.1. STECF Landings by for the three assessment areas in 27.7.e

27.7.e.I								Total	
	BEL	FRA	NLD	IRL	GBG	GBJ	IOM	UK	International
2009	-	36	181	-	-	-	-	2261	2478
2010	-	37	107	-	-	-	-	1029	1173
2011	-	55	-	1	-	-	-	1790	1846
2012	55	7	-	2	-	-	-	2502	2565
2013	1	34	-	1	-	-	-	2372	2409
2014	79	0	-	4	-	-	-	1667	1751
2015	102	0	-	33	-	-	-	3711	3846
2016	71	4	-	28	-	-	0	2836	2938
27.7.e.L.	BEL	FRA	NLD	IRL	GBG	GBJ	IOM	UK	International
2009	-	37	47	-	0	-	-	1725	1809
2010	-	30	16	-	-	-	-	2554	2600
2011	-	40	-	-	-	-	-	3720	3761
2012	13	3	-	-	0	-	-	2953	2969
2013	4	35	-	-	-	-	-	2351	2390
2014	24	0	-	-	-	-	-	1834	1858
2015	10	1	-	-	-	-	-	1246	1257
2016	5	1	-	-	-	-	-	1416	1422
27.7.e.O.	BEL	FRA	NLD	IRL	GBG	GBJ	IOM	UK	International
2009	-	828	66	-	-	-	-	2054	2948
2010	-	808	-	-	0	1	-	3140	3949
2011	-	671	-	-	-	0	-	1638	2309
2012	171	635	-	-	0	-	-	2643	3449
2013	14	817	-	2	-	-	-	3032	3866
2014	104	1141	-	1	-	-	-	1352	2597

2015	47	717	-	3	0	-	-	1055	1823
2016	58	764	-	-	0	-	0	891	1713

International landings data for 2017 are not yet available. There is also a lag in the collation of landings data within the UK. At the time of writing (December 2017), landings data to the end of September (Q3, 2017) are considered reliable.

There is a seasonal pattern within the three areas, with Lyme Bay tending towards a year-round fishery, Inshore Cornwall being more of a Q2-3 fishery and offshore being more a Q3. UK data for the three assessment areas in 27.7.e by quarter are given in Table 3.2.

Table 3.2. Quarterly landings UK data by assessment area in 27.7.e

27.7.e.l.

	Q1	Q2	Q3	Q4
2001	222	1063	1071	145
2002	145	613	1182	95
2003	186	811	1169	207
2004	208	1050	1390	132
2005	441	1330	1388	162
2006	385	1280	1486	126
2007	207	551	684	82
2008	85	259	760	161
2009	219	791	1150	110
2010	92	461	401	80
2011	96	738	893	65
2012	240	1299	856	115
2013	194	823	1250	107
2014	81	578	890	119
2015	173	2255	1113	171
2016	320	1414	877	234
2017	243	875	945	

Table 3.2. Quarterly landings UK data by assessment area in 27.7.e continued

27.7.e.L	Q1	Q2	Q3	Q4
2001	515	423	176	361
2002	518	490	284	176
2003	131	330	276	236
2004	325	511	385	553
2005	626	721	465	977
2006	860	777	194	455
2007	521	740	268	482
2008	332	450	414	542
2009	544	539	395	343
2010	697	695	302	939
2011	1168	934	839	865
2012	964	591	558	915
2013	871	591	493	452
2014	504	611	416	354
2015	293	336	421	321
2016	385	278	408	493
2017	410	533	324	

27.7.e.O.	Q1	Q2	Q3	Q4
2001	183	350	35	11
2002	116	450	118	37
2003	138	572	296	133
2004	205	318	72	105
2005	90	179	91	22
2006	150	140	147	122
2007	417	1108	817	65
2008	94	1022	411	81
2009	428	1299	314	13
2010	418	2251	465	7
2011	350	1116	158	13
2012	939	1488	120	114
2013	449	1351	1165	68
2014	184	427	695	45
2015	133	313	589	20
2016	130	272	480	11
2017	44	307	192	

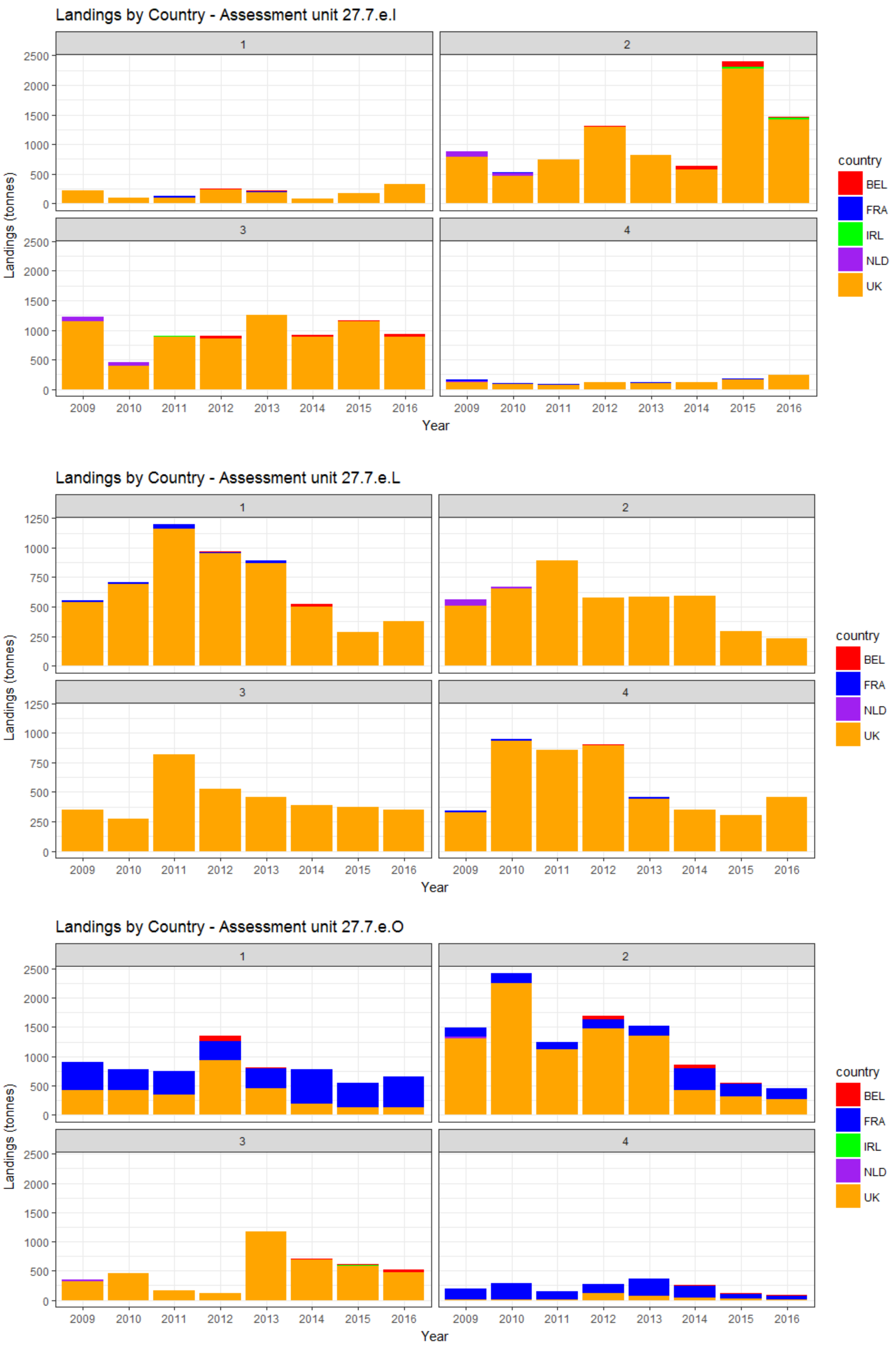

Figure 3.2. Assessment 27.7. Landings by country and by quarter (NB. Isle of Man, Guernsey and Jersey landings <1t per annum. Belgian landings only recorded since 2012).

