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Welsh waters scallop survey – Cardigan Bay to Liverpool Bay June 2012

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Investing in Sustainable Fisheries

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CONTENT

EXECUTIVE SUMMARY

- There were considerable differences in the abundances of scallops within the the four areas sampled: Liverpool Bay, North Western Llyn Peninsula, Tremadog Bay and Cardigan Bay. King scallop abundance was considerably higher in Cardigan Bay compared to the other three areas surveyed. Queen scallops were only occurred at a high density in Liverpool Bay.
- 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 with very few juveniles. This indicated that there has been poor recent recruitment of scallops within these areas. Cardigan Bay had a strong cohort of young scallops but fewer older scallops which is concurrent with recent fishing activity.
- Within Cardigan Bay the closed area within the Special Area of Conservation contained twice as many scallops compared to the seasonally open area.
- There was a slight difference in growth and in the muscle meat: size ratio between the Llyn Peninsula and the other two areas. King scallops at the Llyn Peninsula grew slower and had larger meat weights.
- The amount of by-catch retained in the dredges used in Cardigan Bay was very low while a high biomass of bycatch was retained in the dredges used in Liverpool Bay and at the Llyn Peninsula
- No stony reef features were encountered within Cardigan Bay during the video survey work.
- Further work is needed to understand the connectivity of the different scallop grounds (i.e. their sources and sinks of larvae). It appears that different processes seem to influence the different fishing areas and they therefore may require locally tailored management measures.
- Current evidence suggests that Cardigan Bay has a regular recruitment of scallops and may be self recruiting based on initial modelling work. The high abundance and biomass of scallops within the closed area could potentially support a fishery based on a rotational scheme of open and fallow areas, supported by some permanently closed areas to ensure a continuous supply of larvae.

INTRODUCTION

The Welsh fishing industry is primarily an inshore fleet with only 10% of fishers working in offshore waters (beyond 6nm). Consequently, this inshore fleet is dependent on the sustainability of the local stocks. This is in comparison to nomadic or offshore fleets which can operate extensively around the UK or further afield and are therefore not reliant on local sustainability. It is therefore imperative to the livelihoods of Welsh fishers that the key species providing income to the Welsh fleet are managed sustainably.

The scallop fishing industry (*Pecten maximus and Aequipecten opercularis*) employs 75 fishers in Wales and scallops are the second most valuable species landed in Wales (£3,462,905 annually (source: Welsh Assembly Government)). 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.

The present survey was the first scallop survey undertaken as part of the European Fisheries Fund (EFF) funded project lead by Bangor University in collaboration with the welsh fishing industry. This first survey 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 policy it is not possible to use this method in all parts of Welsh waters. In particular restrictions 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 lead surveys in the future might utilize these techniques.

A *Modiolus modiolus* reef is located to the north of the Llyn Peninsula, close to a known scallop fishing ground. The Countryside Council for Wales (CCW) has concerns over the effect of sediment re-suspension from fishing activity that may then settle onto the reef. Therefore, a buffer zone around the reef is to be implemented. To facilitate the positioning and size of the buffer zone a hydrodynamic model of the area has been developed by Prof. Dave Bowers at Bangor University. However, this model needs accurate sediment grain size data and therefore such samples were collected during the survey.

Specifically the survey had the following objectives:

1. Estimate the abundances of scallops (*P. maximus and A. opercularis*) in four 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 abundance estimates obtained from scallop dredging surveys and from camera tows.
5. |Contribute and add to the habitat mapping data already collected in 2009 and 2010.
6. Collect sediment samples from around the *Modiolus modiolus* reef at the Llyn Peninsula.

METHODS

1- 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. Within these four areas random replicate sampling was carried out at a total of 46 sites. Within the 3 nautical mile limit from the shore and within specific areas of Cardigan Bay SAC (i.e. near any potential features), scallop dredging was not permitted so only camera tows were conducted at these sites (13 sites in total). In all other areas, it was possible to sample using scallop dredges. At 12 sites, both camera tows and scallop dredges were deployed to allow comparison of abundance estimates using the different sampling techniques (Figure 1).

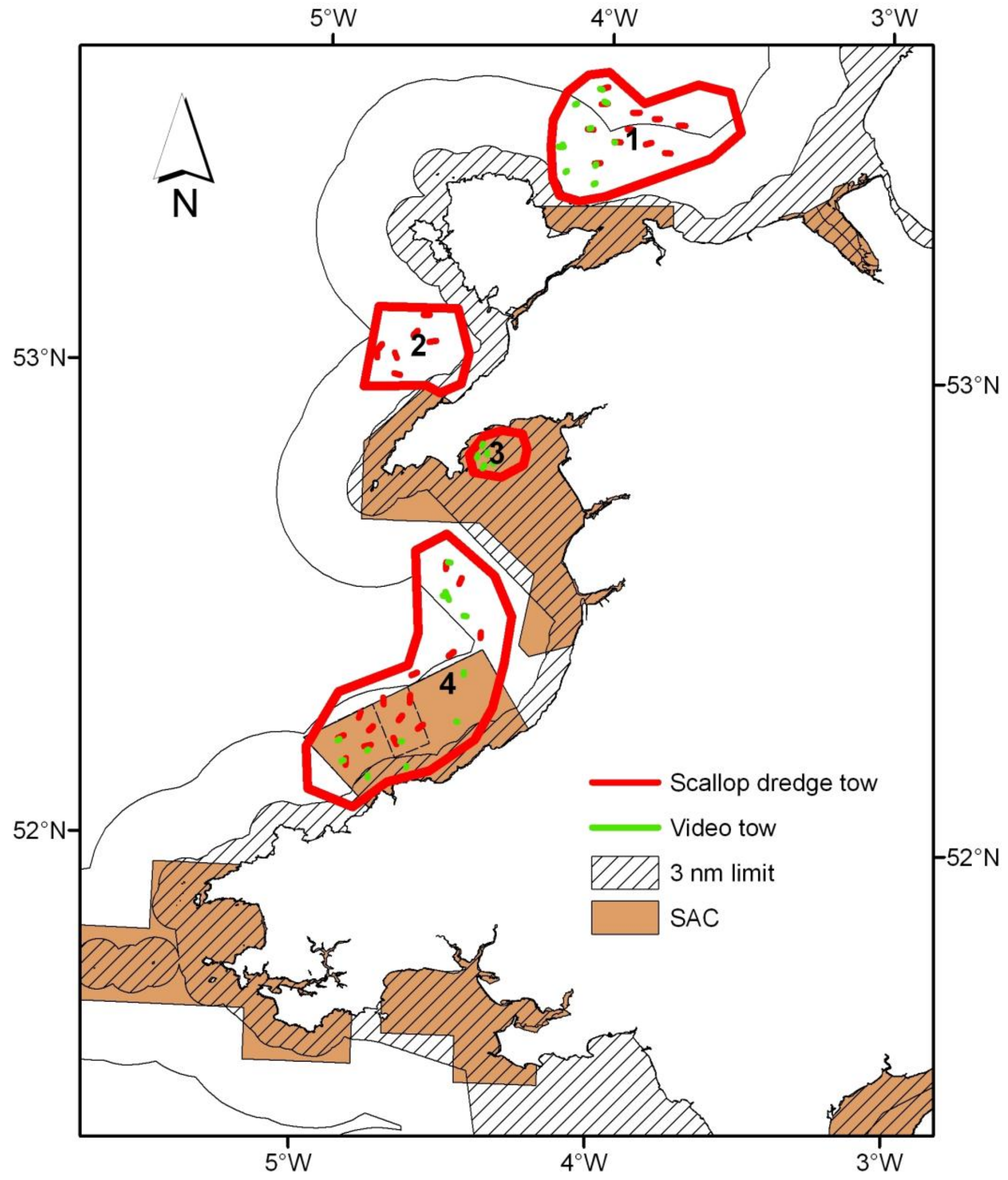

Figure 1. Scallop stock survey design. Areas 1-4 mark the 4 main scallop distribution areas in which scallops were surveyed. Areas within the 3 nm limit could only be sampled by video camera tows shown as green lines. Red lines indicate scallop dredge sampling.

2- Scallop dredging

Four spring-loaded Newhaven scallop dredges were deployed using 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 55mm 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, necessary for the analyses of age and size structure of populations. Each tow was 30 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 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 abundances and biomass (kg) per $100m^2$.

For each tow the contents of each dredge was sorted separately. All scallops captured were separated out into the two species and then the total weight for each species was recorded. If large numbers of scallops were captured then a sub-sample of 40 scallops was collected for each dredge. The scallops in this sub sample were measured (shell length in mm) and 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. These abundances were then converted to densities 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 g/$100m^2$. 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, whole scallops were frozen for the analysis of gonad and meat weight upon return to the laboratory. Tissue samples for genetic analysis were also collected. The aim was to collect 100 scallops from the age groups 3, 4, 5 and 6 from each of the 3 major scallop grounds, i.e. Liverpool Bay, Llyn Peninsula and Cardigan Bay. It was not always possible to collect 100 individuals from each age group but as many as possible were collected in these cases.

3- Camera tows

A sledge mounted video and still camera system was deployed at 25 sampling stations and towed at a speed of approximately 0.5 knots for a period of 30 minutes. A monitor on the vessel enabled observers to make real time records of scallop abundances. Start and end positions of each tow were thus recorded from the point the sledge had visibly reached the sea floor to the point when the sledge lifted off the ground during hauling. While the video system delivered a continuous live picture which was recorded on DVD, the digital stills camera took a high resolution image every 10 seconds. The field of view of the video camera covered an area of approximately $0.12m^2$ (width 0.41m x depth 0.30m). Each still image covered an area of $0.13m^2$ (0.44m x 0.30m).

4- Hamon grab

A single $0.1m^2$ Hamon grab sample was taken at 17 sites around the Modiolus reef at the Llyn Peninsula (Figure 2). Each grab sample was photographed and a subsample of approximately 500g was taken and frozen for grain size analysis in the laboratory. The remaining sample was then passed through a 1mm sieve to remove any fine sediment and then backwashed to extract fauna. The residual sediment was then sorted for remaining fauna which was preserved in formalin.

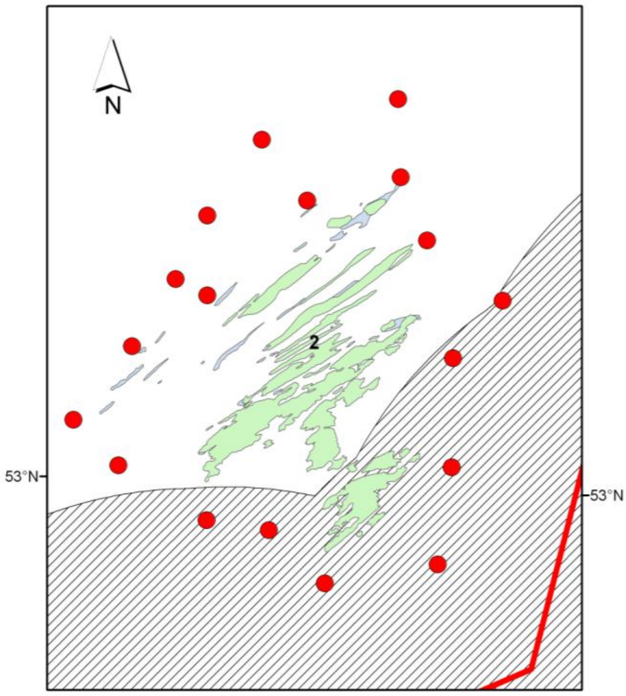

Figure 2. Position of grab samples around the Modiolus bed North East Llyn Peninsula.

5- Estimation of the 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 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 ($0.13m^2$)]. The numbers of scallops seen on each 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 (0.41 m)]. These densities were then recorded in number of scallops per $100m^2$.

6- Sediment type ascertained from still photography

Every 10th photograph at each site was analysed for sediment type. Each image was visualised in Image J v.1.43 (National Institute of Mental Health) and a 2x4 grid, or 8 squares, were placed over the top of the image. The coverage of each sediment type was then visually assessed and given a score out of 8, which was then changed into a percentage. An average proportion of each sediment type was then calculated from all the images from each site. Sediment type categories were classified as: fine sand, coarse sand, gravel, pebbles, cobbles, rock and shell.

7- Gonad and muscle weight analysis

Back in the laboratory, scallop shell length and height (+/- 1mm) and shell weight were measured (+/-1g). Scallops were then dissected and the adductor muscle and gonad separated from the rest of the tissue. The wet weight was then recorded (+/- 0.01g) for each of the gonad, adductor muscle and the remaining tissue. The Gonad Observation Index (GOI), as described by Mason (1958), 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. We also calculated the Relative Gonad to shell Height (RGH) index which standardises the gonad weight in relation to the size of the scallop:

RGH = (gonad weight (g) / Shell Height (cm^3)) * 1000

8- Grain size analysis

Analysis of sediment grain size will be carried out by CCW and will be reported on separately.

RESULTS

1 – Queen scallop *Aequipecten opercularis* density

All three sampling methods (dredges, video and stills) reported highest densities of queen scallops in Liverpool Bay with very low densities at both the Llyn Peninsula and Cardigan Bay (Figures 3 and 4).

