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Welsh waters scallop survey – Cardigan Bay to Liverpool Bay July-August 2013

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CONTENT

EXECUTIVE SUMMARY

- The relationships between still, video and dredge estimates of queen and king scallop densities were good and better in 2013 than in 2012 even though some variance remained. This variance is 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. There is, however, an order of magnitude difference between the still and video estimates, which could be due to the difference in area covered and image quality but this will have to be investigated further in the future.

- There were significant differences in the abundance of scallops within the three areas sampled: Liverpool Bay, North Western Llyn Peninsula and Cardigan Bay. King scallop abundance was considerably higher in Cardigan Bay compared to the other two areas surveyed. From 2 to 4 times higher densities were caught in the king dredges in the open area of Cardigan Bay compared to the other 2 grounds. Queen scallops 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 undersize scallops in 2012 but, in 2013, more small and young scallops were caught in Liverpool Bay. This may indicate stronger recruitment in recent years than expected from the June 2012 survey.

- There was a greater difference between the closed and open areas of the Cardigan Bay SAC in 2013 compared to 2012. In 2013, the size of scallops peaked at 100mm, 3 year old, in the open area, and at 120mm, 5year old, in the closed area. In 2012, in both the open and closed areas the scallops were between 4 and 5 years old and peaked around 120mm. There seemed to have been a shift towards smaller and younger scallops in the open area and towards older and larger scallops in the closed area, with a fairly constant number of undersize scallops in the closed area.

- The number of scallops above MLS caught in the king dredges was under 1 per 100m^2 in the open area and around 4 per 100m^2 in the closed area both in 2012 and 2013. The number of pre-recruits (defined in the present report as scallops under MLS) in the closed area remained very low in 2013, as in 2012. The average has, however, increased in the open area, but the estimates are still highly variable, reflecting the patchiness of the population distribution.

- In 2013, no difference in overall growth was observed between the 3 grounds but there was a slight difference in the muscle meat:size ratio. King scallops at Liverpool Bay had larger meat weights. Across all ages, the meat weight:total weight ratio was the lowest at the Llyn Peninsula, followed by Cardigan Bay, followed by Liverpool Bay.

- 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, two offset peaks were observed at the Llyn Peninsula and in Liverpool Bay. The first peak was around the “filling-up” phase and the second peak was around the “filled up-almost ready to spawn-spent” phase. In Cardigan Bay, the scallops were mostly around the “almost ready to spawn” phase.

- The mortality of scallops of age 5-6 between 2012 and 2013 was highest in the open area of the SAC (Z=1.6). It was about 4 times the natural mortality in the closed area of the SAC, M=0.4. Total mortality was lower outside the SAC than in the open area of the SAC (Z=0.52), reflecting a lower fishing mortality and possibly a lower natural mortality, which could be linked to the lower bycatch level found there compared to inside the closed area of the SAC (less predation). At the Llyn Peninsula, Z was also high, Z=1.2, while it was relatively low in Liverpool Bay, Z=0.25, where king scallops are not the main target species.

- As in 2012, the amount of bycatch retained in the dredges in Liverpool Bay was higher than at the Llyn Peninsula, which was also higher than in Cardigan Bay. The variability between sampled sites was high but there was also on average more bycatch in the closed area of Cardigan Bay SAC than in the open area. The biomass caught remained low at all sites with averages of less than 0.5kg per 100m^2.

- Current evidence suggests that there may have been a poor recruitment to the fishery in 2013 in Cardigan Bay SAC. The status of the stock elsewhere remains unknown as it was not possible to sample closer to shore, within 3nm, off the Llyn Peninsula (or in Tremadog Bay, but this area remains unfished all year round). The poor recruitment to the fishery in the open area of Cardigan Bay SAC could be due to natural environmental fluctuations, i.e negative impact of storms for instance, or poor settlement due to limited juvenile habitat availability following chronic intensive fishing on the same ground. It is also a possibility that the low number of small scallops in the closed area (under 110mm and under age 4) compared to the open area is the result of spatial competition with the high density of large scallops (video estimates of over 0.5 scallop per m^2 in some patches).

INTRODUCTION

The Welsh fishing industry is primarily an inshore fleet with only 10% of fishers working in offshore waters (beyond 6 nautical miles, nm). 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 stocks. 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 second scallop survey undertaken as part of the European Fisheries Fund (EFF) funded project led by Bangor University in collaboration with the Welsh fishing industry. This second 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 legislation 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 to complement the work started with the first survey in June 2012. Additionally, industry led surveys in the future might utilize these techniques.

Another aim of this second survey was to build 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 2 surveys, June 2012 and July-August 2013.

Specifically the survey 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 abundance estimates obtained from scallop dredging surveys and from camera tows.
5. Compare results from 2012 and 2013 to start understanding the dynamics of the stocks in relation to fishing activities.
6. Contribute and add to the habitat mapping data already collected since 2009.

METHODS

1- Survey design

Three commercially fished scallop grounds were chosen for survey (areas 1, 2 and 4, Figure 1) after consultation with the fishing industry over the location of the main scallop grounds in 2012. Those grounds sampled in July-August 2013 were the same as sampled in June 2012, except for ground 3, Tremadog Bay, which was not surveyed in 2013. This is because the inshore area where the scallop beds are likely to be was covered in pots and therefore difficult to sample. Only a few videos were taken but those were too far out at sea and mostly in the mud hole; they are therefore not reported in the present report. Furthermore, the area within 3nm off the north of the Llyn peninsula, in ground 2, was not sampled because of the numerous strings of pots in the area. Within the 3 areas sampled, random replicate sampling was carried out at a total of 78 sites. Of those 78 sites, 22 sites were sampled by camera tows only, 24 by dredge tows only and 32 by both dredge and video tows to allow comparison of abundance estimates using the different sampling techniques (Figure 1).

