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# Cefas Red Bag Scheme Final Report

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# Executive Summary

- Since 2009, Scallops (*Pecten maximus*) have been the most valuable fishery to England, with a first sale value of £28.1 million in 2012 (MMO data).
- The Cefas red bag scheme was launched in 2011 as a means of obtaining sufficient biological information regarding scallop stocks with which to run stock assessments.
- 7 sampling areas were defined on the basis of knowledge regarding fisheries and biology.
  1. North Sea (ICES area IV),
  2. Eastern Channel (ICES area VIId),
  3. Lyme Bay (East VIIe to Start Point, from coastline down to 49° 30<sup>00</sup>N)
  4. VIIe west of Start Point from coastline down to 49° 30<sup>00</sup>N
  5. Offshore (anything south of 49° 30<sup>00</sup>N in VIIe and VIIh)
  6. Celtic Sea (VIIg and VIIf)
  7. Irish Sea (VIIa)
- Samples were to be collected by commercial vessels, passed to processors and the flat shells retained for Cefas. Coordination of vessel identification and sample collection evolved through time but requires a high level of administrative effort.
- Quarterly sampling targets were set (6 samples per area per quarter) but these were rarely met. Sampling was, to an extent, opportunistic the opportunity for obtaining samples was linked to the level of fishing activity.
- A total of 60 vessels contributed to the 150 samples collected between the fourth quarter of 2011 and the second quarter of 2014. Of these vessels, 6 contributed over 50% of the samples and many were the smaller (<15m) vessels.
- Several routes were tried to broaden participation in the scheme including writing to all holders of scallop entitlements. The participation basis has continued to develop but at a relatively slow rate.
- The data collected to date has permitted a preliminary investigation into the potential exploitation rates experienced by two of the stock areas (Inshore Cornwall and Lyme Bay). There were insufficient samples to attempt any form of assessment in the other areas.
- The spatial coverage of the data is not necessarily reflective of the wider stocks, partly due to the number of participating vessels and partly due to the restrictions placed on the fishery by the Western Waters regime. The lack of full spatial coverage may cause bias in the results of the preliminary assessments. Targeted work would be required to estimate the realised magnitude of such potential biases.
- The data from the red bag scheme for the 2012 and 2013 fisheries are insufficient to provide robust, definitive statements regarding the state of the stock either in terms of the stock biomass or the rate at which it is being fished.
- Analysis of the age structure from the landings indicates that fishing activity is unlikely to be below a rate associated with Maximum Sustainable Yield.

- There are however limitations in the data regarding spatial coverage, sample numbers and a relatively small pool of contributing vessels which adds uncertainty to the interpretation of results.

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# 1 Introduction

Since 2009, Scallops (*Pecten maximus*) have been the most valuable fishery to England, with a first sale value of £28.1 million in 2012 (MMO data).

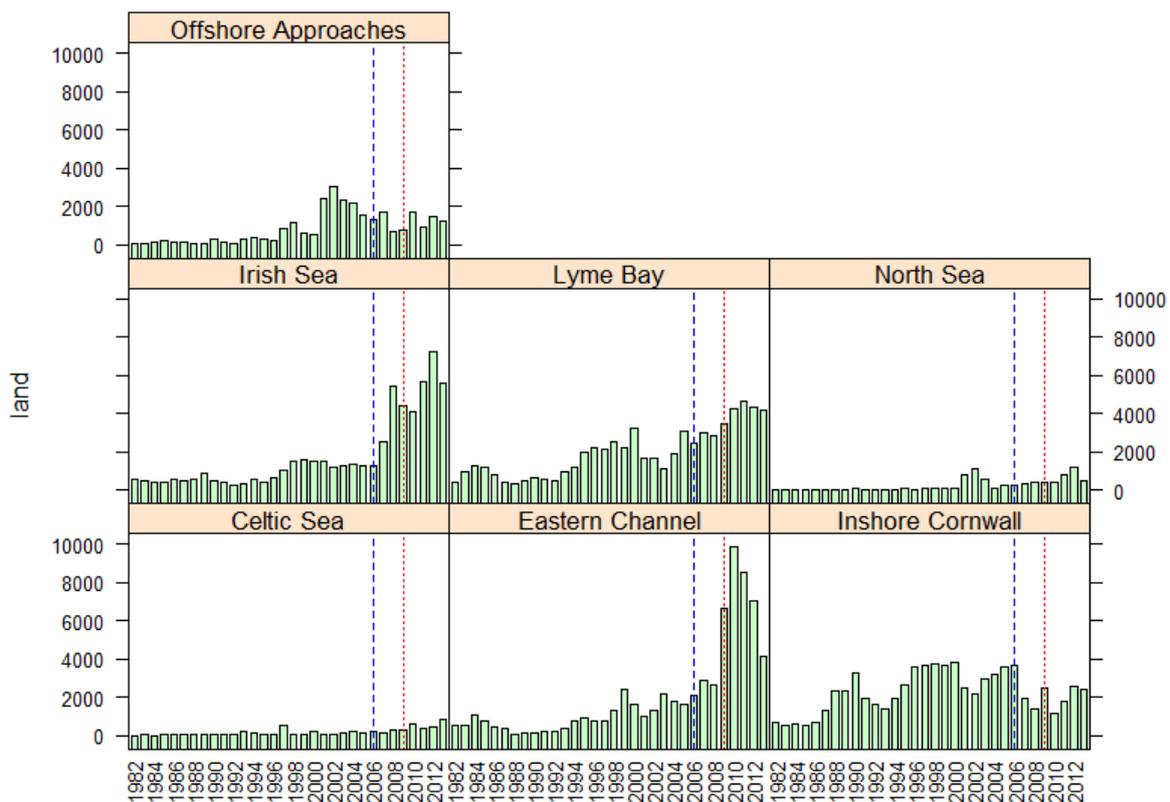


Figure 1.1 Time series of landings of *Pecten maximus* by each Red Bag Zone. The vertical blue line at 2006 represents a change in the way landings were recorded. The vertical red line at 2009 highlights the rapid expansion of the fishery. Data from MMO database on landings and effort.

In 2006 the UK Government introduced legislation requiring the official registration of buyers and sellers of marine fish in response to concern that significant mis-reporting of landings was occurring for a number of species. From 2006 onwards, landings reports corroborated by sales notes from fish merchants, providing greater confidence that records of landings are accurate. The rapid rise in landings around 2009 was driven mostly by activity in the Irish sea and eastern channel.

There are two management measures in force for scallop fisheries within the EU, minimum landing sizes and, for ICES areas VI and VII, the "Western Waters Regime" (WWR). Minimum landing size is 100mm for ICES area IV and VII with the exception of areas VIIA and VIID where the MLS is 110mm to reflect the faster growth rate reported in this region. The WWR was introduced in 2004 as a

means of capping effort in a number of fisheries including those fisheries for scallops. EU legislation 1415/2004 specifies the number of kilowatt-days of fishing activity for vessels >15m in length dredging for scallops, these levels representing the average of reported levels by member state over the reference period 1998-2002.