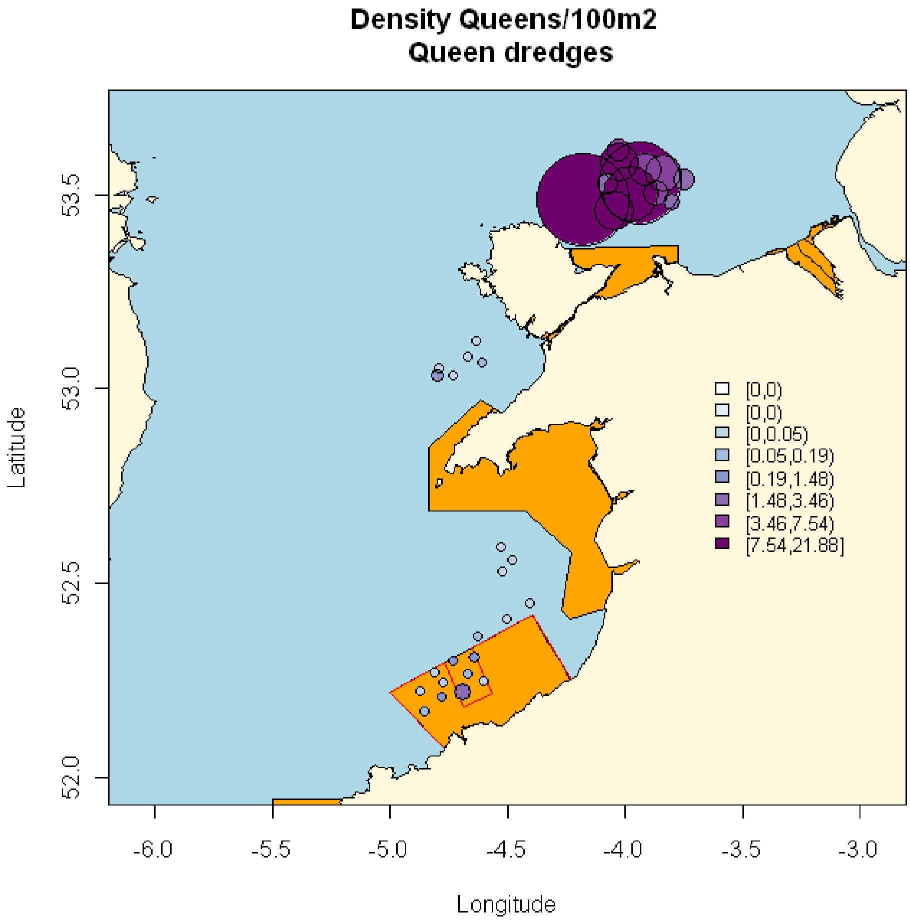

Figure 3. Density of queen scallops (per $100m^2$) estimated using queen scallop dredges.

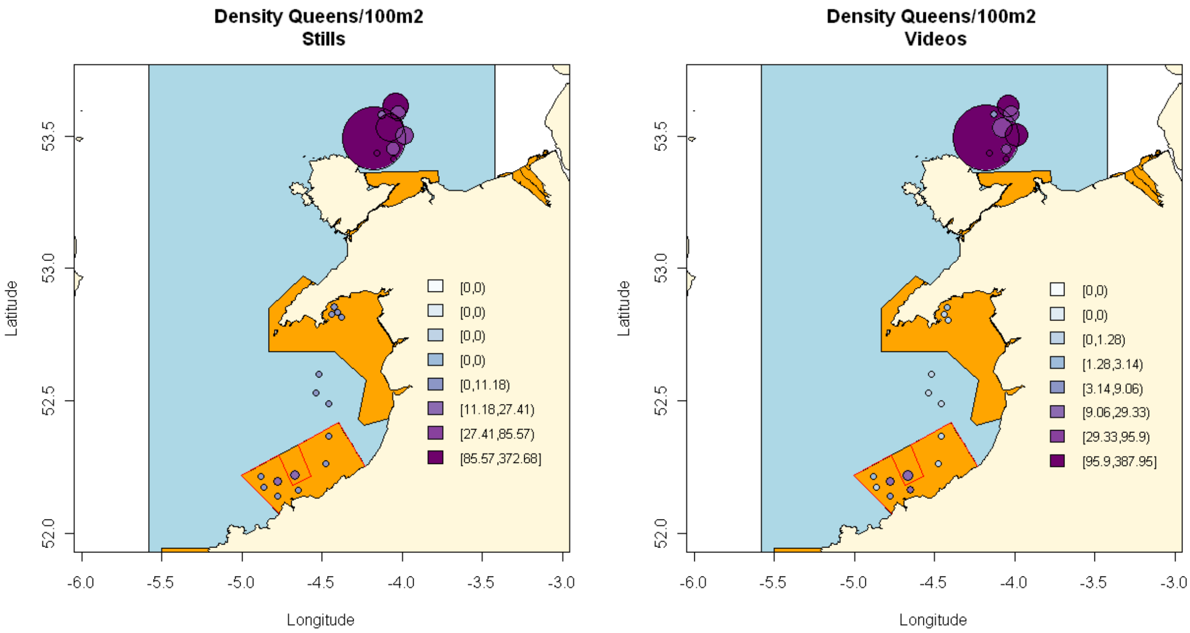

Figure 4. Density of queen scallops (per $100m^2$) estimated from (a) still photographs and (b) videos.

The agreement between scallop density estimates from videos and still photographs was very high (r^2= 0.96) (Figure 5). The estimates obtained from the queen scallop dredges are however an order of magnitude lower than that from the video/still camera estimates (Figure 6) but the relationships are still strong ($r^2_{video-dredge}$=0.80, $r^2_{stills-dredge}$=0.70). The lower densities obtained from the scallop dredges would likely be due to the low efficiency of scallop dredges and therefore give an indication of the catchability of those dredges. The estimates obtained from the cameras are more likely to reflect the real densities on the seabed.

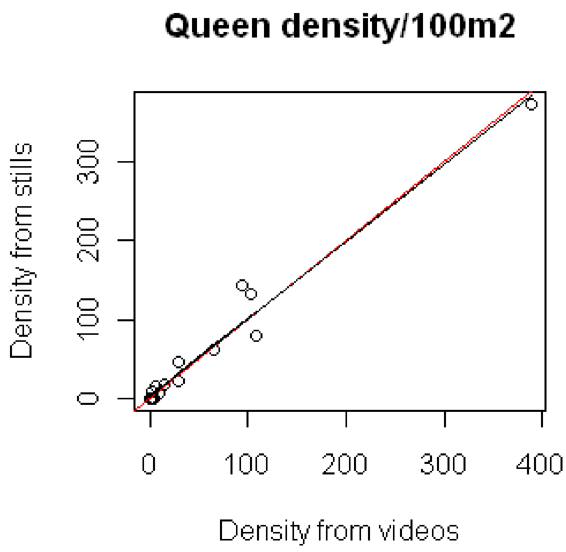

Figure 5. Comparison of queen scallop density estimates (per $100m^2$) from video and still photographs. Black line shows actual relationship, red line shows 1:1 relationship.

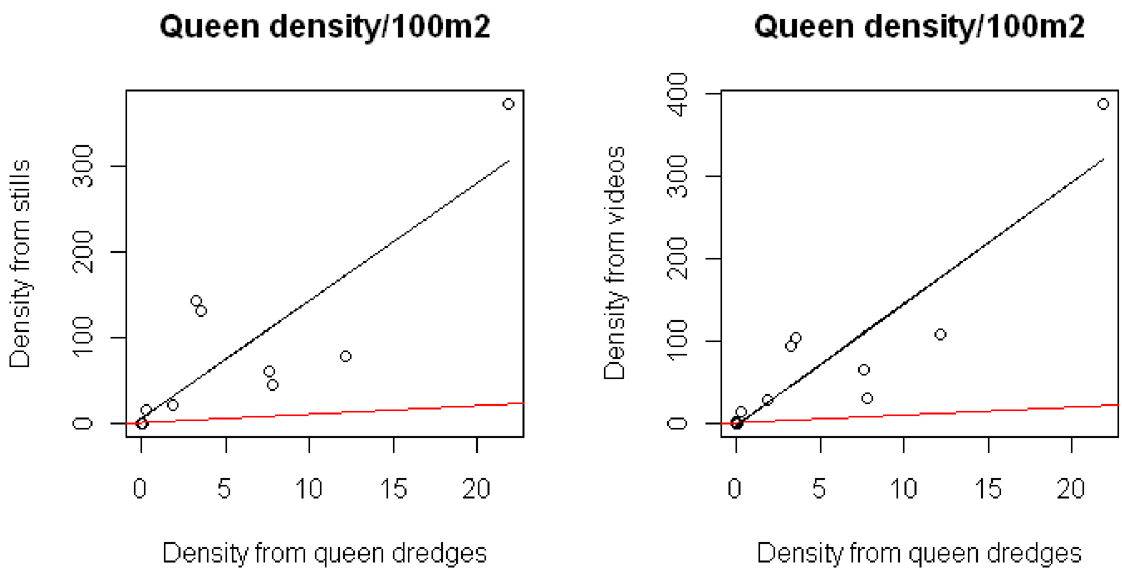

Figure 6. Comparison of queen scallop density estimates (per $100m^2$) from queen Newhaven dredges and (a) still photographs and (b) videos. Black line shows actual relationship, red line shows 1:1 relationship.

2- King scallop *Pecten maximus* densities

All three methods gave estimates of king scallop densities which were high in Cardigan Bay and low in Liverpool Bay, around the Llyn Peninsula and in Tremadog Bay (Figures 7 and 8).

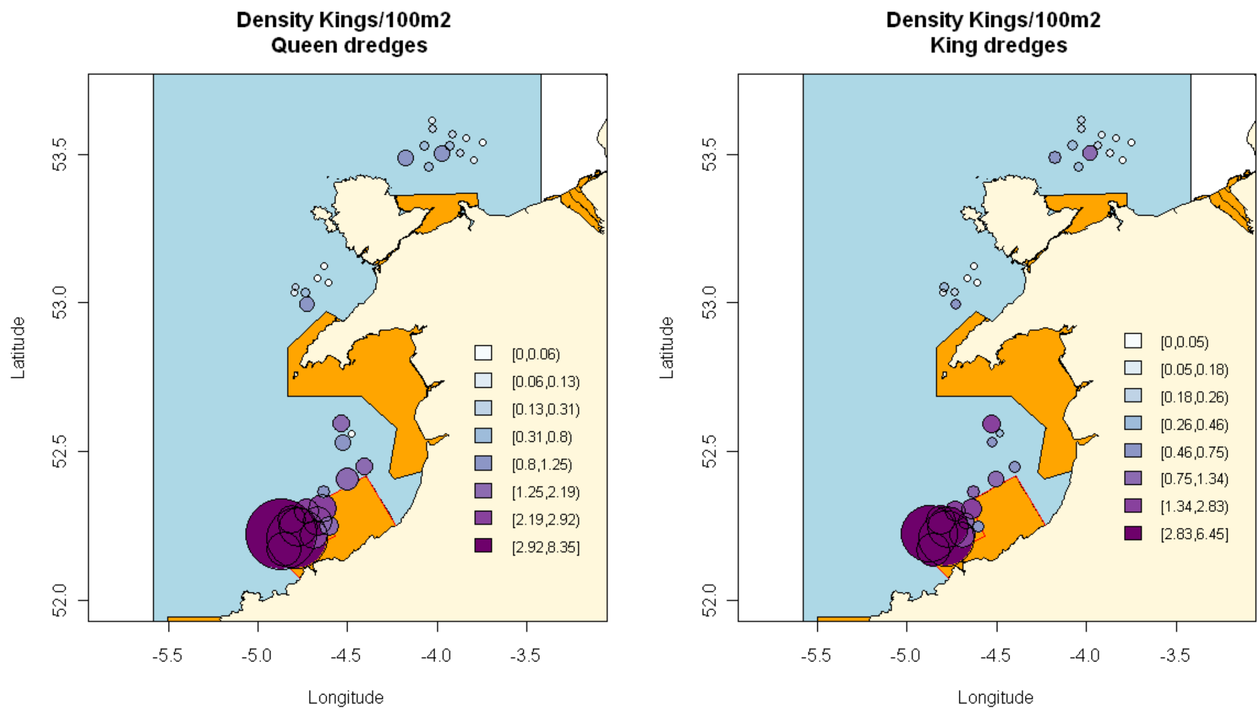

Figure 7. Density of king scallops (per 100m^2) estimated from (a) queen dredges and (b) king dredges.