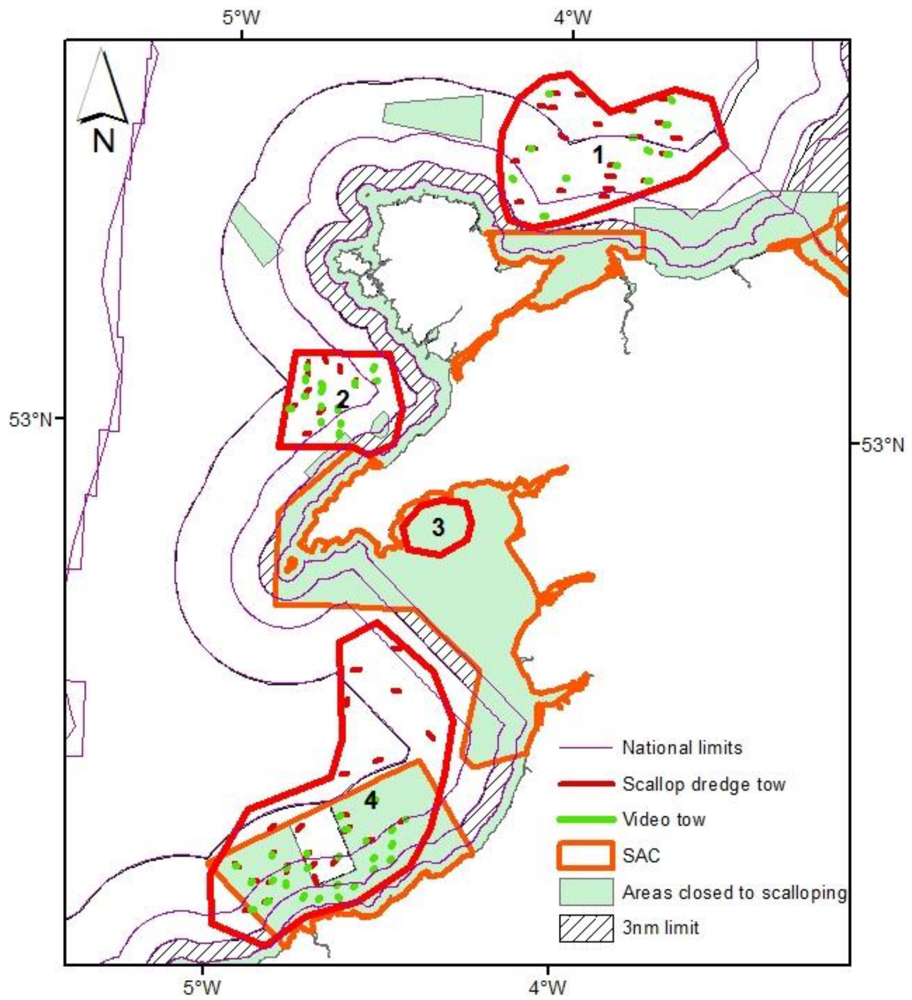


Figure 1. Scallop stock survey design. Areas 1-4 mark the 4 main scallop grounds in which scallops were surveyed. 1- Liverpool Bay, 2- Llyn peninsula, 3- Tremadog Bay, 4- Cardigan Bay. No video tows are reported here in area 3, see text for explanation. Video camera tows are shown as green lines. Red 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 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 necessary for the analyses 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 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, some scallops were used for obtaining biological measurements. 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. Those were then frozen for the analysis of gonad and meat weight upon return to the laboratory. The aim was to collect a representative sample of 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.

3- Camera tows

A sledge mounted video and still camera system was deployed at 54 sampling stations and towed at a speed of approximately 0.5 knots for a period of 20 minutes. 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 seabed during hauling. While the video system delivered a continuous live picture that 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). Those videos were not used for the stock assessment this year as we also fitted a higher quality and larger field of view GoPro camera to the sledge (width FOV

0.80m). Those were used to compare to the abundances of scallops estimated from the still images. Each still image covered an area of $0.13m^2$ (0.44m x 0.30m).

4- 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 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]. These densities were then recorded in number of scallops per $100m^2$.

5- Gonad and muscle weight analysis

Back in the laboratory, the scallop samples were processed. The wet weight was recorded (+/- 0.01g) for each of the gonad, adductor muscle and the remaining tissue. 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.