The fish and shellfish species managed through the Total Allowable Catch (TAC) system of the European Union require annual or biennial stock assessments to service the setting of quotas. Management responsibility for fisheries on species outside the TAC system fall to the individual Member States and until relatively recently there had been no demand for an analytical assessment of scallop stocks and fisheries. In addition to the rise in commercial importance of the scallop fishery, the EU members have signed up to the Marine Strategy Framework Directive (MSFD) which aims to achieve "Good Environmental Status" by 2020 and places obligations upon member states to manage their activities which impact upon the marine environment. There are 11 different aspects (termed "descriptors") to the MSFD with two of them (descriptors 3 and 6 relating to populations of commercial fish/shellfish and Sea Floor Integrity) having particular relevance to the scallop fishery. Descriptor 3 states that

*"Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock"*

With further elaboration that

*In scientific terms, Descriptor 3 has various implications. Stocks should be, (1) exploited sustainably consistent with high long-term yields, (2) have full reproductive capacity in order to maintain stock biomass, and (3) the proportion of older and larger fish/shellfish should be maintained (or increased) being an indicator of a healthy stock*

The EU is using the concept of Maximum Sustainable Yield (MSY) to be the metric against which fishery management objectives are to be set.

Descriptor 6 states that

*"Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected"*

Whilst this report does not make any further reference to descriptor 6, it should be borne in mind that there is a statutory obligation for member states to consider the impacts of any fishing activity which has an impact upon the sea-floor (as dredging does) as part of the overall management objectives.

Given the rise in importance of the fishery and the requirements of the MSFD it has become imperative that work is undertaken to understand the state of the stocks and how the fishery may

be impacting upon them and since 2011 Cefas has been working towards producing stock assessments for scallops. Whilst prior to this there had not been a regular programme directed towards scientific stock assessments, Cefas has in the past run several programmes of scallop research. These include a tagging experiment; a series of annual surveys to study recruitment variability; a study of the primary settlement sites chosen by scallop spat; two depletion fishing experiments to estimate the catching efficiency of commercial dredges; a study of spatial variation in scallop abundance; development of an ageing technique; a number of general stock surveys. Virtually all of these studies were conducted in the Western Channel which was, until the turn of the millennium, the most important scallop fishing area in English waters.

Stock assessments use data from fishery-independent surveys and/or sampling from commercial operations. Data from scientific surveys are used as observations of the stock from which can be deduced what the fishery impacts are, whilst analysis of commercial data works the other way round and the state of the stock is deduced from the fishery outputs. Ideally both of these data streams are used in stock assessments and this is the practice for most of the commercial fin-fish stocks and is the methodology used for assessment of scallop stocks in Scottish waters. Given the available budget for scallop stock monitoring only one pathway could be followed and the decision was made to use sampling of commercial outputs as this had the potential to provide a greater number of samples over a wider area.

Scallops are essentially sedentary animals. Although they have the potential to move, tagging projects have shown that individuals over the age of around 1 do not undergo large scale movements. The larvae on the other hand are present in the water column for around 30 days and are therefore capable of being transported considerable distances. There are no data available for what happens to individuals after they have settled out from the planktonic phase until around 1-2 years of age. Previous Defra funded studies have shown that growth rates of individuals are highly variable over relatively short distances within the English Channel. These factors present significant challenges to obtaining accurate information about stock status. The identification of biologically functioning stocks requires an understanding of the hydrographic currents and larval dispersal. Our understanding of these processes leads to the definition of fairly large stock areas although these are at a smaller scale than most fish-stocks are assessed. Within any one particular year the arrival of larvae will be patchily distributed across the stock area and within the stock unit there will also be areas of different growth rates. In order to ensure that these different factors are appropriately accounted for any sampling scheme needs to ensure that a large number of samples are collected in a spatially distributed manner.

## 2 Red Bag Scheme

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The Red Bag Scheme was devised as a physical means of getting the upper (flat) shells from commercially caught scallops to Cefas for a minimum of inconvenience to fishermen, processors and scientists. The flat shells contain information about age as during the winter there is a period of slower growth where the fine concentric ridges are packed tightly together. By counting these compression areas it is possible to determine the age of individual scallops, and these data can be inputted to assessment models which interpret the change in observed numbers at age into estimates of mortality rates.

A similar process to that adopted for sampling fin-fish was adopted in that the predominant information collected from each sample is the length frequency (numbers at size). A sub-sample (at least 5 per 5mm length class) was taken and the age of each shell determined. The sub-samples are then used to produce an age-length key in order to estimate the age structure of the entire sample. It is impractical to measure the age of each individual as this is a relatively time consuming exercise as each shell must be scrubbed clean, dried, measured, examined under microscope and the data recorded and quality controlled.

The protocol is given below but essentially the fishers were requested to put all scallops above minimum size from two or three dredges into a special red bag along with a waterproof form containing details of the catch. This was then sent to the processor as normal and would be paid for in the same manner as all "normal" sacks. When the processors came to shuck that particular sack, the operative responsible for that sack would work as normal *except* that the flat shells would be put back in the red bag rather than disposed of as normal. Cefas would then arrange for collection of the red bag.

In order for the data to be analysed in a biologically meaningful manner, a zoned approach to data collection was devised. It is already understood that scallops in different areas have markedly different growth rates and are likely to be exploited at different levels, therefore the scheme had to attempt to match these areas. It is acknowledged that any partitioning of data along spatial lines will be arbitrary to some extent as characteristics will change over a gradient rather than adhering to an artificial straight line. Seven sampling zones were defined on the basis of experience and data from previous projects such that each zone broadly represented either a different stock unit, or fishery, or was related to particular biological characteristics of scallops from that ground.

1. North Sea (ICES area IV)
2. Eastern Channel (ICES area VIId)

3. Lyme Bay (East Vlle to Start Point, from coastline down to 49° 30'00"N)
4. Vlle west of Start Point from coastline down to 49° 30'00"N
5. Offshore (anything south of 49° 30'00"N in Vlle and VIIf)
6. Celtic Sea (VIIf and VIIf)
7. Irish Sea (VIIa)

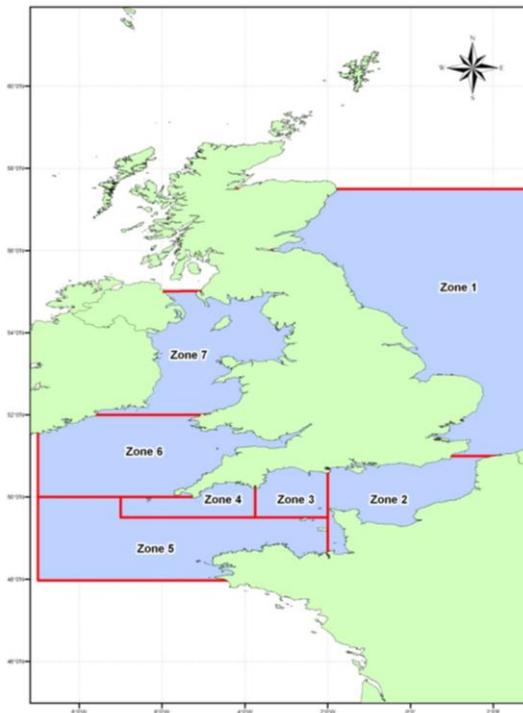


Figure 2.1. Definition of the sampling zones for the Red Bag Scheme

## 2.1 Red Bag Scheme protocol

Skipper:

These samples will go to the processor as normal, but they will retain the flat shells for scientific analysis of age by CEFAS.

A sample of at least 120 above MLS is required. Keep the total catch from each of the number of dredges required to provide the sample. (For example; if two dredges contain only 90 sizeable scallops please add all of the catch from a third dredge, even if this takes the number in the sample much higher than the 120 required).

When sorting the sample, put all scallops above MLS into the Red bag and count the undersize.

Fill in the sample sheet (it will be printed on water-proof paper) and put it in the Red bag with the sample.

Write the Vessel name or number together with the date of capture on the Red bag and seal the bag.

Land the Red bag sample to the processor with the rest of the catch as usual.