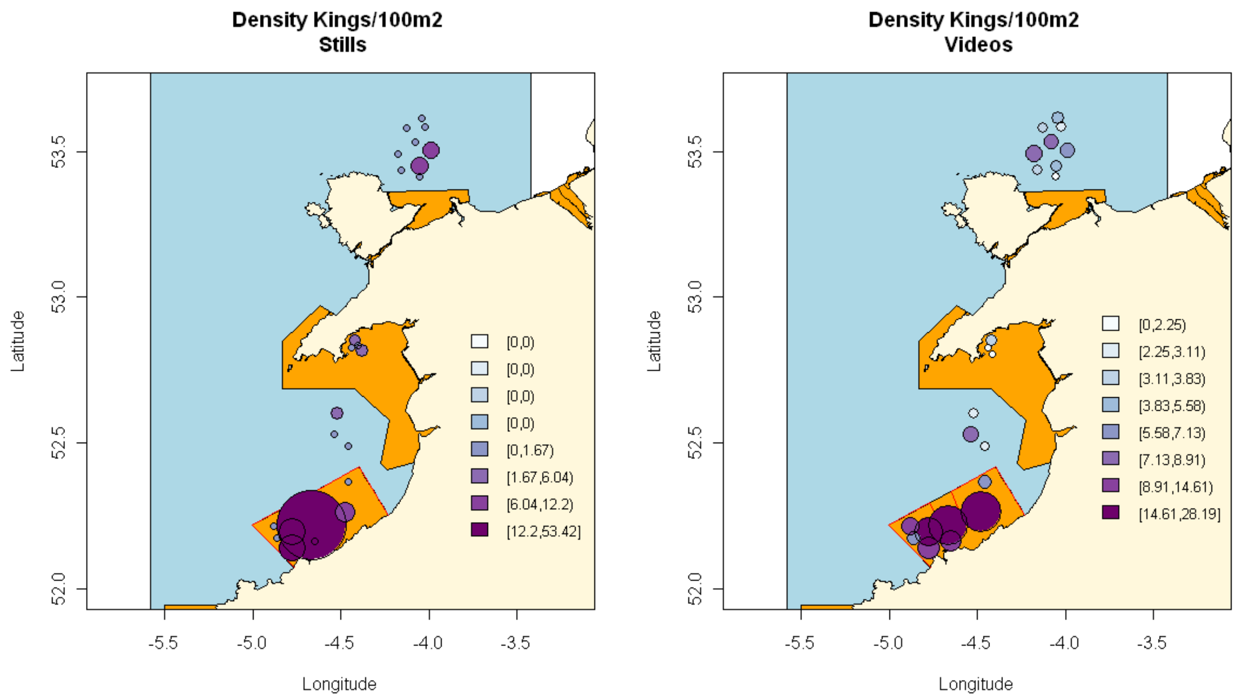

Figure 8. Density of king scallops (per 100m^2) estimated from (a) still photographs and (b) videos.

The agreement between the king scallop density estimates from video and still photographs were not as good as that obtained for queen scallops (r^2=0.53). Densities under 13/100m^2 as estimated from the videos appear to be particularly underestimated by still photographs with most densities equal to 0 (Figure 9). This means that the continuous recording of the seabed along transects gives greater precision when densities are very low than still photographs with the field of view used in this study. On the other side, when densities are high, there seems to be a high variation between the estimates of stills and video techniques. It is therefore difficult to conclude which method works best. It is likely that none of the methods give consistent absolute estimates of the real densities on the seabed.

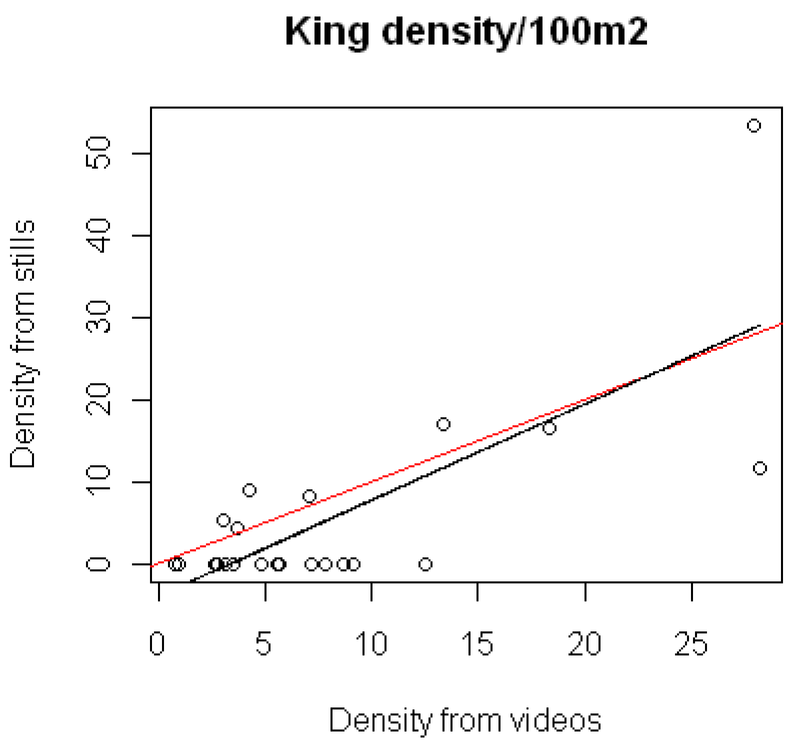

Figure 9. Comparison of king scallop density estimates (per 100m^2) from queen Newhaven dredges and (a) videos and (b) still photographs. Black line shows actual relationship, red line shows 1:1 relationship.

The relationships between density estimates obtained from the dredges and the still/video camera were not as good for king scallops as they were for queen scallops (Figure 10). None of the relationships were actually significant. This was probably mostly due to a single site (CB16) which stood out as being an outlier. This again showed that it is likely that none of the methods give representative results of the real densities on the seabed. The sampling design for king scallop stock has to be revised and improved accordingly.

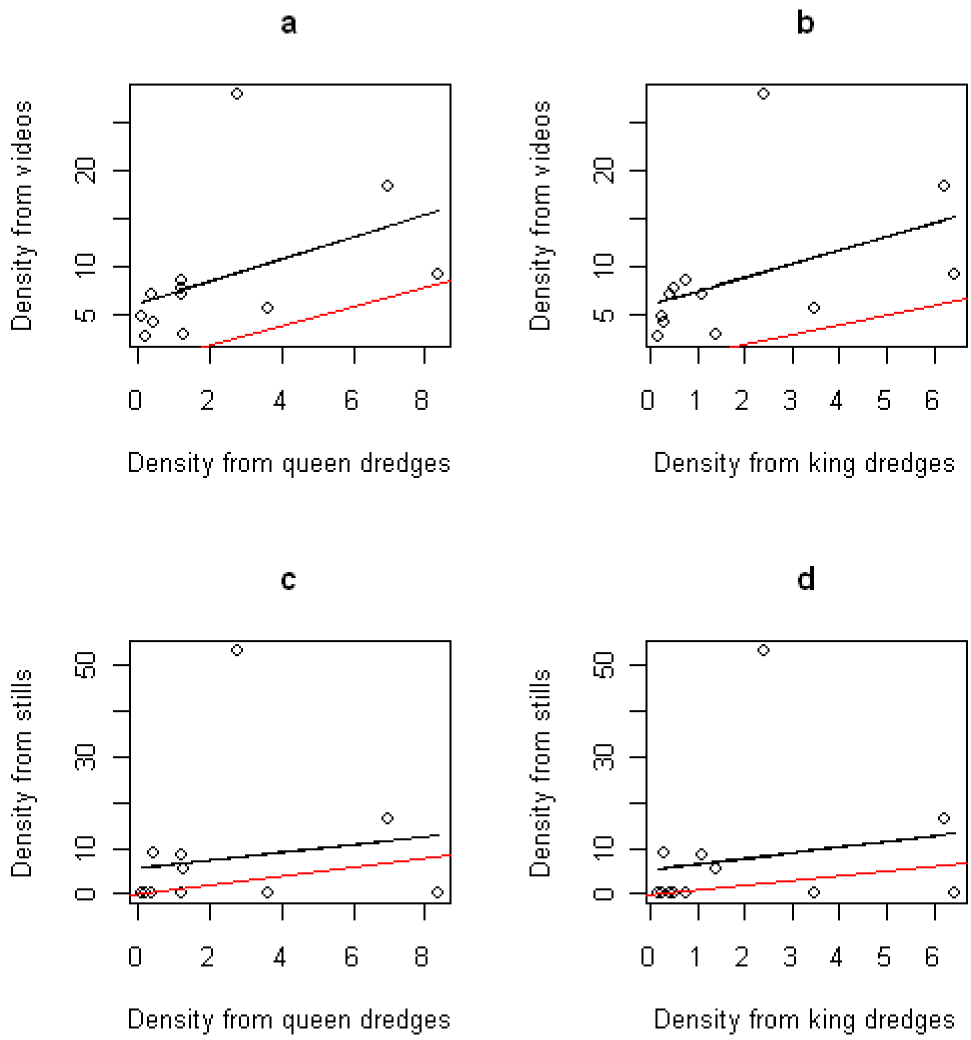

Figure 10. Comparison of king scallop density estimates (per 100m2) between (a) queen scallop dredges and videos (b) king scallop dredges and videos (c) queen scallop dredges and still photographs (d) queen scallop dredges and still photographs. Black line shows actual relationship, red line shows 1:1 relationship.

3- Small scale variation in king scallop densities in Cardigan Bay

Small scale variability in density estimates in the Cardigan Bay were scrutinized using all 3 methods (dredges, stills and videos) as the camera work and dredging were not all conducted everywhere. However, the most reliable method is likely to be the use of video based on the previous observations that the still photographs underestimated king scallop densities compared to videos and that density estimates from dredges were also generally lower than stills and videos estimates.
Figure 11 shows that there is considerable variation in the king scallop densities over small spatial scales within the Cardigan Bay. The queen dredges estimates of king scallops show that the densities are generally higher in the closed area compared to the open area of the SAC with 5.2 individuals/100m^2 and 2.5 individuals/100m^2 on average respectively. Only station CB16, situated in the open area of the SAC, stood out with very high densities detected by the still and videos but not by the dredges.

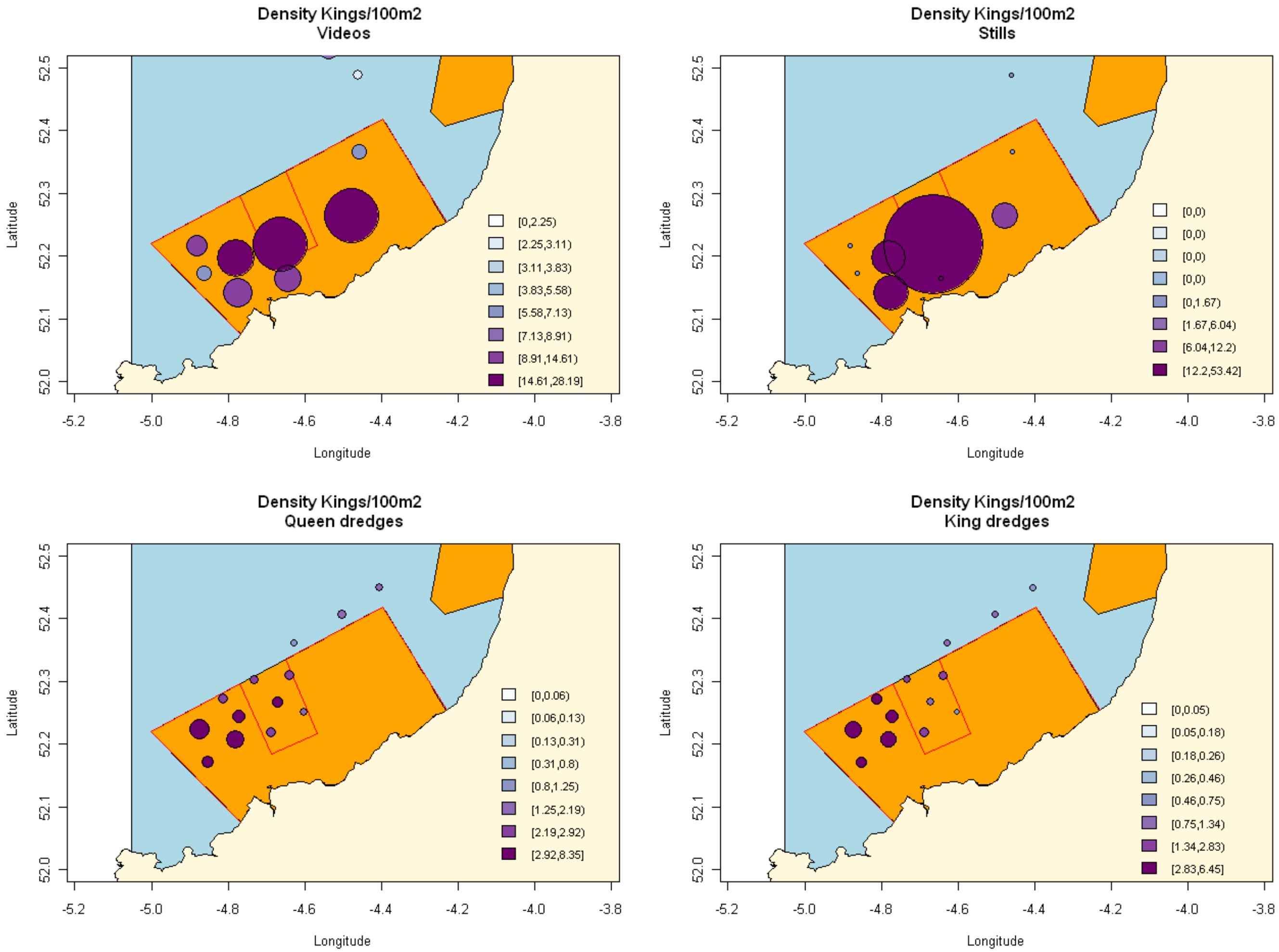

Figure 11. King scallop densities (per 100m^2) in the Cardigan Bay SAC estimated from videos, stills, queen and king dredges.

4- Bycatch analysis

Bycatch levels were higher in queen dredges than king dredges which was due to the respective belly rings sizes (Figure 12). Overall, there were more bycatches in Liverpool Bay than at the Llyn Peninsula or in Cardigan Bay, except for a single site (CB21) where the queen dredges collected 130kg of *Mytilus edulis* (Figure 12).