RESULTS

1 – Queen scallop *Aequipecten opercularis* density

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

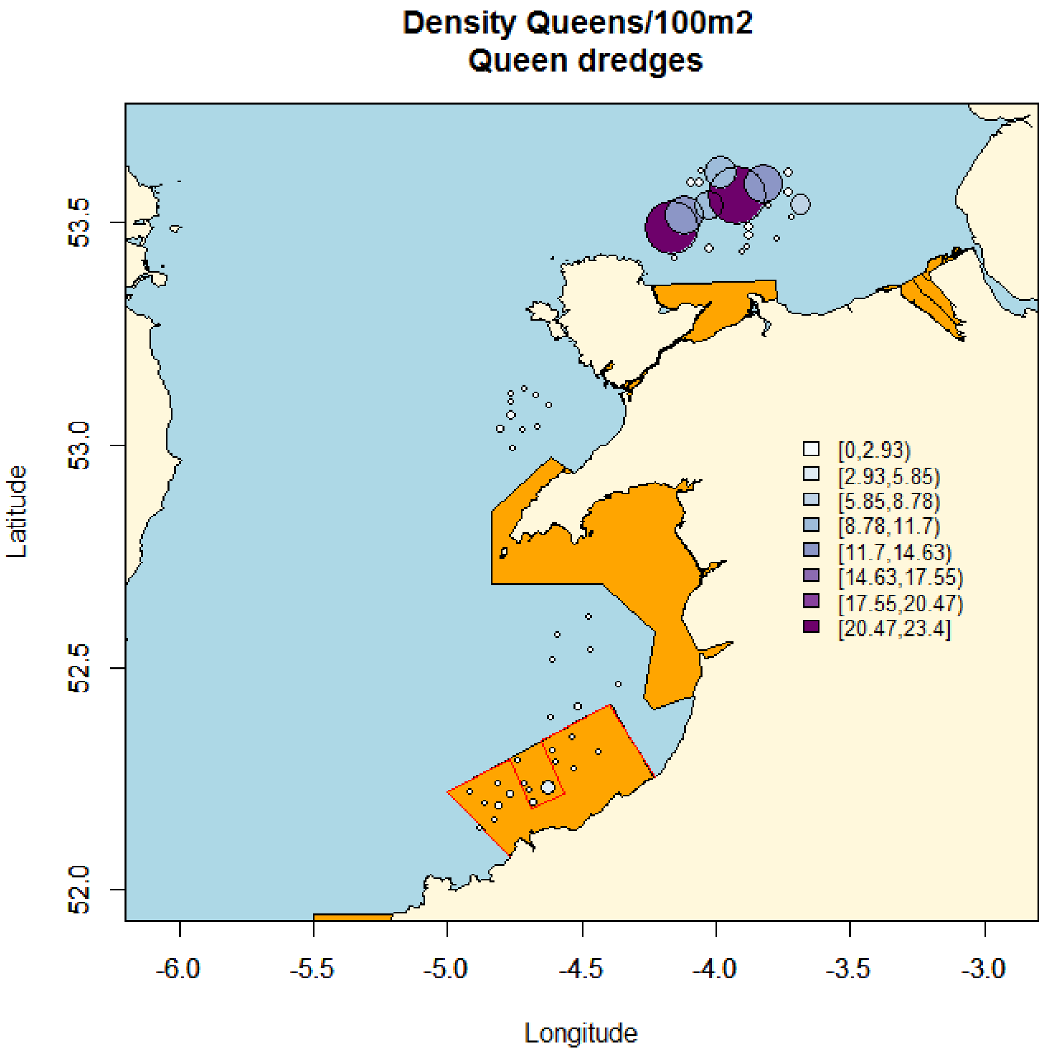


Figure 3. Density of queen scallops (per $100m^2$) estimated using queen scallop dredges.

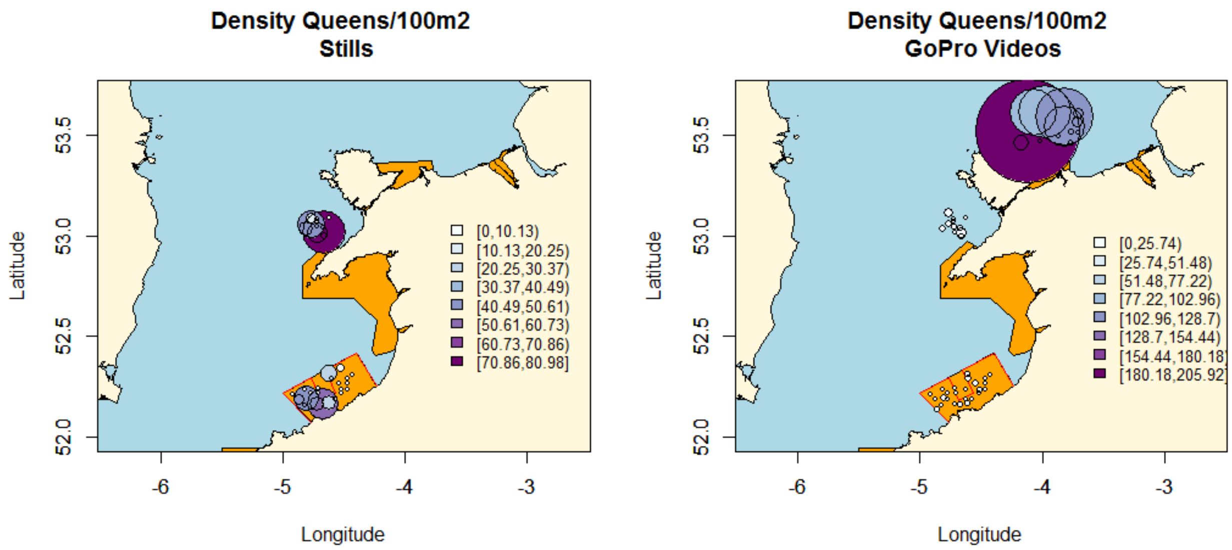


Figure 4. Density of queen scallops (per 100m^2) estimated from (a) still photographs and (b) GoPro videos. NB. No sill images were taken in Liverpool Bay due to the camera malfunctioning.

The agreement between scallop density estimates from videos and still photographs was high (r^2= 0.60) but the densities estimated from the stills were 4.87 times higher than the estimates from the GoPro videos (Figure 5). The estimates obtained from the queen scallop dredges are also an order of magnitude lower than that from the video/still camera estimates (Figure 6) and the relationships are still strong ($r^2_{\text{video-dredge}}$=0.80 with 9.66 more queenies on videos than in dredges and $r^2_{\text{stills-dredge}}$=0.80 with 26.25 more queenies on stills than in dredges [this is likely to be an artefact due to the absence of still images from the main queenie ground, see discussion]).

The lower densities obtained from the queen scallop dredges would likely be due to the low efficiency of dredges and therefore give an indication of their efficiency. Additionally, the estimates of the still images and videos include all undersize scallops (except for small juveniles). The estimates obtained from the cameras are more likely to reflect the real densities on the seabed. The difference between the still images and the GoPro video estimates (estimates approximately 5 times higher from the stills compared to the videos) could be linked to the different field of views and/or the superior quality of the still images. On one hand, the area covered by the GoPro is much larger due to the length of the tow and the larger field of view (on average the area covered by the stills is 13m^2 while the area covered by the GoPro videos is 280m^2), which could lead to the conclusion that the GoPro estimates are more representative of the true densities on the seabed. On the other hand, while it is possible to miscount scallops on the videos, the resolution and quality of the still images is very high and if a scallop is not completely buried, even if it is just 50mm long, it is unlikely to be misidentified or overlooked. If the still estimates were the “true” densities on the seabed then the queen scallop dredges would catch less than 4% of the queenies (regardless of their size) at each pass, which would be a very low catchability. If the GoPro estimates were the “true” densities on the seabed then the queen scallop dredges catch about 10% of the queenies (regardless of their size) at each pass. A depletion experiment using queen scallop dredges, combined to pre- and post- still and video surveys could help determining the real answer.

