Fisheries & Conservation Science

Status of scallop populations in Welsh waters
– Results of 3 years of research surveys 2012 - 2014 –

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EXECUTIVE SUMMARY

- There were significant differences in the abundance of scallops within the three areas sampled: Liverpool Bay, North Western Llyn Peninsula and Cardigan Bay. *Pecten maximus* abundance was considerably higher in Cardigan Bay compared to the other two areas surveyed. We caught 5 to 10 times more scallops in the queen dredges in the open area of the Cardigan Bay SAC than off the Llyn Peninsula or in Liverpool Bay (e.g. in 2012 open area 2.5 scallops per $100m^2$ swept, 0.4 in Liverpool Bay and 0.2 off the Llyn Peninsula). In Cardigan Bay, densities were also consistently higher in the closed area than on grounds where fishing occurred.

- There was a decrease in number of scallops caught in part of the closed area of the Cardigan Bay SAC between 2013 and 2014 and an increase in other parts. Potential reasons for this are explored in the report but this was probably due to a combination of factors such as spatial and temporal variability in catchability and spatial heterogeneity of scallop distribution. Indeed, video estimates did not show such trends but indicated high variability in densities across relatively small areas. Average estimated densities from the 2014 videos were as follows: 3.08 scallops per $100m^2$ in the open area of the SAC, 17.95 in the east (closed area); 19.13 in the experimental area (closed area); 9.66 in the west (closed area); and 9.32 inshore (closed area). So there were 3 to 6 times more scallops on average in the closed area of Cardigan Bay compared to the open area.

- The relationships between still images, video and dredge estimates of king scallop densities were strong even though some variance remained. This variance is likely to be linked to habitat types as it is more difficult to see scallops when they are buried in softer sediments and due to the patchiness of scallop beds as the dredge and video tows were not overlapping. Also the dredges are size selective and this is not accounted for in the comparison. On average the queen dredges caught ca. 29% of the scallops available on the seabed while the king dredges caught ca. 21%.

- Size and age structure within the three areas sampled using scallop dredges showed that king scallops sampled from the Llyn Peninsula and Liverpool Bay were dominated mainly by old individuals (over 6 years old) with few undersize scallops in 2012 but in 2013 and 2014 proportionally more small and young scallops were caught in Liverpool Bay and off the Llyn Peninsula. This may indicate stronger recruitment in recent years than expected from the June 2012 survey.

- There was a significant difference in size and age structure between the closed and open areas of the Cardigan Bay SAC. Most scallops caught in the open areas were just around the minimum landing size (MLS = 110mm, mostly ≤5 year old) while the scallops caught in the closed areas were older and larger (≥120mm and ≥5 year old). The apparent shift towards smaller and younger scallops in the open area and towards older and larger scallops in the closed area observed between 2012 and 2013 was not obvious in 2014.

- The number of scallops above MLS caught in the king dredges was under 1 per $100m^2$ in the open area every year. It fluctuated in the closed area with estimates of around 4 per $100m^2$ both in 2012 and 2013 and down to just above 1 in 2014 (most likely because the highest density area, i.e. the experimental area, was not resampled in 2014). The number of pre-recruits in the closed area (defined as scallops under MLS caught in queen dredges) remained around or under 1 per $100m^2$ over the 3 year period. The number of pre-recruits had however peaked in 2013 in the open area with an average above 3 per $100m^2$. Variation around those estimates highlight the patchiness of scallops on the seabed.

- The total mortality (fishing mortality + natural mortality) of scallops of age group 5 between 2012 and 2013 was highest in the open area of the SAC (Z=1.6). In one of the management areas of the Cardigan Bay SAC we estimated natural mortality rates at 0.15 for age 5 and 0.19 for age 6.

- Combining all data on age and size from the 3 surveys, there appeared to be some variation but no clear pattern in growth rates from north to south. There were some more local differences apparently due to fishing since the average size at age of scallops in the fished areas of Cardigan Bay SAC were ca. 2 to 3mm smaller than in the protected area, west part of the SAC.

- There were some distribution patterns with regards to age, size, growth and distance from shore. In parts of Cardigan Bay SAC densities of younger scallops decreased as distance from shore increased, resulting in an average size of scallops being higher further offshore. In Liverpool Bay, growth rates decreased with distance from shore.

- The gonad status was very different between the 3 grounds in 2013, while no difference had been observed in June 2012. In July-August 2013 and, to some extent, in July-August 2014, the scallops were more mature further north.

- There is no strong evidence of spatial differences in yield or density dependence.

- Every year the amount of bycatch retained in the queen dredges in Liverpool Bay was higher than at the Llyn Peninsula by roughly threefold and higher than in Cardigan Bay by roughly fourfold. The variability between sampled sites was high and there was no consistent pattern in density with regard to open versus closed areas of the Cardigan Bay SAC. The biomass of bycatch caught in Cardigan Bay in the king dredges was less than 0.1 kg per100m^2 dredged (with higher values in the experimental area of the SAC).

- The species composition of the bycatch was very different between Liverpool Bay, the Llyn Peninsula and Cardigan Bay. A higher number and variety of species was found in Liverpool Bay. Within Cardigan Bay there were also some smaller scale differences between the different management areas which appeared to be due to geographical differences rather than fishing restrictions.

- To summarise, the patterns in population dynamics of scallops in Cardigan Bay are spatially defined with clear influence of the management strategy. There was always very few scallops and mostly just small size scallops in the open area compared to the closed area of the Cardigan Bay SAC. It is not clear whether the populations from the closed area are healthy even though they are certainly more abundant and larger animals. The problem is that few undersize scallops have been caught in the closed areas and very few scallops were caught anywhere in the SAC in 2014. This may be due to a problem of catchability and spatial heterogeneity since video estimates did not show such fluctuations. Generally to distinguish between uncertainties around abundance indices, natural fluctuations and significant changes in abundance much longer time series are needed. The status of the stock of the Llyn Peninsula is comparable to Liverpool Bay but a large part remains unstudied as it was not possible to sample closer to shore, within 3nm (or in Tremadog Bay, but this area remains unfished all year round). In Liverpool Bay, the densities (although very low compared to Cardigan Bay) and age and size structure have been stable over the past 3 years and the level of bycatch has been consistently higher than at the other two grounds.

INTRODUCTION

The Welsh scallop fishing industry is primarily an inshore fleet that is dependent on the sustainability of the local stocks. This is in comparison to nomadic or offshore fleets, which operate extensively around the UK or further afield and are therefore not reliant on local stocks. It is therefore important that the national scallop resource in Welsh waters is managed sustainably to support locally based Welsh fisheries.

Scallops are the most valuable uncultivated species landed in Wales (£7,451,003 in 2012 (source: MMO)). However, there is a general paucity of data on the scallop populations within Welsh waters and data are lacking on the distribution, abundance and population dynamics of Welsh scallops to facilitate sustainable management decisions.

Three surveys have been undertaken over three consecutive years as part of the European Fisheries Fund (EFF) funded project led by Bangor University in collaboration with the Welsh fishing industry. These three surveys aimed to gather some of the baseline information on scallop distribution, abundance and population dynamics, as well as test the consistency and robustness of different methodologies to reliably collect such data. Although one of the most common methods of assessing scallop populations is to sample with scallop dredges, due to environmental legislation it is not possible to use this method in all parts of Welsh waters. In particular, restrictions on scallop dredging exist within the 3nm limit within designated Special Areas of Conservation (SACs). Therefore, the feasibility of using non-invasive camera tows (video and still photography) was investigated. Additionally, industry led surveys in the future might utilize these techniques.

Another aim of these surveys was to start building up a time series of stock status information in order to move towards the possibility of conducting stock assessments in the near future. We compare here the results of the 3 surveys: June 2012, July-August 2013 and July-August 2014.

Specifically the surveys had the following objectives:

1. Estimate the abundance of scallops (*P. maximus* and *A. opercularis*) in the main commercial fishing grounds (identified from Vessel Monitoring System (VMS) and directly from fishers' reports).

2. Collect data on the population dynamics of scallops (age and size structure). These data, together with abundance data, represent the start of a long-term time series for accurate stock assessment.
3. Assess bycatch levels associated with fishing over the different fishing grounds.
4. Compare results from 2012, 2013 and 2014 to start understanding the dynamics of the stocks in relation to fishing activities.
5. Contribute and add to the habitat mapping data collected since 2009.

METHODS

Survey design

Four commercially fished scallop grounds were chosen for survey (Figure 1) after consultation with the fishing industry over the location of the main scallop grounds in 2012. Those grounds were sampled in June 2012, July-August 2013 and July-August 2014, except for ground 3, Tremadog Bay, which was only surveyed in 2012. Tremadog Bay is fished with a high density of static gear which makes towed gear survey work problematic. Furthermore, the area within 3nm off the north of the Llyn peninsula was not sampled because of the numerous strings of pots in the area.

Within the three areas sampled each year, random stratified replicate sampling was carried out. The number and location of sites was defined each year based on logistics such as number of days at sea available, weather, etc (see Table 1 and Figure 1). Sampling and subsequent analyses in Cardigan Bay were further stratified based on the management regime of the area. There are at least 6 distinct zones in Cardigan Bay: north of the SAC; closed SAC eastern area; open SAC; closed SAC experimental area; closed SAC western area; and closed inshore SAC (shown below in Figure 3). The sampling was conducted with the RV Prince Madog by scallop dredging and/or taking seabed videos at each site as described below.

Table 1. Number of sites sampled each year during the scallop stock assessment survey using different sampling techniques

Survey	**Dredge**	**Video** (including sites sampled by video for habitat monitoring purposes, i.e. not all of these sites were included in the stock assessment)	**Dredge + Video**
June 2012			
- Liverpool Bay	6	3	6
- Tremadog Bay	-	5	-
- Llyn Peninsula	7	5	6
- Cardigan Bay	10	5	6
July-August 2013			
- Liverpool Bay	10	27	10
- Tremadog Bay	-	-	-
- Llyn Peninsula	3	7	7
- Cardigan Bay	10	43	15
July-August 2014			
- Liverpool Bay	6	4	-
- Tremadog Bay	-	-	-
- Llyn Peninsula	8	2	-
- Cardigan Bay	25	32	-

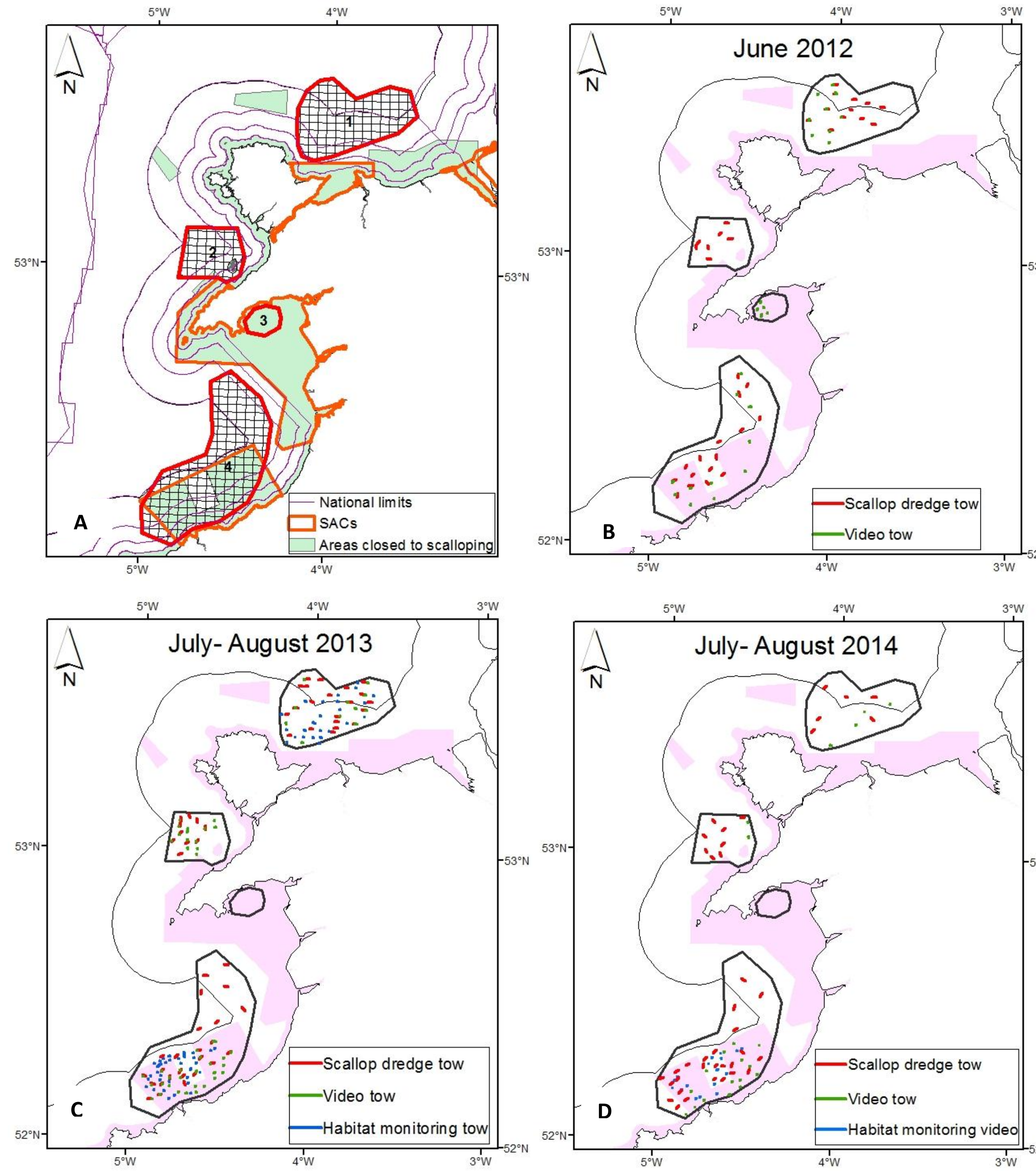

Figure 1. A - Map of sampling areas and the grid used to determine the location of sampling sites within four main fishing grounds: 1 – Liverpool Bay, 2 – Llyn Peninsula, 3 – Tremadog Bay, 4 – Cardigan Bay. B-C-D – Stock assessment sampling sites in 2012, 2013 and 2014, including habitat monitoring sites in Cardigan Bay (some of which were used in the stock assessment in 2014).

Scallop dredging

Four spring-loaded Newhaven scallop dredges were deployed from the RV Prince Madog. Two king dredges (9 teeth of 110mm length with belly rings of 80mm diameter) and two queen dredges (10 teeth of 60mm length with belly rings of 60mm diameter) were used. The king dredges were used to simulate the commercial catch of king scallops whilst the queen dredges were used to catch queen scallops and undersized king scallops, which was necessary for the analysis of age and size structure of populations. Each tow was 20 minutes in length at a speed of approximately 2.5 knots. GPS coordinates were recorded for the start and end of each tow to allow the calculation of the length of the tow. Each dredge was 0.76m in width. Multiplying the length of the tow by the width of the dredge gave the area swept by each dredge, and allowed for calculation of abundance (number of individuals) and biomass (kg) per $100m^2$.

For each tow, the content of each dredge was sorted separately. All scallops captured were separated out by species (queen or king scallops) and then the total weight for each species was recorded. If large numbers of scallops were captured then a sub-sample of ca. 90 scallops was collected from each dredge. The scallops in this sub-sample were measured. Shell length (mm) was measured for king scallops and shell height (mm) for queen scallops. *P. maximus* were aged (using external growth rings). The weight of the sub-sample was then taken to allow estimation of the total abundance by extrapolating up to the total weight of catches. This abundance was then converted to density by dividing the total abundance by the area swept and recorded in number of individuals/$100m^2$. Similarly, total weight was used to calculate density in terms of biomass in kg/$100m^2$. Bycatches were separated and identified to species level wherever possible. The abundance and biomass (g) of each bycatch species was then recorded. From the sub-samples scallop growth and maturity indices were determined. Scallop shell length (to the nearest mm) and shell weight were measured (to the nearest g). Scallops were then dissected and the adductor muscle and gonad separated from the rest of the tissue and weighed (in the lab ± 0.01g in 2012 and 2013 – onboard the RV to the nearest g in 2014). The Gonad Observation Index (GOI), as described by Mason (1983), was also recorded. This index categorises a scallop gonad into one of seven stages. Stages 1 and 2 relate to virgin scallops, stage 3 is the first stage of recovery following spawning, stage 4 and 5 are filling, stage 6 is full and stage 7 is a spent gonad. The aim was to collect a representative sample of scallops from each age group and for the three major scallop grounds, i.e. Liverpool Bay, Llyn Peninsula and Cardigan Bay.

Camera tows

A benthic sledge mounted video and still camera system was deployed from the RV Prince Madog. The sled was towed at a speed of approximately 0.5 knots for a period of 20 minutes. Start and end positions of each tow were recorded from the point the sledge had visibly reached the sea floor to the point the sledge lifted off the seabed during hauling. While the video system filmed forward at an angle and delivered a continuous live picture that was recorded on DVD or external hard drive, the digital stills camera was mounted perpendicular to the seabed and took a high resolution image every 10 seconds. Each still image covered an area of $0.13m^2$ (0.44m x 0.30m).The field of view of the video camera covered an area of approximately $0.12m^2$ (width 0.41m x depth 0.30m). These videos were used to compare to the abundances of scallops estimated from the still images in 2012 (see section below). In 2013 and 2014 we also fitted a higher quality and larger field of view GoPro camera to the sledge (width FOV ca. 0.80m). Videos obtained from the GoPro video camera were used for the purpose of stock assessment due to their wider field of view.

Estimation of scallop abundance from still photography and videos

The still photographs were analysed for the presence of both *P. maximus* and *A. opercularis*. The total number of each species of scallop from all of the photographs in each video/camera sledge tow was recorded along with the total number of photographs taken. Scallop density was then estimated by dividing the number of scallops by the area of seabed photographed [number of photos x image area]. The numbers of scallops seen on each GoPro video tow were also counted. This abundance was then converted to density by calculating the area of seabed imaged [length of tow x width field of view]. The densities were then recorded in number of scallops per $100m^2$. Note that numbers obtained in 2012 and 2013 and presented in previous reports have been corrected for the problem of edge effects that were not accounted for previously. Previously scallops had been counted as a whole regardless of the proportion visible on the photograph, now scallops which were not completely on an image (i.e. only part of it was photographed, the rest was cut off) were counted as fractions, i.e ½ if only half of the scallop was on the picture.

Data analyses

Fluctuation in scallop abundance for each year are presented per fishing ground and management area. The main fishing grounds considered in the analyses are as stated above: Cardigan Bay, the Llyn Peninsula and Liverpool Bay, with six distinct zones within Cardigan Bay: north of the SAC; closed SAC eastern area; open SAC; closed SAC experimental area; closed SAC western area; and closed inshore SAC (shown below in Figure 3). Abundance estimates from still images, videos and dredge sampling were further compared using simple linear regressions.

Scallop abundances by age and size classes were compared between years and grounds to investigate the potential to follow age cohorts and assess scallop mortality using frequency distribution graphs and standard catch curve analysis.

Population parameters, i.e. growth, mortality and maturity, were estimated. Von Bertalanffy growth curves were fitted to data for each fishing ground and management area. A comparison of growth rates was subsequently conducted using an analysis of covariance of size at age between locations and post hoc tests (Tukey's test).

Fishers have reported catching larger scallops further offshore in the Cardigan Bay SAC. Therefore we have tried to document this observation by studying small-scale age, size and growth patterns in relation to distance from shore in each fishing ground and management area. Specific patterns of growth with distance from shore were explored using 3rd degree polynomial linear regressions.

Spatial patterns in weight and weight-length relationships of difference body parts are presented. The variance in weight increased along the size gradient and was not equal between locations. Therefore the log-log relationships between weight and length and the influence of location as a covariate were tested using the generalised least square (GLS) method. This method allows the variance to increase/change along the predictor gradient and between levels of a covariate. Linear regressions of yield vs size and analysis of covariance were used to compare yield between fishing grounds and management areas. Maturity stages differences between grounds were described.

Additionally, differences in bycatch densities between years and areas were presented and species composition was analysed using multivariate statistics. Analysis of similarities (ANOSIM) were used to test the composition difference between all year-location groups (Clarke 1993). Nonmetric multidimensional scaling (MDS) was used to visually display those groups and permutational multivariate analysis of variance (PERMANOVA) was used to test for the significance of the effect of year, location and their interaction with species composition

(Anderson 2001). Species that contributed mostly to the differences between groups were identified by estimation of an indicator value. The indicator value was estimated using the function *indval* in the R package “labdsv”. It is the product of the relative frequency and relative average abundance in clusters (Dufrene and Legendre 1997). The associated p-values identify species typically associated to a particular cluster.

RESULTS

Fluctuations of king scallop density indices between 2012 and 2014

Over the 3 year period during which scientific surveys were undertaken, densities of king scallops were consistently higher and more spatially variable in Cardigan Bay than at the Llyn Peninsula and in Liverpool Bay (Figure 2A).

We compared the variations in scallop densities in the different management zones identified in Cardigan Bay using data from queen scallop dredge samples (Figures 2B and 3). Densities were consistently higher in closed areas than on grounds where fishing occurred (continuous vs dash lines Figure 2B). There was a consistent increase in the number of scallops caught in each management area between 2012 and 2013 and a consistent decrease between 2013 and 2014.