 <b>SCALLOP SAMPLING PROGRAM</b>			
Vessel Name	<input type="text"/>		Vessel RSS <input type="text"/>
<b>Tow Information (END OF HAUL)</b>			
Date	<input type="text" value="___ / ___ / ___"/>		Time <input type="text" value="__:__"/>
Latitude	<input type="text"/>		Belly ring size(mm) <input type="text"/>
Longitude	<input type="text"/>		
(please give position as accurately as you can)			
Tow duration (minutes)	<input type="text"/>		Tow speed (knots) <input type="text"/>
Total number dredges	<input type="text"/>		Total catch (all dredges) in sampled tow <input type="text"/> doz
Number dredges sampled	<input type="text"/>		Number undersize scallops (sampled dredges only) <input type="text"/>

Figure 2.2. The sample information form to be returned with each sample.

Processor:

Collect Red bag along side other scallop bags as usual ensuring that the sample sheet stays with the sample.

When processing scallops from Red bag, return the flat shells back into the Red bag and set aside for collection by Cefas.

Contact Cefas and advise of sample ready for collection

## 2.2 Timeline of activities

The scheme began in late 2011 through discussions with Seafish and the University of Bangor, combined with port and processor visits by senior Cefas scientists. The scheme deliberately started at a fairly small scale in order to establish best practice, albeit working in conjunction with one of the UK's major scallop processing operations (Falfish of Redruth, Cornwall). Cefas were to supply the bags and instruction manuals to a manager at Falfish who would facilitate the organisation of sample collation on the basis that the processors had more up to date knowledge of who was fishing where and when so as to ensure that samples were obtained on an appropriate spatial and temporal scale. Targets of 6 samples per quarter per Scallop area were set as minimum requirements.

This arrangement was reviewed in the spring of 2012 as it was apparent that the scheme needed to be widened to other processors so as to increase the sample numbers and geographic spread. The scheme was publicised through an article in the Fishing News, although this only generated 4 queries, none of which resulted in additional participants in the scheme. Direct approaches were

made to fish processors handling scallops as well as industry contacts through the Scallop Association. The contact schedule was modified and participating processors and interested fishermen were contacted and texted on at least a monthly basis to prompt interest and provide reminders for collecting samples. This promoted a good initial influx of samples through the main participating processors Falfish, Coombes, Samways, A+M, Scott(MacDuff), T+N Trawlers and Ocean Fish. In the fourth quarter of 2012, samples slowed, so the contact schedule was increased with more regular weekly or fortnightly contacts being made to remind participants about red bags along with general requests to obtain more contacts. From November 2012 the Cefas website hosted details of the scheme, including sampling protocols (<http://www.cefas.defra.gov.uk/our-science/fisheries-information/commercial-species/shellfish.aspx>) and this pages were updated on a monthly basis with graphics showing sample locations and progress towards targets. From July 2013 the site also hosted pages detailing preliminary analysis of the samples.

A PhD student at the university of Bangor working on Scallop management issues, jointly supervised by Cefas, undertook a series of interviews and sea-trips with fishers and this opportunity was used to demonstrate and promote the Red Bag Scheme.

Further efforts were made to bring more vessels onto the scheme in order to increase participation and reduce reliance upon a few key vessels. In the second quarter of 2013, a letter was posted to all those registered as having a scallop entitlement on their licence representing over 400 individuals. This approach delivered just one response, and that was from a fisherman explaining that he had sold his vessel. May 2013 saw the publication of the sampling protocol (including the pictorial guide) translated into additional languages of Polish and Filipino in response to industry requests.

In the third quarter 2013 there was another push for sampling and vessels were encouraged to land weekly samples rather than monthly or fortnightly. An email was distributed to all Scallop Association members to encourage further support and interest. Cefas made use of data from the AIS system to locate where and when vessels associated with scalloping were active with the aim of improving the prospects for more complete spatial coverage.

At several occasions since the inception of the scheme, the processes and results of the red bag scheme have been presented at different fora, including the Scallop Association, the Shellfish Association of Great Britain (Molluscan committee) and the Scallop Industry Action Group.

### **2.3 Scheme results to date**

Around 1500 red bags have been distributed and 60 vessels have registered interest in the scheme. As of June 1<sup>st</sup> 2014, 150 samples have been provided to Cefas, generating more than 23,000 shells which have been measured of which over 3,600 have undergone age reading.

The 150 samples are the product of collaboration and participation of 10 processors and 30 vessels. Of these 30 vessels, 10 are under 15m. Sample provision by vessel has been skewed with 6 vessels providing over 50% of the samples (figure 2.3) and of these 6, three are under 15m. In itself this skewing of samples to key vessels is not a problem, provided that the range of locations and fishing operations can be considered to be representative of the fleet as a whole.

The processors involved in the scheme have played an invaluable role from the start and have provided time and resource to assist with requesting and retaining samples (including prompting vessels to remember to land samples). In addition there have been a number of individual, dedicated skippers that have regularly brought in red bags without prompts. The assistance from these persons has been the back bone of this voluntary scheme and their inputs are very much appreciated.