Figure 3.2 shows the landings by country and quarter within the assessment areas in 27.7.e. Annual landings in 7e inshore and Lyme Bay assessment regions are almost exclusively UK landings, with small tonnages in both areas from France, Belgium and the Netherlands. UK landings are most prevalent in 7e offshore with the exception of quarter 4 and the last three years in quarter 1, where French landings are higher.

3.2.2 Discards

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 omission of discard data does not affect the estimation of harvestable biomass. Scallops are assumed to have a high survival rate and therefore discard induced mortality is considered to be low.

3.2.3 Size & age composition

An extensive biological sampling program was set up in 2016 and is described in Annex 1. The program collected both length and age samples with a higher sample collection rate of lengths than ages as is standard for fishery data collection programs. Age determination for scallops age older than 8 is problematic and so all animals age 8 or older are classified into an eight-plus (8+) group.

Length samples were raised to UK landings for 2017 on a quarterly basis and then converted to age using age-length keys (ALKs).

The number of samples collected is shown below along with the number of age samples collected during the dredge survey.

Due to the low numbers of age samples taken in 27.7.e.O it was necessary to pool the age-length data from the dredge and biological sampling schemes. ALKs for 27.7.e.I and 27.7.e.L use fishery sourced ALKs only. All ALKs were constructed on an annual basis and then applied to the quarterly length distributions. The raised landed numbers at age are shown in Figure 3.3.

Table 3.3 *Sampling programme summary*

Stock assessment area	Length samples	Animals measured	Age samples	Shells aged	Age samples from dredge survey	Shells aged from dredge survey
27.7.e.I	22	4178	9	237	8	329
27.7.e.L	21	3937	7	272	3	141
27.7.e.O	8	1340	3	85	6	260

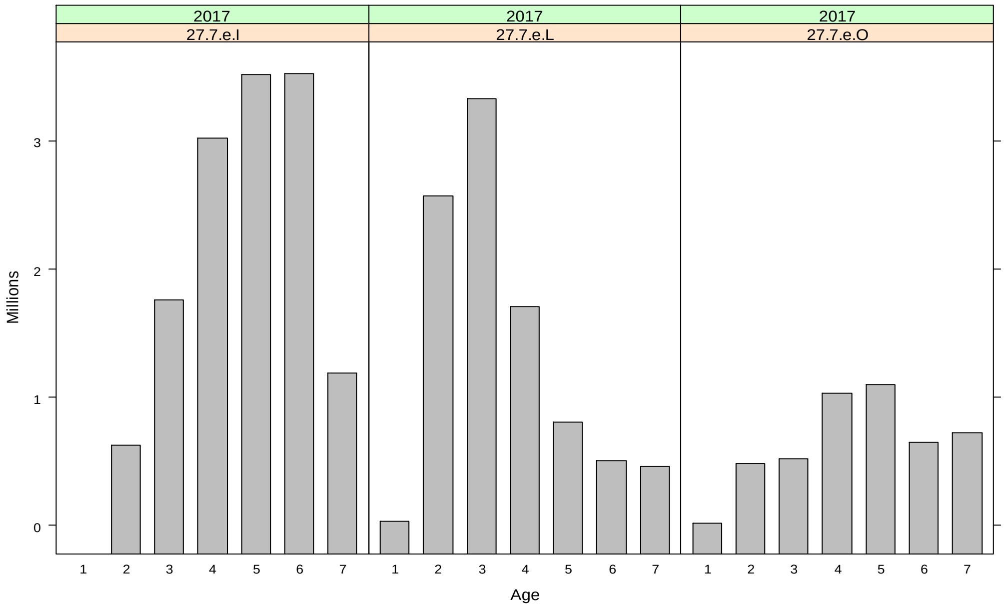

Figure 3.3 Numbers at age landed during the period 01/01/2017 – 30/09/2017

3.3 Biological Parameters and Dredge Efficiency

3.3.1 Natural mortality

Predation is the likely cause of most of the natural mortality, with the brown crab and starfish being the most significant predator 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 but 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).

3.3.2 Size of maturity

Animals above MLS (100 mm shell length) are almost exclusively found to be mature. Maturity is assumed to be knife-edged at 80mm shell height (based on Cefas data, unpublished).

3.3.3 Growth

Methodology for ageing at Cefas is based on work carried out by Dare and Deith (1989). Oxygen isotope assay was used to validate traditional ring counting methods and to produce von Bertalanffy growth parameters. A review of historic growth estimates including different grounds in the English Channel by Dare and Palmer (1994) was available but more recent estimates by Palmer *(*Cefas, unpublished data*)* are used for assessment areas in 27.7.e.

The von Bertalanffy model was used to estimate size at age:

$$\boldsymbol{Shell\ ht} = \boldsymbol{H\infty}\ (\mathbf{1} - \boldsymbol{exp}(-\boldsymbol{k}(\boldsymbol{age} - \boldsymbol{t0})))$$

where $\boldsymbol{H\infty}$ = shell height of an infinitely old scallop, $\boldsymbol{k}$ =growth rate and $\boldsymbol{t0}$ is the time at zero size.

3.3.4 Shell metric conversions

The growing edge of scallop shells is the most fragile part of the shell and prone to damage. Scientific shell measurements are always taken on shell height (perpendicular to the hinge) as this axis has the least potential for damage, however the minimum landing size for scallop is set on the length (parallel to the hinge across the widest point). As one purpose of the stock assessment is to estimate harvestable biomass it is desirable to present results in length equivalents. Consequently, parameters for converting shell metrics to the equivalent length of the round shell have been determined.

The linear relationships between round shell length and both flat shell height and round shell height was investigated using an Analysis of Covariance. In this report we specifically state which size metric is used.

3.3.5 Weight – length relationship

Scallops were not individually weighed as part of this project but an earlier Cefas project weighed component parts which when combined provide total weight of individuals (Cefas, 2012 unpublished report). Samples were collected from 5 sea areas in the English Channel, described as; 1. East of the Eddystone, 2. West of the Eddystone, 3. Scillies, 4. Offshore, 5. Lyme Bay (348 samples, 10,680 scallops).