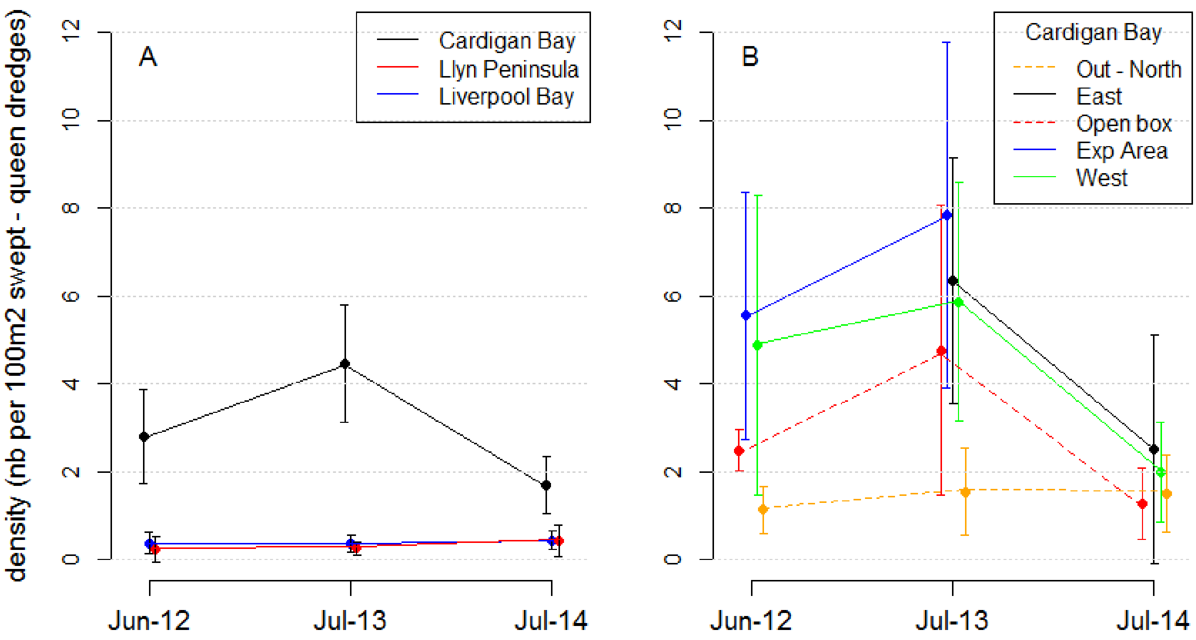

Figure 2. Estimates of scallop densities caught in queen dredges during RV Prince Madog surveys around Wales. A – Comparison of the three main fishing grounds. B – Comparison of the five different management areas in Cardigan Bay. The error bars represent the 95% confidence interval (see Figure 3 for map of management areas in Cardigan Bay).

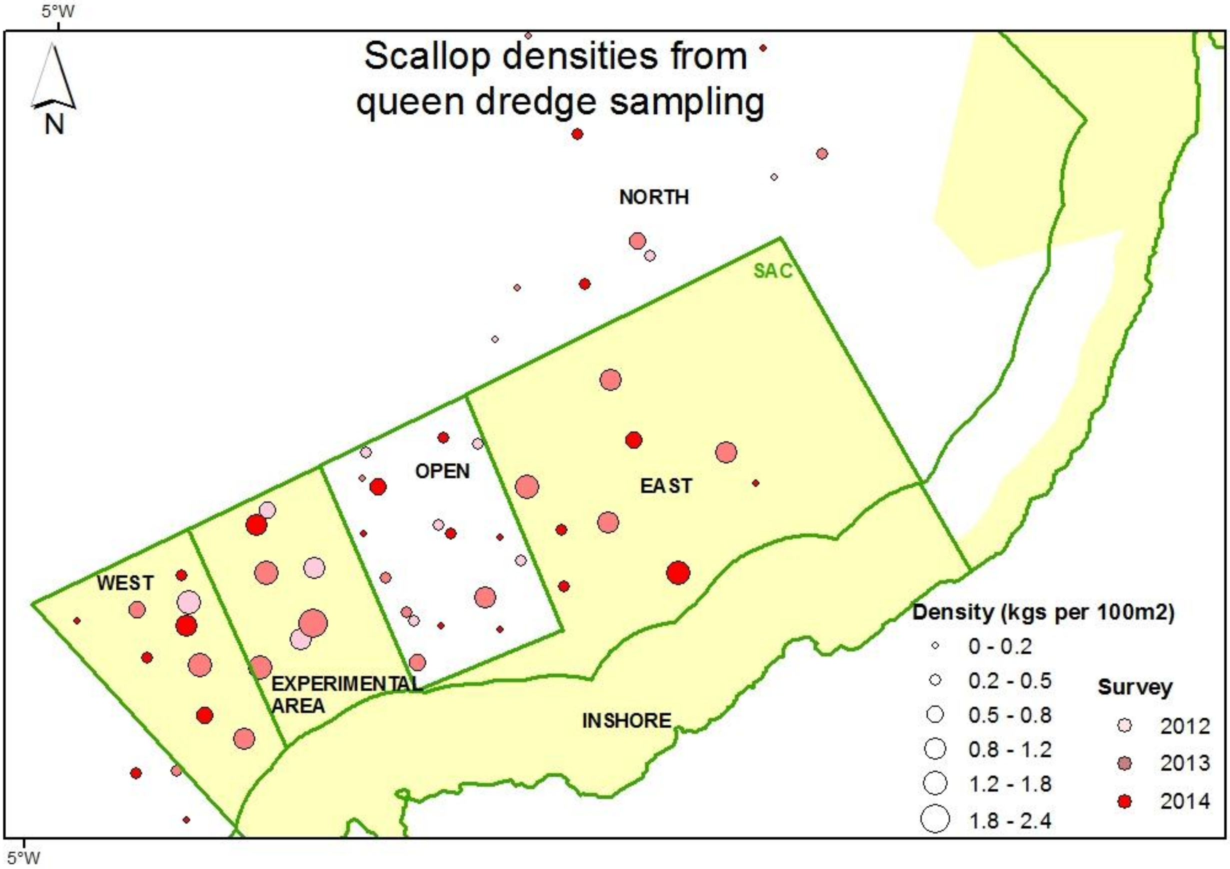

Figure 3. Map of scallop densities in kgs caught in queen dredges over the three years of surveys

Figure 4 illustrates how changes in densities over time are due to undersize scallops in the open area of the SAC (Figure 4A) and to oversize scallops in the closed areas (Figure 4B). This reflects the size and age structure of the stock in the different management zones as discussed later in the report.

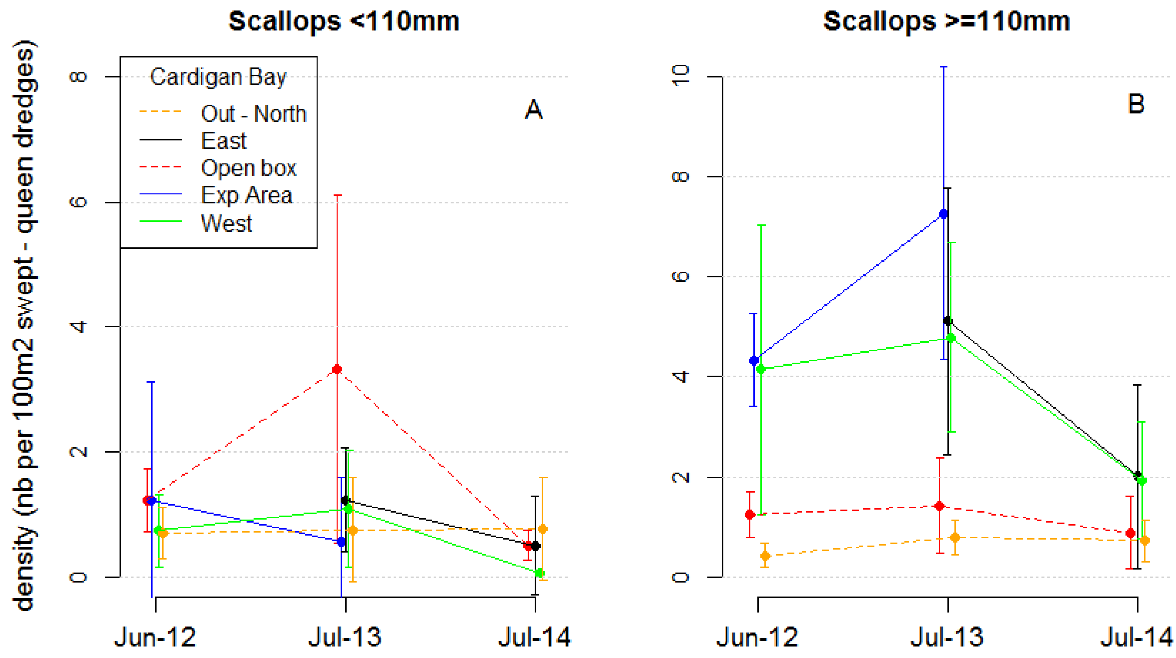

Figure 4. Estimates of scallop densities caught in queen dredges during RV Prince Madog surveys in Cardigan Bay. A – Scallops under minimum landing size (MLS). B – Scallops over minimum landing size (MLS). The error bars represent the 95% confidence interval.

Comparison of RV survey with industry catches

The experimental area (in blue on Figures 2 and 4) was not resampled in July-August 2014 because of the experiment that took place in April 2014 which would have altered the natural fluctuations in scallop densities. However, this area is of particular interest as it was the area of highest density in the SAC in 2012 and 2013 and the catches reported during the experiment in April 2014 were still high, which contrasted with the observation that densities of scallops had dramatically declined in other parts of the SAC between 2013 and 2014 (mostly east and west areas – black and green on Figure 4). We therefore compared our experimental area standard research survey estimates from 2012 and 2013 to the data obtained onboard fishing vessels during the April 2014 experiment in the same experimental area. Since the fishers only reported catches of scallops over the MLS (>110mm) and were using king scallop dredges for fishing, we compared the data from the April 2014 experiment to the RV Prince Madog estimates of scallops over >110mm sampled in the king dredges in 2012 and 2013 (Figure 5). Data from the experiment were reported as the number of bags per tow, so the average bag weight was combined with observer data to determine the number of scallops per bag to obtain a number of scallops per tow. There were 13 fished corridors during the experiment, for each of these corridors we averaged out the densities of scallop caught during the first 10 tows (or less if less tows were conducted) to obtain an estimate of scallop densities for each experimental corridor (or site) prior to being fished down throughout April 2014.

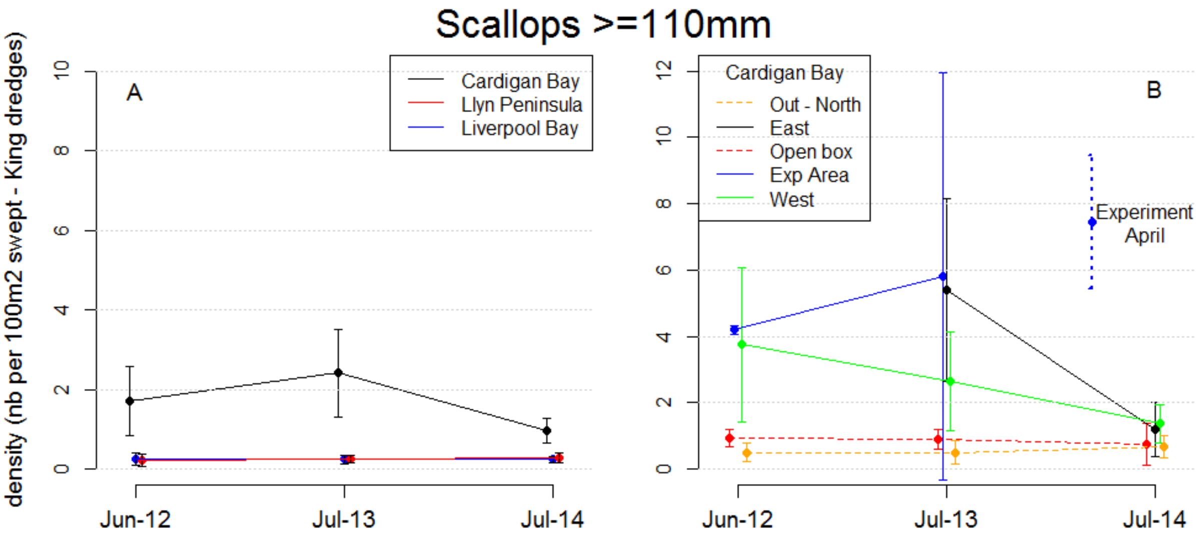

Figure 5. Estimates of mean scallop densities for scallops >110 mm caught in king dredges during RV Prince Madog surveys around Wales. A – Comparison of the three main fishing grounds. B – Comparison of five different management areas in Cardigan Bay. Also shown are the data collected onboard fishing vessels in the experimental area in April 2014 (labelled on the figure). The error bars represent the 95% confidence interval.

Figure 5 shows that changes in the numbers of scallops >110 mm caught with king dredges during the RV Prince Madog surveys reflect the overall changes observed in the queen dredges samples presented earlier in Figure 2. Catches in the open area of the SAC were consistently low and did not show as much variation between 2012 and 2014 while there was still a decrease in the western and eastern closed areas of the SAC (Figure 5B). However, data from the fishing vessels during the April 2014 experiment suggested an increase in scallop densities in the experimental area.

To summarise, the RV Prince Madog survey data suggest a decrease in density in specific parts of the closed area between 2013 and 2014 while the data extracted from the April 2104 experiment shows that at least part of the SAC may have seen an increase in density during that time. There can be several explanations to these observations such as variable catchability, spatial heterogeneity of scallop distribution, scallop movement, natural fluctuations etc. With regards to catchability issues, it has to be noted that the storms before the April 2014 experiment may have dislodged scallops and made them more vulnerable to fishing gear as direct observations suggested that a significant amount of scallops were not recessed in the seabed but lying on top of the seabed during a video survey conducted in March 2014. Furthermore we were able to catch up to 45 kg of scallops in a 5 minute tow with a 2m-beam trawl, a fishing technique which does not usually catch any scallops (pers. obs.). This could part explain why the data from April 2014 are different from data from July-August 2014. The catchability of the fleet that fished in the experimental area in April 2014 might have also been higher than the catchability of the RV Prince Madog as fishing vessels may be more efficient than the research vessel.

Catchability

In order to address the issue of catchability and assess whether catchability of the fleet is different to the catchability of the RV Prince Madog, we used VMS and logbook data obtained for the open area of the Cardigan Bay SAC between 2012 and 2014. Logbook data were combined with VMS data to assess the catch per unit effort (CPUE) of the fleet on a monthly basis. We were specifically interested in the data for the April and November CPUE recorded since 2012, i.e. the last month of fishing before the research surveys and the first month of fishing after the research surveys, since the research surveys occurred during the closed season. Since logbook catch data are in weight and not in number, we expressed the survey indices of abundance and the fishery CPUE indices in kgs per 100m^2 (Figure 6). It has to be noted that the CPUE derived indices of the fishing fleet will be investigated further in future work and were only indicative here (i.e. effort can be estimated in different ways which will affect the estimates of CPUE and this requires some further investigation).

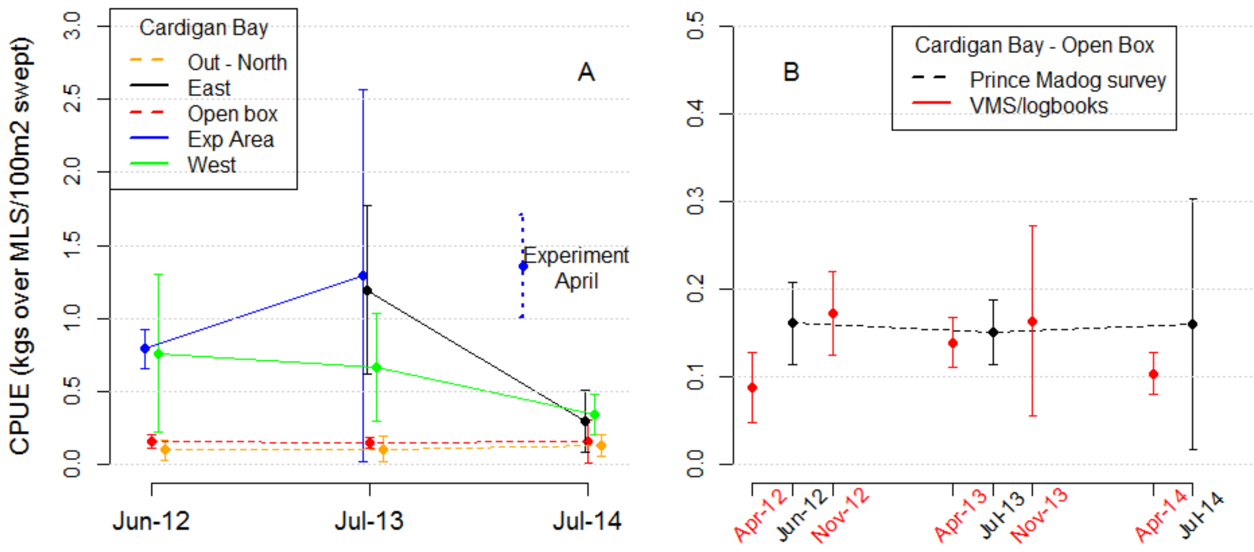

Figure 6. Weight estimates of >110mm scallop densities in the Cardigan Bay SAC. A – Comparison of five different management areas in Cardigan Bay (king dredge estimates). B – Comparison of VMS/logbook derived estimates and research survey estimates in the open area of Cardigan Bay SAC. The error bars represent the 95% confidence interval.

Figure 6A shows the combination of weight density estimates from the research survey and from the fishing fleet during the experiment (similar to Figure 5B but in weight instead of number of scallops). Figure 6B compares estimates from the fishing fleet and estimates based on the research survey with the RV Prince Madog, based on data from the open area of the Cardigan Bay SAC. In this low density area, estimates from both fishing vessels and the RV Prince Madog correspond well, with an expected increase in CPUE between April and November every year likely due to the spring/summer growth of the scallops which continues through to November. In addition the status of the gonads (roe) at the time of fishing will also affect the ultimate weight of the catch.

To conclude, data obtained from fishing vessels and the research vessel do match up so it can be concluded that between summer 2013 and April 2014 there was an increase in number of scallops caught in the experimental area while there was a decrease in number of scallops caught in the west and east closed areas between summers 2013 and 2014. It is possible that the decrease in the apparent abundance of scallops caught during the research survey was due to a change in catchability following the winter storms. Scallops may have had a higher catchability in April and much reduced catchability in July 2014 compared to July 2013.

Comparison between video, still images and dredge scallop density estimates

Video imaging should be less prone to issues of catchability, hence for this reason we used video data to understand the variations in the catchability of the fishing gear and spatial heterogeneity of scallop distribution by plotting video density estimates over time (Figure 7).

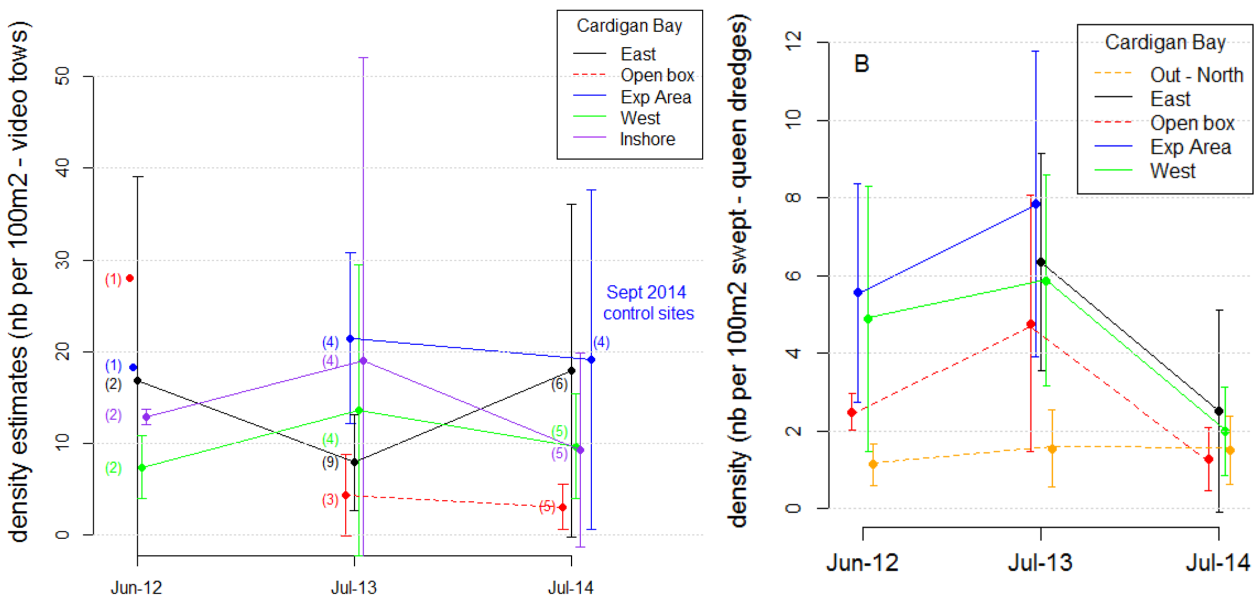

Figure 7. A - Estimate of scallop densities from videos in five different management areas in the Cardigan Bay SAC (including all video). Note that no videos were taken offshore, north of Cardigan Bay SAC but some videos were taken inshore, within 3nm. The numbers in brackets are the number of sites used to make this figure. B – Density estimates from queen dredges (same as Figure 2B). The error bars represent the 95% confidence interval.

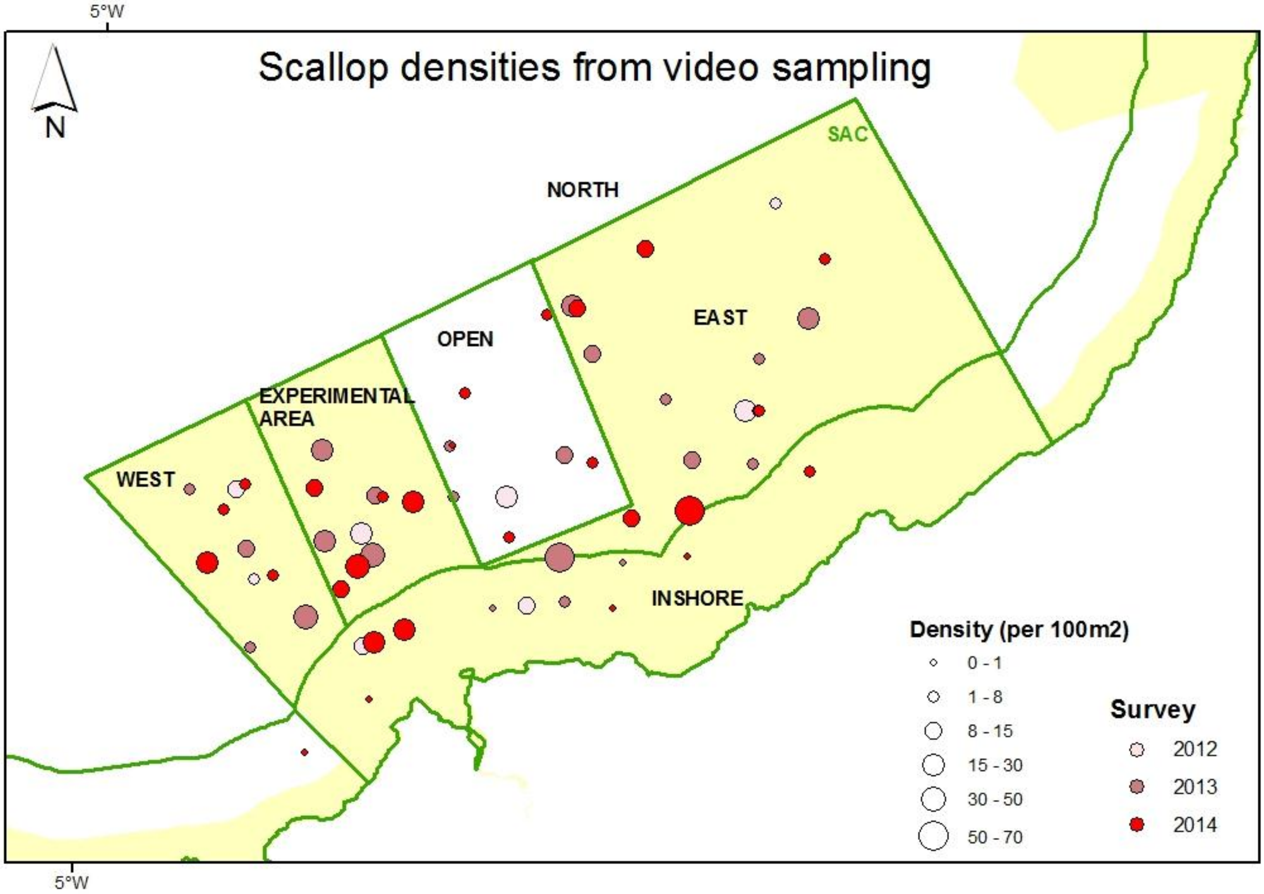

Figure 8. Map of video density estimates in Cardigan Bay SAC for 2012, 2013 and 2014. The three colours of the symbols represent the three surveys while their sizes reflect the densities.