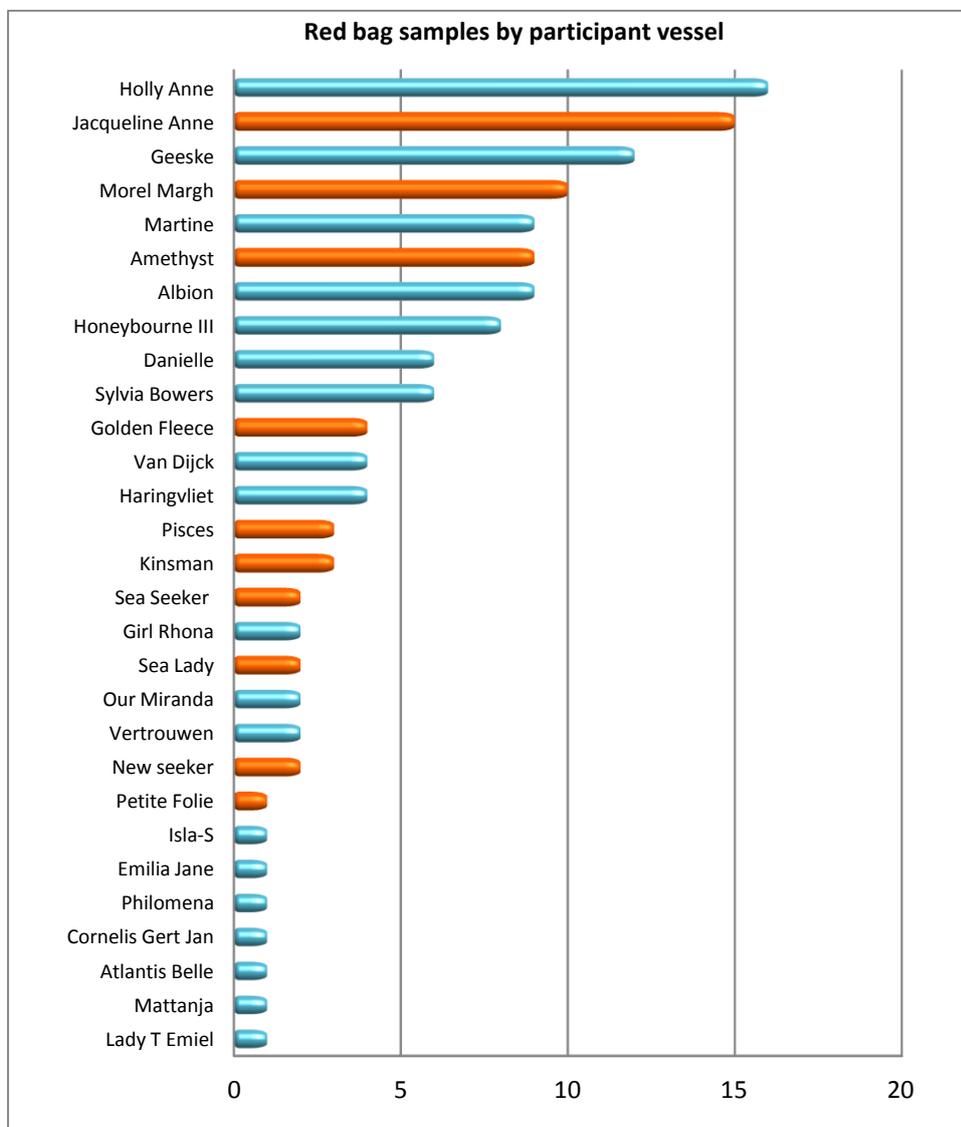


Figure 2.3 Samples received at Cefas per vessel. Blue bars are vessels >15m, orange are below 15m.

Since its inception the scheme has struggled to reach the target level of 6 samples per quarter per area, with only one of the regions (Lyme Bay region) achieving this level with any regularity (figure 2.4). The sampling level is such that preliminary assessments have been conducted for areas 3 and 4 pooling the results from the 2012 and 2013 sampling programmes. The data from other areas are considered insufficient to offer anything of sufficient robustness for analysis.

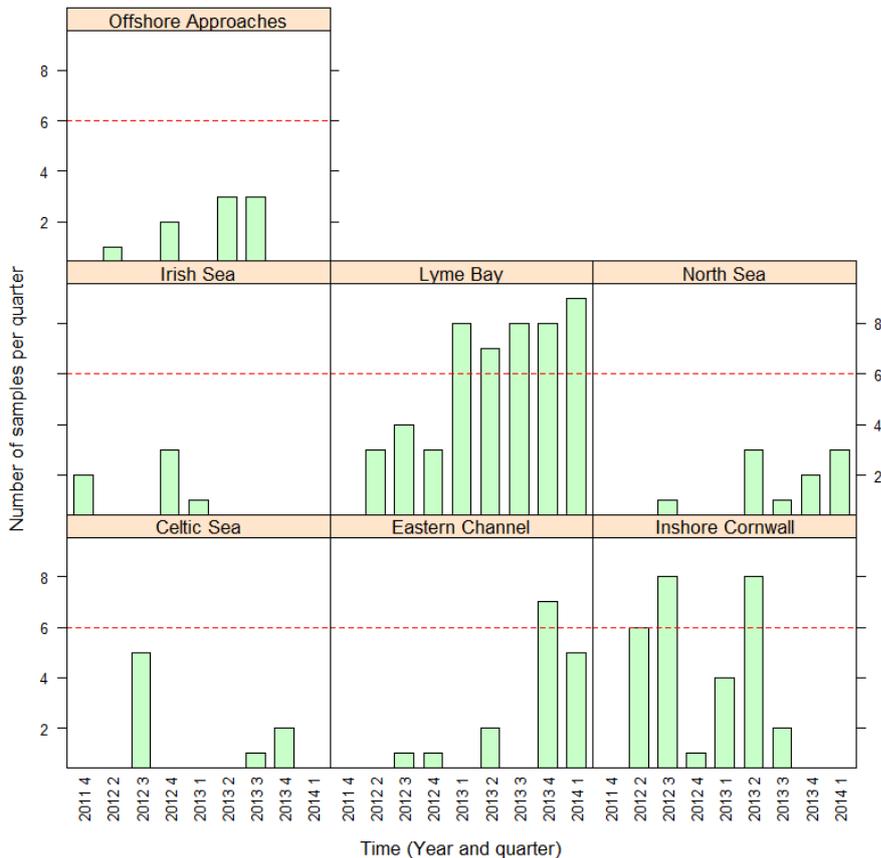


Figure 2.3. Number of samples generated per quarter per sampling zone. The red dashed line gives the target figure of 6 samples per quarter.

The spatial distribution of samples within the English Channel for 2012 and 2013 are shown in figure 2.4. In the eastern channel (zone 2) there were only two samples in 2012 and these are reported to come from the extreme western end of the fishing area, whereas the bulk of the activity appears to have been around 70km to the west. Conversely for 2013 the zone 2 samples all came from the western end of the zone whilst the VMS activity is more evenly spread along the zone. Within zone 3 (Lyme bay), VMS activity and sample locations appear to be well matched with a reasonable spread of sample locations. The samples from zone 4 (Inshore Cornwall) are mostly from close inshore and come from the <15m sector, which explains the disparity with the sample location and

VMS activity although it does raise questions regarding the representativeness of the samples to the zone as a whole.

The spatial distribution of fishing effort in the channel is somewhat dynamic, with some areas receiving regular visits whilst other areas are more sporadic (figure 2.5). The intensity of effort within these patches also varies on an annual basis and is likely to be a partial reflection of localised recruitment events to the stocks. Unfortunately the effort data for the <15m fleet is at a much coarser spatial scale and so we are unable to investigate the potential for different exploitation rates within and between grounds for the scalloping fleet as a whole.