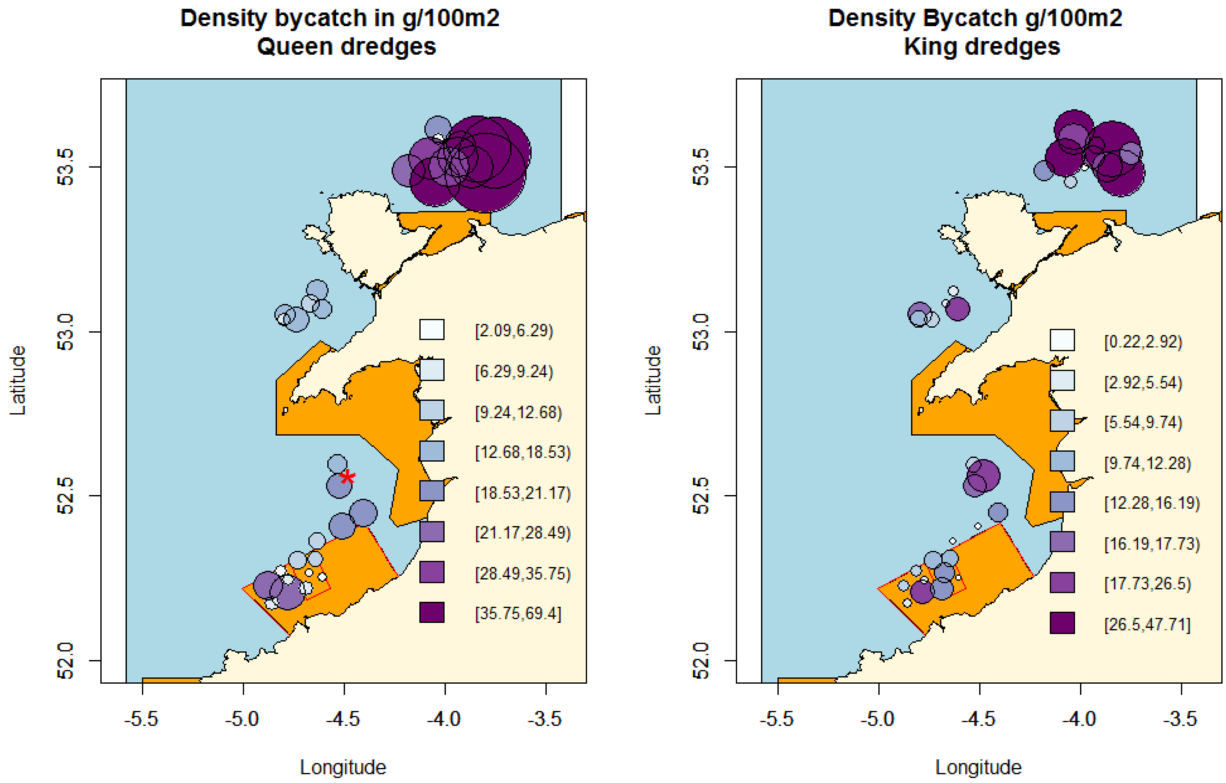

Figure 12. Density of bycatch caught in (a) queen scallop dredges and (b) king scallop dredges. The red asterisk represents the station where 130kgs of *Mytilus edulis* were caught in the queen dredges (disproportionately higher than any other bycatches).

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 13 and 14). 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 (Figure 14). In the king dredges, the biomass of bycatches in the open area of the SAC was 10.42 (± 6.12) and 7.29(±6.15) g/100m^2 in the closed area. In the queen dredges, the biomass of bycatches in the open area of the SAC was 7.01 (±4.06) and 13.81(±9.85) g/100m^2 in the closed area.

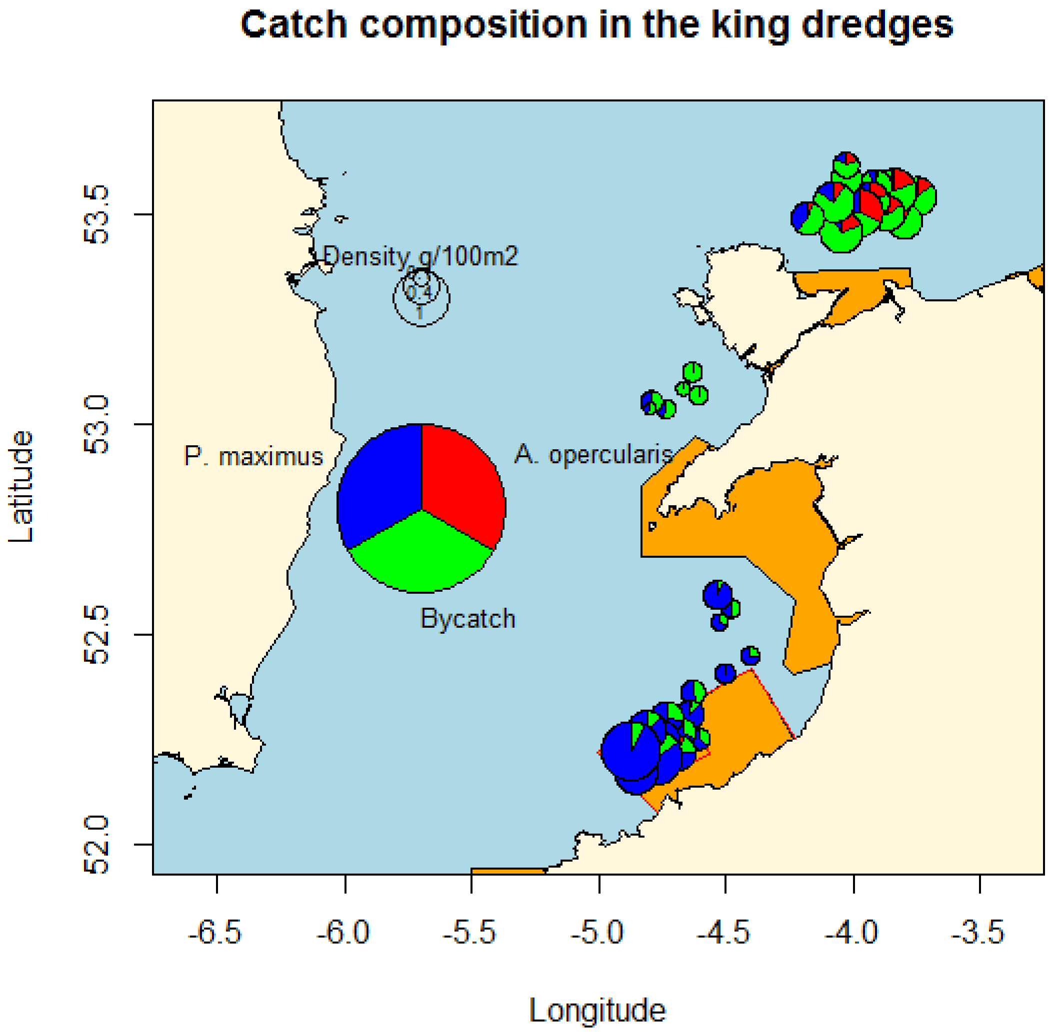

Figure 13. Catch composition using king scallop dredges. Size of circle indicates total biomass of catch (g/100m^2). Blue indicates the proportion of the target species *P. maximus* in the catch, red indicates the proportion of queen scallops *A. opercularis* and green indicates the proportion of bycatch in the catch.

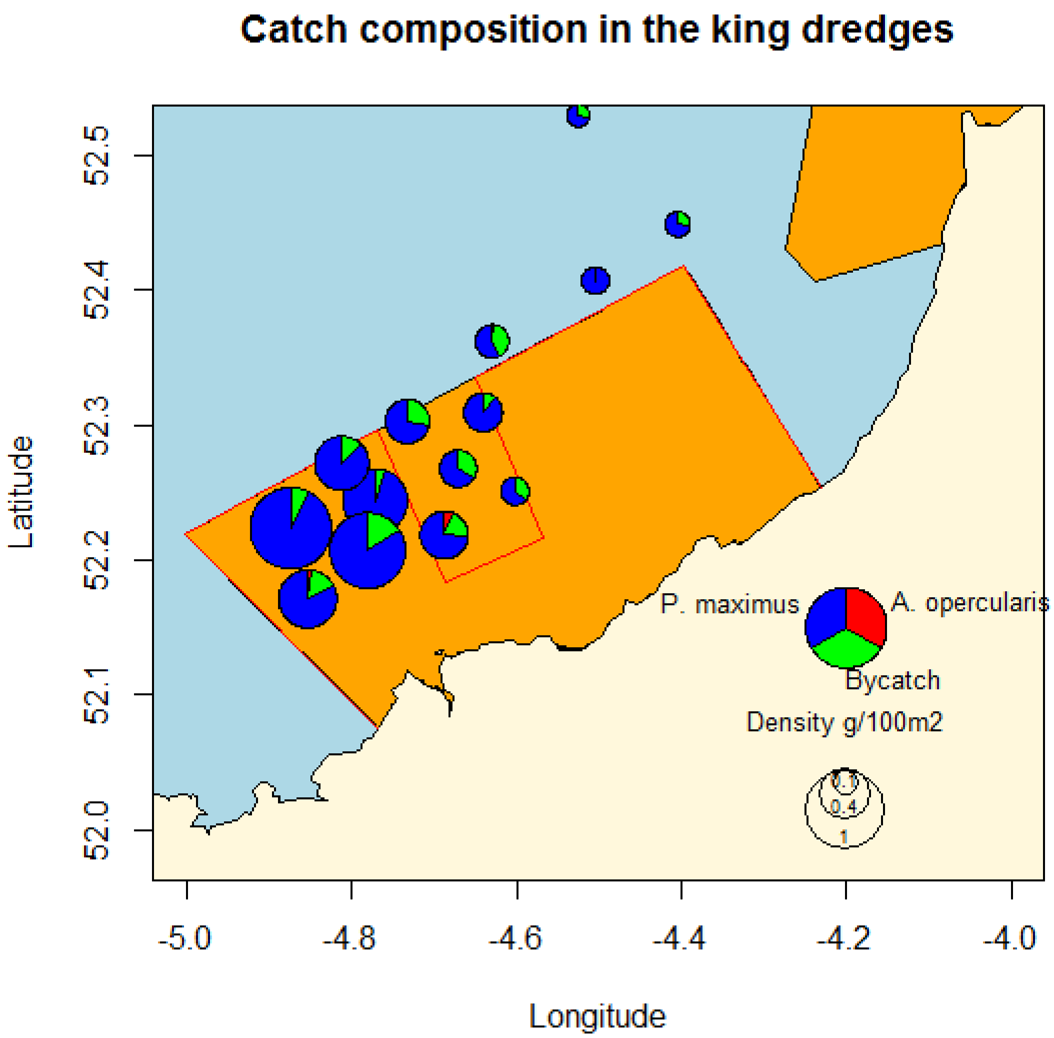

Figure 14. Catch composition of king scallop dredges in the Cardigan Bay. Size of circle indicates total density of catch (g/100m2). Blue indicates the proportion of the target species *P. maximus* in the catch, red indicates the proportion of queen scallops *A. opercularis* and green indicates the proportion of bycatch in the catch.

The species composition of the bycatch between the three areas varied significantly (Anosim results, r^2=0.46, p=0.001). The MDS plot showed that all sites from the same area clustered separately to of the other areas (Figure 15).

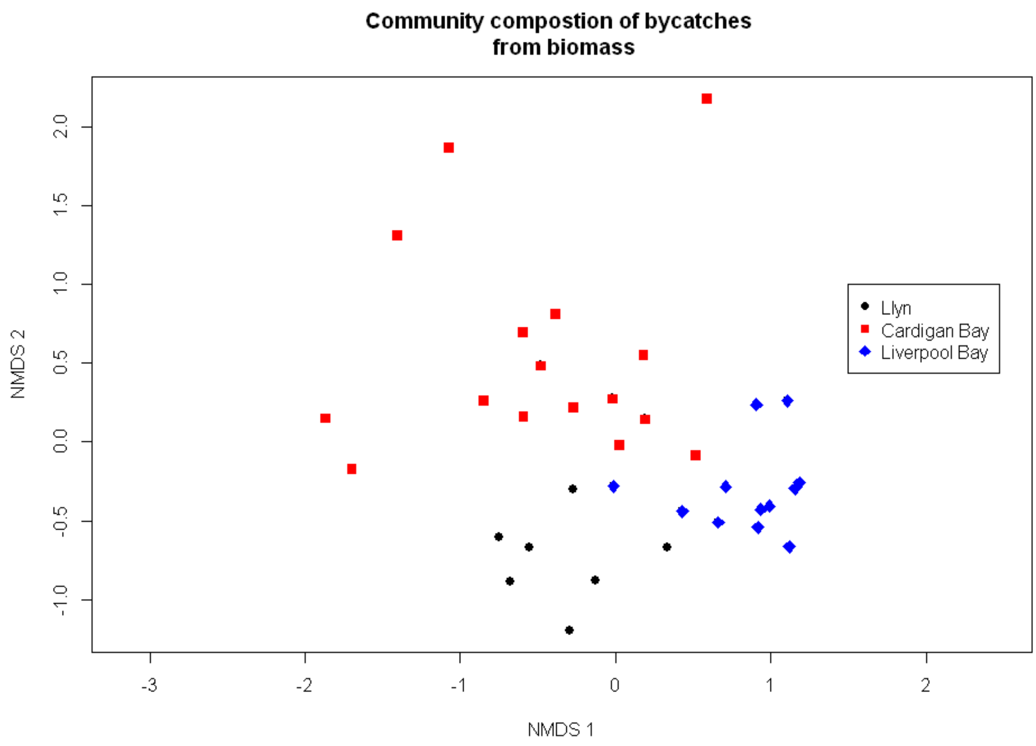

Figure 15. MDS plot representing the community composition of the bycatch from scallop dredges in three areas traditionally fished for king scallops.