Video data for the 3 year period matched up the dredges estimates in terms of consistent differences between management areas in the Cardigan Bay SAC. On average, the highest densities were found in the experimental area, followed by the eastern area (comparable to the inshore area – not dredged during any of the surveys), then the western area and last the open area (Figures 7 and 8).Video data showed consistent average densities over time as opposed to decreasing densities in eastern and western areas as suggested by the dredge data, however it also displayed large confidence intervals highlighting the patchiness of scallops on the ground which could affect CPUE indices. This could not be investigated any further in terms of selectivity of the gear as densities estimated from videos could not be linked to scallop size since the current video system does not allow for accurate size measurement. However, we could assess the catchability of the fishing gear in 2012 and 2013 as we had conducted both video and dredge tows at the same sites (Figure 9). Unfortunately, because of time constraints, the same comparison was not conducted in 2014.

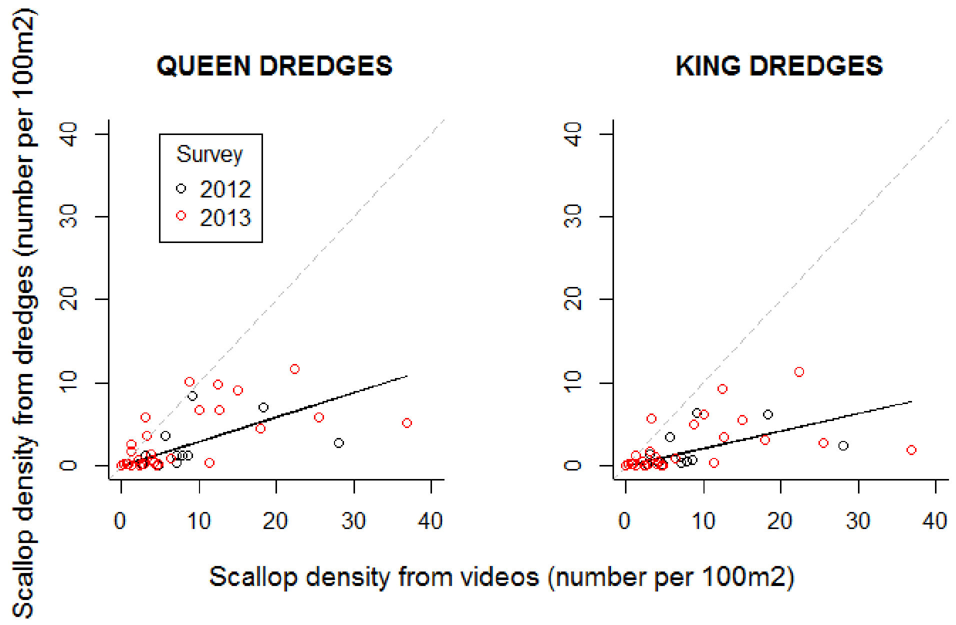

Figure 9. Comparison of scallop densities estimated from videos and densities caught in dredges – queen dredges left and king dredges right. The grey dotted line is the 1:1 relationship, the black line is the linear regression between videos and dredges estimates (with intercept set at 0).

The relationship between catch in the dredges and abundance on the videos is not strong because there is a habitat effect which affect both fishing gear catchability and “video catchability”, i.e. some scallops may be difficult to see in sediment types where they can bury and hide. Also the comparison does not account for the size selectivity of the gear (Figure 9). On average the queen dredges catch 29% of what is on the seabed while the king dredges catch 21%. The overlap of the 2012 and 2013 data suggest that at least there was no change in catchability between those 2 years. The video data used here were initially reported in previous reports (Lambert et al 2012 and 2013) but have since been revised and corrected to account for differences between observers, miscounting and edge effect (i.e. when a scallop is not 100% in the frame, it is now counted as a fraction of scallop instead of a whole scallop). The observation errors were therefore corrected and the match between estimates from videos and still images data was substantially improved (Figure 10). Under 10 scallops per 100m^2 there appeared to be a mismatch between video and stills estimates, with densities estimated from stills often at 0. This is because still images only cover a surface of 14.3 m^2 on average (counting 110 pictures per tow). If there are 10 scallops per 100m^2 it means that less than 1.5 scallops can be captured on pictures. Since scallops are not equally spaced out on the seabed it is likely that these 1.5 scallops are missed altogether. Conversely, a video tow of 450m will record over 250m^2 of seabed corresponding to 25 scallops if there were 10 scallops per 100m^2, which is why video estimates are more reliable at low densities. The otherwise good match between videos and still images suggest that the method and quality of recording might not matter as much as the surface area covered during the tow. Note that the videos from 2012, 2013 and 2014 were not the same: in 2012 we used our standard video system (field of view 0.40m), in 2013 we used a GoPro that was facing straight down and was partly obstructed by the light attached to the sled (field of view ca. 62cm) and in 2014 we used a GoPro slightly inclined to record forward, free of obstructions (field of view ca. 86cm).

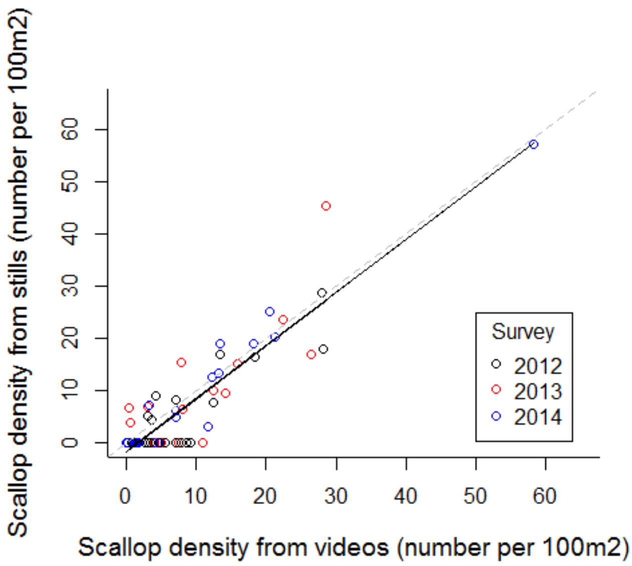

Figure 10. Comparison of scallop densities estimated from videos and densities estimated from still images. The grey dotted line is the 1:1 relationship, the black line is the linear regression between videos and stills estimates.

If patchiness of scallops affect the CPUE estimates, it is difficult to estimate changes in biomass over time and thereby to estimate fishing and natural mortality as attempted in a previous report (Lambert et al. 2013). However, selectivity should be specific to the gear used during the survey and should not be as affected as catchability by external factors. Changes in size structure of the stock can therefore still be estimated from survey samples and potentially give an indication of mortality and exploitation rate.

Spatio-temporal changes in scallop size and age structure between 2012 and 2014

Differences in size and age structure of scallop populations from different fishing grounds were investigated as well as changes over time to assess the health status of scallop populations around Wales and within different management zones. We first analysed the changes in age and size composition at the Llyn Peninsula and in Liverpool Bay (Figures 11 and 12).

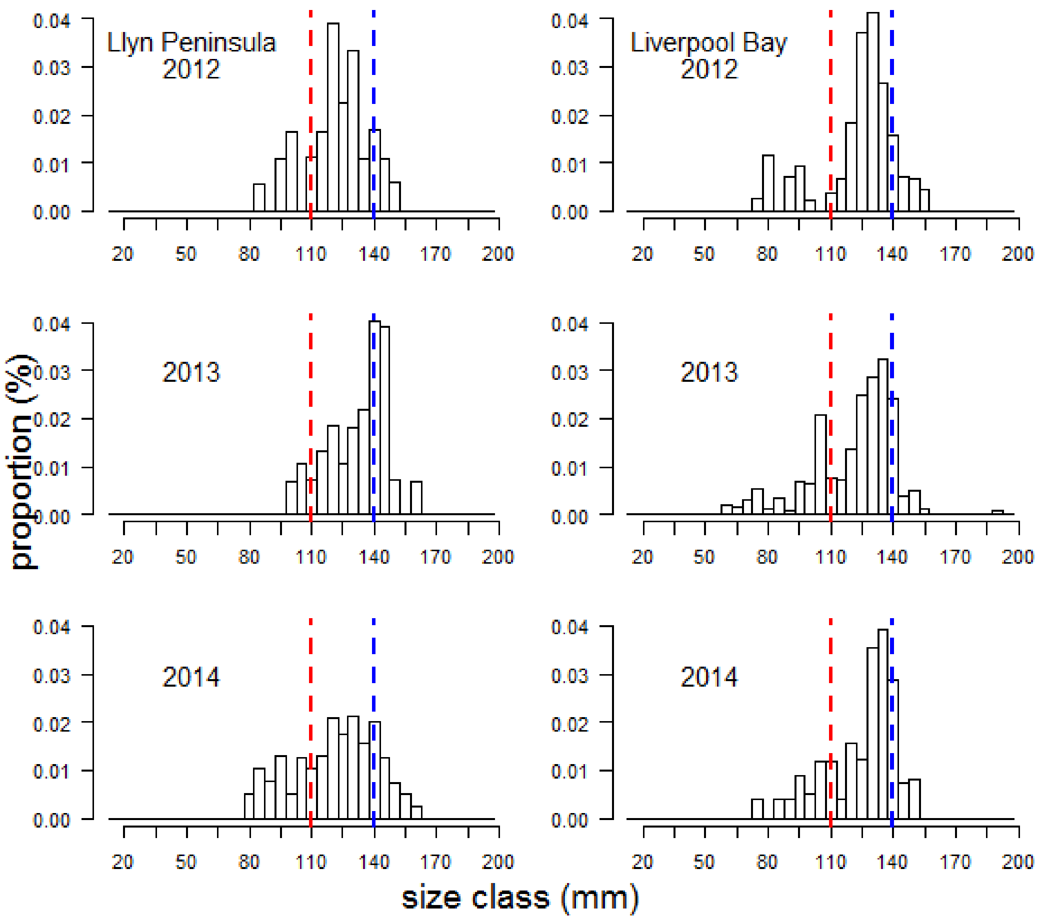

Figure 11. Frequency distribution of size classes of 5mm at the Llyn Peninsula and in Liverpool Bay (from queen scallop dredge samples). The red dash line represents 110 mm (MLS) and the blue one 140mm for visual ease of interpretation.

At both the Llyn Peninsula and in Liverpool Bay scallops were mostly large, over MLS (Figure 11), and a significant proportion is above age 5, although some recruitment was observed every year (Figure 12).

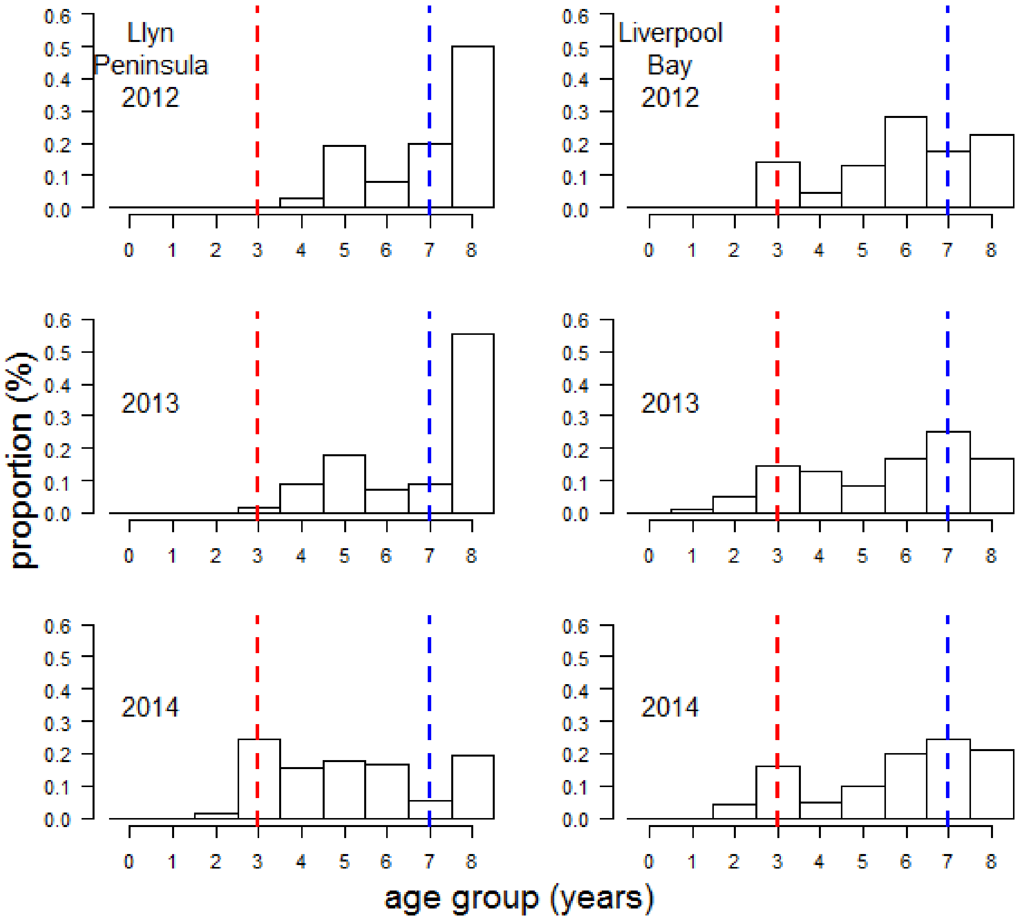

Figure 12. Frequency distribution of age groups at the Llyn Peninsula and in Liverpool Bay (from queen scallop dredge samples). The red dash line represents 3 year old (~ MLS) and the blue one 7 year old for visual ease of interpretation. Not that age 8 is in fact 8+, i.e. including all ages above 8.

Combining information on proportion at size or age and density should help identifying strong and weak cohorts (Figure 13). At the Llyn Peninsula it is clear that the most abundant scallops caught in the dredges peaked between 120mm and 145mm and some new recruitment arrived mostly in 2014. There was a large part of the population above 8 year old and truncating the data at age 8 might not be appropriate for these older populations. In Liverpool Bay the data appeared more similar from year to year with a slow increase in size visible between 2012 and 2013, a comparable recruitment every year and a fairly balanced density at all age groups. Because of the low densities of scallops, the small number of samples taken compared to the areas covered, the limited number of years sampled and also the fact that those populations might not be separate units, or whole stocks, we are not attempting here to follow cohorts through and assess mortality rates.

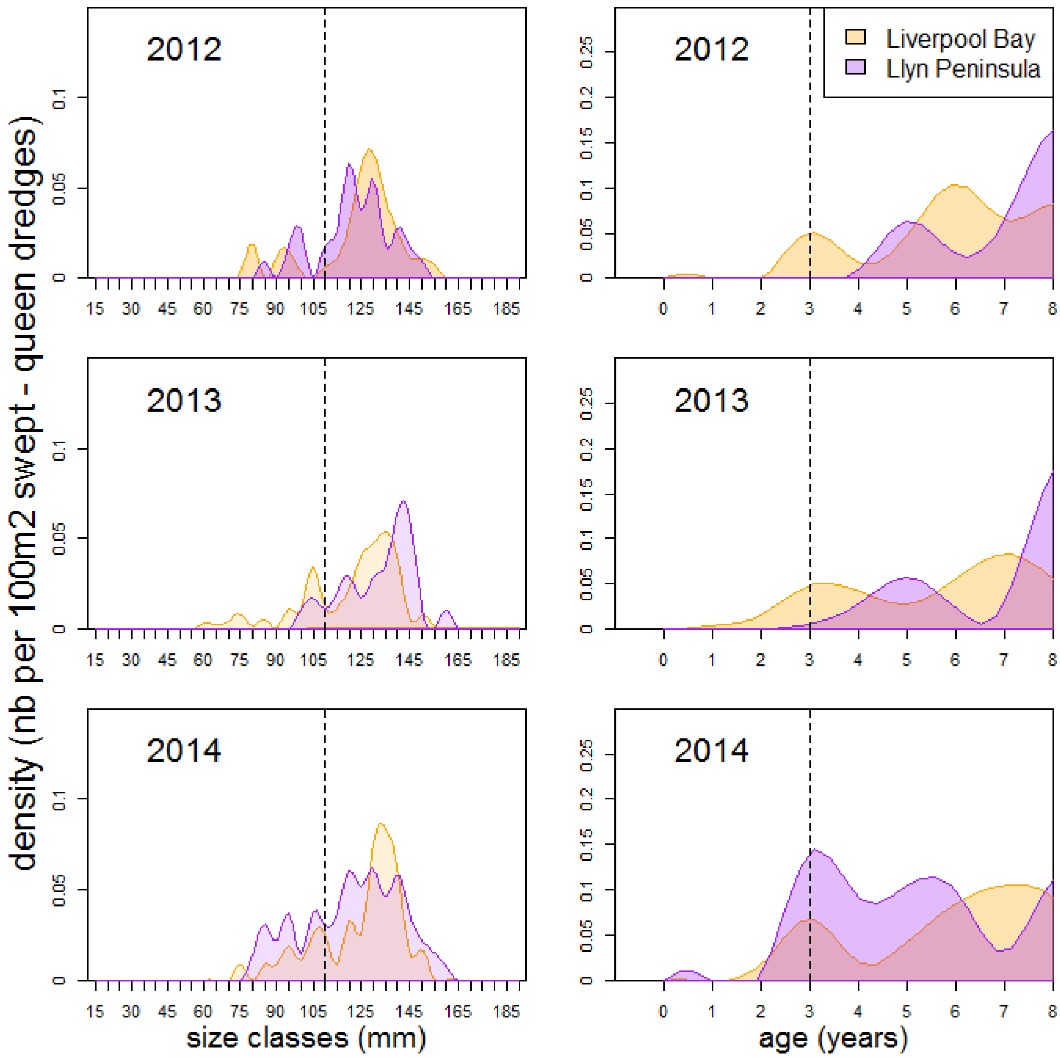

Figure 13. Density per size classes of 5mm and age group at the Llyn Peninsula and in Liverpool Bay (from queen scallop dredge samples).

In the Cardigan Bay SAC, data were disaggregated spatially to account for the spatial management units defined earlier. Because of the relatively more intense sampling in the different management areas of the SAC it was possible to distinguish specific patterns. The most obvious was that the open area is very different from the closed area, with a higher proportion of small, under MLS, and young scallops, under age 5 (Figures 14 and 15).

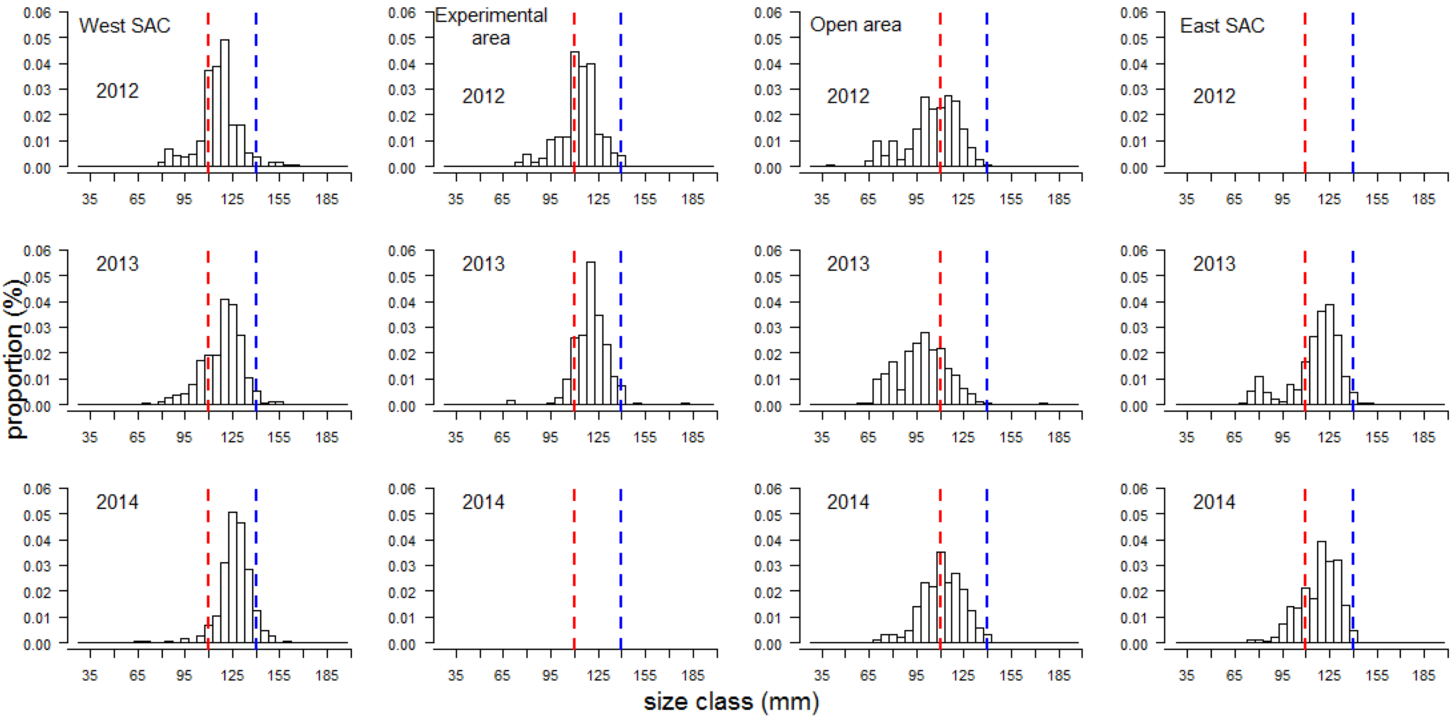

Figure 14. Frequency distribution of size classes of 5mm inside the Cardigan Bay SAC (from queen scallop dredge samples). The red dash line represents 110 mm (MLS) and the blue one 140mm for visual ease of interpretation.