The relationship between live weight and shell length is defined by:

$$\boldsymbol{Live\ wt = a.Shell\ length^{b}}$$

3.3.6 Dredge efficiency

Pecten maximus inhabits substrates from fine sand through to coarse sand and gravels 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 the fishing gear. 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 such variations in gear performance. Indeed, the harvestable biomass estimates from the dredge surveys used for this assessment are sensitive to the choice of substrate specific efficiency parameters. The efficiency of spring loaded dredges have been studied using diver observations, mark recapture methods and depletion studies (Chapman *et al.*, 1977, Jenkins *et al.,* 2001 and Dare *et al* 1993 and 1994). However, it is a subset of results from a more recent depletion study carried out in the English Channel by Palmer *et al* (Cefas, unpublished data) that we use for the basis of our estimates. The efficiency is defined as the percentage of scallops in the path of the dredge that are captured.

The parameters, biological and dredge efficiency, used in this assessment are presented in Table 3.4.

Table 3.4. Assessment parameters

PARAMETER	DESCRIPTION	STOCK AREA	GROUND TYPE	SOURCE
30%	Gear efficiency	27.7.e.I, O and L	Clean or clean becoming stony	Cefas (Palmer, 2001, unpublished)
43%	Gear efficiency	27.7.e.I, O and L	Flint cobbles	Cefas (Palmer, 2001 unpublished)
a= $8.08X10^{-4}$ b=2.573519	Weight – shell length	27.7.e.I (bed 1 and 2)	NA	Cefas 2012 (unpublished)
a= $1.189X10^{-3}$ b=2.488354	Weight – shell length	27.7.e.O (bed 4, 5, 7 and 8)	NA	Cefas 2012 (unpublished)
a=1.209837 b=-4.904044	Shell metric conversion - flat height to round length	27.7.e.o, i and l	NA	Western channel dredge survey 2017
80mm shell hgt (~90 length)	Size of maturity	27.7.e.i, o and l	NA	Cefas (unpublished data)
0.15 all ages	Natural mortality	27.7.e.i, o and l	NA	Cook *et al*., 1990
H∞=116.5, k=0.584, t0=0.715	Von Bertalanffy Growth	27.7.e. L	NA	Cefas (unpublished data)
H∞=106.3, k=0.518, t0=0.921	Von Bertalanffy Growth	27.7.e. O	NA	Cefas (unpublished data)
H∞=105.5, k=0.437, t0=0.682	Von Bertalanffy Growth	27.7.e. I	NA	Cefas (unpublished data)

3.4 Dredge and Underwater TV Surveys

3.4.1 2017 dredge survey

The survey design was essentially the same as that for the survey in 27.7.d and described in Annex 2. The commercial scallop vessel outlined in survey description for 27.7.d (Section 2.3) was used for dredge surveys in 27.7.e.

One hundred and three randomly selected stations and 35 industry selected stations were carried out in the English and Guernsey EEZ (138 stations) between 17-27th May 2017 and operated from the Devon ports of Brixham and Plymouth (Figure 3.4). Permission to survey on the French side of the median line was not available at time of survey. One position was not viable and four displaced due to the presence of static gear. Data available for analysis are described in Table 3.5.

Table 3.5. Sampling summary from dredge survey

Bed	Number stations (of which industry selected)	Number scallop samples	Number age samples	Number measured	Number aged
1	19 (5)	19	3	1348	306
2	32 (9)	32	4	3326	407
3	0		0	0	0
4	31 (8)	31	4	1936	461
5	18 (5)	18	2	1096	124
6	0		0	0	0
7	9 (2)	9	1	536	108
8	21 (6)	21	3	3472	264

The same gear deployment configuration and sampling procedure outlined in survey description for 27.7.d was used except different numbers of teeth were used on both the commercial and modified dredges. The standard gear had 9 teeth swords (tooth bars) and the modified dredges were fitted with 13 teeth swords. N.B. In this first year, the length distributions from the 4 modified dredges have been used for exploratory purposes only and are not included in this assessment.

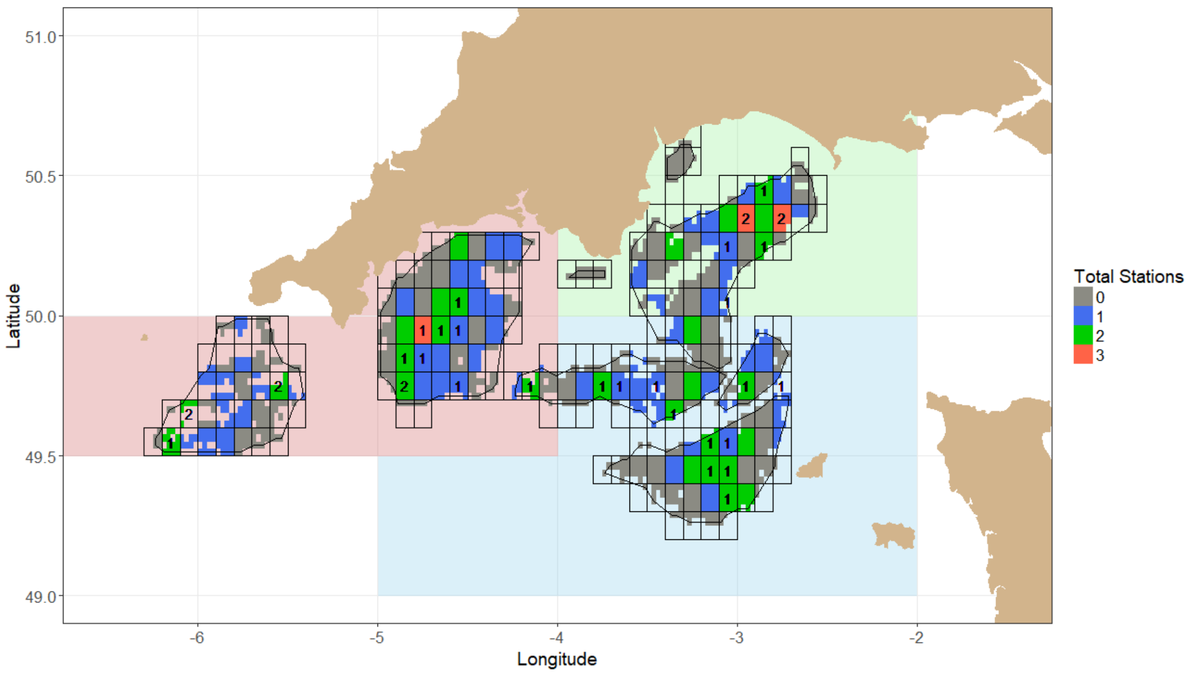

Figure 3.4 Sampled blocks in Beds 1-8, 27.7.e.I, O and L. Block shading indicates the total number of stations within each block 0 =grey, 1=blue, 2=green and 3=red. The number of industry selected tows comprising the total within each block is given as a numeric. N.B. the area of bed 8 in the French EEZ was not surveyed this year but was included in the analysis by extrapolation using the survey median.

3.4.2 Video survey

Underwater TV (UWTV) surveys were used to determine the distribution and relative abundance of scallops in areas inaccessible to fishing gear including Marine Protected Areas and areas with unsuitable ground types.

Beds where scallop fishing takes place had already been defined for the scallop dredge survey. For the UWTV, survey area boundaries were defined as likely scallop ground (from habitat modelling) and areas considered by industry to be potential scallop ground but unable to be fished due to management or gear conflict issues. This resulted in four non-dredged zones (Figure 3.5) adjacent to current fishing grounds that are typically not fished by scallop dredgers due to unsuitable ground type, gear conflicts or perceived lack of scallops. Limited survey vessel time necessitated prioritisation of the survey areas and the areas south of the Start Point was not surveyed in this, the initial year.