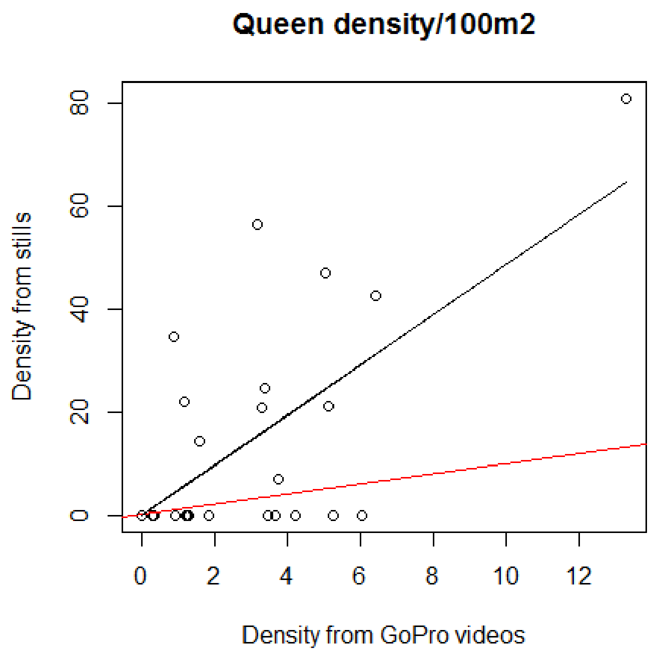


Figure 5. Comparison of queen scallop density estimates (per 100m^2) from GoPro video and still photographs. Black line shows actual relationship, red line shows 1:1 relationship.

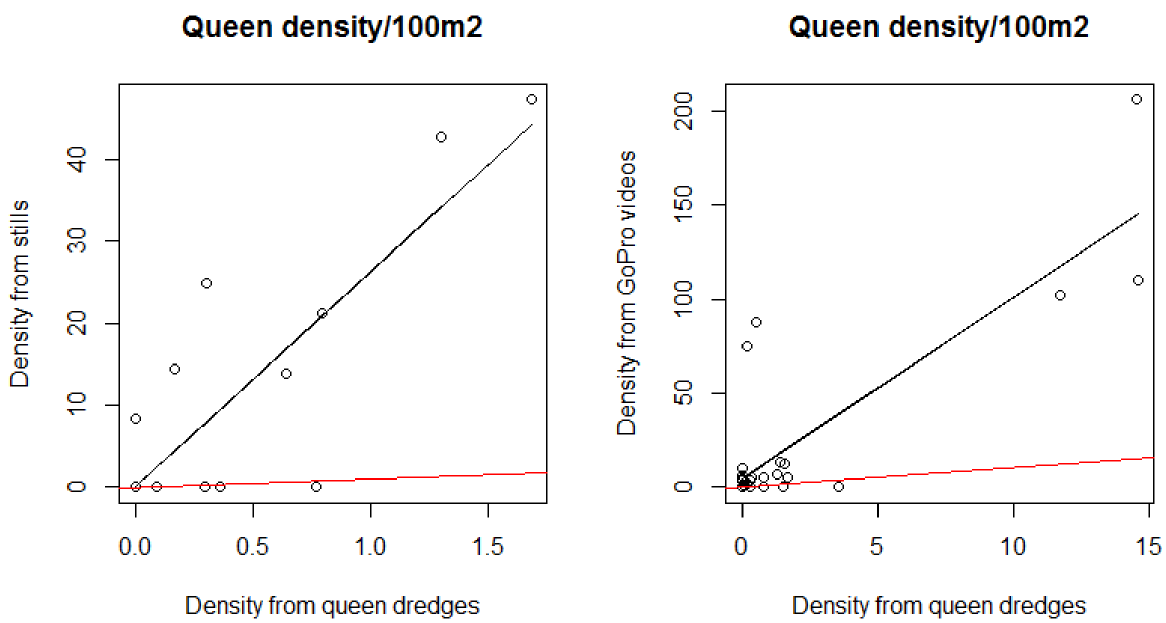


Figure 6. Comparison of queen scallop density estimates (per 100m^2) from queen Newhaven dredges and (a) still photographs and (b) GoPro videos. Black line shows actual relationship, red line shows 1:1 relationship.

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).

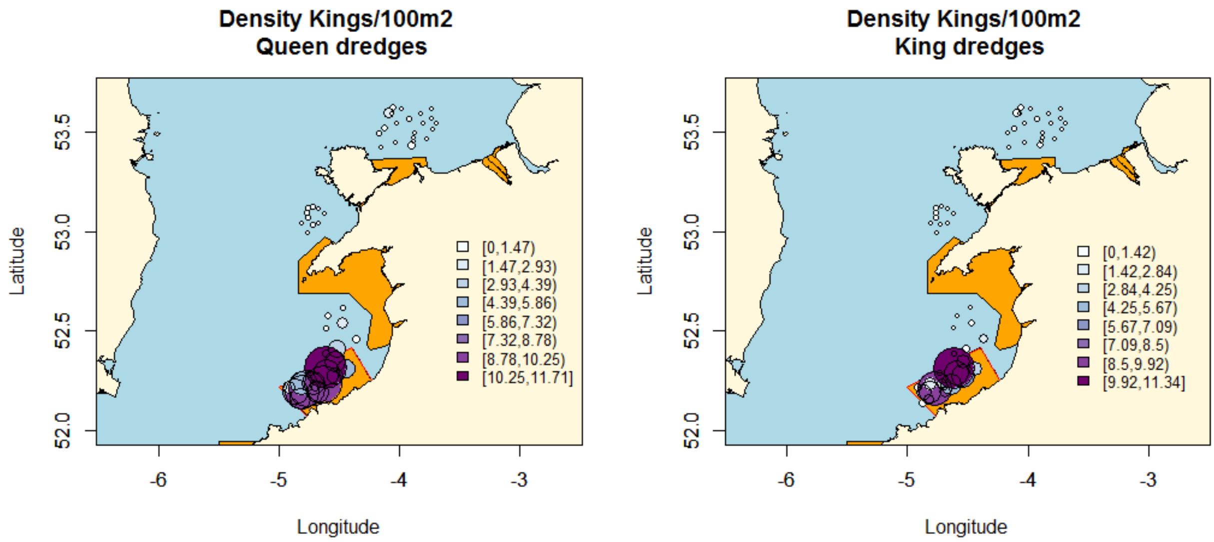


Figure 7. Density of king scallops (per 100m^2) estimated from (a) queen dredges and (b) king dredges.