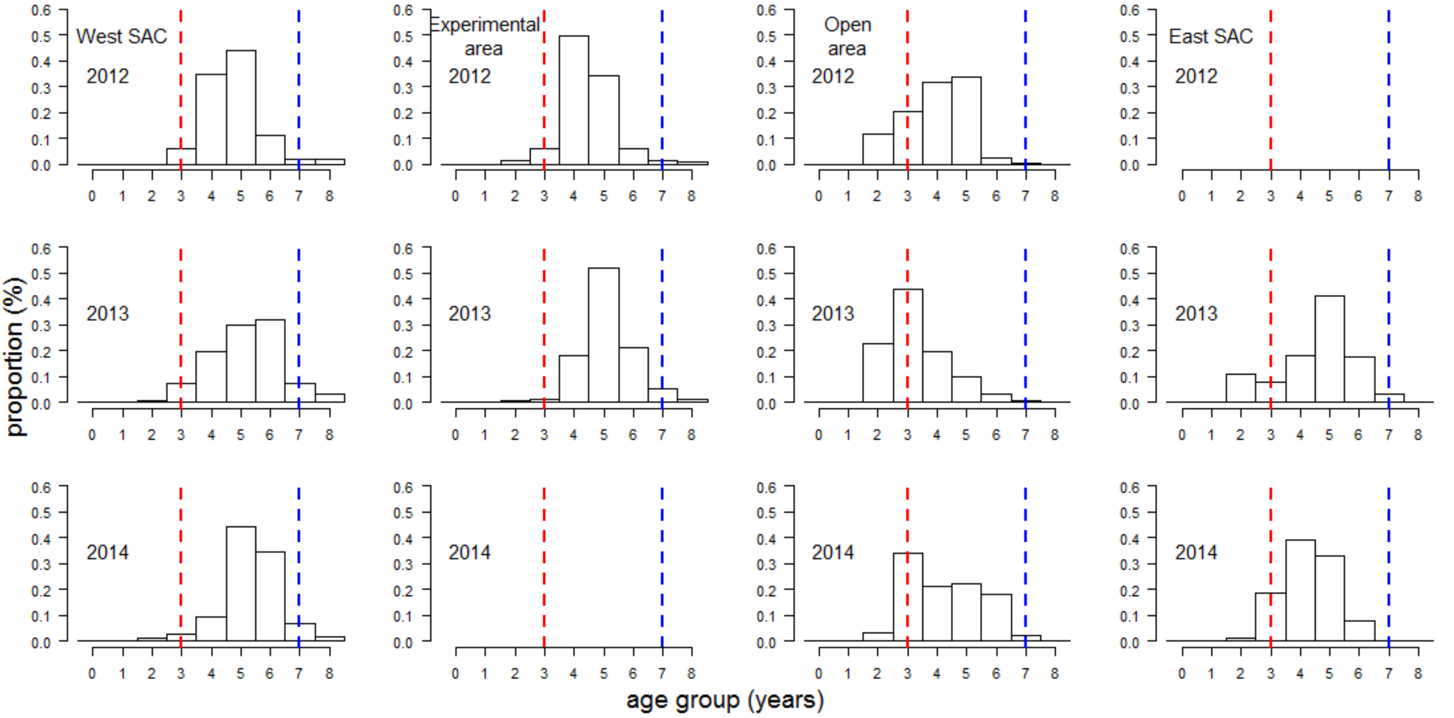

Figure 15. Frequency distribution of age groups inside the Cardigan Bay SAC (from queen scallop dredge samples). The red dash line represents 110 mm (MLS) and the blue one 140mm for ease of interpretation.

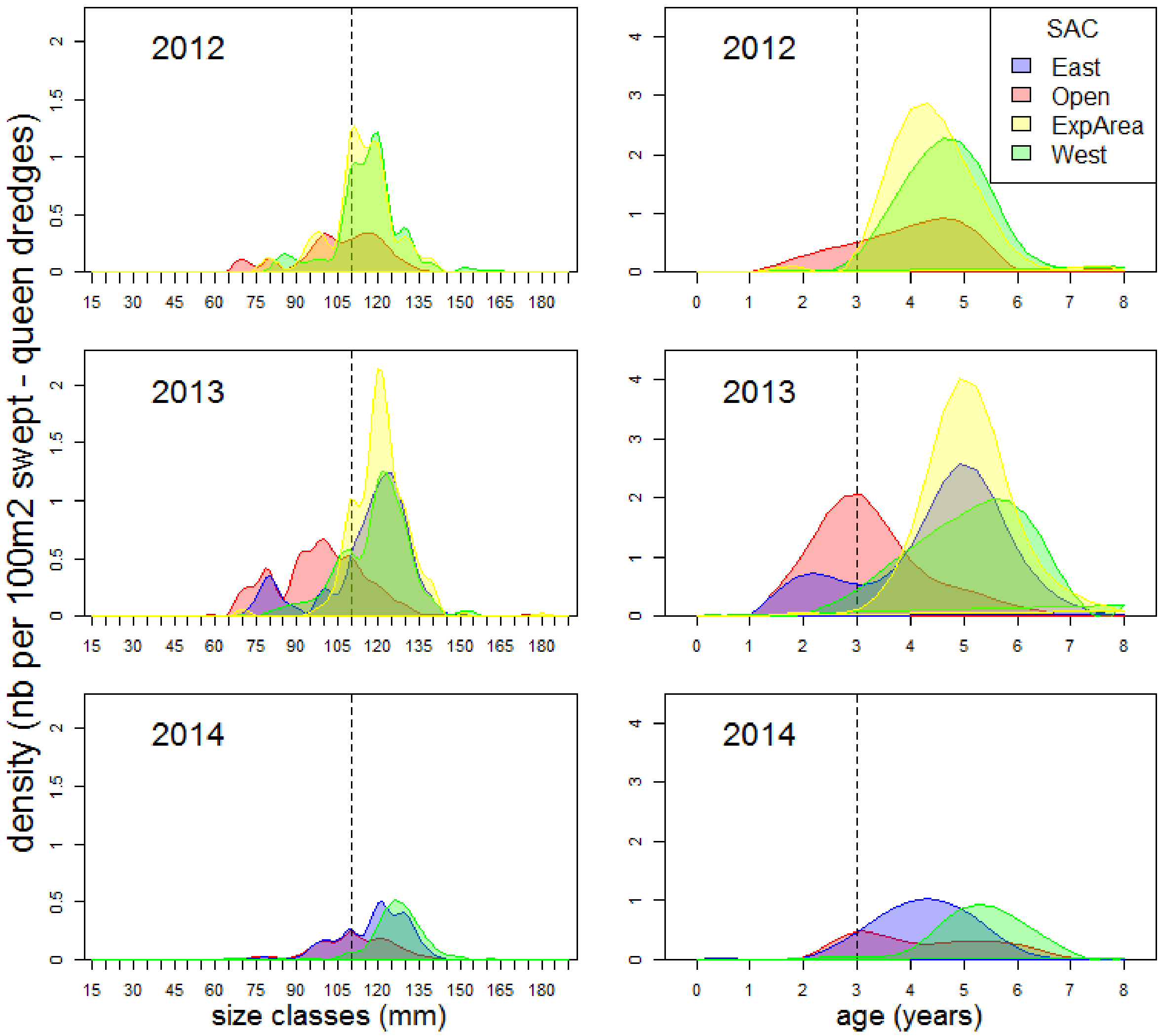

Figure 16. Density per size classes of 5mm and age group inside the Cardigan Bay SAC (from queen scallop dredge samples).

Although it seems possible to follow the cohorts through in the SAC, the very low abundance of scallops caught in 2014 will bias mortality estimates of fully recruited age groups (Figure 16 and 17). It is clear from Figure 17 that scallops at age 3 are not yet fully recruited to the queen scallop dredges, as there can be a positive difference in abundance in the catch between age 3 and 4 of the same cohort. We estimated total mortality rates, Z, for age groups 4, 5 and 6. Mortality at age 7 was not considered as age 8 is a plus-group, i.e. gathering all older ages. Estimates of mortality from the west area of the SAC, which is where we had the most consistent number of samples, suggest that age 4 might not be totally recruited to the queen scallop dredges and that mortality of age groups 5 and 6 from 2012 to 2013 would be 0.15 and 0.19 respectively. In the open area, Z between 2012 and 2013 was 1.64 for age group 5 and

0.77 for age group 6. It was overall lower in the open ground north of the SAC with Z=0.34 for age group 5 and 0.98 for age group 6. Z from 2013 to 2014 is not discussed further as it is likely to have been overestimated because of catchability issues discussed earlier.

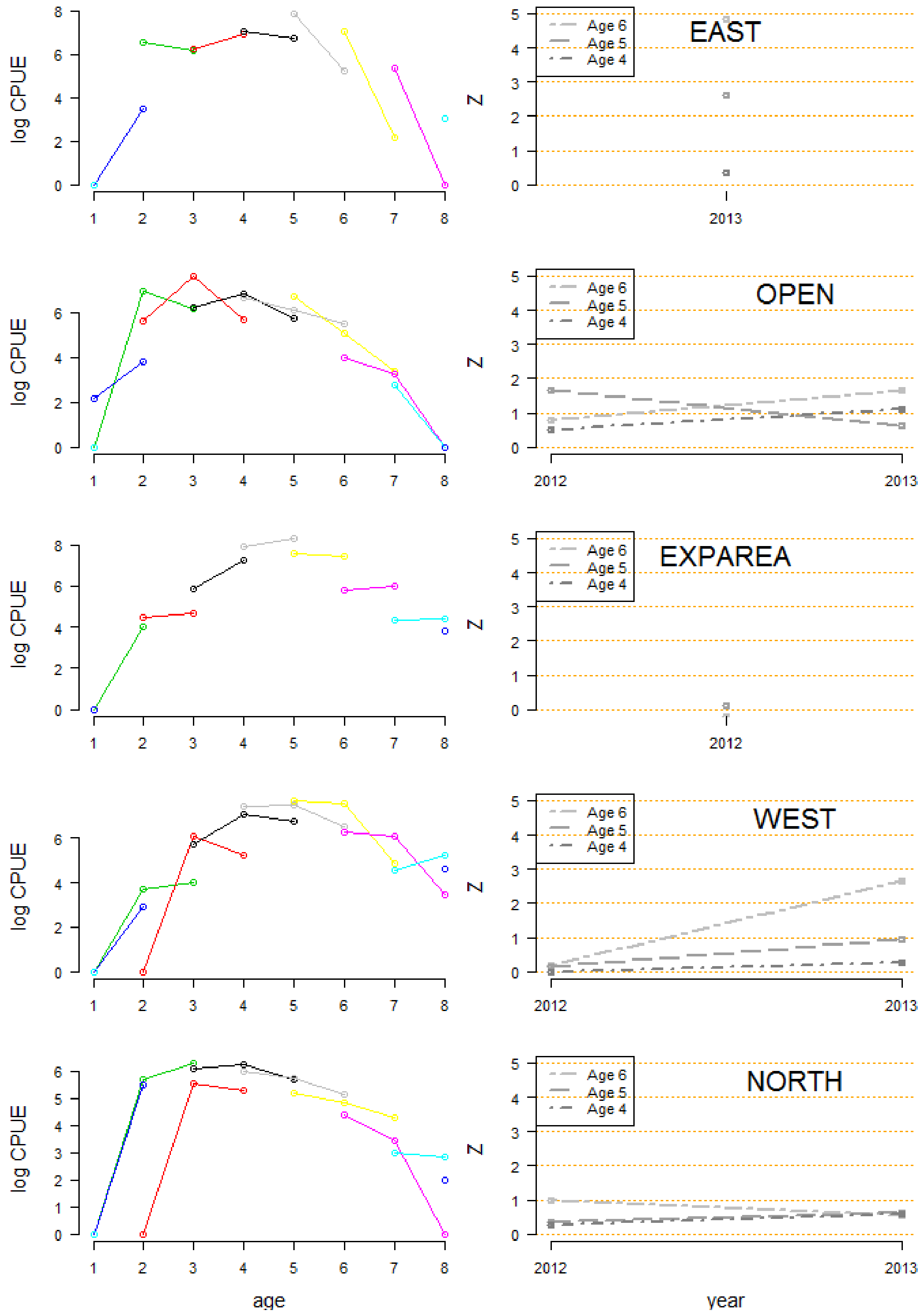

Figure 17. Catch at age and mortality rate (Z) in Cardigan Bay, by management area.

We studied the growth rates on the different grounds and within management areas in Cardigan Bay combining all data from the 3 years of surveys (Figures 18 and 19).

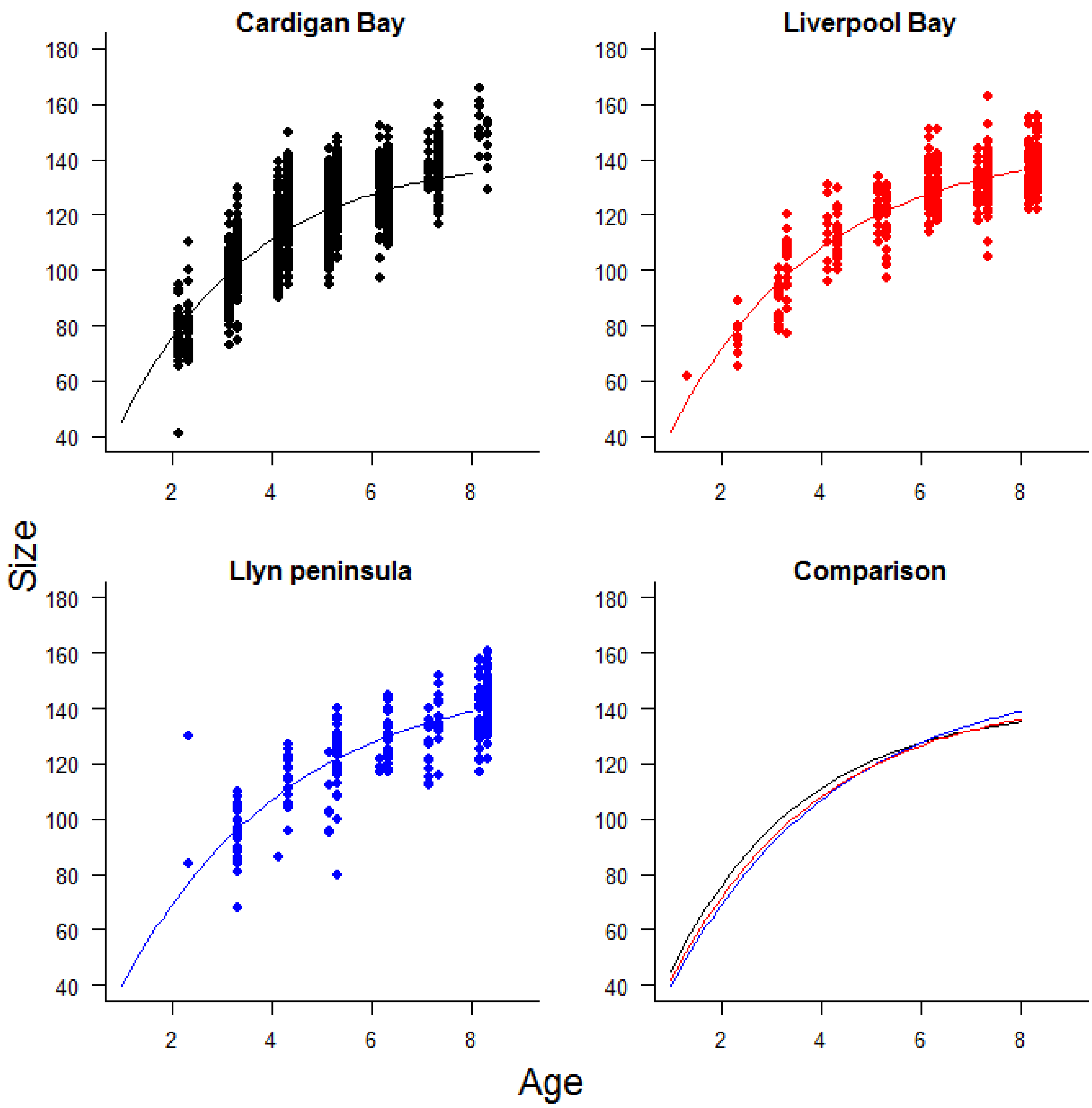

Figure 18. Von Bertalanffy growth curves in the 3 main fishing grounds, from 2012 to 2014 data collected from both queen and king dredges during research surveys. It was assumed that all scallops were born on the 1st of April and age was corrected accordingly (i.e. age 2 from June 2012 are 2.15 year-old while age 2 from end of July 2013 are 2.33). Data from both king and queen scallop dredges – curves fitted based on weighted size data (weight = density of age group at each site). Size represents scallop width here.

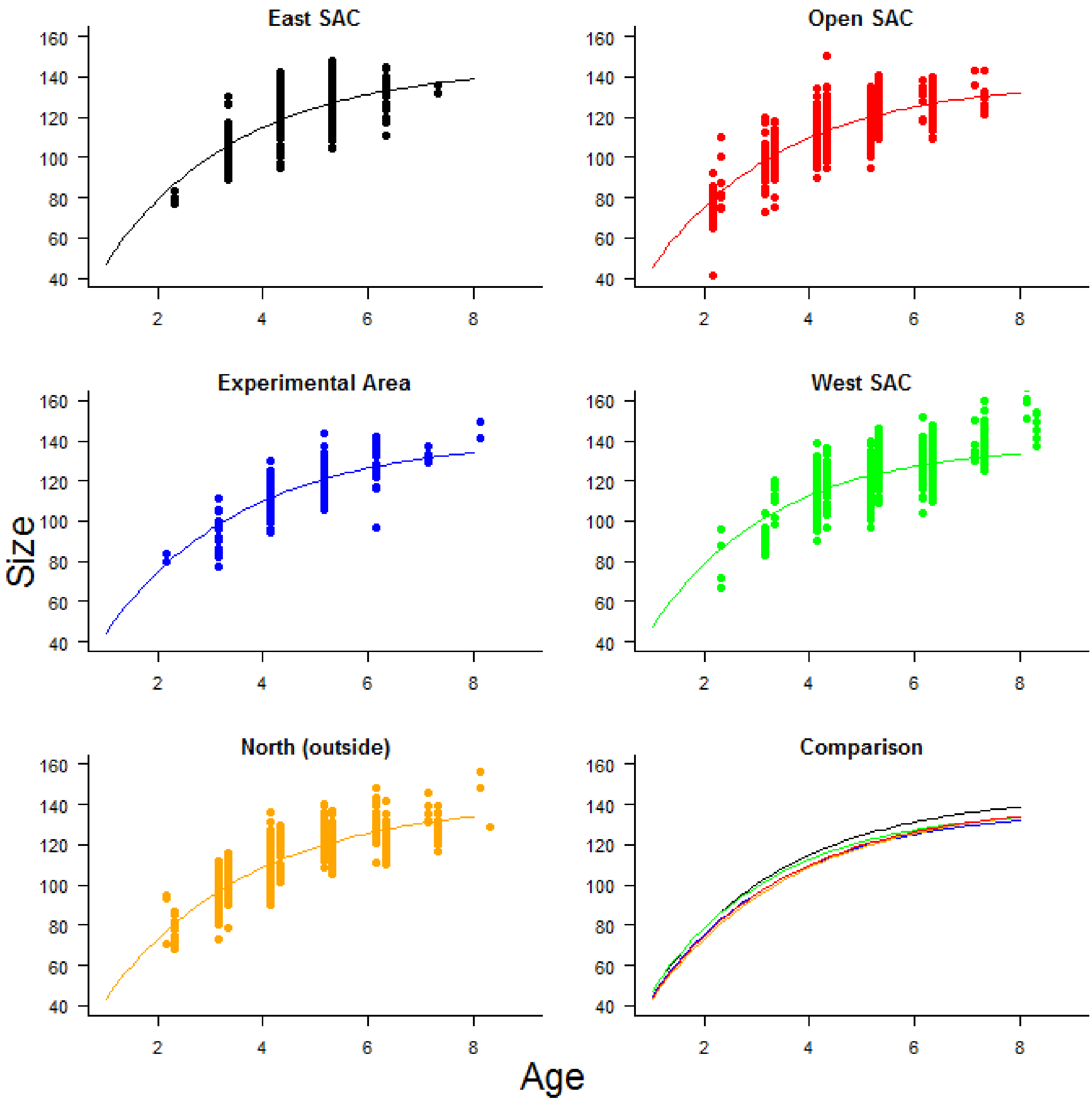

Figure 19. Von Bertalanffy growth curves in the different management areas of the Cardigan Bay SAC, from 2012 to 2014 data collected from both queen and king dredges during research surveys. It was assumed that all scallops were born on the 1st of April and age was corrected accordingly (i.e. age 2 from June 2012 are 2.15 year-old while age 2 from end of July 2013 are 2.33). Data from both king and queen scallop dredges – curves fitted based on weighted size data (weight = density of age group at each site). Size represents scallop width here.

Table 2. Von Bertalanffy parameters – Height has been estimated from the equation Height= 9.22 + 0.82*Width ($p<0.001$, df= 309, F= 6973.4, $R^2=0.96$), derived from samples measured during the 2012 survey. The 3rd parameter of the VB equation, t0, was set at 0.

	Width of shells		Height of shells	
	K	Linf	K	Linf
Cardigan Bay	**0.38**	**141.8**	**0.41**	**124.0**
East SAC	0.39	145.0	0.42	126.7
Open SAC	0.39	137.9	0.43	120.3
Experimental Area	0.38	140.9	0.41	123.3
West SAC	0.42	138.3	0.45	121.8
North (out SAC)	0.36	141.5	0.40	123.2
Llyn Peninsula	**0.30**	**152.7**	**0.33**	**132.8**
Liverpool Bay	**0.34**	**145.9**	**0.36**	**127.6**

Table 2 gives the Von Bertalanffy parameters for all the growth curves showed in Figures 18 and 19. There did not appear to be a latitudinal pattern in maximum size or growth rate. Within Cardigan Bay, there was no clear pattern except a suggestion that scallops could grow larger in the east of the SAC and decrease in size further west, with the lowest maximum size in the open area of Cardigan Bay. This was investigated further (Figures 20 and 21, Table3).