Once the non-dredged zones had been determined random positions were selected using the same procedure as for the dredge surveys (Annex 2. Section 2.2).

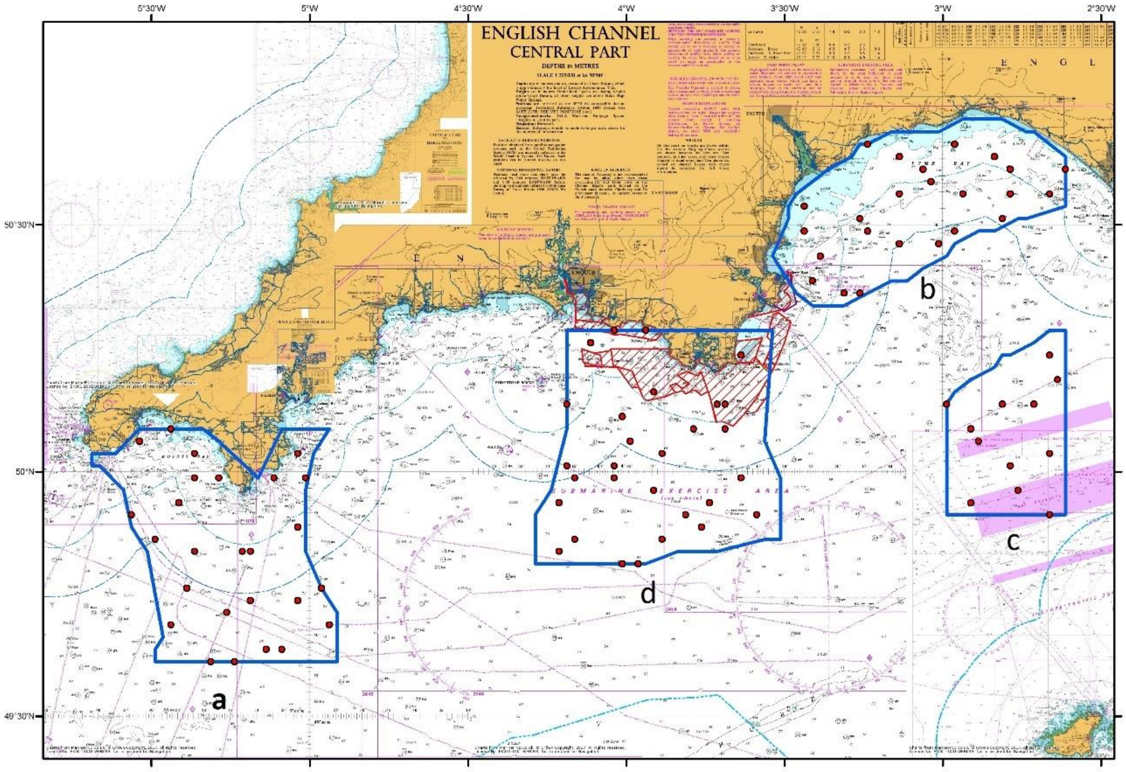

Figure 3.5 The UWTV survey non-dredged zones (Zone d was not surveyed in 2017).

The research vessel Cefas Endeavour was used to survey a grid of randomly selected survey positions in Zones a, b and c. At each position, an STR High Definition (HD) video camera and SLR stills camera was deployed on an STR drop frame system for an 11min transect. 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 100m. An altimeter on the drop frame enabled it to be maintained at a relatively consistent depth of 0.5m off the seabed. Field of view was determined by the view within the drop frame (~1.35m) and determination of scale facilitated with point lasers fitted to the camera mounts marked a consistent distance on the seabed.

Video images were viewed live on board the RV and all observed scallops 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 UWTV surveys, video footage was reviewed later by trained staff for additional verification and the median count per transect standardised to area. The Linn's Concordance Correlation Coefficient methodology used for the Cefas *Nephrops* UWTV survey quality control 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 are waived.

3.5 Survey Processing

The processing of the dredge survey data is detailed in Annex 3. The essence of the approach is to determine the swept area of the gear and then determine the relative biomass density of caught scallops above MLS from the swept area and catch of scallop >MLS. These densities are then converted to absolute densities using the gear efficiency parameters in Table 3.4. As no reliable geostatistical method could be found to raise the observed scallop densities, an arithmetic approach was taken, with the observed cells of randomly selected stations first being raised to the valid surface area of the block the cell was in. Cells within unsampled blocks were assumed to have the same density as the median sample density from randomly selected stations, the median density (rather than mean density) was used as it is statistically more appropriate for the skewed distribution of the station densities. This last step was required to retain the statistical integrity of the sampling design.

The process for raising the survey data to the Scallop assessment areas in ICES division 27.7.e are presented in Annex 3.

3.5.1 Age-length key – dredge survey

Age-Length keys were generated for Beds 1-8 (Figure 3.6) before compiling to assessment area ALKs. These were generated from age samples, taken as subsets of length samples from the dredge survey. Each age sample was a mix from two or more survey stations. Size stratified samples were taken for aging in an attempt to ensure that the full-length distribution was sampled. However, some length classes at either end of the length distribution were unaged, and the age distribution for the nearest length class was assigned to the unsampled ones.