Multivariate analyses were conducted to identify the bycatch species that were most 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.

In the Liverpool Bay, a high number of species were caught at most sampled sites that were relatively rare in Cardigan Bay and the Llyn Peninsula. The species included *Aphrodita aculeata, Arctica islandica, Ascidian spp., Asterias rubens, Buccinum undatum, Callionymus lyra, Calliostoma zizyphinum, Colus gracilis, Henricia occulta, Holothuroidea spp., Hyas spp., Modiolus modiolus, Neptunea antiqua, Ophiothrix fragilis, Ophiura albida, Pagurus bernhardus, Pagurus prideauxi, Psammechinus miliaris, Raja brachyuran, Scyliorhinus canicula and Spatangus purpureus*.
The species specifically caught at the Llyn Peninsula included *Anseropoda placenta, Astropecten irregularis, Flustra foliacea, Hydrallmania spp. and other* Hydrozoans., *Luidia ciliaris, Raja clavata and Raja montagui.*
The only species that characterized Cardigan Bay was *Maja squinado*. The ground was therefore mostly distinguished by the very low abundances and diversity of bycatches compared to the other two sites.

5- Population dynamics

a) Size and age distribution

The average length of scallops caught in the queen dredges in Cardigan Bay was 112mm compared to 122mm in Liverpool Bay and 119mm at the Llyn Peninsula. The numbers of scallops caught above the minimum landing size (MLS) of 110mm rapidly drops off in Cardigan Bay, whereas there is a much more even distribution of the larger size classes found in Liverpool Bay and the Llyn Peninsula (Figure 16). These larger sizes in Liverpool Bay and the Llyn Peninsula represent older scallops, i.e. scallops were on average 5 and 6 year old respectively, compared to Cardigan Bay where scallops were on average 3 year old (Figure 17).

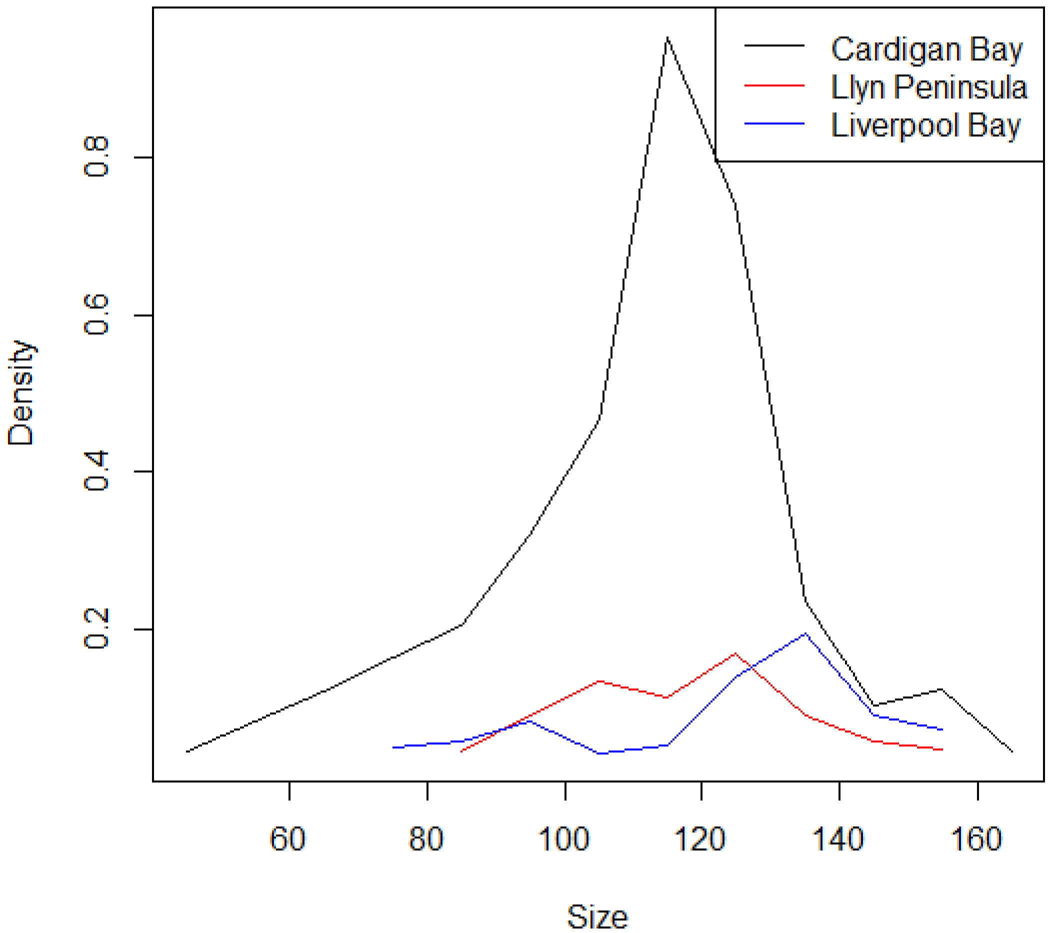

Figure 16. Size distribution of king scallops from the three different fishing grounds. Density is in number of individuals/100m^2. Size is in mm.

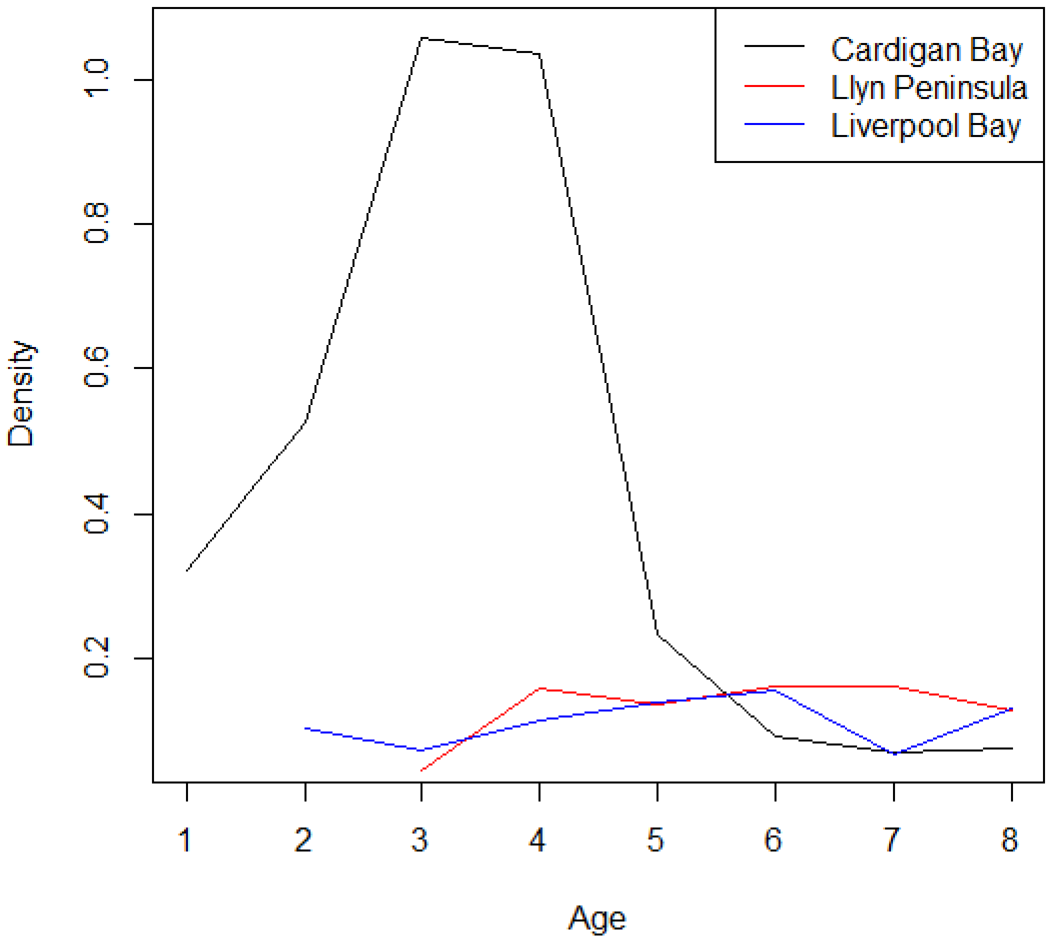

Figure 17. Age distribution of king scallops from the three different fishing grounds. Density is in number of individuals/100m^2. Age is in years.

There were also some differences in size between the closed and open areas in Cardigan Bay. The average size in the closed area of the SAC is 117mm vs. 105mm in the open area of the SAC and the average age in the closed area is 3.5 vs. 3 in the open area (Figure 18). This was likely to be due to the presence of older scallops up to age 8+ in the closed area while scallops only seemed to reach age 6 in the open area i.e. older individuals have been fished out.

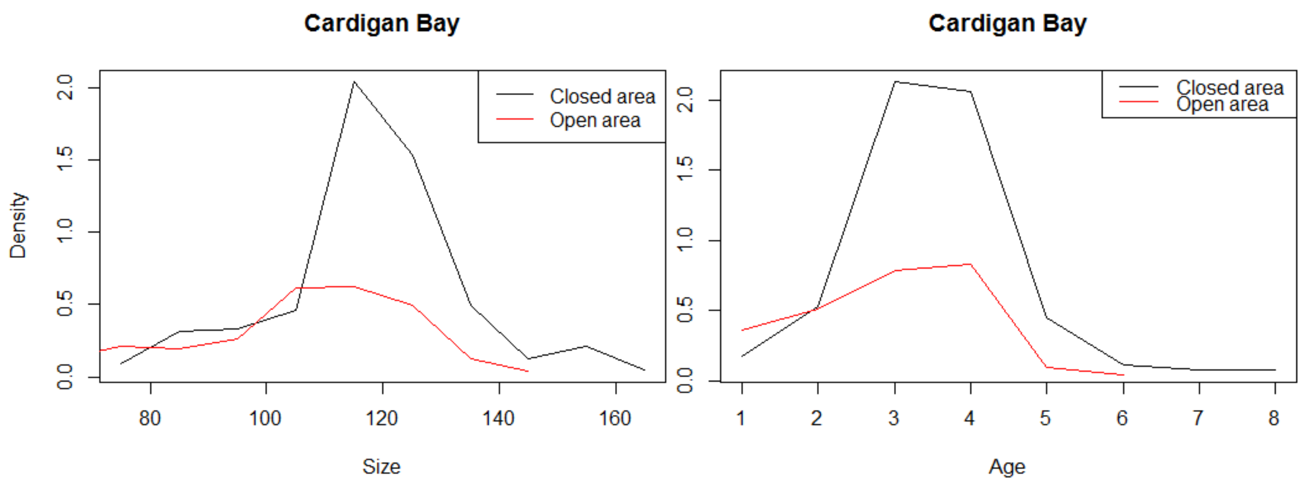

Figure 18. Size and age distribution of kind scallops sampled from queen dredges in the SAC of the Cardigan Bay. Comparison between open and close areas. Density is in number of individuals/100m^2. Size is in mm and age is in years.