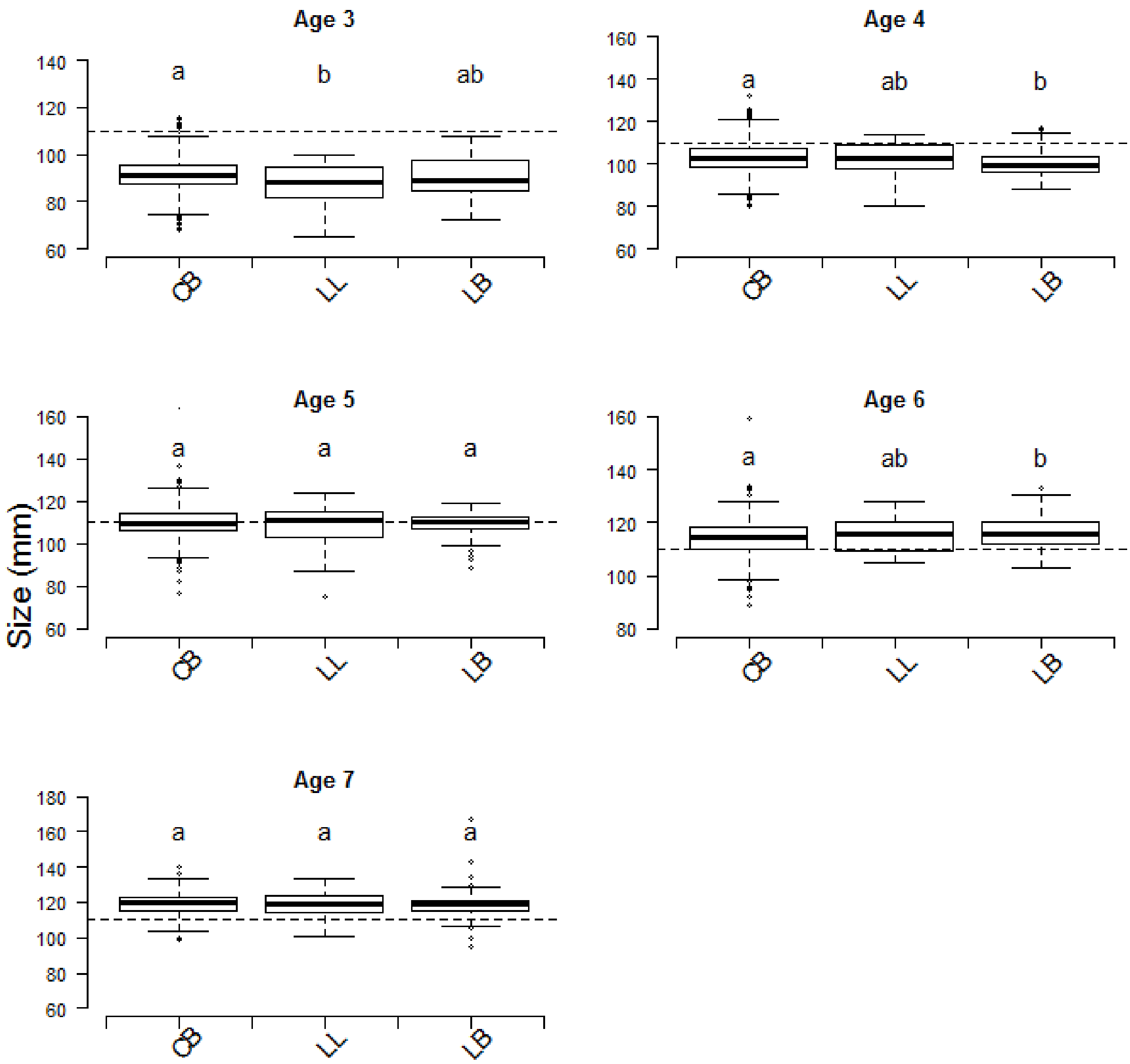

Figure 20. Differences in size at age between Cardigan bay (CB), the Llyn Peninsula (LL) and Liverpool Bay (LB) (data from both king and queen dredges). The letters indicate the significant groups based on a Tukey post hoc test.

Figure 21 shows the differences in size at age between management areas in Cardigan Bay. Sizes at all ages were on average 2 to 3mm smaller in the fished areas than in the protected areas of the west of the Cardigan Bay SAC (Table 3). This was unlikely to be due exclusively to different environmental conditions since the position of the open area compared to the closed areas (i.e. enclosed in the middle). It is possible that the fishery, by removing the largest individuals as they enter the fishery (as suggested previously in Figures 14 to 16), select for only smaller individuals to reach older age groups. Another possibility is that growth rates are directly affected as undersize animals are damaged by the fishing gear.

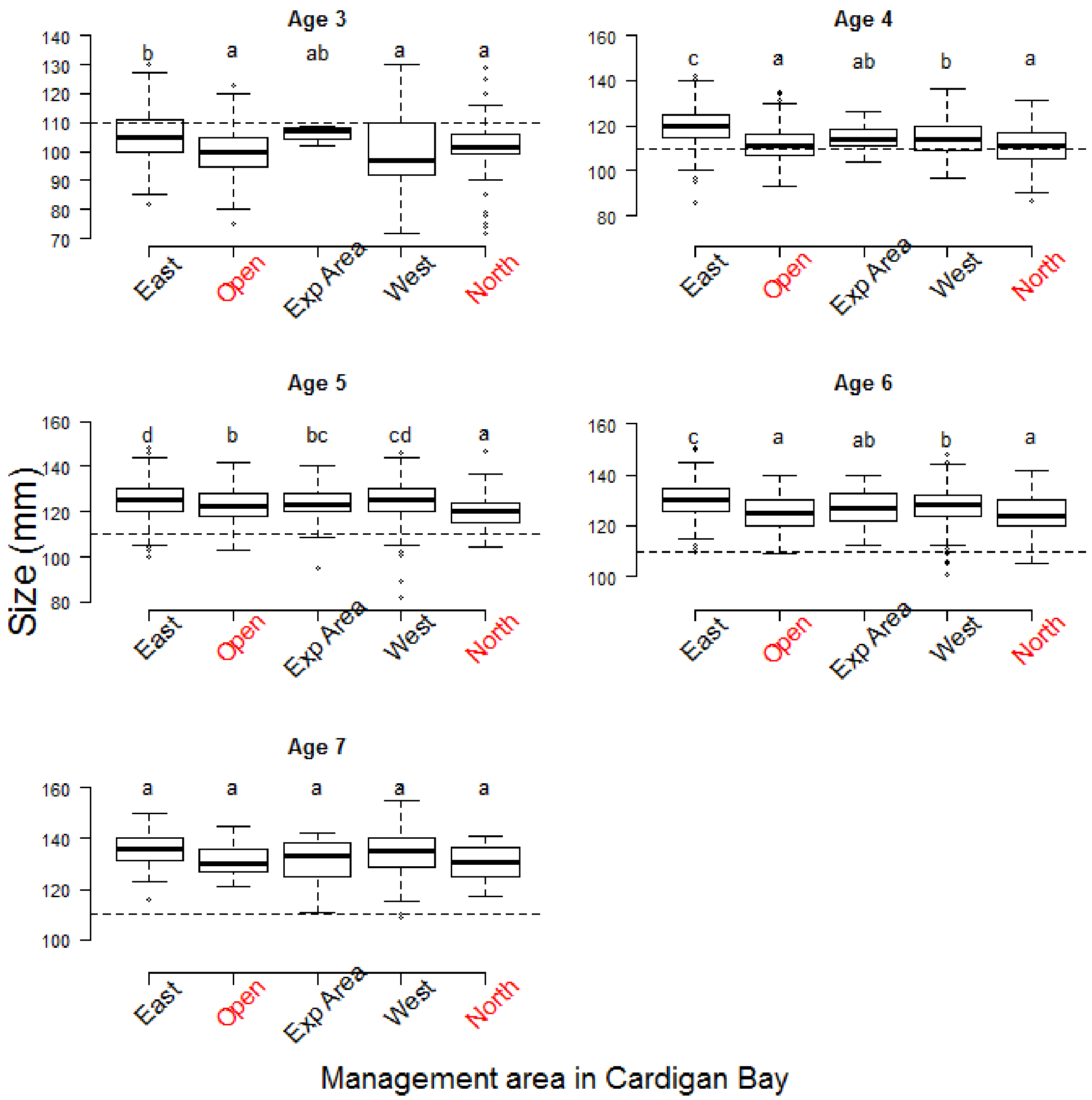

Figure 21. Differences in size at age between different management areas in Cardigan bay SAC (omitting 2012 data as the survey was a couple of months earlier than the 2013 and 2014 surveys – data from both king and queen dredges). The letters indicate the significant groups based on a Tukey post hoc test.

Table 3. Analysis of variance statistics for Figure 21. Size at age was weighed by abundance of scallops per age group caught in each tow. Highlighted in green are the values of particular interest. The interaction age-management area was not significant.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	102.2582	0.4662	219.351	< 2e-16 ***
Age 4	12.9007	0.4380	29.454	< 2e-16 ***
Age 5	21.2857	0.4292	49.590	< 2e-16 ***
Age 6	25.0895	0.4927	50.922	< 2e-16 ***
Age 7	30.4197	1.1994	25.362	< 2e-16 ***
EAST	1.2804	0.2848	4.495	7.10e-06 ***
OPEN	-2.3254	0.4556	-5.104	3.45e-07 ***
EXP AREA	-0.6240	0.3618	-1.725	0.0846 .
NORTH	-3.4042	0.5938	-5.733	1.05e-08 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 9.281 on 4923 degrees of freedom
Multiple R-squared: 0.637, Adjusted R-squared: 0.6364
F-statistic: 1080 on 8 and 4923 DF, p-value: < 2.2e-16

Detailed analysis of growth patterns with distance from shore

Table 4 at the end of this section summarises the findings which are illustrated in Figures 22 to 28 below.

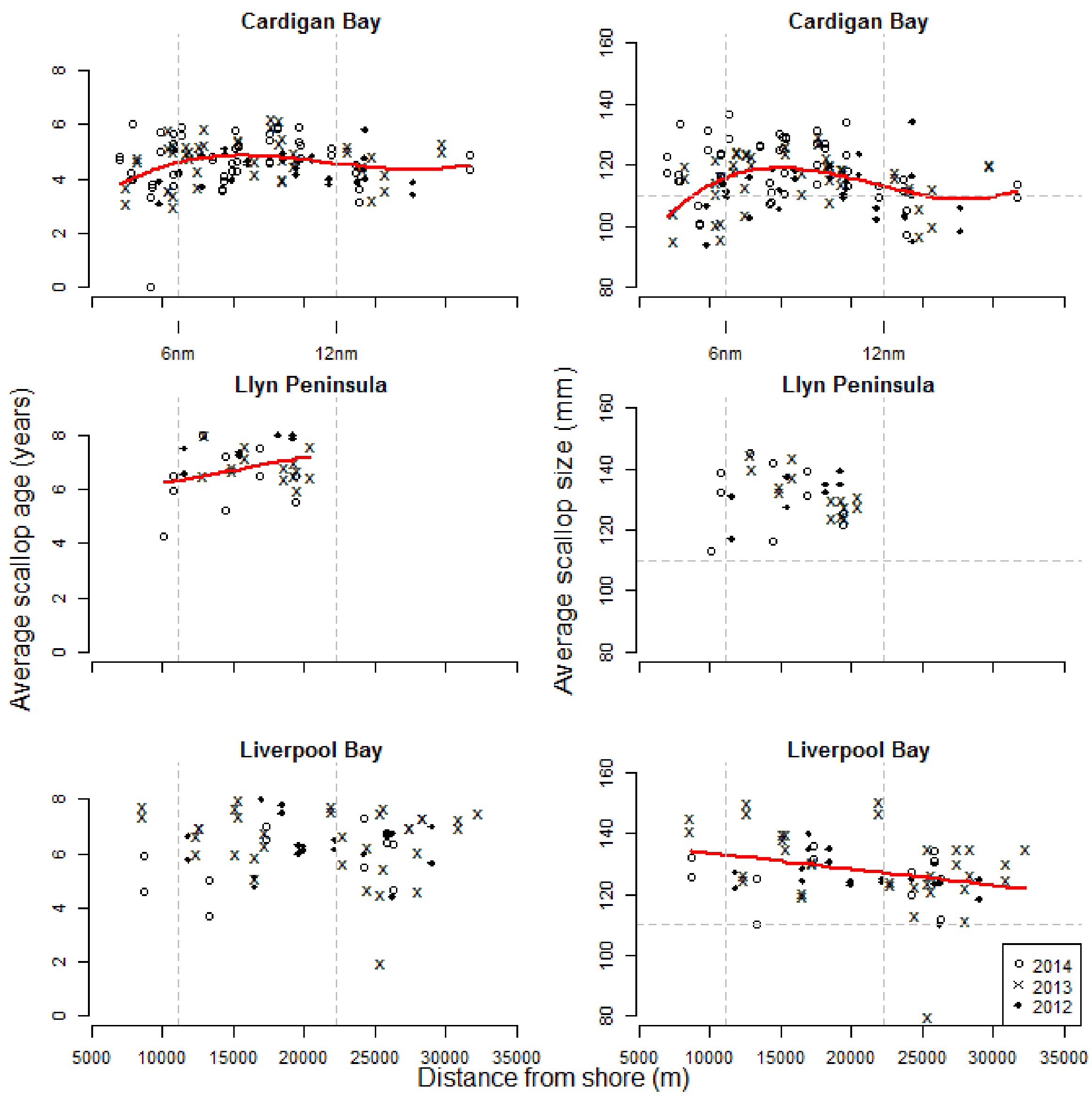

Figure 22. Average age of scallops with distance from shore (left) and average size of scallops with distance from shore (right) on the 3 main scallop grounds.

Figure 22 shows that there exist some complex patterns in Cardigan Bay and that there is a decrease in growth rate with increasing distance from shore in Liverpool Bay. Older scallops were found further offshore at the Llyn Peninsula. We investigated these patterns further, first in Cardigan Bay (Figures 23 to 26).

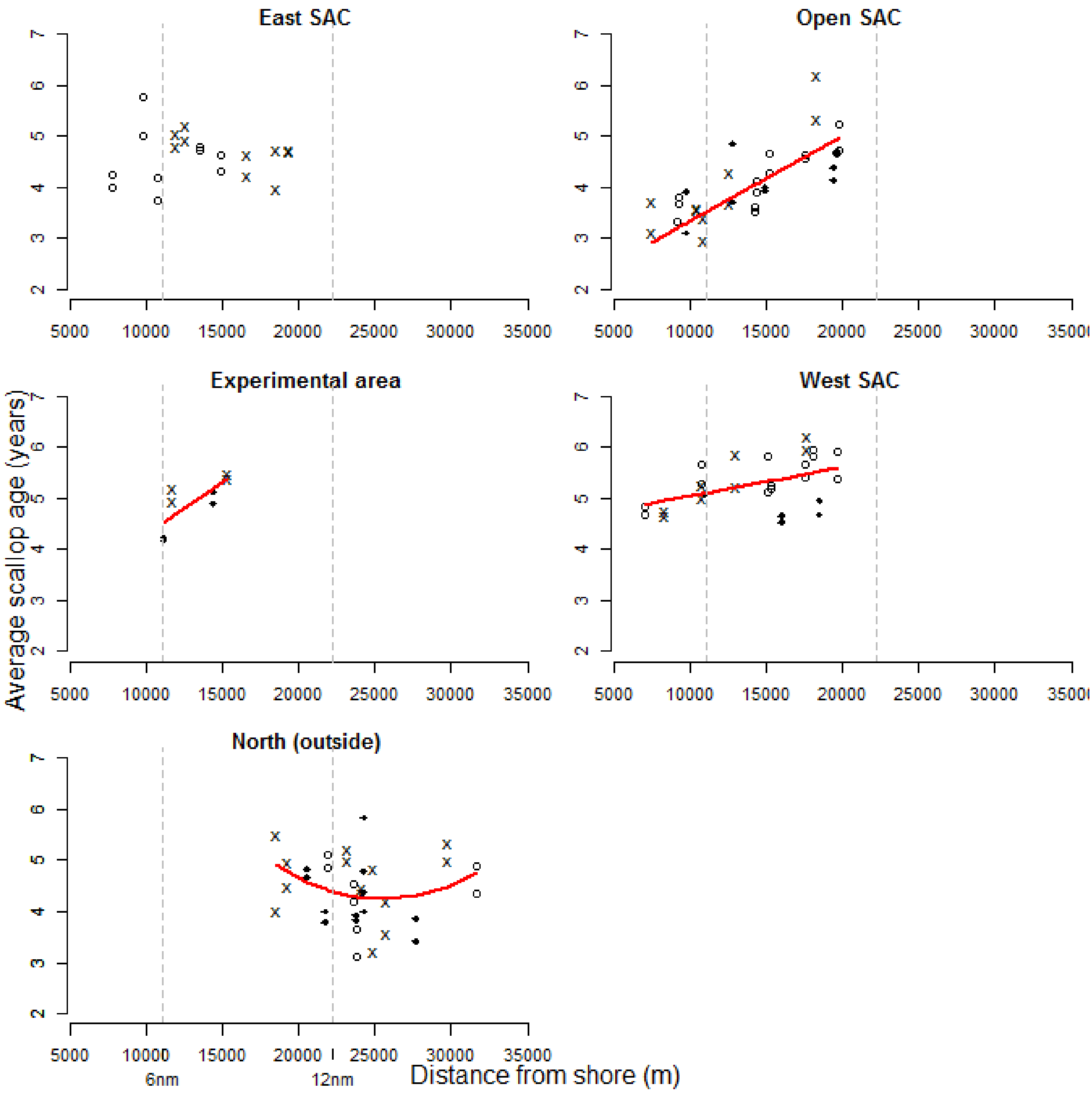

Figure 23. Average age of scallops with distance from shore in the different management areas in Cardigan Bay.

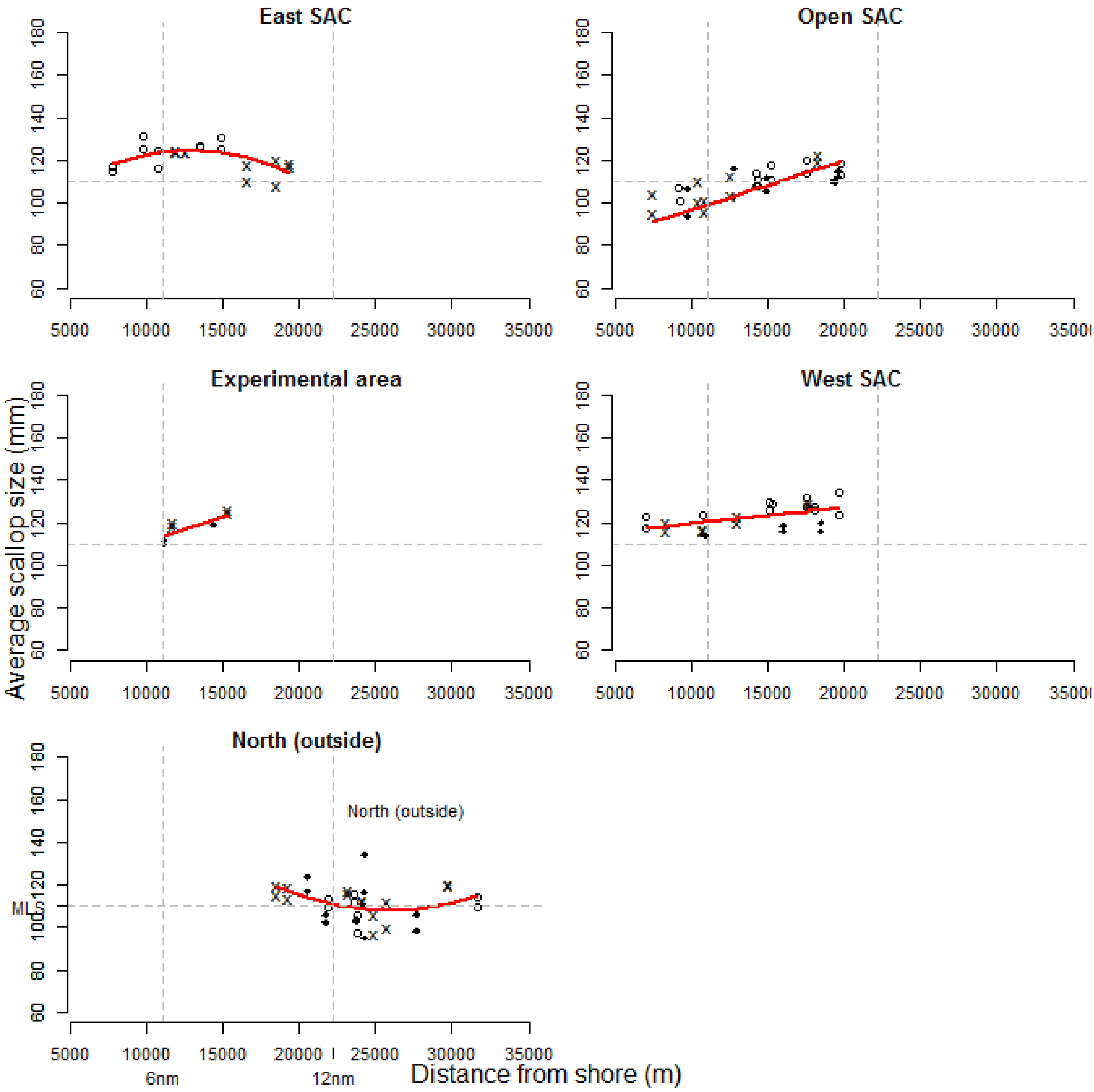

Figure 24. Average size of scallops with distance from shore in the different management areas in Cardigan Bay.