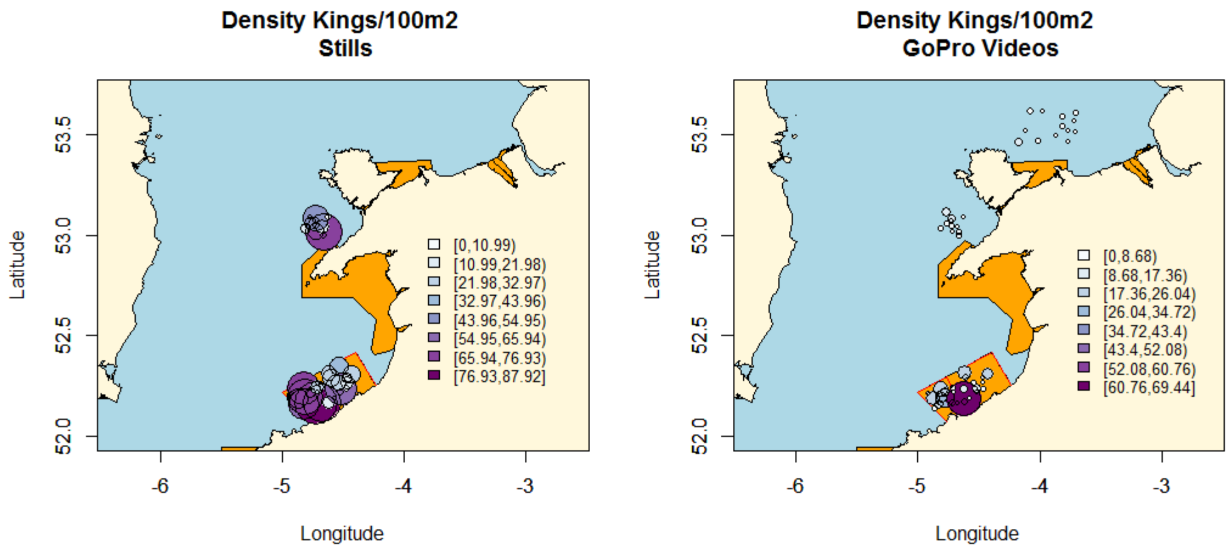


Figure 8. Density of king scallops (per 100m^2) estimated from (a) still photographs and (b) videos.

The agreement between the king scallop density estimates from video and still photographs was similar to that obtained for queen scallops (r^2=0.50) but the difference between the estimates derived from the two methods was lower. The stills gave estimates which were 2.85 times higher than the GoPro videos (Figure 9).

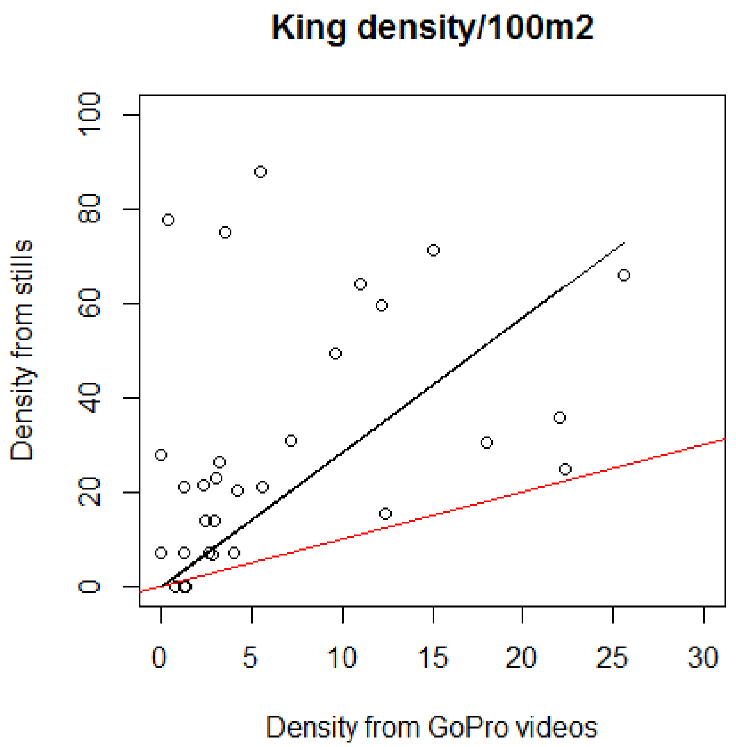


Figure 9. Comparison of king scallop density estimates (per $100m^2$) from GoPro video and still photographs. Black line shows actual relationship, red line shows 1:1 relationship.

The relationships between density estimates obtained from the dredges and the still/video camera were strong (Figure 10). The relationships were as follow:

- $r^2_{\text{video - queen dredge}}$ = 0.7 with 1.77 times more scallops on videos than in the queen dredges
- $r^2_{\text{video - king dredge}}$ = 0.59 with 2.11 times more scallops on videos than in the king dredges
- $r^2_{\text{stills - queen dredge}}$ = 0.66 with 4.85 times more scallops on stills than in the queen dredges
- $r^2_{\text{stills - king dredge}}$ = 0.45 with 5 times more scallops on stills than in the king dredges