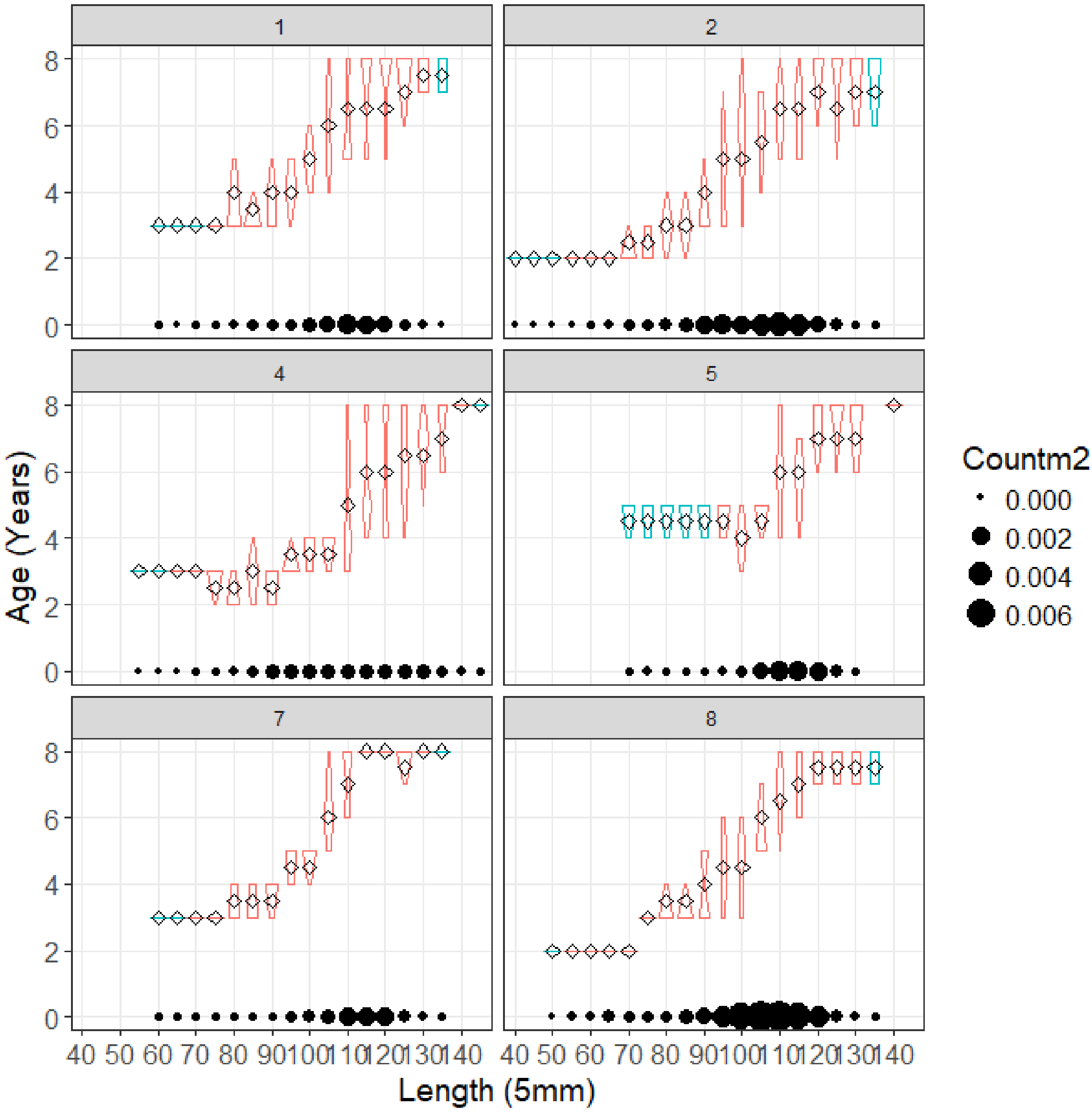

Figure 3.6 - Age-Length key for Beds 1-8. Unsampled length classes (blue) were assigned the age distribution from the nearest sampled length class. (Hollow triangles give mean age at length. Filled circles represent the length distribution from the dredge survey, sized proportionally to the number of scallops at length per m2.)

3.5.2 Video survey processing

Geostatistical techniques were not appropriate for these data and traditional arithmetic methods were used to raise observed counts to survey areas using an identical 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 the scallops we observe. 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 will be used. In terms of size-selectivity there is, as yet, no information on the size range of animals observed. It is assumed the survey has an effective knife-edge selection at 80mm height and 100% efficiency, therefore observes the absolute density of mature individuals.

3.5.3 Raised biomass estimates and uncertainty

The estimated harvestable biomass of harvestable scallop (>100mm) raised to each block is presented in Figure 3.7.

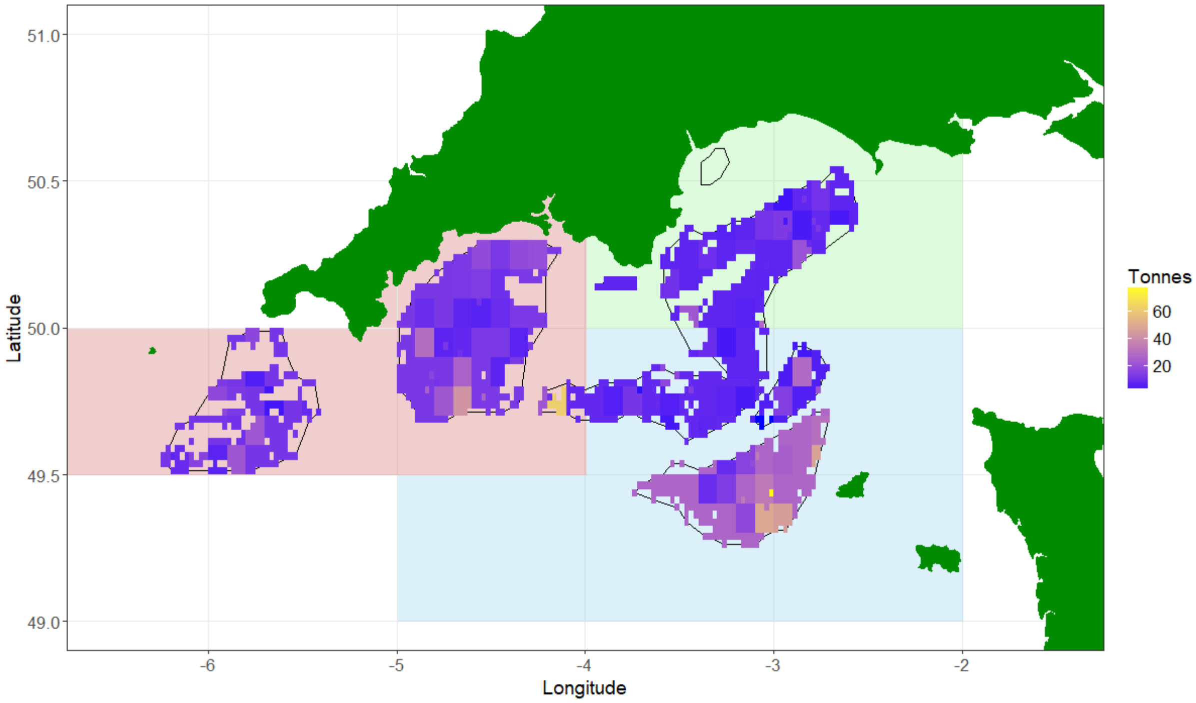

Figure 3.7 - Biomass (Tonnes) of harvestable (above 100mm length) scallops in the surveyed areas within 27.7.e.I (red), 27.7.e.L (green) and 27.7.e.O (blue)

In order to estimate the uncertainty around the estimate of harvestable biomass, the samples for each bed were bootstrapped 5000 times with replacement (Figure 3.8). For each iteration, the same raising procedure was used as for the main biomass estimation routine. The median, 25th and 75th percentiles and point estimates are given in Table 3.6.