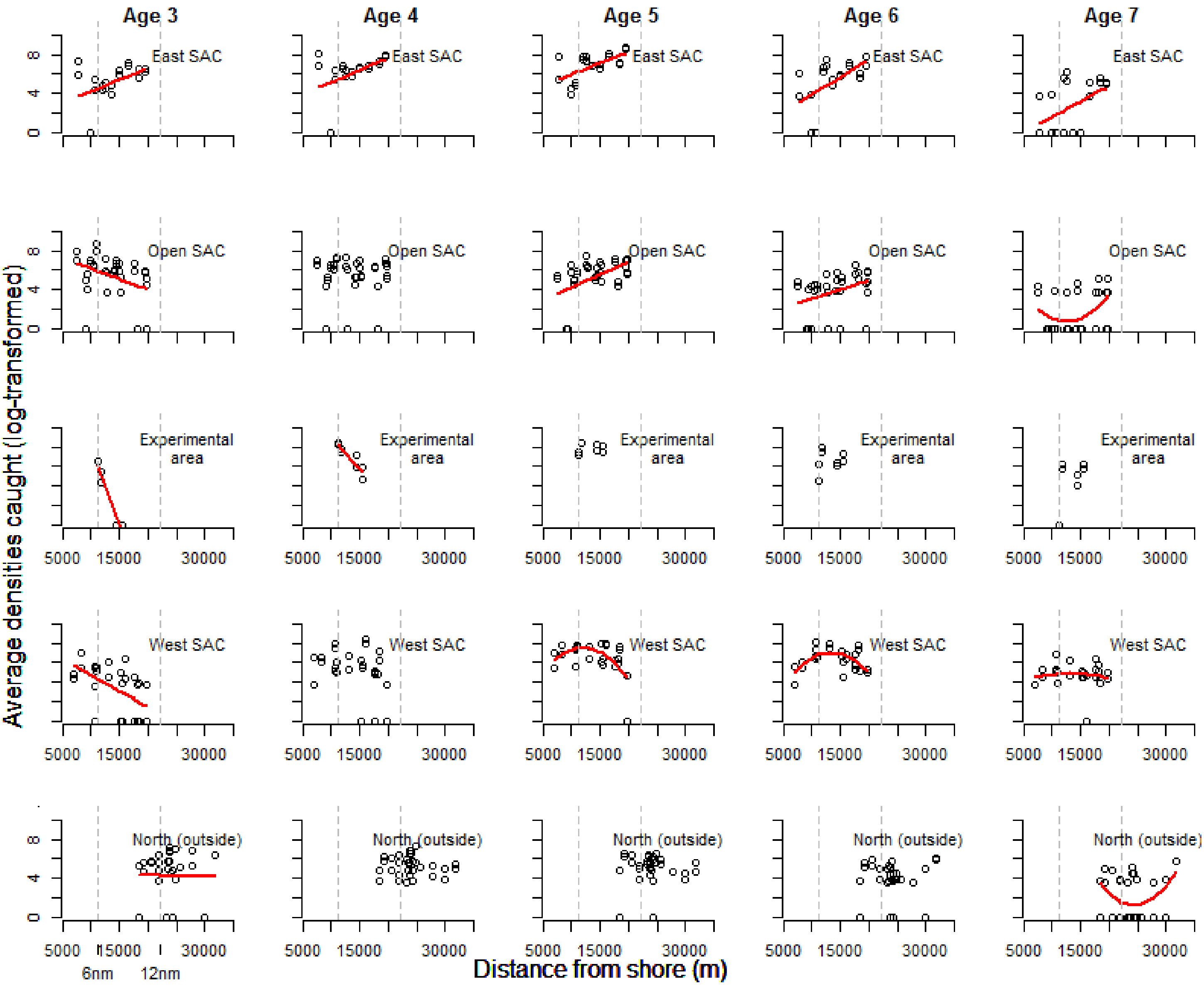

Figure 25. Average densities of scallops with distance from shore in the different management areas in Cardigan Bay.

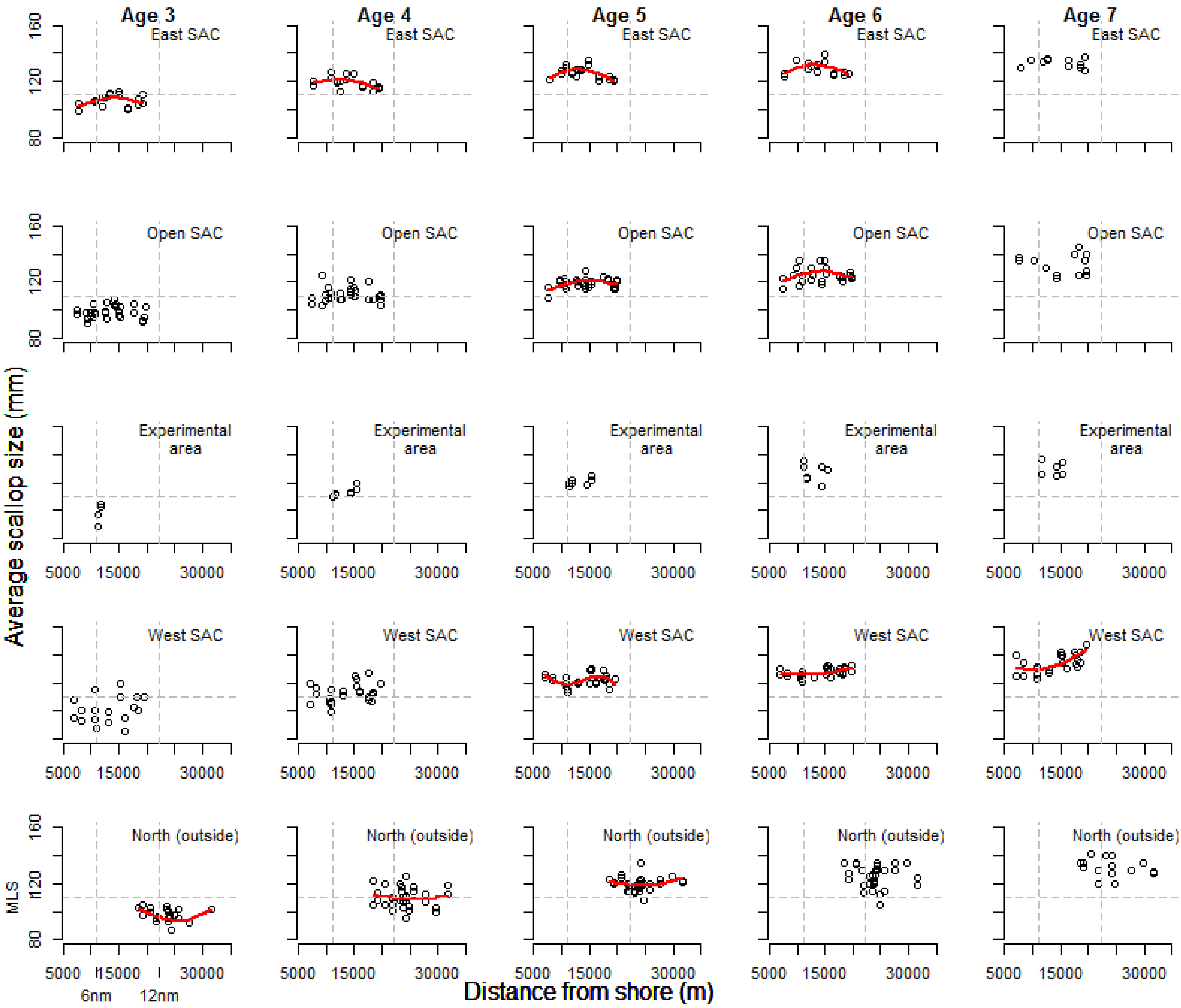

Figure 26. Growth of scallops with distance from shore in the different management areas in Cardigan Bay.

The pattern observed in Cardigan Bay needed to be studied at a smaller scale and it showed that the population was on average older and larger further offshore in the central and western part of the SAC (Figures 23 and 24). There was no clear pattern in the east or further north. This translated into variations in densities at age (Figure 25). Densities of younger scallops were lower further offshore in the central and western part of the SAC. The growth rate did not seem to be affected as no clear pattern could be observed (Figure 26).

At the Llyn Peninsula, where we observed that the average age of scallops increased further offshore (Figure 22), we observed a weak correlation between density at age and distance from shore but no link with growth rates (Figures 27 and 28).

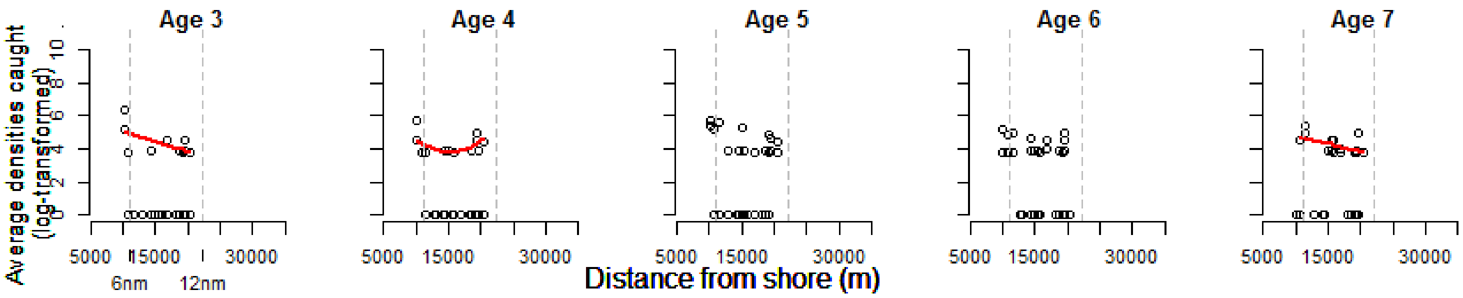

Figure 27. Scallop density at age with distance from shore at the Llyn Peninsula.

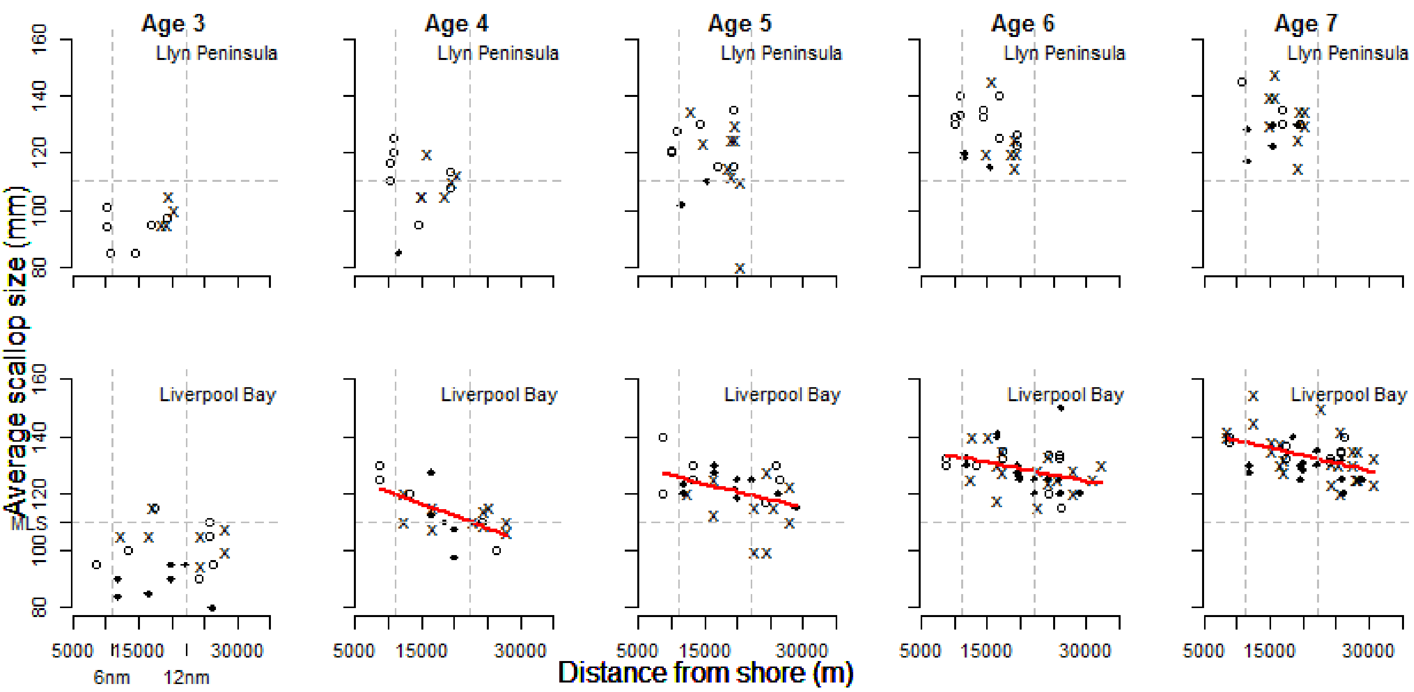

Figure 28. Scallop size at age with distance from shore at the Llyn Peninsula and in Liverpool Bay.

As suggested in Figure 22, growth rates were linked to distance from shore in Liverpool Bay with a marked decrease in size at age for all age groups (Figure 28).

Table 4. Summary table of findings with regards to distance to shore analyses. In red are the significant findings.

	Average Age	Density at age	Average Size	Growth rate
Cardigan Bay East SAC	No difference *(fig. 23)*	Increase in density further offshore regardless of age group *(fig. 25)*	No difference *(fig. 24)*	No difference – complex pattern (maybe slightly larger animals then smaller with distance from shore) *(fig. 26)*
Cardigan Bay Open SAC	Increasing offshore *(fig. 23)*	Age 3 densities decrease further offshore – Age 5 and 6 increase *(fig. 25)*	Increasing offshore *(fig. 24)*	No difference – complex pattern (maybe slightly larger animals then smaller with distance from shore) *(fig. 26)*
Cardigan Bay Exp. Area SAC	Increasing offshore *(fig. 23)*	Age 3 and 4 densities decrease further offshore *(fig. 25)*	Increasing offshore *(fig. 24)*	No difference *(fig. 26)*
Cardigan Bay West SAC	Increasing offshore *(fig. 23)*	Age 3 densities decrease further offshore – more complex for age 5+ (increase then decrease) *(fig. 25)*	Increasing offshore *(fig. 24)*	No difference – trend towards larger animals further offshore *(fig. 26)*
Cardigan Bay North (out SAC)	Weak trend towards decreasing *(fig. 23)*	No difference *(fig. 25)*	Weak trend towards decreasing *(fig. 24)*	No difference *(fig. 26)*
Llyn Peninsula	Increasing offshore *(fig.22)*	Weak trend of decreasing densities at age 3 and to a lesser extent at age 7 with distance from shore *(fig.27)*	No difference *(fig.22)*	No difference *(fig.28)*
Liverpool Bay	No difference *(fig.22)*	_ (not investigated since no mean age difference)	Decreasing offshore *(fig.22)*	Animals size at age smaller offshore for all age groups except age group 3 *(fig.28)*

Other population dynamics parameters of scallop populations around Wales

Here we compared growth in weight of the different body parts of scallops between the different grounds. We further studied yield and gonad status.

Table 5. Growth in weight parameters for data from 2013 – for equation Total weight = a × Size^b

	Width of shells		Height of shells	
	a ($\times 10^{-3}$)	b	a ($\times 10^{-3}$)	b
Cardigan Bay	**1.0**	**2.5**	**0.4**	**2.8**
East SAC	2.6	2.3	1.0	2.6
Open SAC	0.7	2.6	0.2	2.9
Experimental area	2.7	2.3	1.3	2.5
West SAC	8.5	2.1	4.6	2.2
North SAC	-	-	-	-
Llyn Peninsula	**0.6**	**2.6**	**0.2**	**2.9**
Liverpool Bay	**1.4**	**2.4**	**0.8**	**2.6**

Table 5 summarises the weight-length relationship for the different grounds. Further details are given below for the different scallop body parts (Figures 29 and 30).

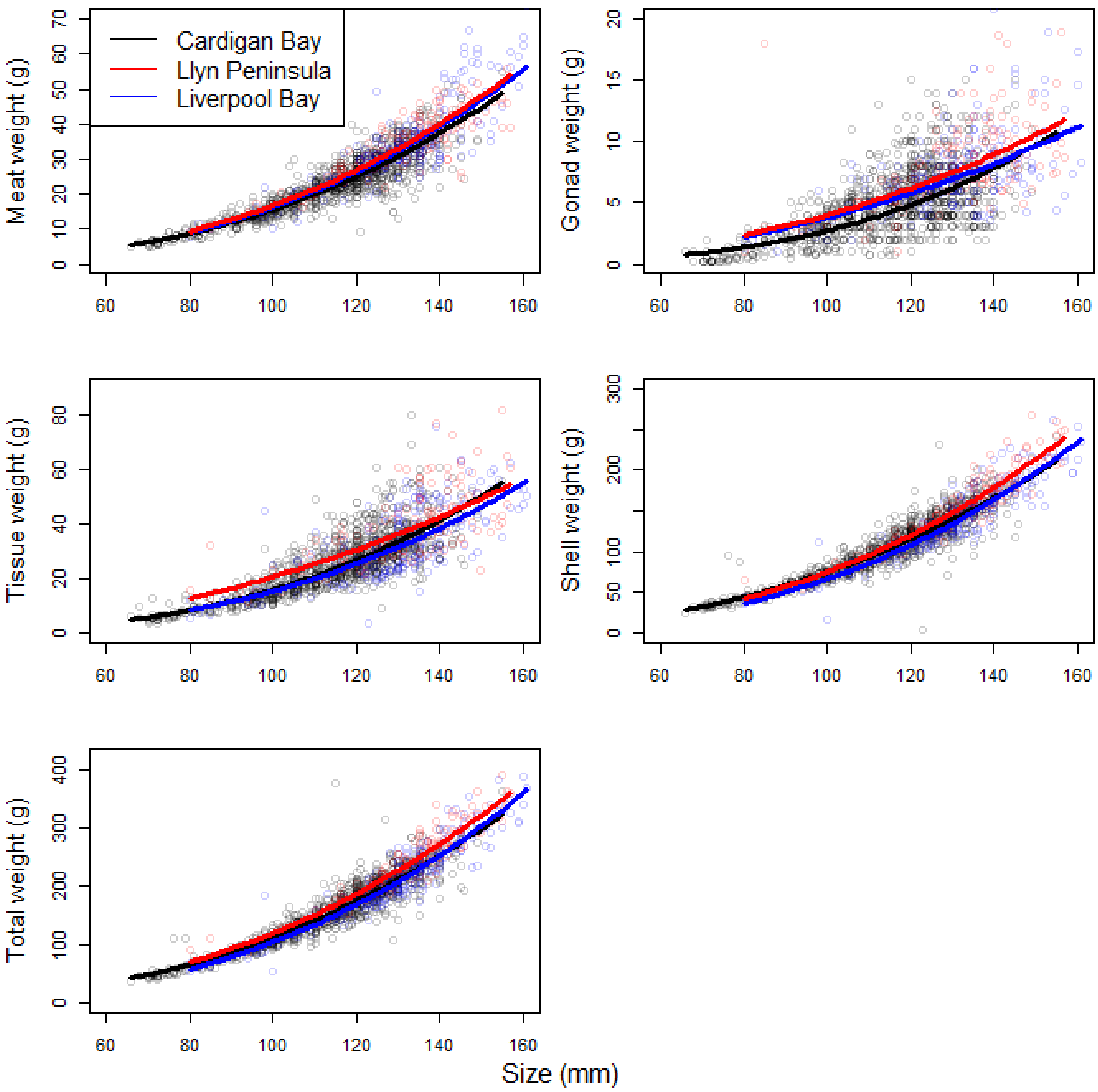

Figure 29. Comparison of weight at size of different body parts of scallops between grounds, all years combined. The regression lines represent the fit of the models described in the methods section. The location effect and/or the interaction between location and size were always significant (statistics outputs not reported).

There were significant differences between grounds and, although those differences were not consistent for all body parts, generally scallops from Cardigan Bay tended to have the lowest weights while scallops from Liverpool Bay had the highest weights across most of the size range (Figure 29).

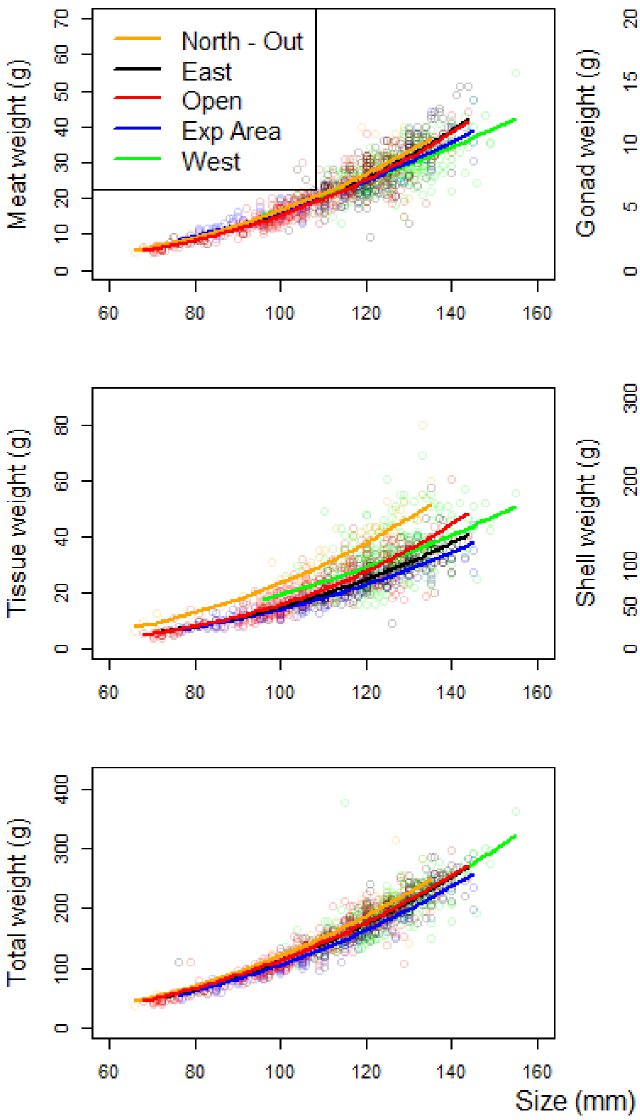

Figure 30. Comparison of weight at size of different body parts of scallops between management areas in Cardigan Bay, all years combined. The regression lines represent the fit of the models described in the methods section. The location effect and/or the interaction between location and size were always significant (statistics outputs not reported).

Figure 30 did not show any consistency in size-weight relationships between the different management areas. Differences in yield are explored below (Figure 31). There did not appear to be a consistent difference between areas over the 3 years of surveys and no evidence of relationship between yield and density (since highest density areas within Cardigan Bay did not show significantly lower yields than the open areas or the grounds of the Llyn Peninsula and Liverpool Bay).