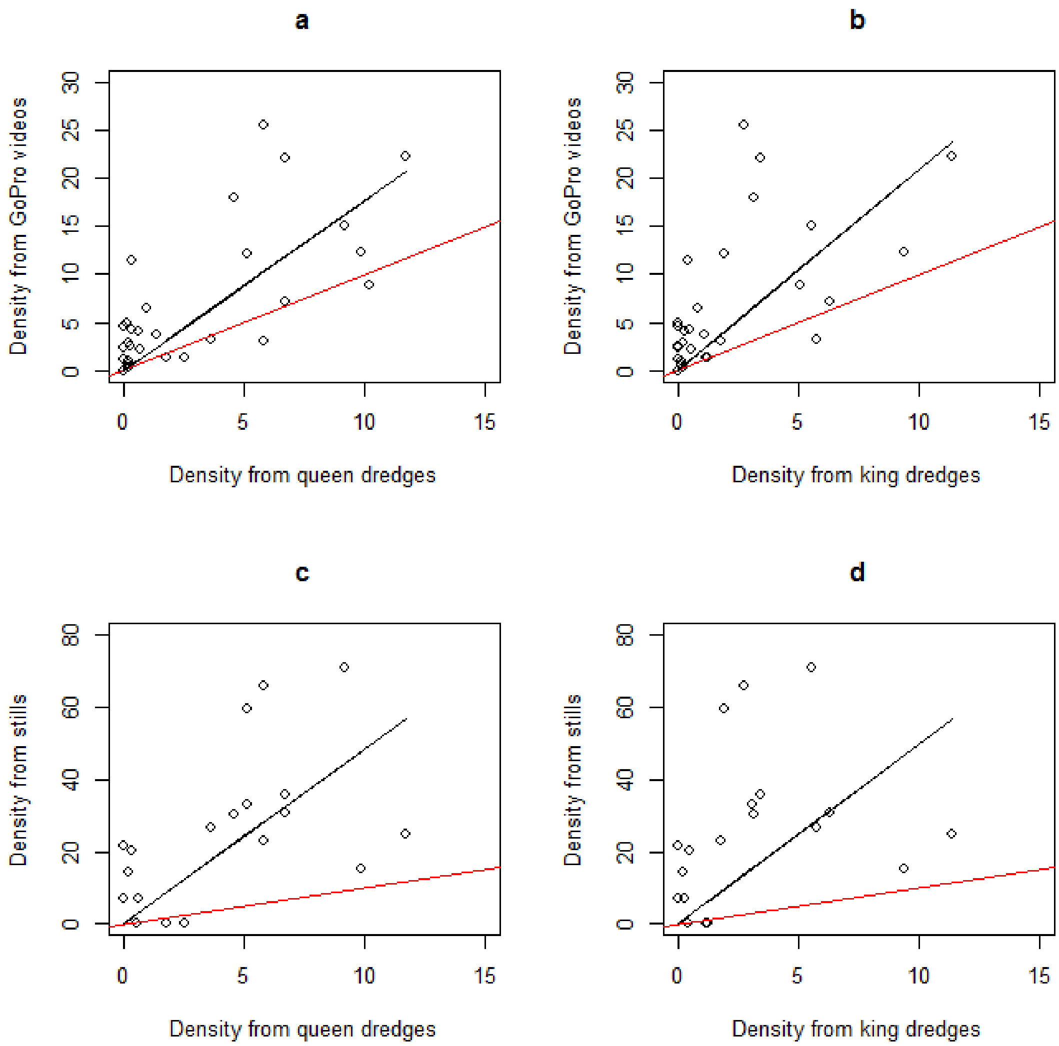


Figure 10. Comparison of king scallop density estimates (per 100m^2) between (a) queen scallop dredges and videos (b) king scallop dredges and videos (c) queen scallop dredges and still photographs (d) queen scallop dredges and still photographs. Black line shows actual relationship, red line shows 1:1 relationship.

The difference between the estimates of scallop densities obtained from the different survey methods was not as pronounced for king scallops as for queen scallops, but the field of view and total area covered by stills compared to the videos still plays a major role in estimating the densities. This reflects the different efficiency of the survey methods for the two species of interest. If the GoPro estimates are the true densities on the seabed then the king dredges catch 47% of the scallops (regardless of their size) at each pass. If the still estimates are the true densities on the seabed then the king scallop dredges catch 20% of the scallops (regardless of their size) at each pass. Again, a depletion experiment using king scallop dredges, combined to pre- and post- still and video surveys could help accurately determine scallop dredge selectivity.

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

Small scale variability in density estimates in Cardigan Bay were scrutinized using all 3 methods (dredges, stills and videos) as the camera work and dredging were not all conducted everywhere.

Figure 11 shows that there is considerable variation in the king scallop densities over small spatial scales within the Cardigan Bay. The queen dredge estimates of king scallops show that the densities of scallops caught are generally higher in the closed area compared to the open area of the SAC with 5.92 individuals/100m^2 and 4.77 individuals/100m^2 on average respectively. The estimate of 4.77 ind/100m^2 in the open area remains high due to a higher number of undersize scallops found at one station. In comparison, in the king scallop dredges, 4.48 ind/100m^2 were caught in the closed area against 2.17 ind/100m^2 in the open area. A more detailed and comprehensive estimate of scallop densities in the SAC can be found in the population dynamics section and at the end of the report. Note also that those estimates differ from the ones given in the feedback to industry short report published in September 2013 (http://fisheries-conservation.bangor.ac.uk/wales/documents/ Preliminaryresults-ScallopStockAssessment2013.pdf) because we give here estimates from queen dredges while the data in the previous report were an average over all dredges (king and queen dredges).