Although Liverpool Bay and the Llyn Peninsula had greater proportions of older, larger scallops, there were very low levels of smaller, younger scallops recruiting to these two grounds, whereas Cardigan Bay showed higher numbers of pre-recruits (<110mm) (Figures 19 and 20). There was no obvious difference in the number of pre-recruits between the closed and open areas of the SAC (Figure 20). The density of prerecruits in the open area of the SAC was 1.23 (± 0.58) /100m^2 and 0.94 (± 0.81)/10m2 in the closed area. The difference was not significantly different (Anova, df=9, F=0.44, p=0.53)

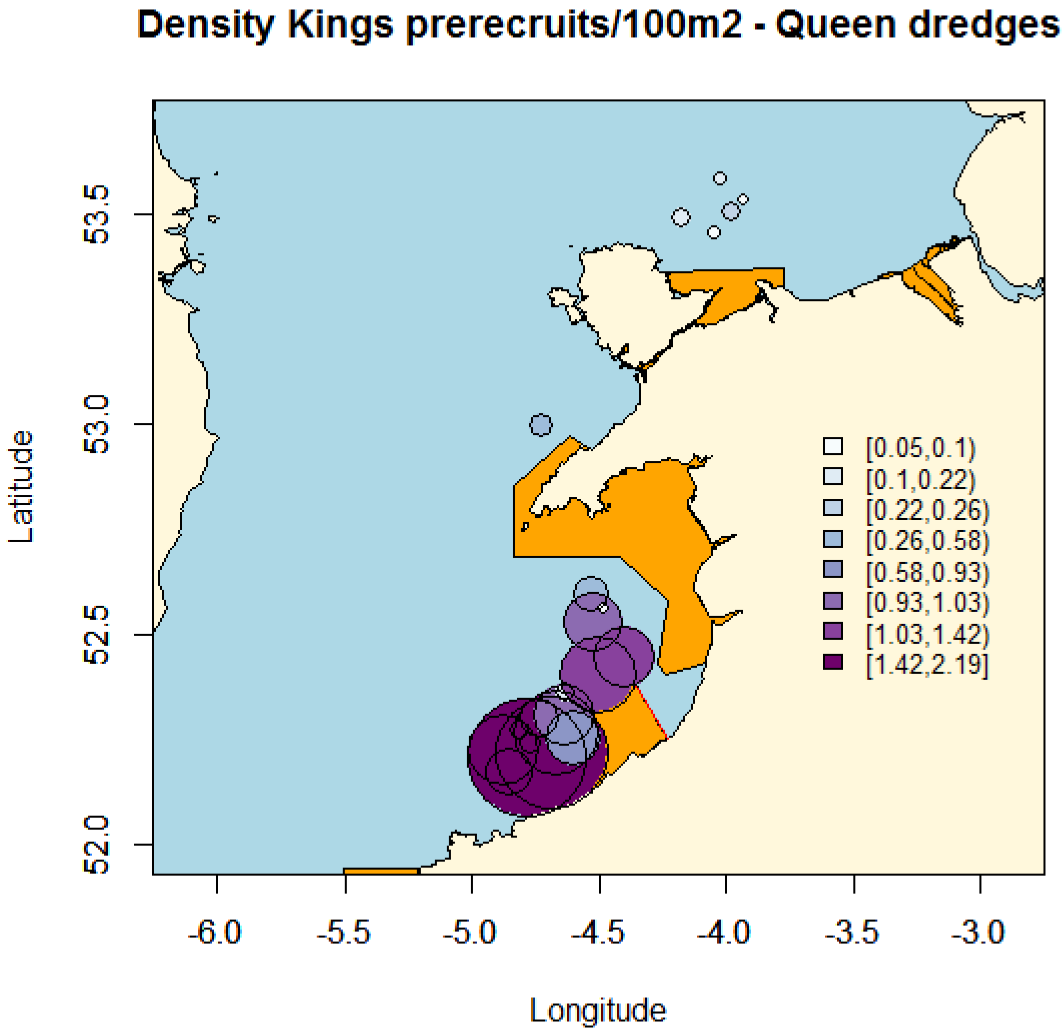

Figure 19. Densities of pre-recruit (<110mm) king scallops at three fishing grounds in Welsh waters.

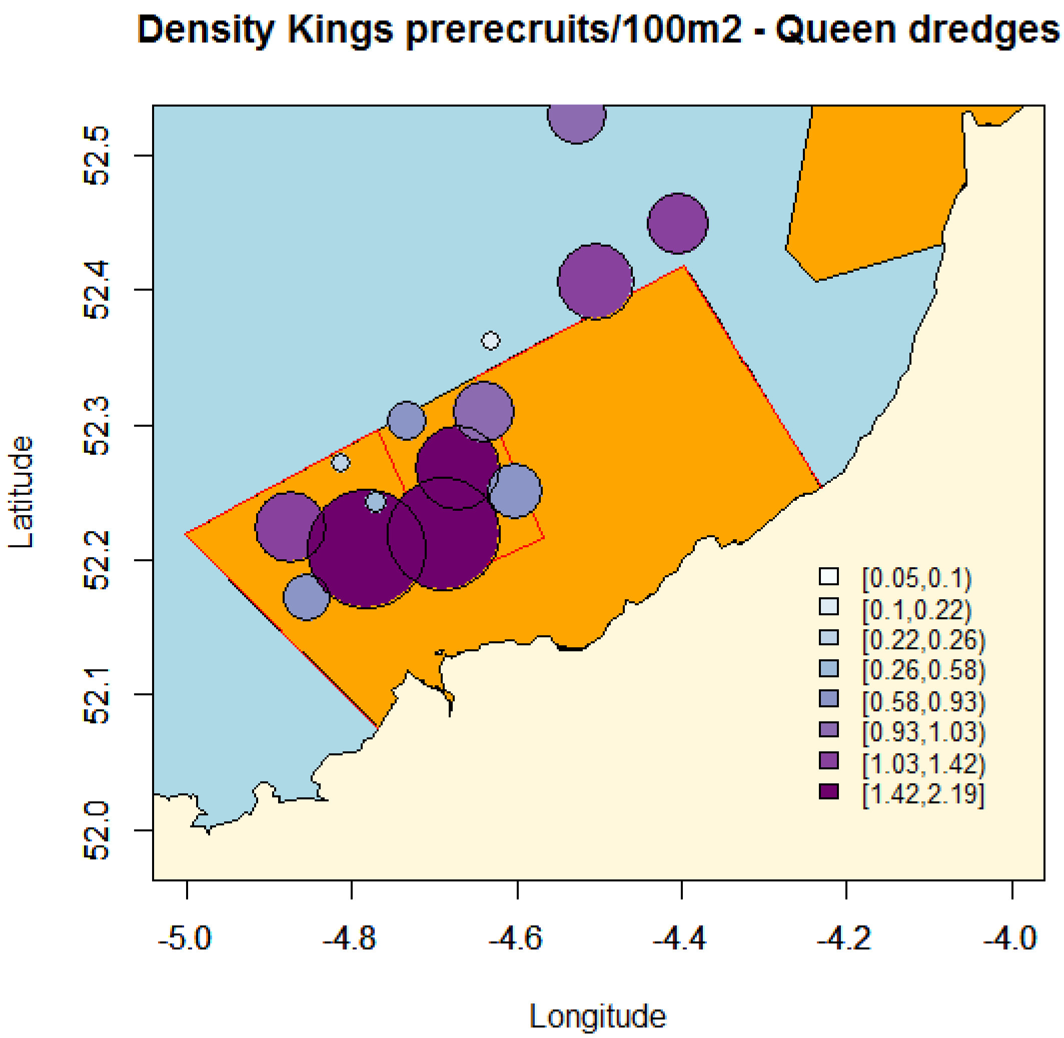

Figure 20. Densities of pre-recruit (<110mm) king scallops in the Cardigan Bay SAC.

b) Growth rates

The growth rates of king scallops is slower at the sites sampled off the Llyn Peninsula compared to Liverpool Bay and Cardigan Bay which, according to this preliminary survey, also differ to a lesser extent (F-tests: pooled Cardigan Bay-Liverpool Bay vs. Llyn Peninsula, $F=24.76$, $p<0.001$; Cardigan Bay vs. Liverpool Bay, $F=4.28$, $p=0.014$) (Figure 21). However, there were hardly any scallops under age 4 in the Llyn Peninsula sample and this may have biased the growth rate estimate.

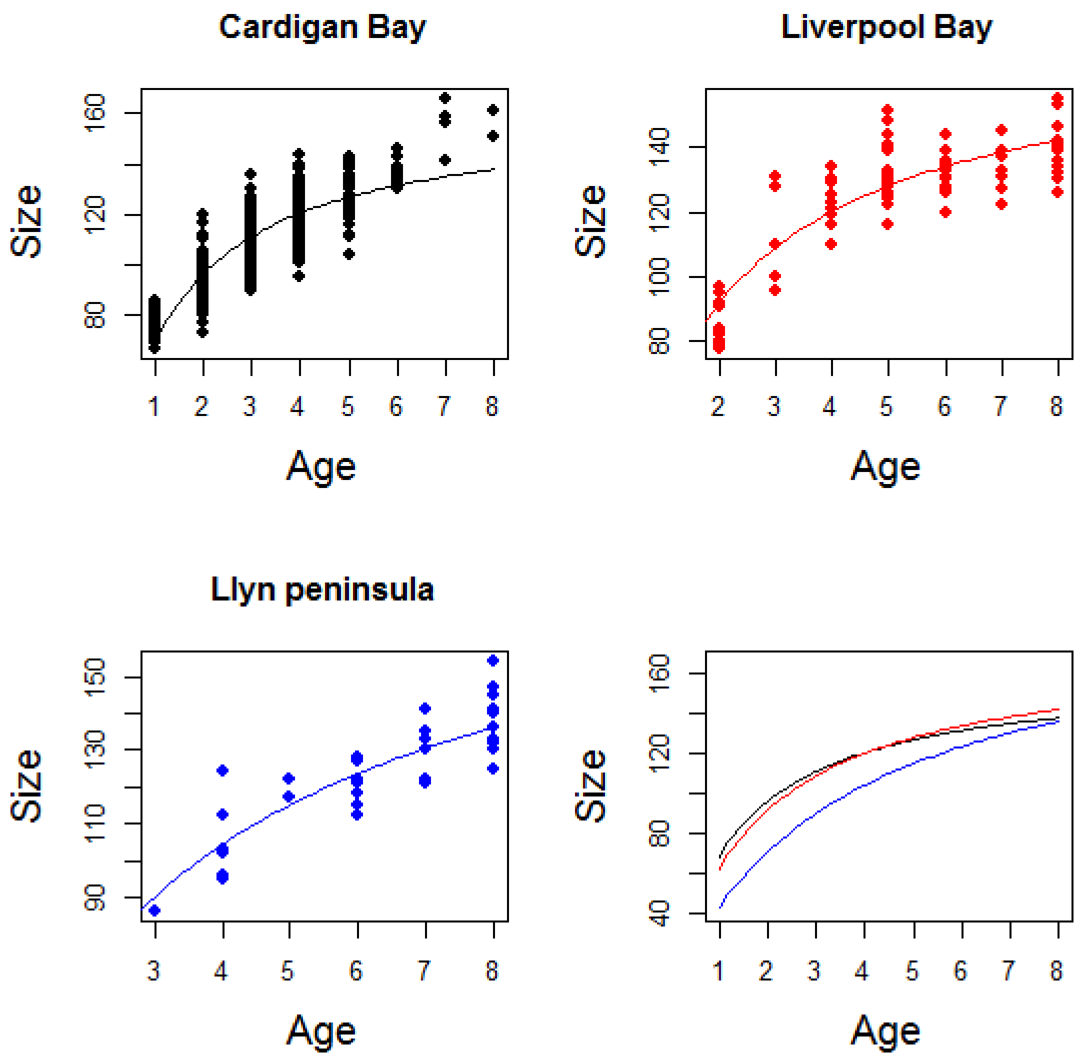

Figure 21. Growth curves of the 3 areas sampled, i.e. Cardigan Bay, Liverpool Bay, Llyn Peninsula. The bottom right panel is for comparison of the growth rates between areas, the black, red and blue curves represent Cardigan Bay, Liverpool Bay and Llyn Peninsula respectively.

c) Weight and reproductive status

- Meat weight- length relationship

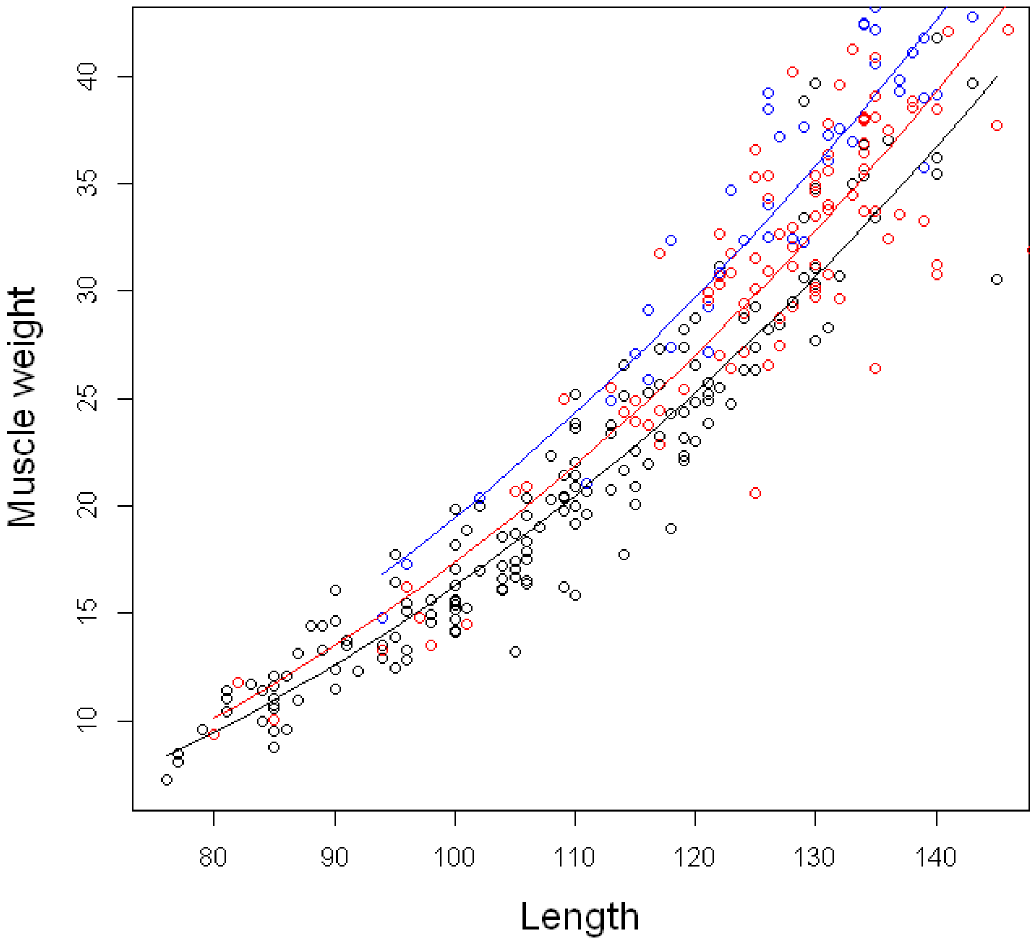

Figure 22. Length-weight relationship for Cardigan Bay (black), Liverpool Bay (red), Llyn Peninsula (blue).