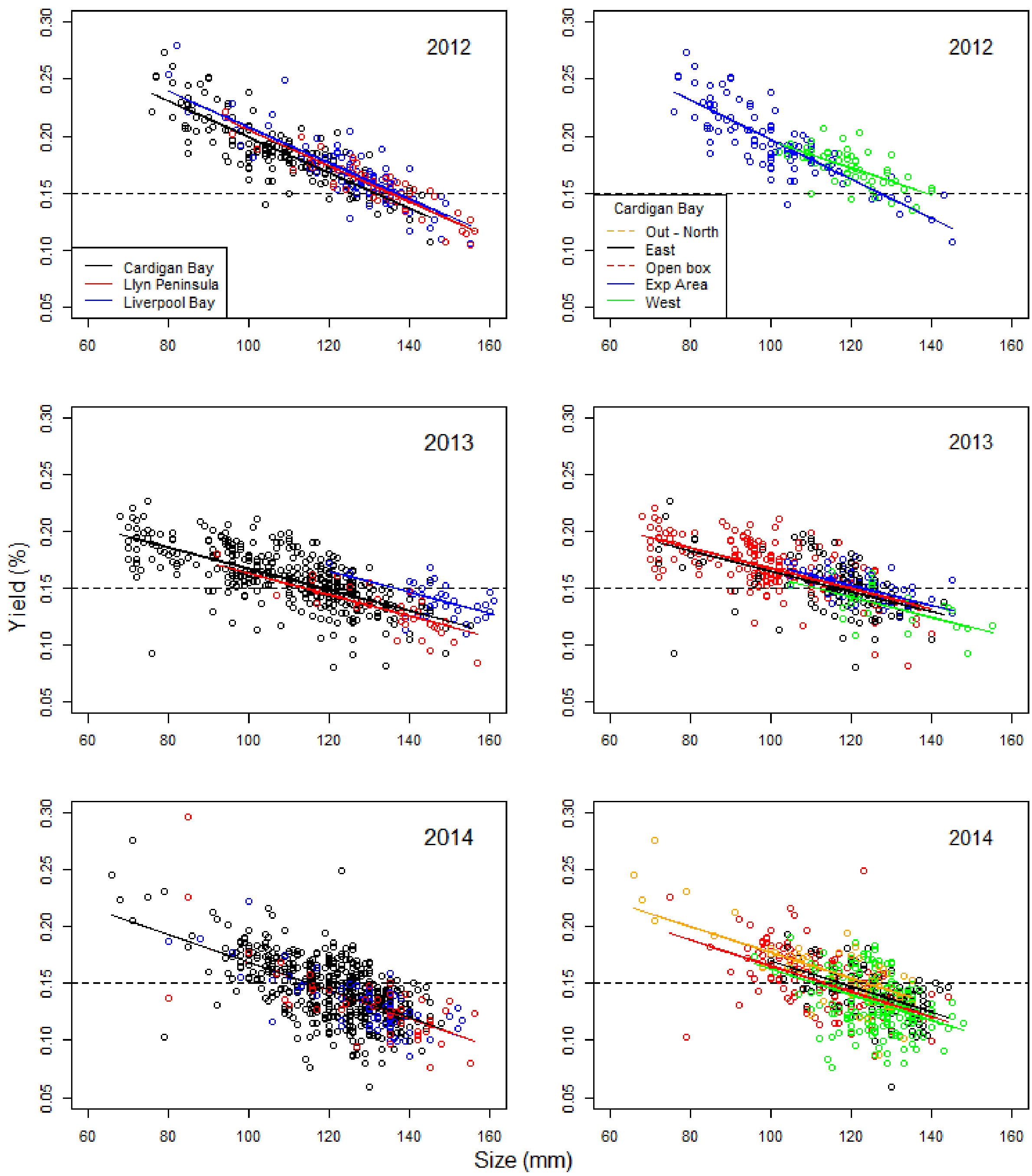

Figure 31. Scallop yield in relation to shell size on all fishing grounds and within management areas in Cardigan Bay. The lines represent the significant regression lines resulting from the analysis of covariance analysis.

Yield will also vary with gonad maturity stages (Figure 32). In June 2012 the gonad stages were markedly different from the July-August surveys of 2013 and 2014. In 2013 and, to some extent, in 2014, the scallops were more mature as we moved north. This could partly reflect some of the differences in gonad weight observed earlier between grounds (Figure 29), i.e. heavier gonads further north, with slightly lighter gonads on average in Liverpool Bay compared to the Llyn Peninsula as part of the gonads collected were spent, i.e. had just spawned. No obvious pattern was observed by comparing the open to the closed SAC in Cardigan Bay (Figure 33).

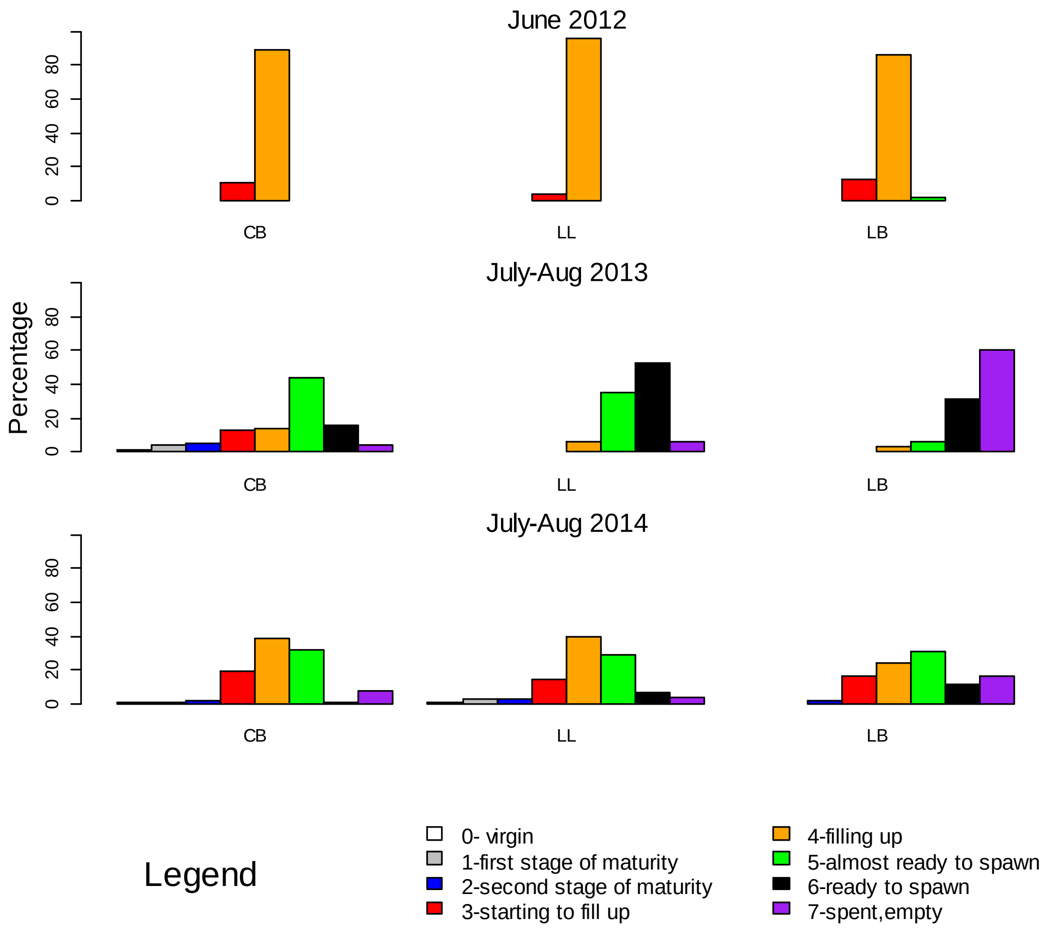

Figure 32. Gonad maturity stages in the main scallop grounds during the 3 surveys. CB= Cardigan Bay, LL= Llyn Peninsula and LB= Liverpool Bay.

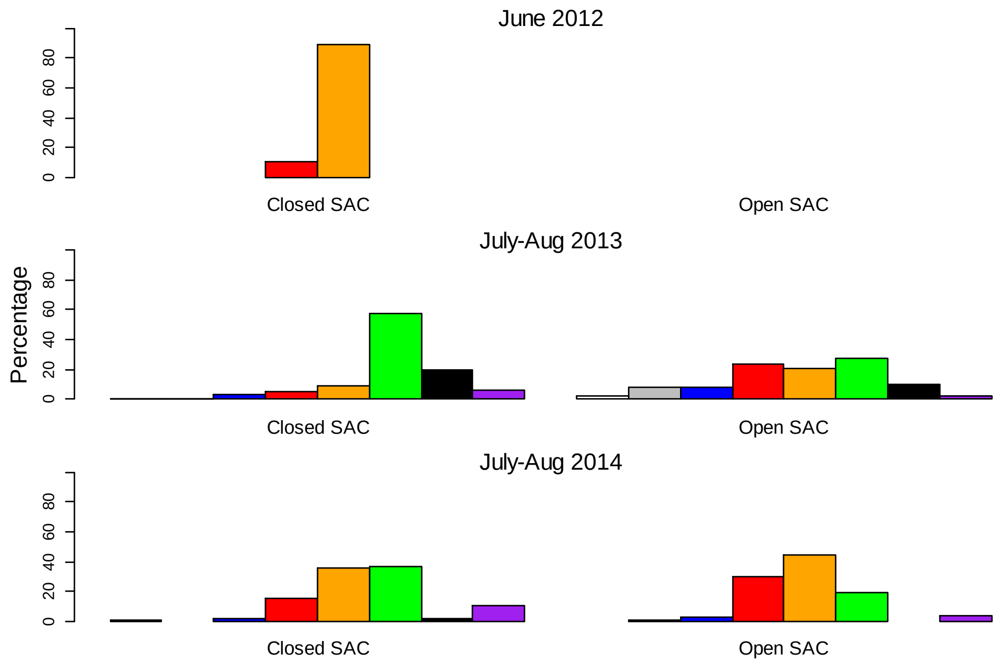

Figure 33. Gonad maturity stages in the closed vs open area of the Cardigan Bay SAC during the 3 surveys.

Bycatch on the Welsh scallop fishing grounds

Bycatch levels were higher in queen dredges than king dredges, which was due to the respective belly rings sizes (Figure 34). Overall, there was more bycatch in Liverpool Bay than at the Llyn Peninsula or in Cardigan Bay (Figure 34).

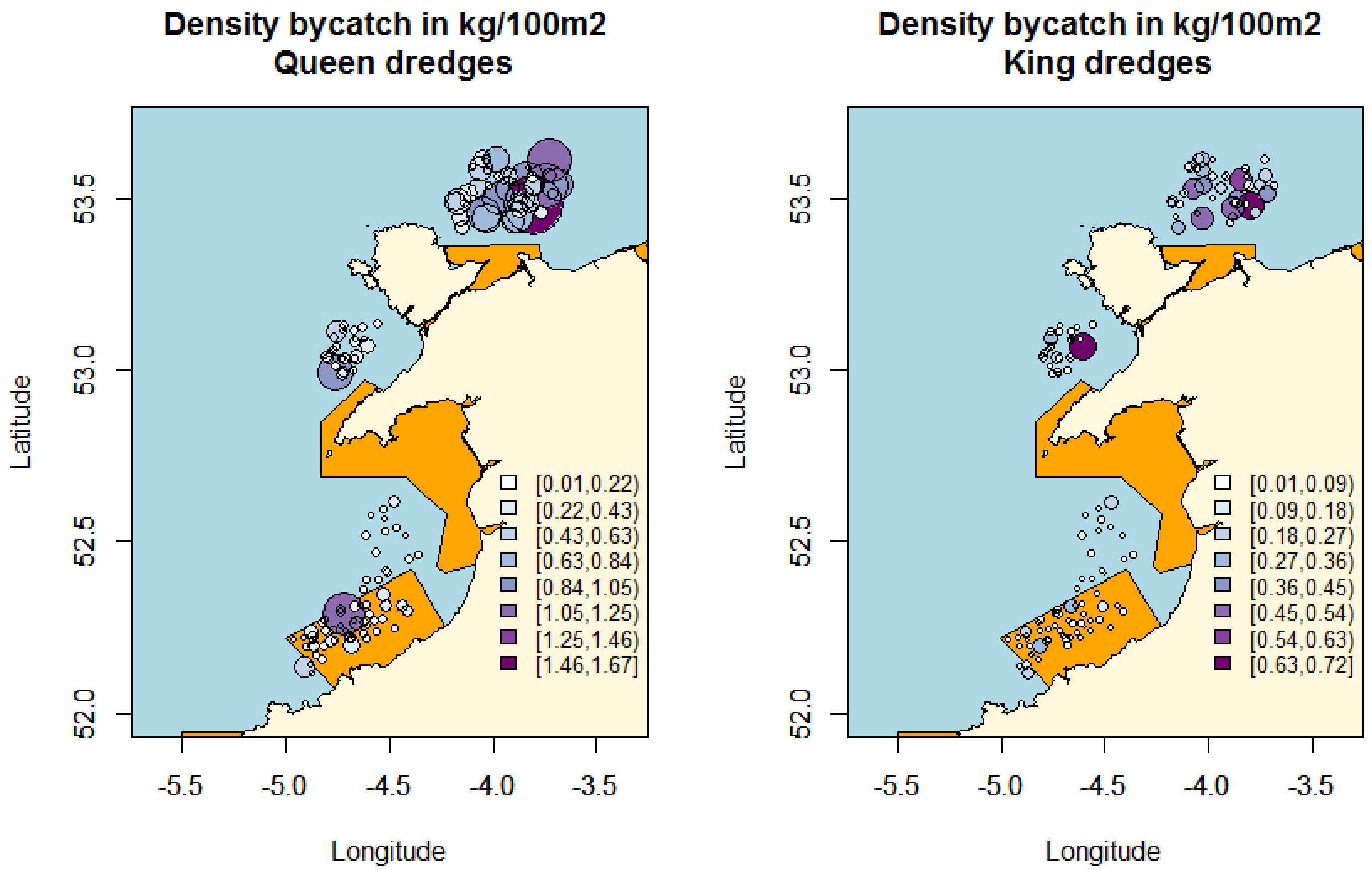

Figure 34. Density of bycatch caught in queen scallop dredges (left) and king scallop dredges (right) for three years of surveys combined.

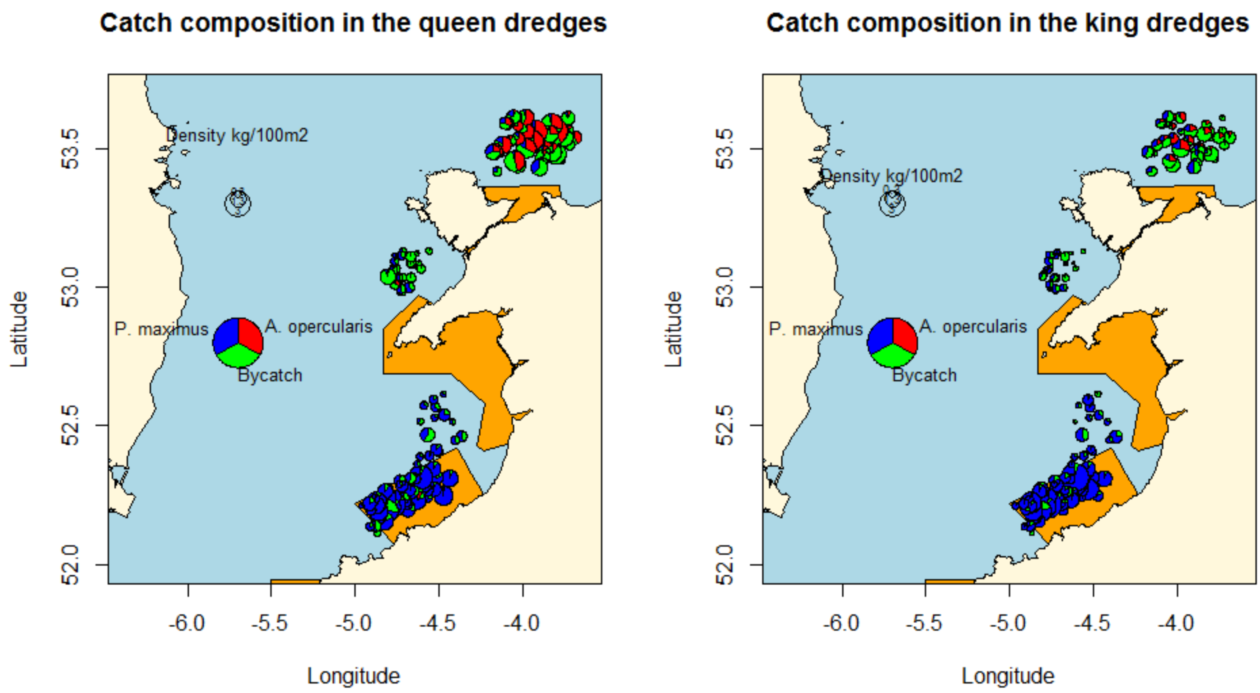

Figure 35. Catch composition in king scallop dredges. Size of circle indicates total biomass of catch (kg/100m^2). Blue indicates the proportion of the target species *P. maximus* in the catch, red indicates the proportion of queen scallops *A. opercularis* and green indicates the proportion of bycatch in the total catch.

The bycatch:scallop ratio was much higher in Liverpool Bay and the Llyn Peninsula than in Cardigan Bay where the majority of the catch was composed of the target species, *P. maximus* (Figures 35 and 36). There did not appear to be a clear difference in the bycatch:catch ratio between the closed and open area in the king dredges' samples taken in the SAC because of the high variability between sampled sites, although the average total catch biomass was higher in the closed area (Figure 36).

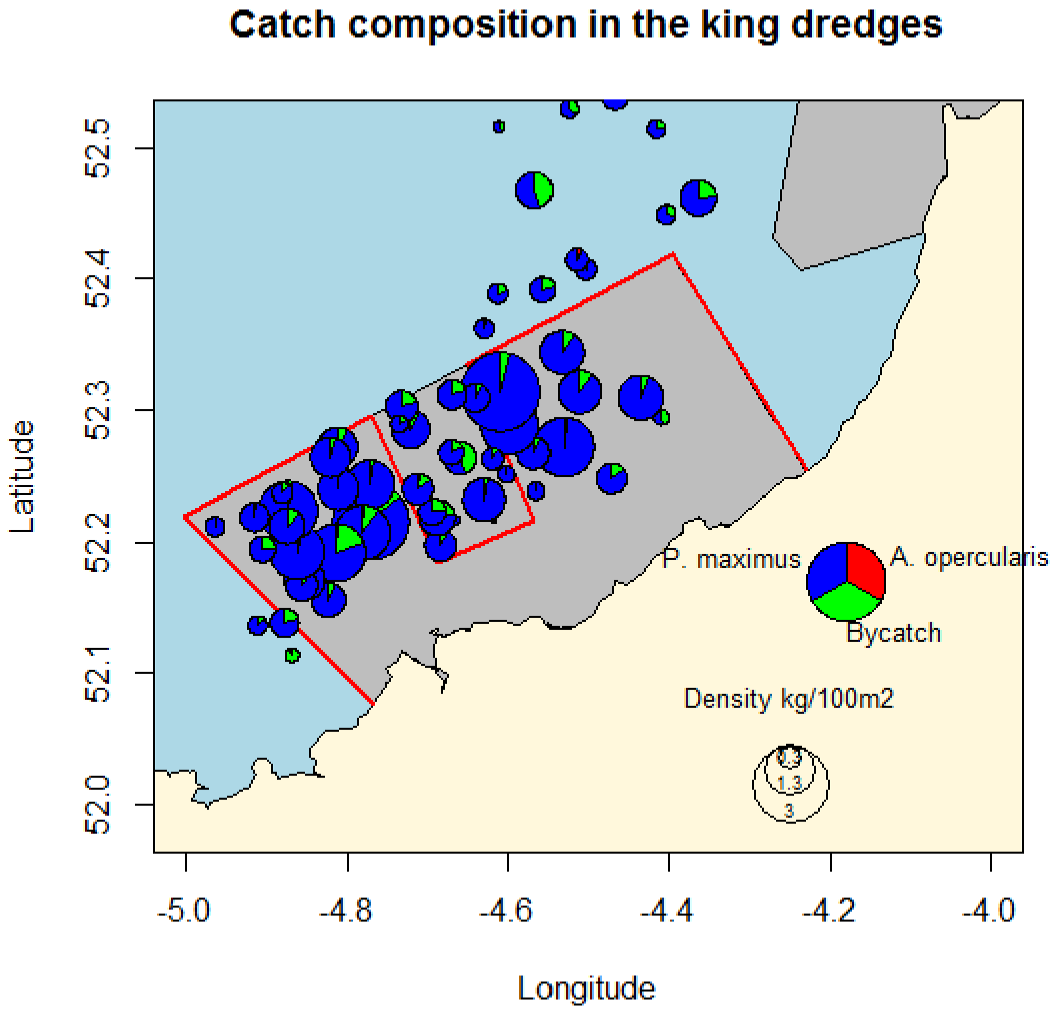

Figure 36. Catch composition of king scallop dredges in Cardigan Bay. Size of circle indicates total density of catch (kg/100m^2). Blue indicates the proportion of the target species *P. maximus* in the catch, red indicates the proportion of queen scallops *A. opercularis* and green indicates the proportion of bycatch in the total catch.

Overall, in the king dredges, the bycatch biomass was 0. 04 (± 0.06 sd) in the open area of the SAC and 0.06 (±0.07 sd) kg/100m^2 in the closed area. In the queen dredges, the bycatch biomass was 0.11 (±0.09) in the open area of the SAC and 0.13 (±0.12) kg/100m^2 in the closed area.

Figures 37 and 38 show the differences in densities of bycatch per area and year. No consistent difference in density of bycatch was observed between closed and open areas of the SAC.