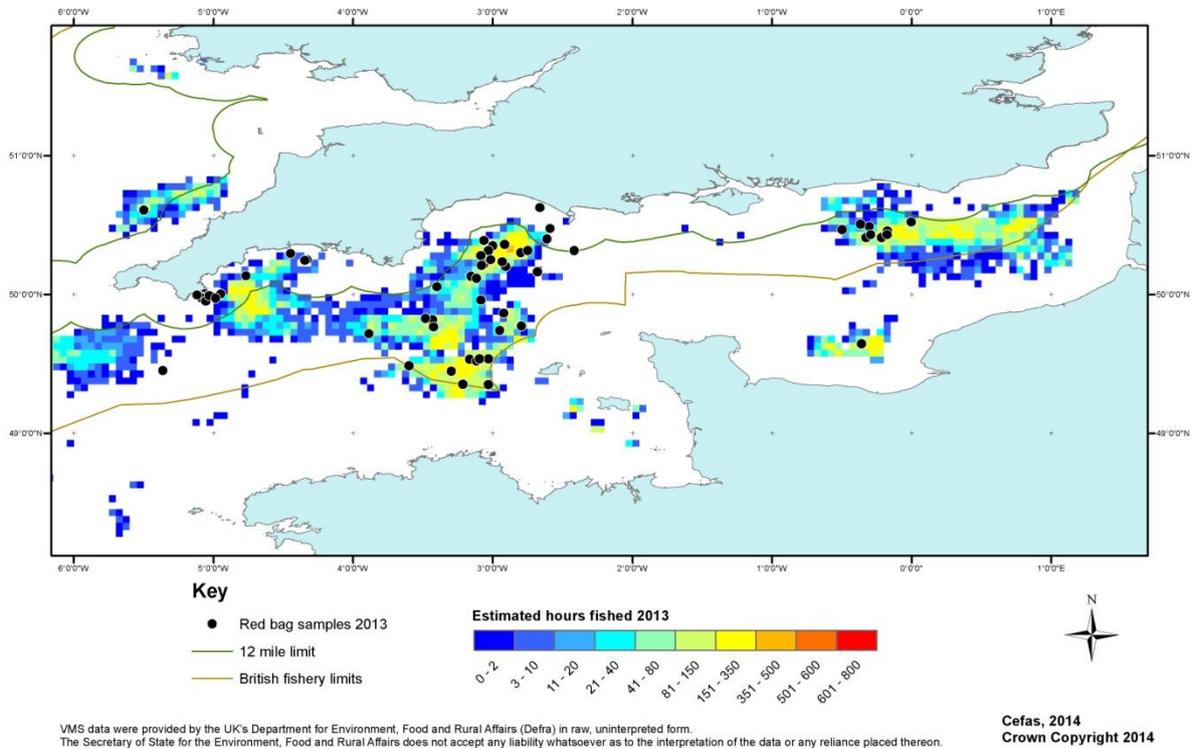
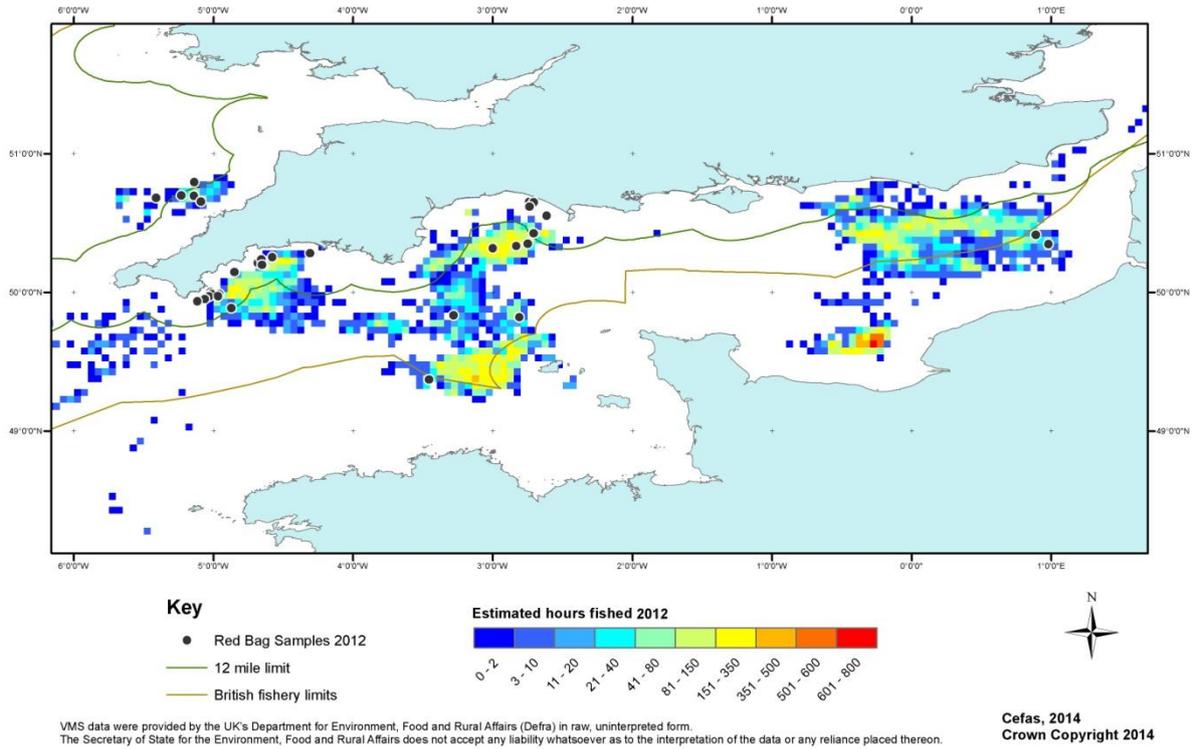
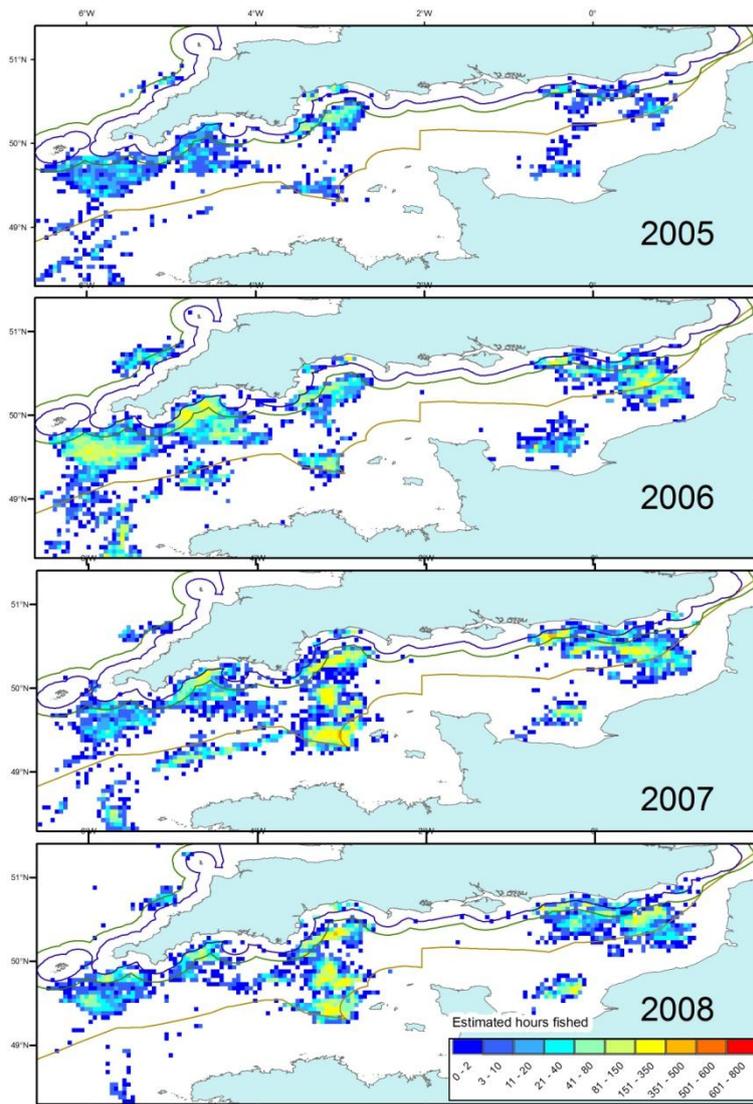


Figure 2.4 Sample locations (black dots) within the English Channel for 2012 and 2013 overlaid on UK fishing activity as estimated through VMS data.