For the same length, the meat weight is higher at the Llyn Peninsula, followed by Liverpool Bay and then the Cardigan Bay (Figure 22). This observation was statistically tested and found highly significant (r^2=0.94, p<0.001). The relationship is similar for all measured characteristics: shell weight, remaining tissue weight and overall weight (Figure 23), except that the Liverpool Bay and Cardigan Bay are not significantly different and the gonad weight/length relationship is not significantly different between grounds.

However, for the youngest year classes, age 3 and 4, the meat weight to total weight relationship is higher in Liverpool Bay. Older age classes do not significantly differ between grounds (Figure 24).

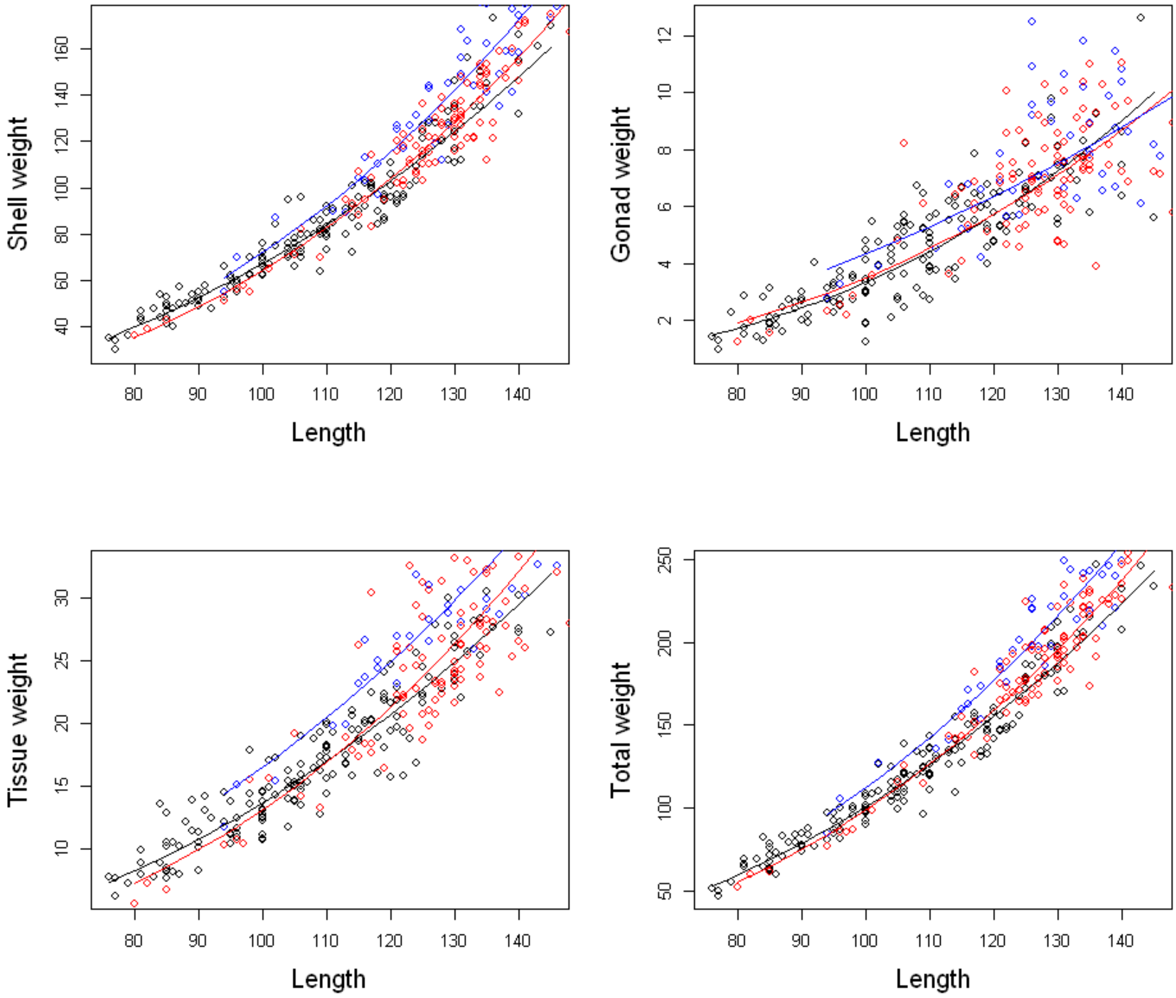

Figure 23. Length-weight relationships for shell, gonad, tissue and overall weight for Cardigan Bay (black), Liverpool Bay (red), Llyn Peninsula (blue).

- Meat weight- total weight relationship

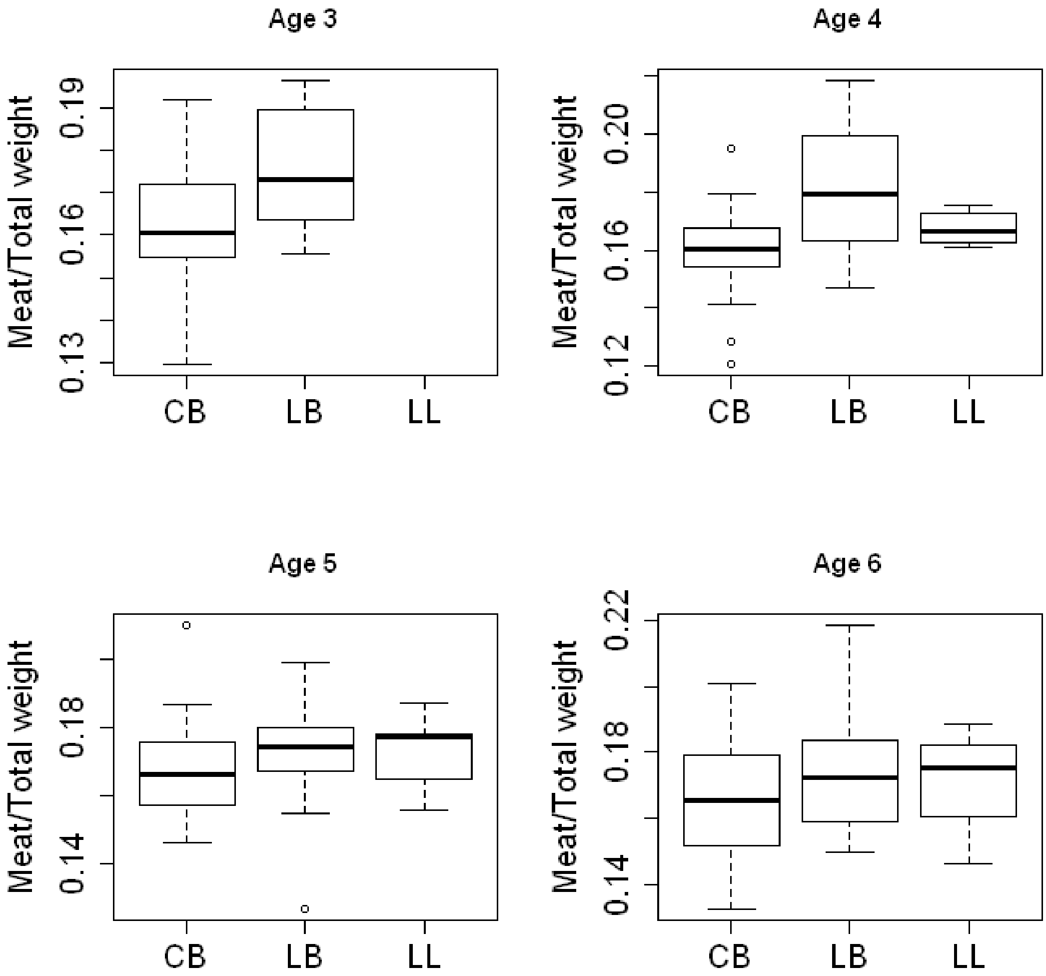

Figure 24. Meat to total weight ratio for Cardigan Bay (CB), Liverpool Bay(LB) and the Llyn Peninsula (LL) in the four main age groups caught by the fishery.

- Gonad status

The majority of gonads at all four sites were at stage four which indicates that they have recovered from the previous spawning event but have not yet started to fill ready for the next spawning event. There was no difference in the gonad status between grounds. The lower percentage of stage 3 gonads at the Llyn Peninsula was not significant.

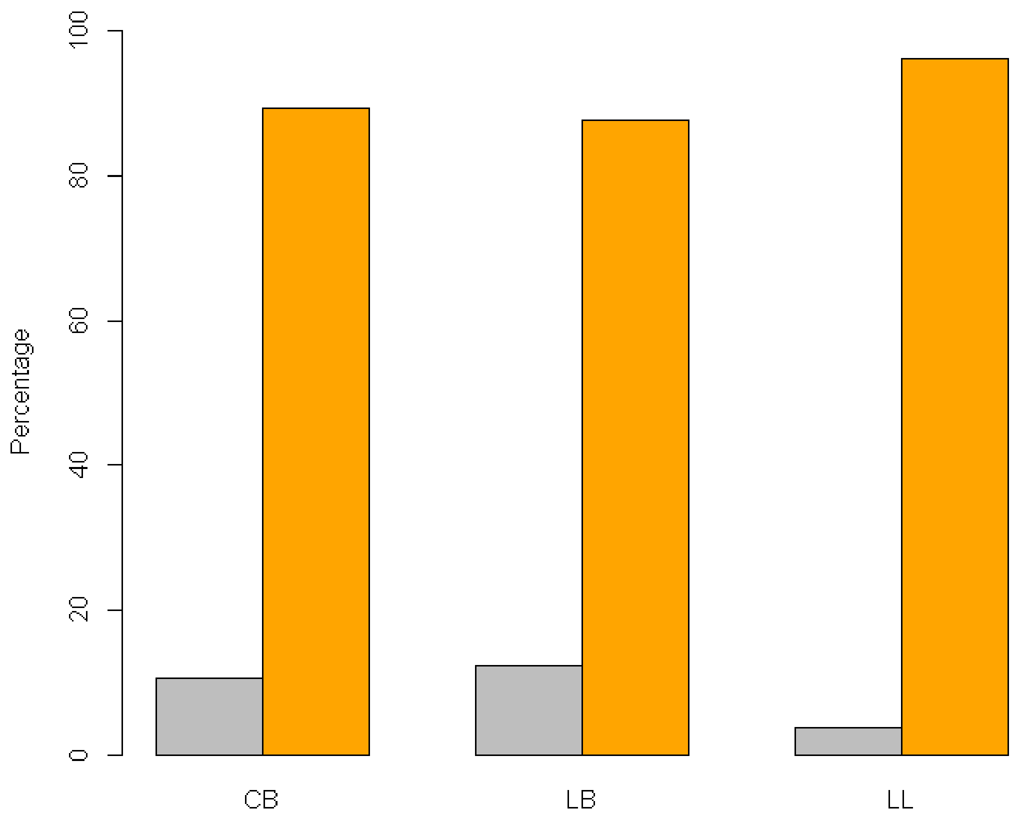

Figure 25. Gonad status in the three fishing grounds, Cardigan Bay (CB), Liverpool Bay (LB) and the Llyn Peninsula (LL). Grey indicates first stage of recovery following spawning; orange indicates gonads which have recovered to the "resting" stage four following spawning.

6- Habitats

The results of the photographs analyses with regards to sediment types of the different grounds are given in Figure 26. Generally, the Cardigan Bay is mostly dominated by fine and coarse sands with presence of gravel and shells, while Liverpool Bay is dominated by gravels with presence of shells and coarse sand.

The presence of cobbles was important to identify since stony reefs are a protected feature within Cardigan Bay (SAC). Cobbles were present in most stations sampled in the Cardigan Bay SAC but in very low quantities (Figure 27). The station where most cobbles were found (i.e. ca. 15% of the composition of the sediment) is the only station that was sampled in the open area of the SAC (see Figure 27). It needs to be noted that the presence of cobbles does not imply the presence of a stony reef.