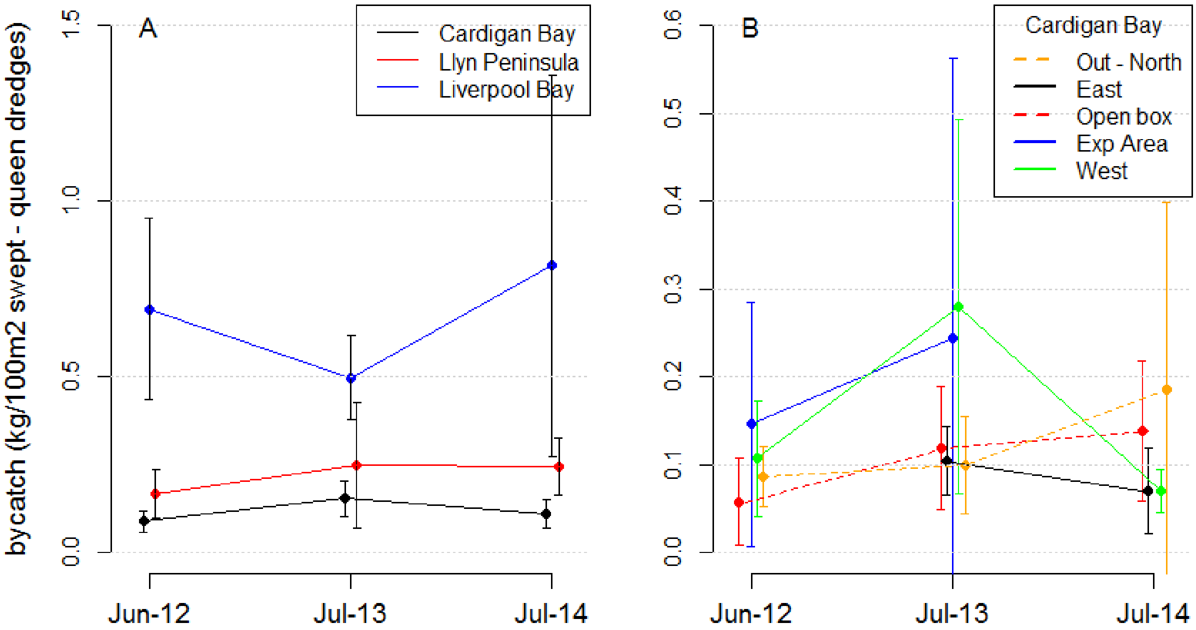

Figure 37. Bycatch in the queen dredges per scallop ground (A) and management area in Cardigan Bay (B)

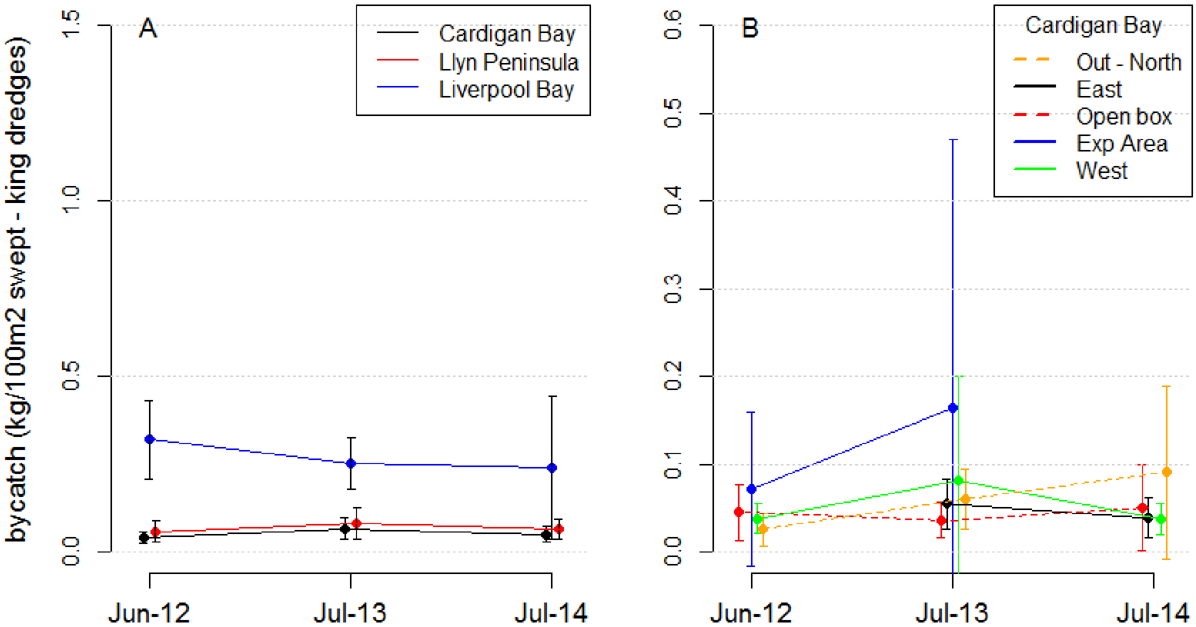

Figure 38. Bycatch in the king dredges per scallop ground (A) and management area in Cardigan Bay (B).

The species composition of the bycatch between the three main grounds varied significantly when combining queen and king scallop dredges data (Anosim results, r^2=0.39, p=0.001). The MDS plot showed that the 3 areas clustered separately from each other and that the composition of bycatch was consistent between years despite some small variation (Figure 39). The PERMANOVA test confirmed that year, location and the interaction between the two were significantly affecting species composition, although year and the interaction between year and location had a smaller effect than location itself (year - partial R^2 = 0.02, p<0.001; location - partial R^2 = 0.19, p<0.001; interaction - partial R^2 = 0.02, p=0.018).

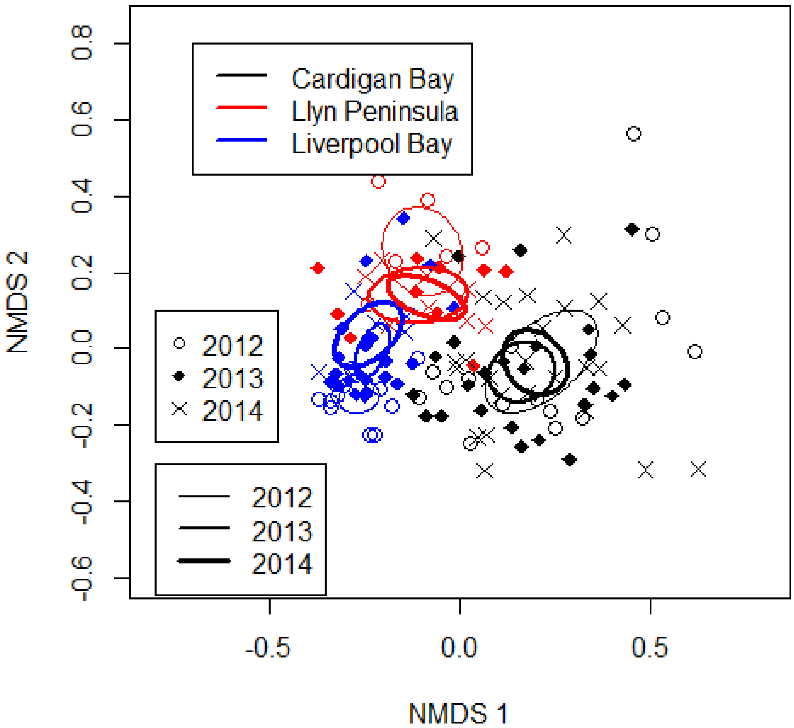

Figure 39. MDS plot representing the community composition of the bycatch from king and queen scallop dredges in Cardigan Bay, Liverpool Bay and off the Llyn Peninsula in 2012, 2013 and 2014 from biomass data. The ellipsoids represent the standard error of the mean with 95% confidence interval.

Further analyses were conducted to identify the bycatch species that were typical of the different grounds and were contributing to differentiating them on the MDS plot. A species helps to significantly distinguish a ground from the others if it is highly abundant in this ground compared to the others and if it is found in most sites sampled on that particular ground. Those species which are typical of one specific ground are called indicator species. There was a high number of indicator species in Liverpool Bay compared to Cardigan Bay and the Llyn Peninsula. Cardigan Bay was therefore mostly distinguished by the very low abundances and diversity of bycatch compared to the other two sites. The list of significant indicator species is presented in Table 5.

Table 5. List of indicator species in the bycatch in king and queen scallop dredges. Data pooled for 2012, 2013 and 2014.

	Cardigan Bay	Llyn Peninsula	Liverpool Bay
Anemones			*Adamsia carciniopados*
Ascidians		*Ascidian (undetermined)* *Botryllus schlosseri*	*Ciona intestinalis*
Bivalves	*Glycymeris glycymeris*	*Arctica islandica*	*Hiatella arctica* *Modiolus modiolus*
Bryozoans		*Alcyonidium diaphanum* *Bugula* spp. *Cellepora* spp.	
Crustaceans	*Cancer pagurus* *Maja squinado* *Necora puber*		*Atelecyclus rotundatus* *Eurynome* spp. *Galathea* spp. *Hyas areneus* *Hyas coarctatos* *Pagurus bernhardus* *Pagurus prideauxi* *Pisidia longicornis*
Echinoderms		*Anseropoda placenta* *Astropecten irregularis* *Crossaster papposus* *Luidia ciliaris*	*Asterias rubens* *Echinus esculentus* *Henricia oculata* *Holothurian* spp. *Ophiothrix fragilis* *Ophiura albida* *Ophiura ophiura* *Psammechinus miliaris* *Spatangus purpureus*
Fish/Sharks/Rays			*Callionymus* spp. *Raja brachyura* *Scyliorhinus canicula*
Gastropods	*Aporrhais pespelecani*		*Buccinum undatum* *Colus gracilis* *Diodora graeca* *Neptunea antiqua* *Nudibranch*
Hydroids		*Sertularella gayi* *Sertularia* spp.	*Abietinaria abietina* *Hydrallmania* spp. *Tubularia indivisa*
Soft corals			*Alcyonium digitatum*
Sponges		*Suberites domuncula*	
Worms			*Aphrodita aculeata* *Lanice conchilega*

There is a similar distinction between grounds when looking at bycatch from king scallop dredges only (Anosim results, r^2=0.23, p=0.001).The PERMANOVA test confirmed that year and location were significantly affecting species composition. The interaction between the two was no longer significant. Year still had a very small effect in comparison to location (year - partial R^2 = 0.02, p<0.001; location - partial R^2 = 0.14, p<0.001; interaction - partial R^2 = 0.01, p=0.253).

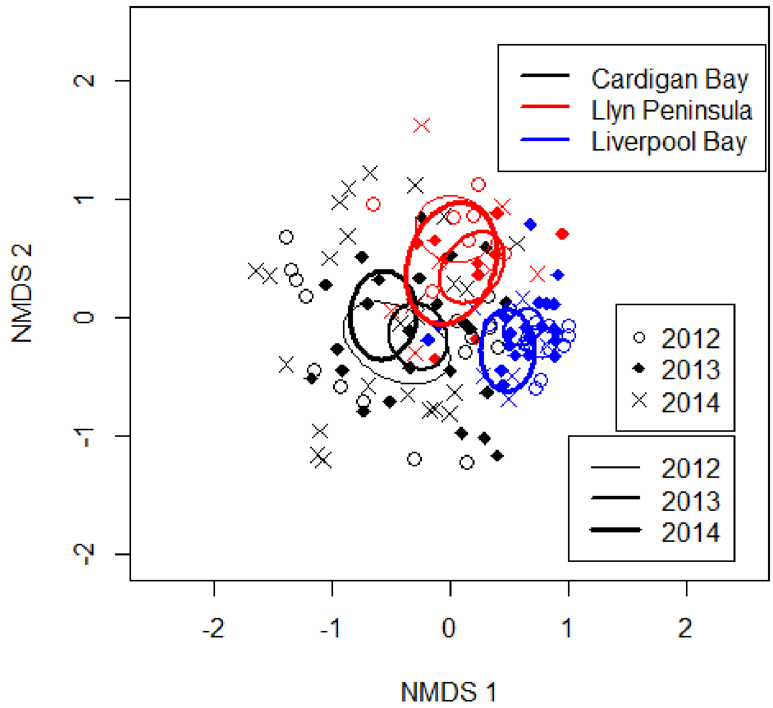

Figure 40. MDS plot representing the community composition of the bycatch from king scallop dredges only in Cardigan Bay, Liverpool Bay and off the Llyn Peninsula in 2012, 2013 and 2014. The ellipsoid represent the standard error of the mean with 95% confidence intervals.

Table 6 presents the list of indicator species from king scallop dredge bycatch. The list is very similar to the list from queen scallop dredges but with less species.

Table 6. List of indicator species in the bycatch in king scallop dredges only. Data pooled for 2012, 2013 and 2014.

	Cardigan Bay	Llyn Peninsula	Liverpool Bay
Ascidians			*Ciona intestinalis* *Haliclona oculata*
Bivalves			*Modiolus modiolus*
Bryozoans		*Alcyonidium diaphanum* *Bugula* spp. *Cellepora* spp.	
Crustaceans	*Cancer pagurus* *Maja squinado*		*Eurynome* spp. *Hyas areneus* *Hyas coarctatos* *Inachus* spp. *Macropodia* spp. *Pagurus bernhardus* *Pagurus prideauxi* *Pisidia longicornis*
Echinoderms		*Anseropoda placenta* *Luidia ciliaris*	*Asterias rubens* *Crossaster papposus* *Echinus esculentus* *Henricia oculata* *Holothurian* spp. *Ophiocomina nigra* *Ophiothrix fragilis* *Ophiura albida* *Ophiura ophiura* *Psammechinus miliaris* *Spatangus purpureus*
Fish/Sharks/Rays		*Aspitrigla cuculus* *Raja clavata*	*Raja brachyura* *Scyliorhinus canicula*
Gastropods			*Buccinum undatum* *Colus gracilis* *Neptunea antiqua*
Hydroids		*Sertularella gayi* *Sertularia* spp.	*Abietinaria abietina* *Hydrallmania spp* *Tubularia indivisa*
Soft corals			*Alcyonium digitatum*
Sponges		*Suberites domuncula*	
Worms			*Aphrodita aculeata* *Lanice conchilega*

We further studied the bycatch composition within Cardigan Bay, again both in queen and king dredges.

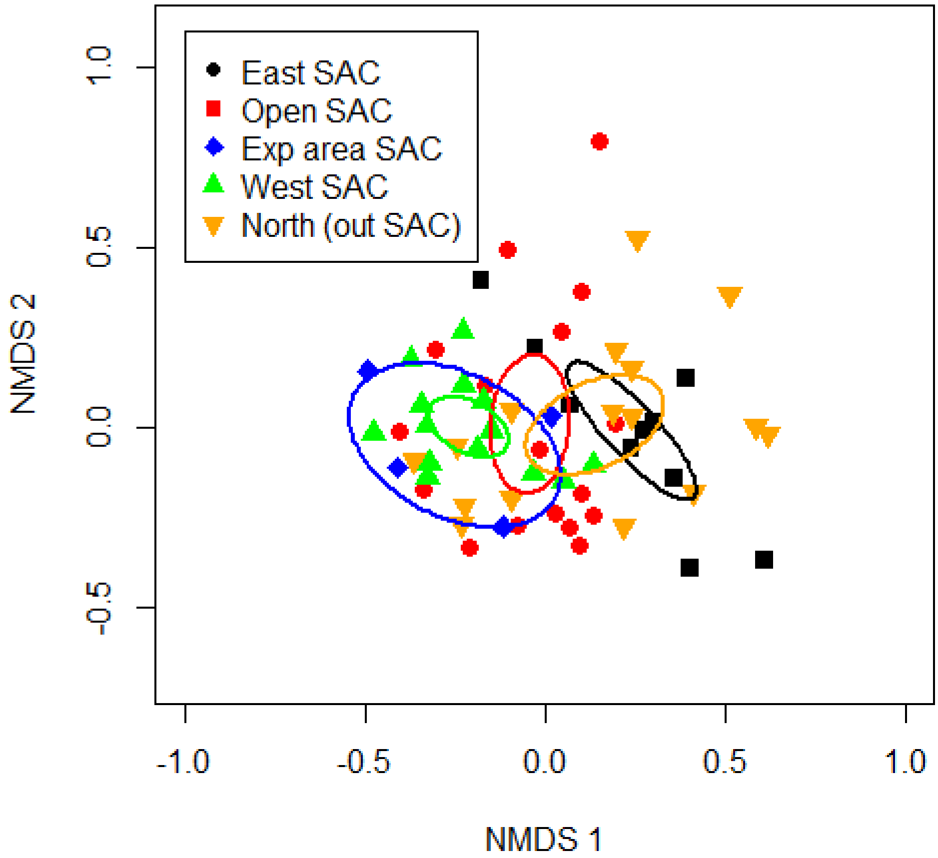

Figure 41. MDS plot representing the community composition of the bycatch from king and queen scallop dredges in Cardigan Bay management areas, combining 2012, 2013 and 2014. The ellipsoids represent the standard error of the mean with 95% confidence interval.

There is a distinction between management areas of the Cardigan Bay SAC when looking at bycatch from queen and king scallop dredges combined (Anosim results, r^2=0.22, p=0.001), although not as clear as the distinction between the 3 major grounds (Llyn Peninsula, Liverpool Bay, Cardigan Bay). The neighboring west and experimental area overlap and the open area is between the east, the north and the western areas. The patterns seem to match geographical location over fishing restrictions. The PERMANOVA test showed that location and, to a lesser extent, year affected species composition (year - partial R^2 = 0.02, p=0.038; location - partial R^2 = 0.14, p<0.001; interaction (not significant) - partial R^2 = 0.07, p=0.294). Table 7 lists the significant indicator species. Note that there are no indicator species in the open area of the SAC.

Table 7. List of indicator species in the bycatch in queen and king scallop dredges in Cardigan Bay. Data pooled for 2012, 2013 and 2014.

	East	Open	Experimental area	West	North
Bryozoans					*Flustra foliacea*
Crustaceans	*Liocarcinus depurator*				
Echinoderms			*Asterias rubens* *Ophiura albida*	*Anseropoda placenta*	
Fish	*Pleuronectes platessa*				
Hydroids			*Nemertesia* spp.	*Hydrallmania* spp.	
Soft corals			*Alcyonium digitatum*		
Sponges					*Halichondria spp*

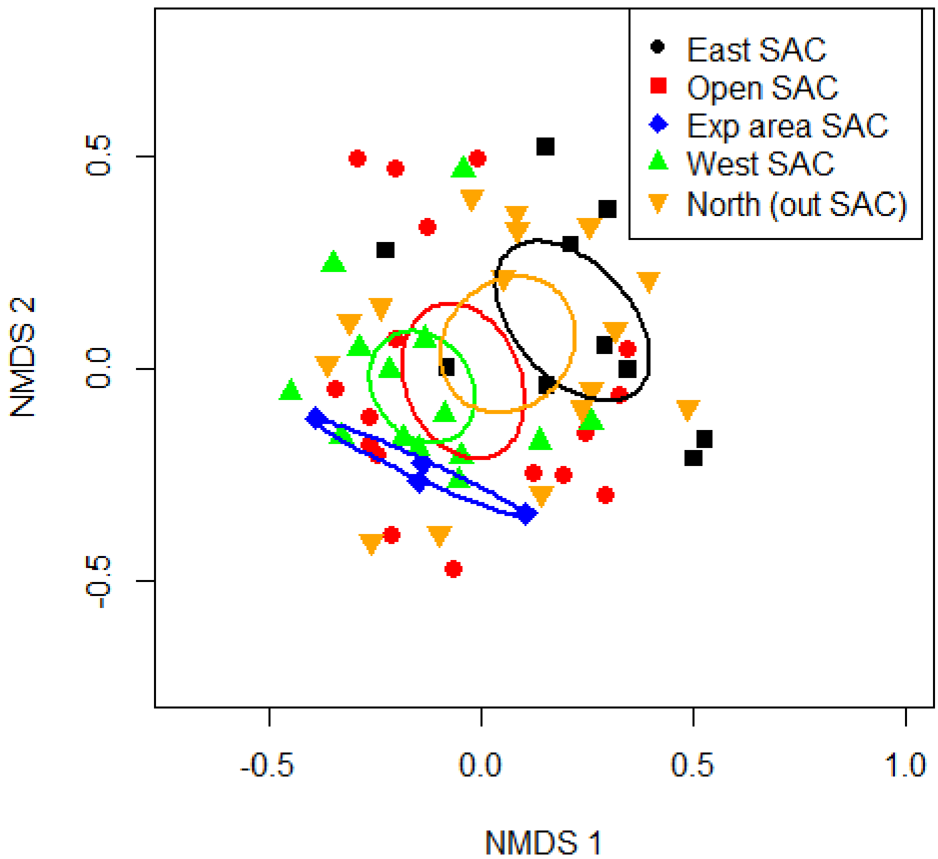

Figure 42. MDS plot representing the community composition of the bycatch from king scallop dredges only in Cardigan Bay management areas, combining 2012, 2013 and 2014. The ellipsoid represent the standard error of the mean with 95% confidence interval.

There is still a distinction between management areas of the Cardigan Bay SAC when looking at bycatch from king scallop dredges only (Anosim results, r^2=0.13, p=0.002) that seems to match seem geographical location over fishing restrictions. Again, the PERMANOVA test showed that location affected species composition but year did not appear to have a significant effect here (year (not significant) - partial R^2 = 0.02, p=0.071; location - partial R^2 = 0.15, p<0.001; interaction (not significant) - partial R^2 = 0.07, p=0.461). Table 8 lists the significant indicator species. Note that there are no indicator species in the open area of the SAC. The experimental area seems to be the most diverse although there are still very few indicator species compared to the Llyn Peninsula and Liverpool Bay.

Table 8. List of indicator species in the bycatch in king scallop dredges only in Cardigan Bay. Data pooled for 2012, 2013 and 2014.

	East	Open	Experimental area	West	North
Bryozoans					*Flustra foliacea*
Crustaceans			*Pagurus bernhardus*		
Echinoderms			*Asterias rubens* *Ophiura albida* *Psammechinus miliaris*	*Luidia ciliaris*	
Fish	*Pleuronectes platessa*				
Gastropods			*Buccinum undatum*		
Soft corals			*Alcyonium digitatum*		

Discussion

Conducting three years of research surveys has helped us gathering all the basic population dynamics information needed to start monitoring the status of the scallop stocks in Wales. There is no sign of major change over the past three years although some question marks remain, mostly due to apparent problems of catchability and spatial heterogeneity of scallop distribution in 2014. Generally to distinguish between uncertainties around abundance indices, natural fluctuations and significant changes in abundance much longer time series are needed. For future surveys we recommend that dredge vs video comparisons are conducted wherever possible to be able to correct for inter-annual variation in catchability. Improving the current video system so that scallop sizes can be accurately measured would also be necessary in order to better assess the status of the stock and estimate the size selectivity of the gear.

Further work on stock status will be conducted by analysing catch per unit effort (CPUE) obtained from vessel monitoring systems (VMS) and logbook data (source MMO). However, no fishery dependent data (i.e. size and age data) have ever been collected in Wales and this limits the use of the CPUE data to conduct stock assessments. Data collected during research surveys can be used in combination with fishery CPUE data to inform stock assessments but longer time series are required.

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