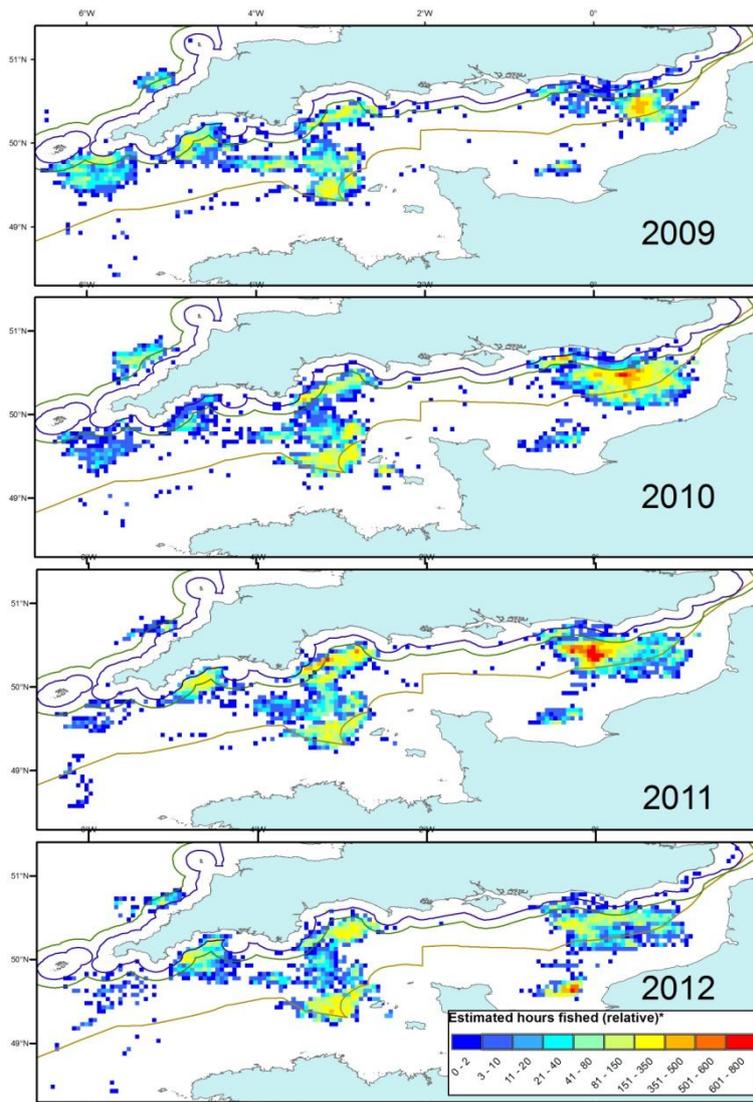


Figure 2.5 Estimated fishing activity by UK dredgers >15m from VMS data

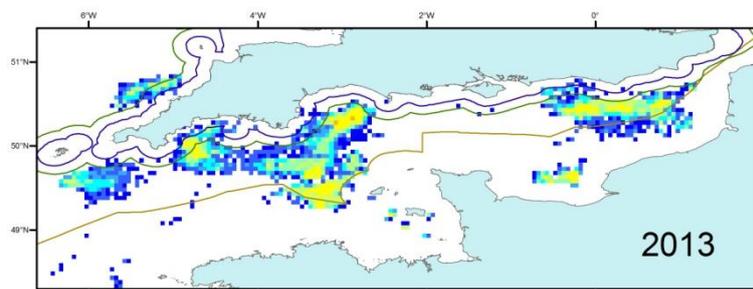


Figure 2.5 (continued) Estimated fishing activity by UK dredgers >15m from VMS data

## 2.4 Logistical issues

Cefas is spending considerable time in communication with the Scheme participants in order to obtain samples. It typically takes between 6 to 15 communication events to generate each sample delivery. There was some initial caution regarding participating in the scheme so has required to

settle in with time and once on-board, skippers generally seem content to continue working with the scheme although there have been some recent withdrawals. As described above, developing new connections and contacts has required considerable effort. One plan to use the email system connected to the VMS units on the larger vessels was unsuccessful as the MMO would not pass on the email addresses due to data confidentiality concerns.

In addition to the main problem of insufficient sample numbers a number of issues have caused problems in obtaining the data including:

- Data form completion. This has been a notable problem and has included samples landed with no data forms at all, missing data entries or incorrect or illegible data recorded. The data requested was important for analysis and missing data directly affects the quality of the analysis possible on a sample. Invariably the skippers have filled in the PLN of the vessel rather than the RSS identifier requested. This causes problems when establishing the vessel characteristics from MMO data as the PLN is not unique and can be transferred to different vessels, whereas RSS is always unique.
- Samples have been lost or discarded accidentally prior to Cefas collection.
- Round shells have been retained at the processors instead of flat.
- Samples have been collected outside of scheme boundaries.

## 3 Stock Status Assessment

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### **3.1 Assessment methodology**

The purpose behind the RBS was to generate data of sufficient quality to undertake stock assessments and estimate the exploitation rate on the stocks.

All stock assessment approaches currently used in ICES require time series of data including annual landings (preferably disaggregated to age or length) and some proxy for stock abundance, usually taken as catch per unit effort (CPUE) from a survey and/or commercial fishery if appropriate (see section 3.2). The length of time series required depends somewhat upon the life-history of the species, but should be sufficient to track at least one cohort as it passes through the fishery.

The "gold standard" of fisheries stock assessment is the age based assessment, in which annual cohorts of individuals are followed from an early age (usually 0 or 1 year olds) to their effective extinction with the fishing rate being estimated annually.

Evidently the data collected so far in the RBS does not meet the requirements for a full age-based assessment. The approach adopted here is a bespoke assessment model which determines the most

likely fishing rate given the short time series of age structures available. The model simulates the evolution of a population of scallops over a long sequence of cohorts (a time series of 1000 cohorts was used). Within the model, the cohorts were exploited by a fishery using a fixed selection pattern (probability of selection by the fishery by age), and a fixed overall fishing rate. This process generates catch numbers at age and the model seeks to match these projected age distributions to the ones observed in the red bag scheme by adjusting the fishing rate and selection pattern. The large number of years is used to explore assumptions about variable recruitment (outlined below). Alternative approaches to age-based assessment, such as surplus-production modelling, are less data-demanding were considered but there are significant issues with such approaches which cast doubt on their suitability for scallops. Although the data requirements for surplus-production modelling are lower in that age or length based data are not necessary, the model is dependent upon a long time series of fishery data (landings and effort), preferably back to the inception of the fishery. In addition to this the concept that commercial CPUE is linearly related to stock abundance is statistically flawed for sedentary species such as scallop.

### **3.2 Appropriateness of CPUE as an index for scallops**

For CPUE (or, more accurately, landings per unit effort, LPUE) to be linked to stock abundance, there is the assumption of instantaneous random mixing after each fishing event. In effect what this means is that every individual in the population has the same probability of encounter with the fishing gear. For highly mobile species this assumption is not too badly violated unless the species exhibits strong shoaling behaviour, but for sedentary species such as *Pecten maximus* there is sufficient concern that commercial CPUE will not be linearly related to stock abundance.

Fishing is largely an economic activity with fishers seeking to maximise profit. With known beds of scallops, fishers will target areas likely to provide the highest catch rates and will move on when catch rates fall below a certain threshold. In addition they may sequentially move over a bed rather than repeatedly fishing the same tows or at random. In the example below, a fishing operation moves sequentially over a bed with 100% efficiency. In the first pass they catch 25 individuals, covering 5 squares giving a CPUE of 5. This action is then repeated in the second pass but shifted to a different fishing line, resulting in another catch of 25 and a CPUE of 5. This fishing pattern is repeated until all the ground is covered. At the end of this the CPUE has been at a constant level of 5 whilst the stock has decreased to zero. If however either the fishing pattern, or the individuals moved at random, then the CPUE would gradually decrease in line with stock abundance. Whilst scallop fishing operations are not as extreme as the above example they are not a completely random action. The maintenance of a near-constant catch rate whilst stock numbers decline is

termed "hyper-stability" and had been observed in many stocks, including scallops (e.g. Falkland Islands) and therefore the use of commercial CPUE as a linear measure of stock abundance is not considered appropriate. CPUE from scientifically organised processes in which gears are standardised and fishing tows undertaken in a prescribed (non-profit driven) manner could produce sufficiently robust data to use for assessment purposes.