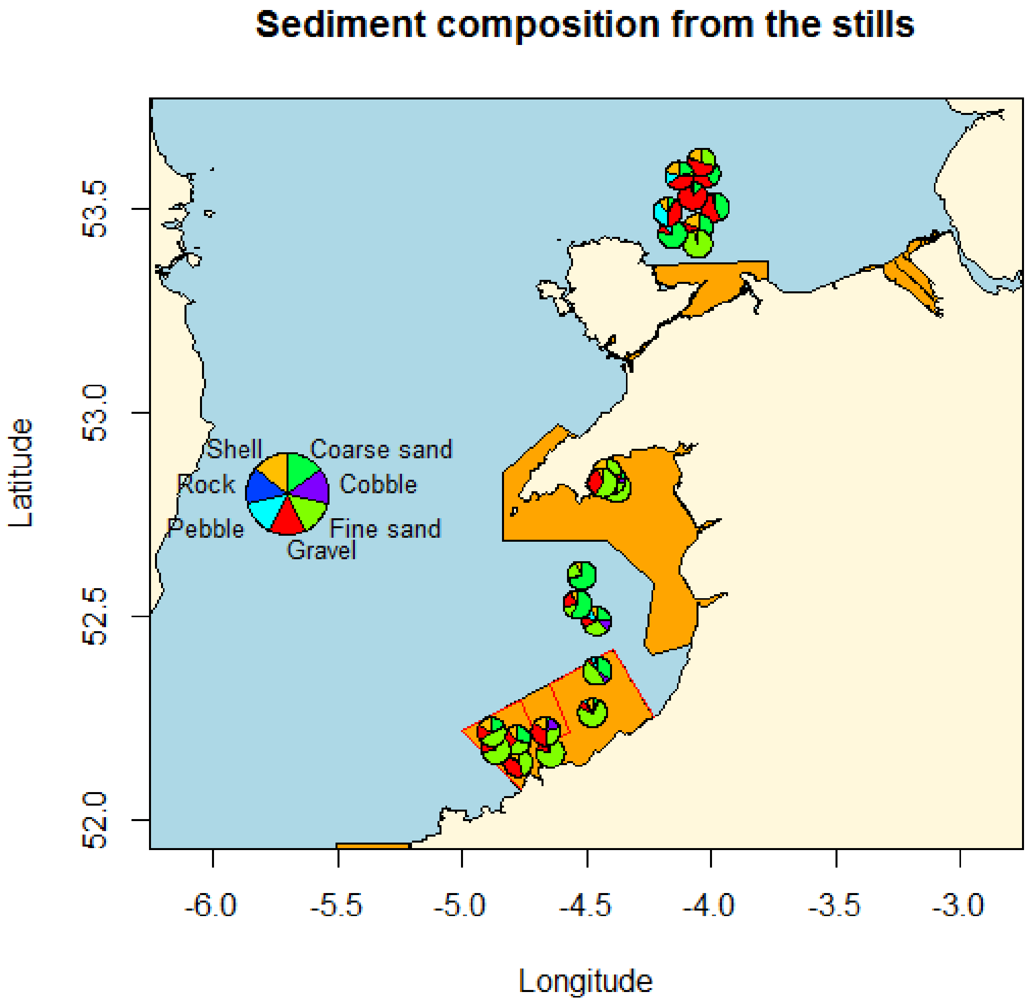

Figure 26. Sediment composition of the sampled stations based on an analysis of the still photographs.

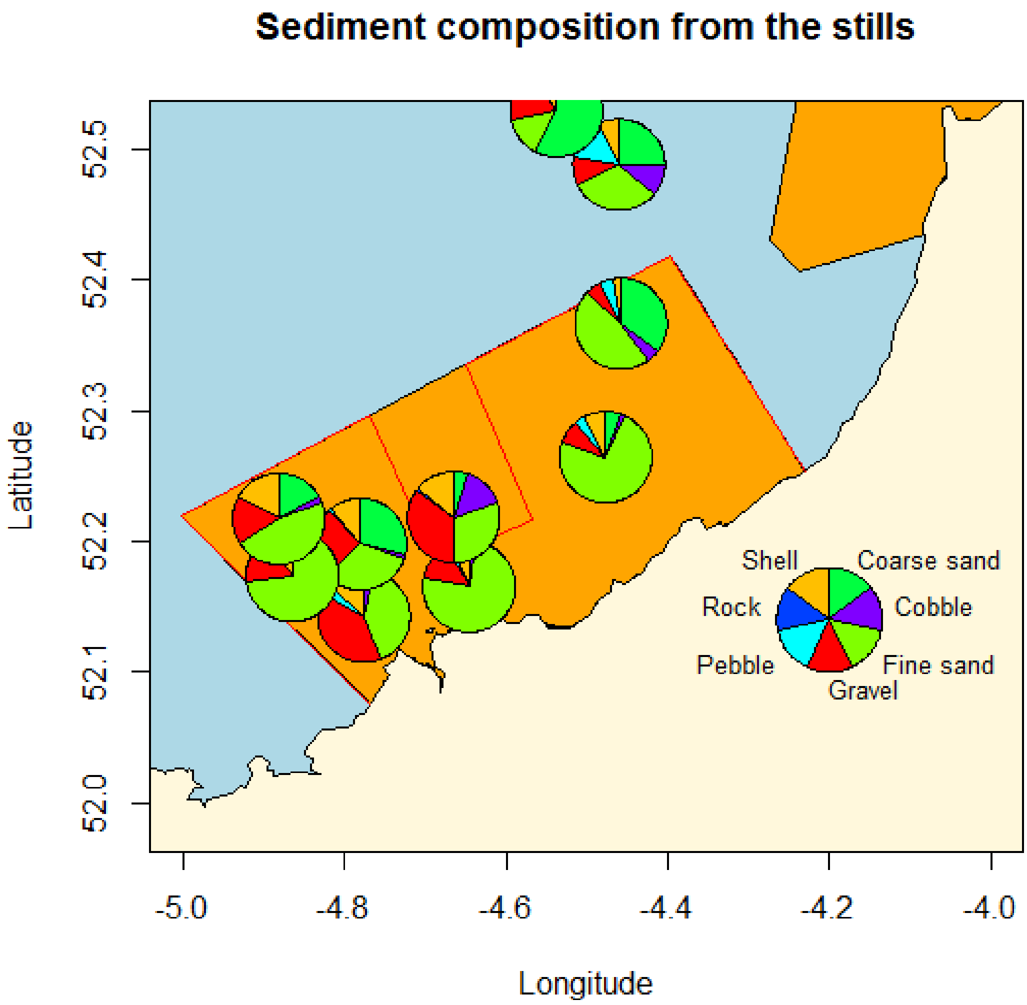

Figure 27. Sediment composition of the sampled stations based on an analysis of the still photographs, zoomed onto the Cardigan Bay SAC.

CONCLUSIONS

State of Scallop stocks

The results of the scallop survey showed that there were some considerable differences between the four main fishing grounds sampled. The first obvious finding is that the abundance of king scallops *P. maximus* were much higher in Cardigan Bay (2.27 (±1.97) individuals/100m^2 king scallop dredges) than at the Llyn Peninsula (0.16 (±0.18) individuals/100m^2 from king scallop dredges), Liverpool Bay (0.30 (±0.32) individuals/100m^2 from king scallop dredges). Equally, the video tows conducted in Tremadog Bay showed lower abundances (1.48 (±1.95) individuals/100m^2 from video transects) compared to Cardigan Bay. It is important to note that the mean estimates of abundances will differ depending on the sampling gear used (see results and conclusions below). With respect to Cardigan Bay the abundance of king scallops were twice as high within the closed area of the SAC (5.2 individuals/100m^2) compared to the open area (2.5 individuals/100m^2).

The only area that where queen scallops occurred with a high abundance was Liverpool Bay. Abundance was estimated to be 8.14 (±6.45) individuals/100m^2 (estimate from queen scallop gear). In Cardigan Bay, queen scallops were found at very low abundances. Interestingly, old maps seem to indicate that this area did contain queen scallops in the past (Mason 1983). [but can you infer abundance from Mason?, they may have occurred but in very low densities]

The age and size structure of the king scallop population can be used to assess the state of the stock. A healthy stock would be expected to have large cohorts (i.e. age groups) of young individuals and smaller cohorts of old ones reaching the upper limit of the species' lifespan. Here, the dredging sampling method did not allow to representative sampling of very small scallops (age 1-2). However, at age 3, scallops have started to reach the size targeted by the queen dredges. High abundances of age groups 3 and 4 were sampled in Cardigan Bay while older king scallops (6+) were rare. This pattern suggests that older individual have been removed by the fishery. However, at the same time the large numbers of younger cohorts seem to suggest that there is regular recruitment of scallops into the area . Contrary to this result, populations both at the Llyn Peninsula and in Liverpool Bay were dominated by large and old individuals (Liverpool Bay, mean age 5, size 122mm; Llyn Peninsula, mean age 6, size 119mm).

The observation of low abundances and lack of young scallops in Liverpool Bay and at the Llyn Peninsula seems to suggest that these areas do not receive sufficient and/or regular supplies of larvae or that young scallops suffer high mortality rates. The lack of larvae seems to be a plausible explanation although predation cannot firmly be excluded (i.e. bycatch levels were considerably higher in these areas). It would be worth investigating why larvae supply might be low in these areas. There is the possibility that these populations are self recruiting and that the low densities observed are not sufficient to support a higher reproductive output. It is possible that for successful fertilization scallop need to be maintained at sufficient density. These densities are however currently unknown to science. To answer the question whether the areas are self recruiting could be solved by the use of particle tracking models in the future. It is also possible that there was an external source of recruitment to the area that does not exist anymore (changes in currents patterns or a source area has been fished out for instance). The high abundance of bycatch species in this area indicated that there were ample settlement substrata for larvae settling in the area and hence this is not considered to be a limiting factor in Liverpool Bay. Understanding recruitment processes in Welsh waters will be crucial for management as only with such knowledge can the stock be effectively managed. For self recruiting populations enhancing reproductive outputs of local scallops would certainly be an advantage. Preliminary studies of larval transport in Cardigan Bay have shown that this area appears to be predominantly self recruiting. Thus active management of this area should benefit the productivity of the local fishing ground.

Another question arises from the differences in age structure of the three areas. To our knowledge, there is no evidence in the literature of the relationship between age of the spawning cohort and success of the recruitment. We know that older scallops produce more eggs however we do not know if the quality of the eggs, and the subsequent survival of the larvae produced, are as good as (or better or worse than) the eggs produced by younger scallops. This question is important for management purposes since Cardigan Bay, which seems to have a young population, is the most productive area and therefore the area that will require very well informed management strategies to be sustainable. Also the stock in Liverpool Bay may need extra protection if it was found to be self recruiting and the low quality of the eggs produced by the local stock would not allow for its sustainability.

Overall, it can be concluded that, while genetically the Welsh stock is highly likely to form one unit, there seems to be strong spatial patterns (i.e. potentially related to larval transport) that would require more localized management strategies of the different grounds.

King scallop growth, gonad and meat status

Difference in growth rates of king scallop were recorded with scallops from Liverpool Bay and Cardigan Bay growing faster compared to the Llyn Peninsula. Nevertheless, the muscle meat weight for larger scallops was higher at the LLyn compared to the other two areas.

In all areas, over 90% of the gonads were were recovered from the previous spawning event but had not yet filled ready for the next spawning event. The remaining gonads showed that they were in the first stages of recovery from the last spawning event. There were no differences between the three main scallop grounds with respect to gonad status and weight.

By-catch levels and environmental context

Bycatch in Liverpool Bay and at the Llyn Peninsula were higher (means in queen dredges 36.25 (±18.38) and 13.23(±4.15) g/100m^2 respectively) compared to the Cardigan Bay (mean in queen dredges 12.74 (±7.60)g/100m^2 when *Mytilus edulis* bed of station CB21 excluded). In particular, Liverpool Bay showed a very diverse and rich fauna with many fragile species such as the purple sea urchin *Spartangus purpureus* which seems to indicate that this area has not been highly impacted by fishing in recent years. This finding further emphasizes that the low scallop abundances within this area are related to a lack in recruitment rather than? Not sure what you mean here.

Cardigan Bay is thought to be a high energy environment as deducted from the sediment type and morphology (see Hinz et al. 20010a, 2010b). Therefore, it is likely that the abundance of associated epifauna is limited by the local environmental conditions. The catch in the Cardigan Bay were mostly ‘clean’, consisting mainly of the target species *P. maximus*. There was also no significant difference between the bycatches of the closed and open area which seem to indicate that despite the 4 year closure there has been little change with respect to this component of the benthic fauna [in the king dredges, open area 10.42 (± 6.12), closed area 7.29(±6.15) g/100m^2; in the queen dredges, open area 7.01 (±4.06), closed area 13.81(±9.85) g/100m^2]. This finding concurs with some of our previous work where we similarly could not detect any differences between the open and closed areas despite continued fishing in the open area (Scriberras et al. 2012). This suggests that the impact of the fishery on the ecosystem in the closed area would be limited regarding the living biota present there. However, it is worth noting that the Cardigan Bay system appears to be self recruiting with the inherent risk of over-fishing and the risk of limiting reproductive output. Thus, the fishing effort should be spatially and temporally controlled to keep a sustainable stock and limit ecosystem impacts.

During our survey no cobble reef was detected within the Cardigan Bay SAC. The videos of the habitats and species will be analyzed in more detail in the future.

Assessment of sampling equipment

The survey also allowed us to test out our sampling methods. Abundance indices of the queen scallops population are reliable and consistent. However, the king scallop populations were found to be more difficult to sample. This may be a result of the limited area covered by the video and still camera field of view. The king scallop are more difficult to spot than queen scallop since they are generally slightly buried in the sediment and sometimes covered in sessile epifauna. They also appear to be spatially more patchily distributed compared to queen scallops. The sediment type also plays a role in the level of detection. King scallops are easier to see on sandy grounds than on more rocky ones with developed epifaunal habitats. Therefore, we will try and improve our sampling device by increasing the field of view of our cameras and compare again the results with dredge estimates to get an estimate of catchability of the gear and assess the consistency of the sampling methods. This is important since scallop abundance surveys are generally conducted with dredges but this may not be possible everywhere in the SAC (i.e. where cobble reefs have been observed for instance).

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