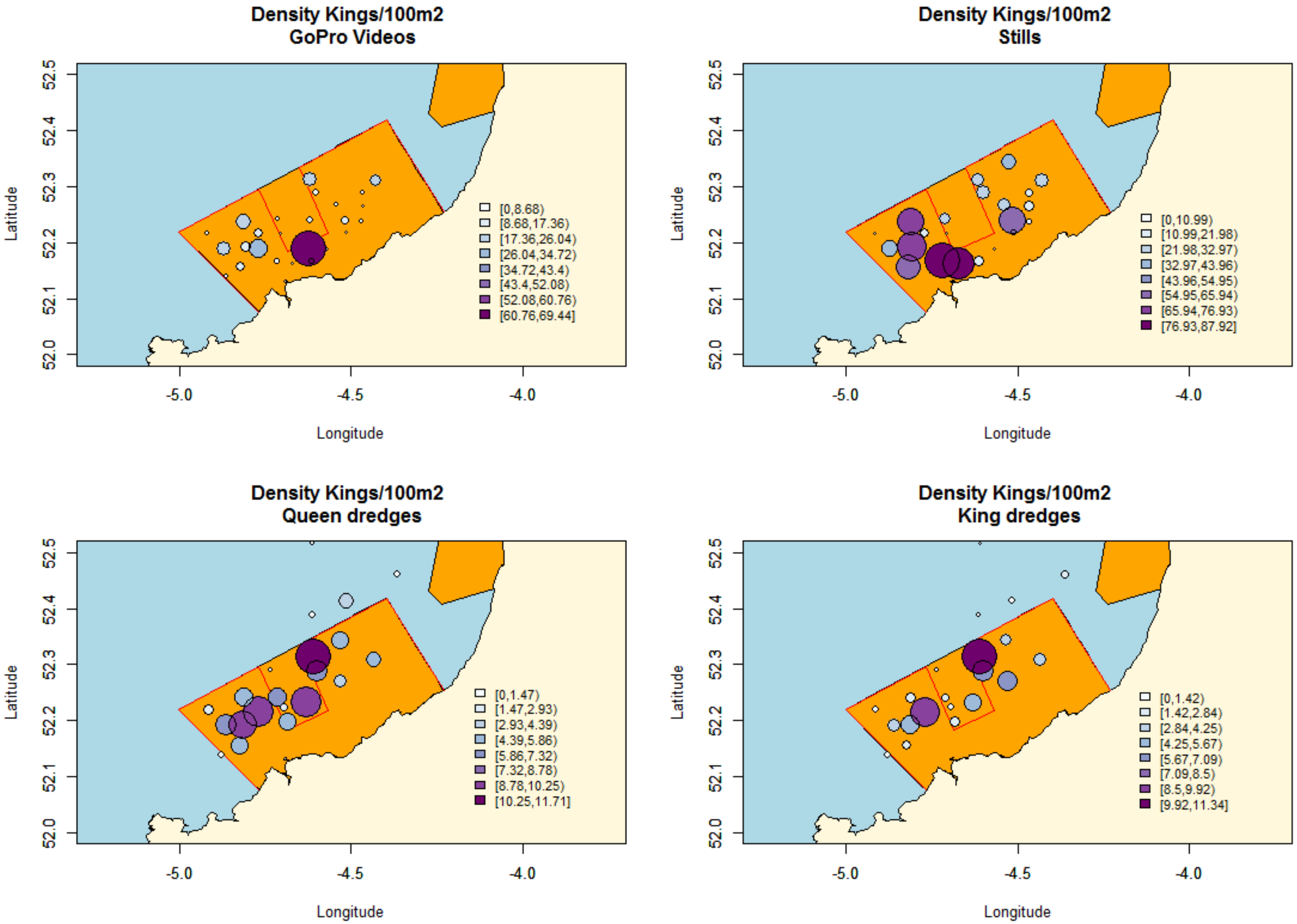


Figure 11. King scallop densities (per 100m^2) in the Cardigan Bay SAC estimated from Go Pro videos, stills, queen and king dredges.

The stock assessment survey of July-August 2013 was combined with a more extensive video habitat survey, covering mostly the Cardigan Bay SAC. We used those extra images to estimate more accurately the scallop stock in the open box of the SAC and in the area west of it, where we propose to conduct an experiment in April 2014.

Figure 12 shows the patchiness of the distribution of the king scallops in the SAC, with very low densities in the open area compared to the closed one.

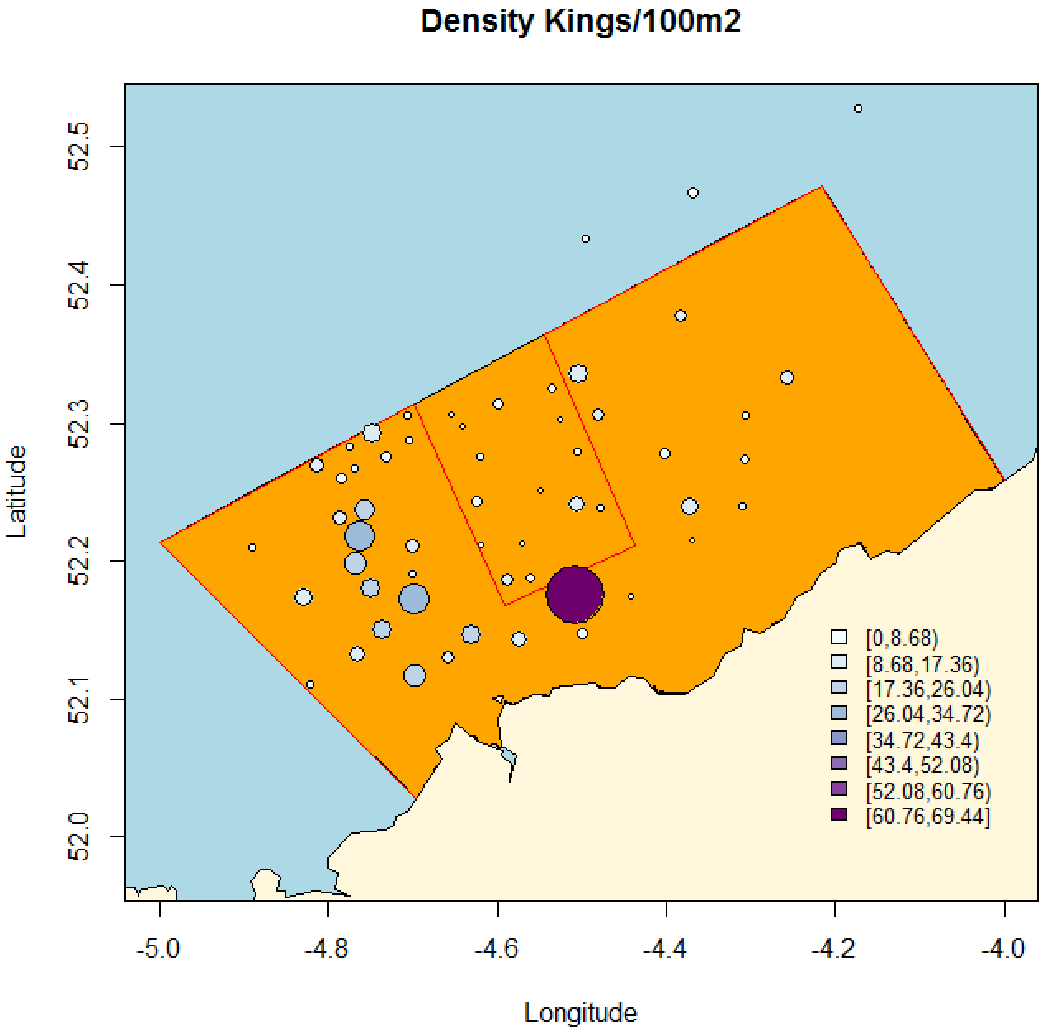
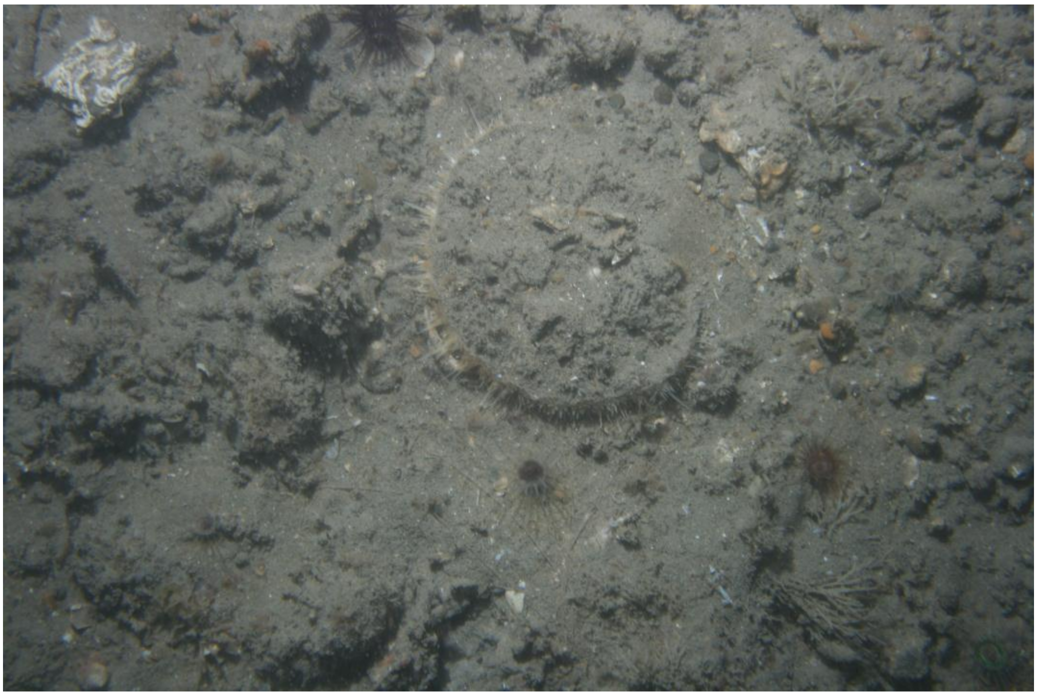