Virgin state	First pass	Second pass	Third pass
5 5 5 5 5	0 5 5 5 5	0 0 5 5 5	0 0 0 5 5
5 5 5 5 5	0 5 5 5 5	0 0 5 5 5	0 0 0 5 5
5 5 5 5 5	0 5 5 5 5	0 0 5 5 5	0 0 0 5 5
5 5 5 5 5	0 5 5 5 5	0 0 5 5 5	0 0 0 5 5
5 5 5 5 5	0 5 5 5 5	0 0 5 5 5	0 0 0 5 5
Stock = 125 (100%)	Stock = 100 (80%)	Stock = 75 (60%)	Stock = 50 (40%)
Expected CPUE = average density= 125/25=5	Expected CPUE= average density= 100/25=4	Expected CPUE = average density= 75/25=3.33	Expected CPUE = average density= 50/25=2
Catch=25, effort=5 Observed CPUE=5	Catch=25, effort=5 Observed CPUE=5	Catch=25, effort=5 Observed CPUE=5	Catch=25, effort=5 Observed CPUE=5

Figure 3.1 Demonstration of how CPUE can be a flawed proxy for stock abundance when there is a lack of random mixing of stock and/or fishery operations.

### 3.3 Assumptions used

Given the short time series of age-based data, the analysis presented here is forced to make some key assumptions, primarily around the concept of the stock being at equilibrium. This means that the stock is assumed to have experienced constant recruitment and fishing mortality for the life duration of the animals in the model. The step-change in fishing effort in 2009 clearly violates this assumption. The majority of animals observed in the 2012 and 2013 fisheries were aged between 3

and 7. Individuals aged 7 in 2013 were age 3 in 2009 meaning that the fishery has always been acting on them at the higher level (there should be little effect for the younger ages as they will be mostly under the minimum landing size). Only those individuals aged 7 in 2012 will have experienced the lower and higher levels of fishing effort. We therefore assume that the 2009 effort shift will have minimal impact.

There are insufficient data to estimate the strength of each year-class within the observed data, hence the basic assumption of constant recruitment. In order to better capture the uncertainty in historic recruitments, the model was constructed to simulate population structure over a long time period (1000 years) in which recruitment varied (around a mean with a log-normal distribution). The potential influence of the level of recruitment variance was tested by running the model with different levels of variance.

The model uses the standard Baranov catch equations (as used in the normal ICES stock assessments) to project the development of the cohorts through time and estimate fishery extractions. For each model scenario, a minimisation algorithm was used to determine which fishing mortality and selection parameters could best replicate the age distribution observed from the Red Bag Scheme samples, the model producing not only the best fit parameters but also an estimate of the uncertainty around each parameter.

Fishery selection at age is assumed to be a sigmoid function whose parameters are fitted as part of the modelling process. The use of this function means that selection by the fishery increases with age and then reaches a plateau. Some fisheries experience reduced selection at age as animals are less catchable through either a behavioural response (e.g. swim faster or move to different habitats) or are physically excluded from the gear. There are no concerns regarding a change in behaviour of scallops with age and although there may be some issues of gear selectivity at very large sizes it is not thought to be an issue for the sizes of scallops observed in the sampling.

What may be of greater concern is the sole reliance of the model upon commercial operations which are profit driven and therefore more likely to seek out areas of highest catch rates. Given the patchy nature of scallop recruitment, there is the potential that the younger, more abundant age classes will be spatially distinct from areas holding older individuals and therefore fishery operations seeking to maximise catch rates will end up having a greater focus on areas of younger individuals. There is therefore the possibility that the commercially obtained samples may be inadvertently biased towards younger ages whilst the model used here assumes there is no bias in the sampling. The model interprets any lack of older scallops as evidence of high fishing rates and therefore any such bias in the samples could result in an over-estimate of fishing rates. Having said that, stock assessments of *Pecten maximus* produced by Marine Scotland (Science) which incorporate both

commercially derived samples and fishery-independent samples do not show evidence of significant targeting of younger ages by the commercial fleet. The assumption in this preliminary assessment is therefore that the same practices occur in English fisheries as the Scottish ones.

Input parameters to the model are the rates of natural mortality and maturity rates along with a fixed value of recruitment. Natural mortality is assumed to be low (0.15) for the sizes that occur in the fishery. Sources of mortality are recorded as burial (from sediment transport), temperature changes (severe cold), predation (starfish and brown crab), plankton blooms, and incidental damage from trawls. With regards to predation events *P. maximus* have been shown to demonstrate escape responses from starfish ("clapping" of the adductor muscle to propel themselves away), and *Cancer pagurus* have not been observed to prey upon *P. maximus* which are greater than around 80mm shell height (i.e. below the sizes observed in the fishery and therefore below the size included in the model). Whilst predation obviously occurs, it is unlikely that it is been grossly underestimated given the maximum age that can be achieved (typically ~15 years, ~25 years in exceptional cases). The low rate of 0.15 that is used here and widely used across the North East Atlantic scallop stocks is consequently considered to be a plausible value in the current analysis.

Maturity at age estimates were derived from analysis of historical data sets which give maturity at size, combined with current growth rate estimates from the Red Bag Scheme data.

### **3.4 Maximum sustainable yield**

The fishing mortality rates which should deliver Maximum Sustainable Yield (FMSY) were estimated using the same protocol as used for crab, lobster and Nephrops. The model estimates the fishing mortality which allows the stock to generate spawning biomass from each recruit at 35% of the virgin (unfished) state. There is some academic debate as to the optimal percentage used for an FMSY proxy, with suggested proxies ranging between 30%-40%, consequently 35% is commonly used as a general proxy for FMSY.

The effect of uncertainty surrounding natural mortalities was tested by adding  $\pm 25\%$  to the value used in ICES assessments.

### **3.5 Results**

The results of the modelling are shown in figure 3.2.

The current estimates of fishing mortality are uncertain with 95% confidence limits of around  $\pm 30\%$ .

The different levels of assumed recruitment variability have little impact upon the model results.

There is a slight narrowing of the confidence intervals of the model fit with increasing recruitment variability which fits with the fundamental understanding of scallop recruitment dynamics as being

highly variable. For the purposes of comparison between different model scenarios (table 3.1) a high level of recruitment variability of 0.9 has been used as this is considered in line with the level of variability observed on the ground.

Natural Mortality assumption	M=0.15			M -25%	M +25%
Year range	2012 + 2013	2012	2013	2012 + 2013	2012 + 2013
Lyme Bay	0.37 (0.20)	0.37 (0.20)	0.37 (0.22)	0.38 (0.16)	0.32 (0.23)
Inshore Cornwall	0.64 (0.16)	0.56 (0.19)	0.79 (0.18)	0.66 (0.13)	0.62 (0.19)

Table 3.1 Results from preliminary assessments under different model scenarios. Values are the 50th centile Fishing mortality values at an assumed recruitment variability of 0.9 . The estimate of FMSY is given in the brackets.

The Lyme Bay stock appears to be fished at a much lower rate than the Inshore Cornwall stock. This result stands whether looking at the pooled years or the separate years. For Lyme Bay there is a high degree of consistency between the two separate years, suggesting that the sampling level achieved in this area is providing robust results (as we would not expect this assessment methodology to produce large inter-annual differences). There is some difference between the results of two years of Inshore Cornwall data indicating that the lower sampling rate was not sufficient for robust results, although the difference is well within the confidence interval of the model. The standard practice for assessments using an equilibrium assumption (i.e. assuming a static level of fishing mortality over several years) is to pool length frequencies together over several years, so it is reasonable to assume that the results from the pooled years are more appropriate than the separate years, particularly for the Inshore Cornwall stock.

The 50<sup>th</sup> centile estimate of fishing mortality is above the FMSY rate for all model scenarios of both stocks. There is some overlap of the confidence interval of fishing rate and FMSY for the Lyme Bay stock when a higher natural mortality rate is used, but this overlap is small. The FMSY estimate for the Lyme Bay stock is higher than for the Cornwall stock, this being a function of the more rapid growth rate of the Lyme Bay individuals.