Table 3.6 Biomass estimation for the dredge surveyed areas in 27.7.e.I, L and O

Assessment area	25th centile (tonnes)	Median harvestable biomass tonnes	Point estimate (tonnes)	75th centile (tonnes)
27.7.E.I	9254	10155	10717	11022
27.7.E.L	3626	3791	3901	4036
27.7.E.O	10175	12429	12622	13791

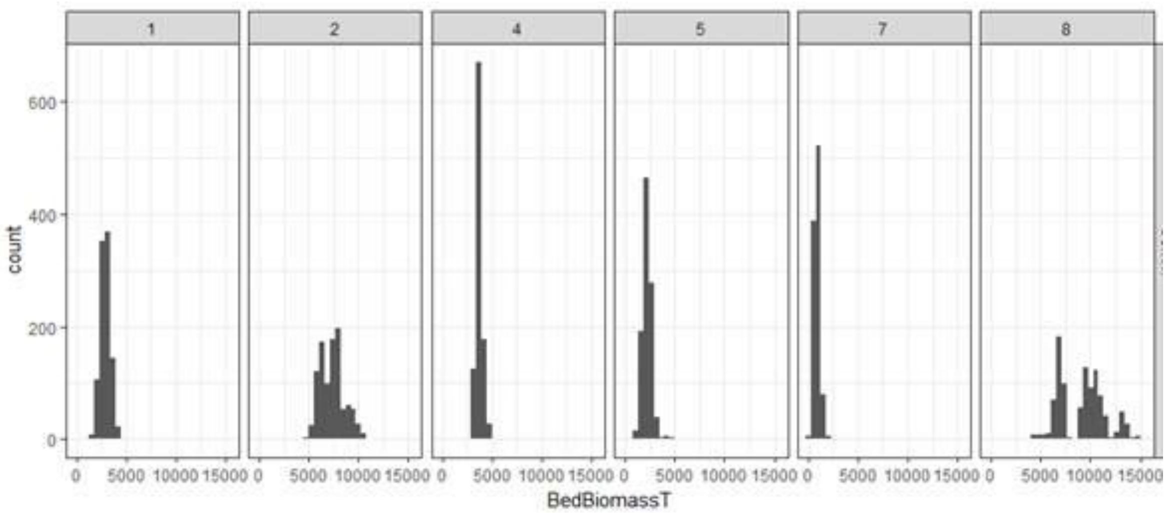

Figure 3.8 Distribution of biomass estimates for beds 1-8 from bootstrapping procedure

3.5.4 Size and age composition from dredge survey

From the size frequencies taken at each station, a total length frequency was first derived by Bed (Figure 3.9), which were then pooled to the total population estimate for each assessment area. Age samples were used to construct a single age-length key for the bed (binned in 5mm groups, Figure 3.10) and this was applied to the total length distribution to derive the age composition observed during the survey. A significant portion of the catch from assessment areas in 27.7.e was below the MLS (Table 3.7).

Table 3.7. Assessment in 27.7.e. Proportion of scallops below the MLS in the commercial dredges from the dredge survey.

Assessment area	Percentage under MLS
27.7.e.I.	21%
27.7.e.O.	32%
27.7.e.L.	16%

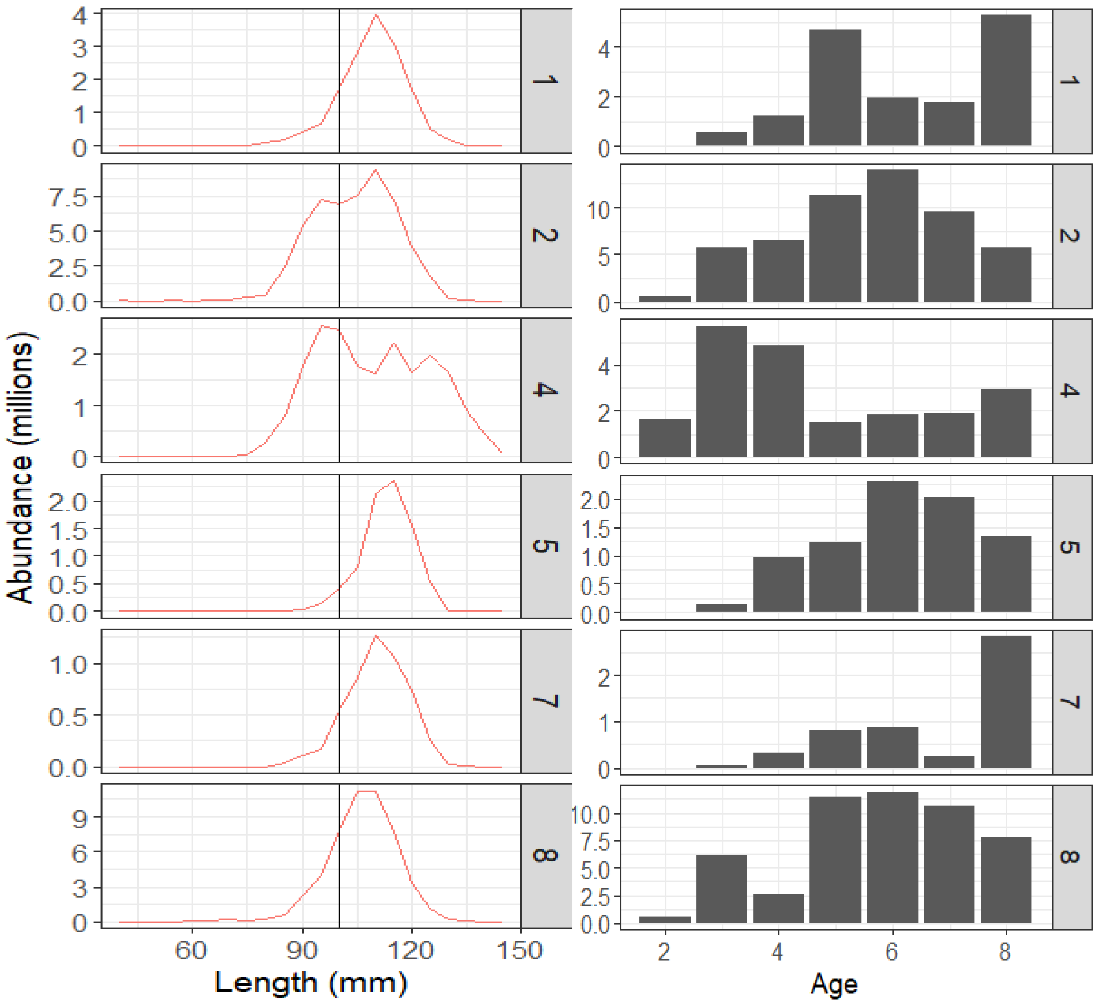

Figure 3.9 – Dredge survey: Bed raised length distribution and age profile for Beds 1-8.