Changing the assumption of natural mortality has some effect upon the model results, a higher natural mortality rate decreases the estimate of current fishing rate and also increases the value of FMSY. As described earlier, the rate of natural mortality used in this exercise is the same as used across the North Eastern Atlantic and is considered appropriate given the potential maximum age that scallops are observed to achieve. Even if natural mortality is 25% higher than the value assumed, the current fishing mortality is estimated to remain above FMSY.

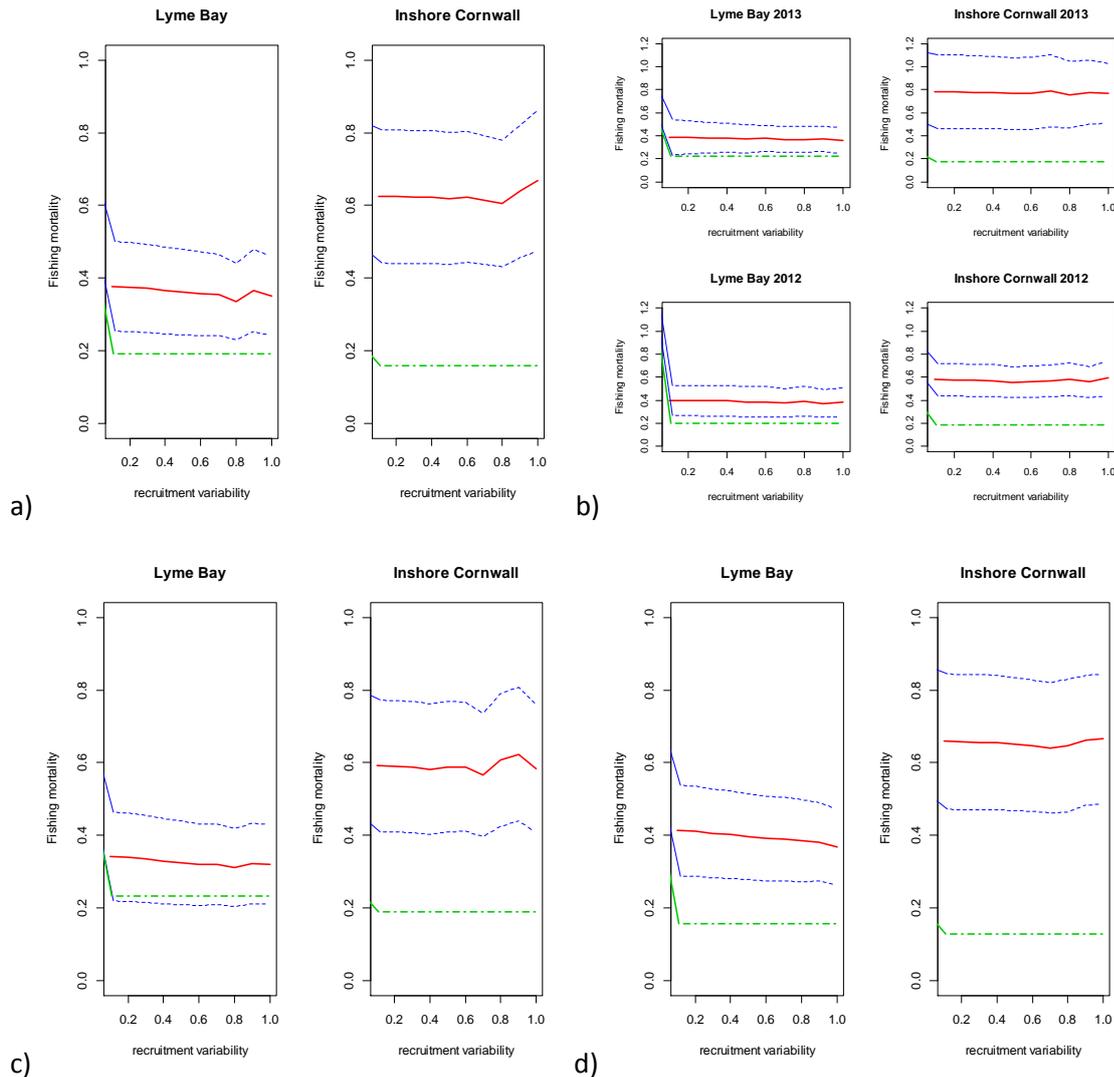


Figure 3.2 Estimate of current fishing mortality ( $F$ ) against different assumed levels of recruitment variability for Lyme Bay and Inshore Cornwall stocks (natural values of recruitment variability are expected to be towards the upper end of the range presented here). The green dashed line represents the estimate of  $F$  for Maximum Sustainable Yield, the solid red line represents the most likely estimate of current  $F$  and the blue dotted lines give the 95% confidence intervals. a) Baseline results, using the ICES standard natural mortality value (0.15) and pooling data for 2012 and 2013. b) as (a) but separating the years, c) as (a) but increasing natural mortality by 25% , d) as (a) but decreasing natural mortality by 25%

## 4 Conclusions

- The data from the red bag scheme for the 2012 and 2013 fisheries are insufficient to provide robust, definitive statements regarding the state of the stock either in terms of the stock biomass or the rate at which it is being fished.

- Analysis of the age structure from the landings indicates that fishing activity is unlikely to be below a rate associated with Maximum Sustainable Yield.
- There are however limitations in the data regarding spatial coverage, sample numbers and a relatively small pool of contributing vessels which adds uncertainty to the interpretation of results.

As described in the introduction, stock assessment methodologies require robust data and the reliability of any outputs from a stock assessment process are contingent on the reliability of the input data.

Clearly the biggest issue for this scheme has been the ability to collect sufficient regular samples from five of the seven areas. The sampling rate achieved for the Inshore Cornwall stock was marginal in terms of sample numbers and the geographic spread of the samples is restricted compared to the spatial extent of the fishery (and therefore presumably the stock). This leaves just one stock unit where we have achieved a representative sampling level and can begin to estimate the current exploitation rate with any confidence.

The two main difficulties with the current scheme are the sample numbers and the spatial coverage of the samples. It is vital that these issues are addressed in order to ensure that any sampling scheme for scallops provides robust information which is representative of the stocks.

The biology of scallops is such that samples from the entire stock area are required to establish the true age structure of the population. One way to achieve this could be saturation sampling (i.e. a very high level of sample production) which would also counter the problem of having insufficient samples for the purposes of stock assessment. The resourcing of the scientific side is such that Cefas would be unable to cope with processing thousands of samples per year, so a mechanism would be required by which the coordinator could select which red bags to include scientifically. This would place a greater burden on processors who would be receiving a high number of red bags and who would need to relay the sample details to a coordinator prior to processing. It would also mean that the additional burden on fishers who collate the sample on deck was largely wasted.

An alternative approach would be for a mechanism to be identified by which the coordinator of the sampling scheme can readily identify the location of fishing vessels within the scheme prior to any fishing operation so as to be able to make specific, targeted requests for data. Under the current scheme this would imply Cefas having access to real-time data on location for all vessels, which is presently limited to those with AIS and accessing this information is time consuming. An alternative approach might be vessels on the scheme having a specified area to target. This approach might also provide some insight into the potential for bias in the current sampling scheme (section 3.3) but could impact upon the commercial interests of the fishing vessels.

Despite the difficulties with the current scheme there have also been positive effects. There is a much better working relationship between science and industry and the cooperation of the participants has been greatly appreciated.

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