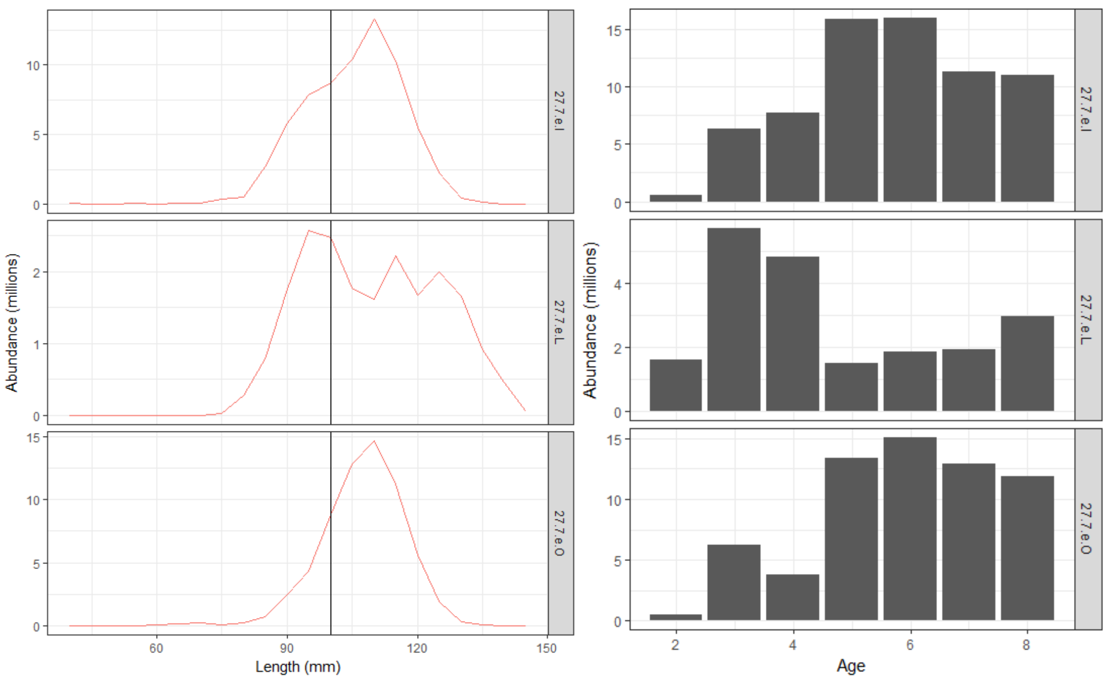

Figure 3.10 – Dredge survey: Age and length distributions for the scallop population in surveyed areas of 27.7.e.I, 27.7.e.L and 27.7.e.O.

3.5.5 Relative abundance from video survey

The video survey observed scallops to be distributed on the seabed in the non-dredged zones at low density. The survey carried out 11-minute tows to optimise coverage in the survey grid with the ship time available, and in line with similar underwater surveys. The camera drop frame required a slow tow speed and these limited the transect length to a little over 100m. As such, a significant proportion of the transects gave zero counts and the highest observed number scallops observed was 7.01 scallops per 100m^2 (Table 3.8). This has given rise to some data distribution anomalies resulting in greater uncertainty in the bootstraps (e.g. the point estimate of biomass lies outside the 75th centile of bootstrapped distributions). Although zero densities are not uncommon in surveys where target species are aggregated on the sea bed, further development of the camera deployment platform and subsequent data processing is planned for 2018-2019.

For comparison 9 video transects were carried out in fished Bed 4 at sites subsequently surveyed as part of the dredge survey a week later. The low densities observed on the video survey were typically consistent with scallop densities taken by the dredges on the dredge survey.

Video survey was not carried out in non-dredged areas of assessment area 27.7.e.O in this initial year.

Table 3.8. Summary of video survey results by non-dredged Zones a, b and c. Number of transects, median density, minimum and maximum numbers 100m^2 and the number of transects with no observed scallops are shown.

Non-dredged zone	Number of transects	Median number 100m^2	Min density	Max density	Number of zero counts
a	25	0.67	0	7.01	9
b	26	<0.01	0	3.71	19
c	12	<0.01	0	2.42	7

Estimated abundance in millions of scallops presented by block in the surveyed non-dredged zones show that highest numbers of scallops were observed in the eastern side of Zone a (Figure 3.11).

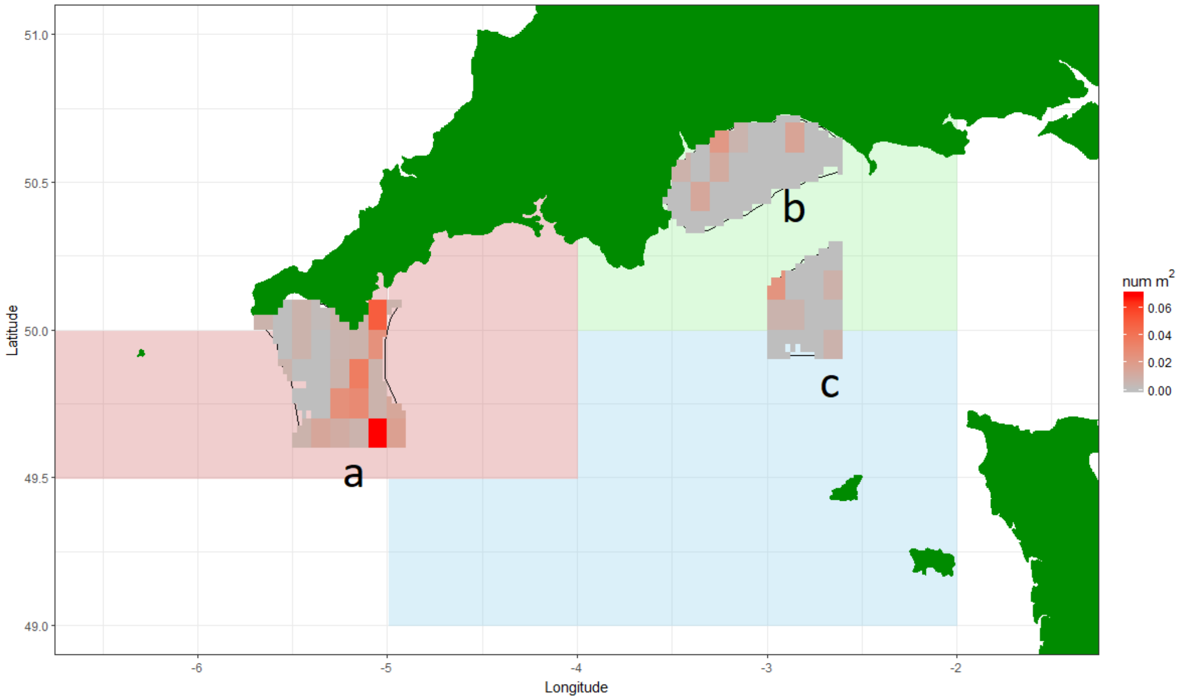

Figure 3.11 Estimated density (numbers m^2) on the TV survey by block and non-dredged Zones a, b and c.

Table 3.9 Bed abundance and percentiles (in millions) from non-dredged areas (estimated by underwater TV survey) and estimated fishable biomass and SSB.

Non-dredged zone	Assessment area	25th centile (millions)	Median abundance (millions)	Point estimate (millions)	75th centile (millions)	Estimated harvestable biomass tonnes	Estimated ssb tonnes
a	27.7.e.i	33.2	40.7	43.4	49.5	6248	6413
b	27.7.e.l	4.4	5.9	8.2	7.7	1523	1675
c	27.7.e.l	3.0	4.0	5.6	6.9	1041	1145

3.6 Harvest Rate Estimation

The harvest rate (i.e. the ratio of landings to total harvestable biomass) is proposed to give a proxy for the fishing mortality experienced by this stock area (Table 3.10). Ideally this will be constructed from the biomass immediately prior to the fishery and then compared to the removals from the observed biomass, however as the survey was undertaken prior to the main fishery in 2017, this is not possible in this first instance. Instead the international landings from 2016 are used.

Table 3.10 Harvestable biomass estimates and harvest rates for the areas covered by the dredge survey.

Assessment area	International landings (tonnes)	Biomass estimate in dredged area (tonnes)	Harvest Rate on dredged portion of stock (Cohort Model)	Harvest rate range
27.7.e.I	2938	10717	27.4%	26.7% - 31.7%
27.7.e.L	1422	3901	36.5%	35.2% - 39.2%
27.7.e.O	1713	12622	13.6%	12.4% - 16.8%

Table 3.11 International landings (tonnes), estimated harvestable biomass (tonnes) and harvest rate (%) incorporating biomass estimate from dredge and TV survey by assessment area.

Assessment area	**International landings**	**Estimated harvestable biomass from dredge survey areas**	**Estimated harvestable biomass from TV survey areas (not 100%)**	**Estimated total harvestable biomass**	**Harvest Rate for wider stock where UWTV available (not 100% coverage)**	**Harvest rate range**
27.7.e.I	2938	10717	6248	16965	17.3%	16.2% - 20.9%
27.7.e.L	1422	3901	2564	6465	22.0%	21.0% - 28.4%
27.7.e.O	1713	12622	NA	NA	NA	NA

3.6.1 Fishing mortality estimates from the landings age composition

Most fully analytical fish stock assessments use a time series of age composition of the landings (along with other data such as total landings/catch and a survey series) to estimate the rate at which the fishery is exploiting the stock. Attempting to glean information regarding fishing mortality from a single year of age composition is fraught with uncertainty and the estimate of fishing pressure arising from the dredge survey is considered to be more robust at this stage.

An investigation into the use of the age composition to estimate fishing mortality was made using a cohort model assumption. This assumes that for the time-span of the ages observed

(8 years in this case), the population has been in equilibrium – that is that fishing effort, recruitment and growth have all been constant. Deviations from this assumption will cause the model to give unreliable answers.

The model requires growth and natural mortality parameters (Table 3.4). Selection at age was estimated using the growth parameters and an assumption that the fishery has knife-edge selection at the minimum landing size. The model estimates the size of recruitment and the fishing pressure required to generate the observed catch numbers at age and the results of the models for the three assessment areas are shown in Figure 3.12.

The estimated fishing mortalities and harvest rates are given in Table 3.12 and candidate MSY reference points are given in table 3.13. The preliminary estimates of harvest rate for stock area 27.7.e.O have an age structure with sufficient proportion of large animals to indicate a low fishing mortality (slightly lower than that implied for MSY). The other stock areas have a truncated age range in relation to the stock status under MSY considerations and therefore the estimated fishing mortality is higher than the MSY reference points.

As well as the highly preliminary and uncertain nature of these estimates of fishing pressure, it should be noted that the MSY harvest rates only relate to the fished portion of the stock. In situations where there are significant portions of non-dredged stock that are contributing offspring to the fished areas, the MSY harvest rate will need to be adjusted to compensate for this.

Table 3.12 Fishing mortality and implied harvest rate by assessment area as estimated by the cohort model on the single year of age data. Initial harvest rates for MSY are also given (see section 3.7).

STOCK (DREDGED PORTION THEREOF)	FISHING MORTALITY	IMPLIED Harvest Rate on dredged portion of stock (Cohort Model)	TARGET HR TO ACHIEVE MSY PROXY
27.7.E.I	0.45	35.3%	24.5%
27.7.E.L	0.42	32.5%	21.0%
27.7.E.O	0.35	28.6%	32.8%

Figure 3.12. Model estimates the size of recruitment and the fishing pressure required to generate the observed catch numbers at age by assessment area.

3.7 MSY Reference Point Estimation

Full estimation of the fishing mortality that generates maximum sustainable yield (MSY) requires a full analytical assessment and an estimate of the stock-recruitment relationship. Clearly this is not yet possible as is the case with many stocks assessed by ICES. In such cases, ICES 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%SpR) is a commonly used reference point, both within ICES and more widely around the globe. Fmax, the fishing mortality which gets the maximum yield from each recruited individual is also sometimes used as a proxy for Fmsy, but is unlinked to spawning potential, is more uncertain in its estimation and in some circumstances, suggests fishing rates which are highly risky for the stock size.

The current estimate of virgin SpR is given in Table 3.13 (the MSY target would to be at at least 35%). Initial estimates of MSY harvest rates are given in table 3.12. The Fmax estimates for this stock are very high because there is relatively little growth potential after the MLS has been reached compared to expected losses through natural mortality. Following the Fmax estimates for all three of these stock units would remove all spawning stock in one year and is therefore highly risky. The recommended FMSY reference point for these stock units are therefore the F35%SpR ones.

Table 3.13 Estimated stock size as a % of unfished status.

Stock	Stock size as a % virign SpR
27.7.E.I	28%
27.7.E.L	27%
27.7.E.O	39%

3.8 Conclusions

This is the initial stock assessment undertaken for scallops in this region. Single years of data are always more uncertain than when a time series are available, so the results of this assessment should be viewed with some caution.

A presentation of the assessment approaches to the ICES Scallop Working Group highlighted that there are several key areas of uncertainty that require further work to better understand their impact and influence. With both the swept area biomass assessment and the underwater TV assessment of the non-dredged area, the key parameter is the gear-efficiency estimate, and even relatively small changes to this estimate would have a significant impact upon the estimated biomass and harvest rate. With the UWTV estimate of “fishable” biomass, the assumption that all individuals observed were >80mm height will also be highly influential on the final result.

The estimate of moderately high fishing pressure arising from the age-structure of landings is driven by the relatively low numbers of scallops age ~6 and older. For a species which is capable of living to >20 years old, the scarcity of such animals points to a fairly high mortality rate, however as previously mentioned caution should be used over interpretation of single years of age data.

We would hope that in future assessments we will be able to see weak and strong year-classes moving through the population structure to give confidence that the sampling scheme is able to adequately follow the population development.

The estimates of current harvest rate obtained from both the survey data and the commercial catch compositions are both subject to high uncertainty due to the limited data available so far (Table 3.14). Similar considerations also apply to the estimate of a harvest rate corresponding to MSY. There is clearly some conflict in the available data regarding the harvesting rate of these three stocks. The cohort model is estimating a much higher fishing rate than the biomass approaches and this will be caused by a relative lack of old animals observed in the landings. This may either be because of a high fishing pressure over the last 8 years, or better recruitment in recent years (or a combination of both). The inclusion of the non-dredged stock areas makes a significant difference to the perception of stock status, moving 27.7.e.I from being fished above the candidate MSY harvest rate to below it. Fishery managers should be confident that the unfished stock is genuinely contributing to the spawning potential of the fished stock before incorporating such estimates in their consideration of stock status.

Table 3.14. Summary of harvest rate estimates for the three assessment areas in 27.7.e

	HR (Dredge Survey Only)	**HR (Inc available Tv Estimate)**	**HR (Cohort Model, dredged stock portion only)**	**HR for initial MSY estimate**
27.7.e.I.	27.4%	17.3%	35.3%	24.5%
27.7.e.L.	36.5%	22.0%	32.5%	21.0%
27.7.e.O.	13.6%	-	28.6%	32.8%

4 Future Developments

These assessments mark the first in what is expected to be an ongoing series of assessments for scallop stocks around the English coast. The assessment techniques employed are expected to evolve over the coming years as more data become available and data quality improves.

Key data issues to develop in the next 12-24 months include

- Gear efficiency (dredge and UWTV) estimates
- UWTV size-selection and/or size frequency
- Improved age sampling
- LPUE linkage with stock size
- Greater understanding of the recruitment linkage between scallop beds and dredged/un-dredged areas.

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Centre for Environment Fisheries & Aquaculture Science

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