Figure 12. King scallop densities (per 100m^2) in Cardigan Bay estimated from GoPro (or data transformed from stills or dredges to GoPro estimates using the relationships between sampling methods quantified in the results section 2, pp12-13)

A patch of high density can be observed just inshore of the open box. This corresponds mostly to adult scallops living in a gravelly muddy habitat, as shown in the picture below.



Picture of an adult king scallop (over 130mm) in the hotspot of high density, inshore of the open area of the SAC, within 3nm

4- Bycatch analysis

Bycatch levels were higher in queen dredges than king dredges, which was due to the respective belly rings sizes (Figure 13). Overall, there was more bycatch in Liverpool Bay than at the Llyn Peninsula or in Cardigan Bay (Figure 13).

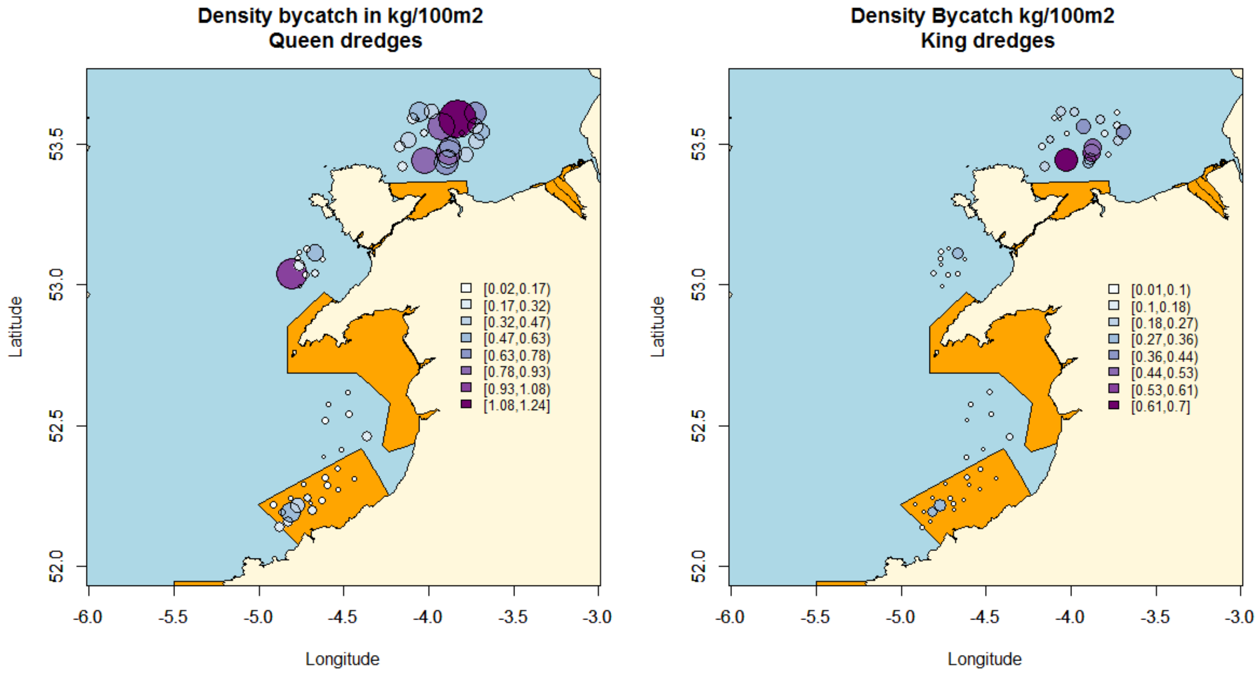


Figure 13. Density of bycatch caught in (a) queen scallop dredges and (b) king scallop dredges.

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 14 and 15). 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 biomass was higher in the closed area (Figure 15).

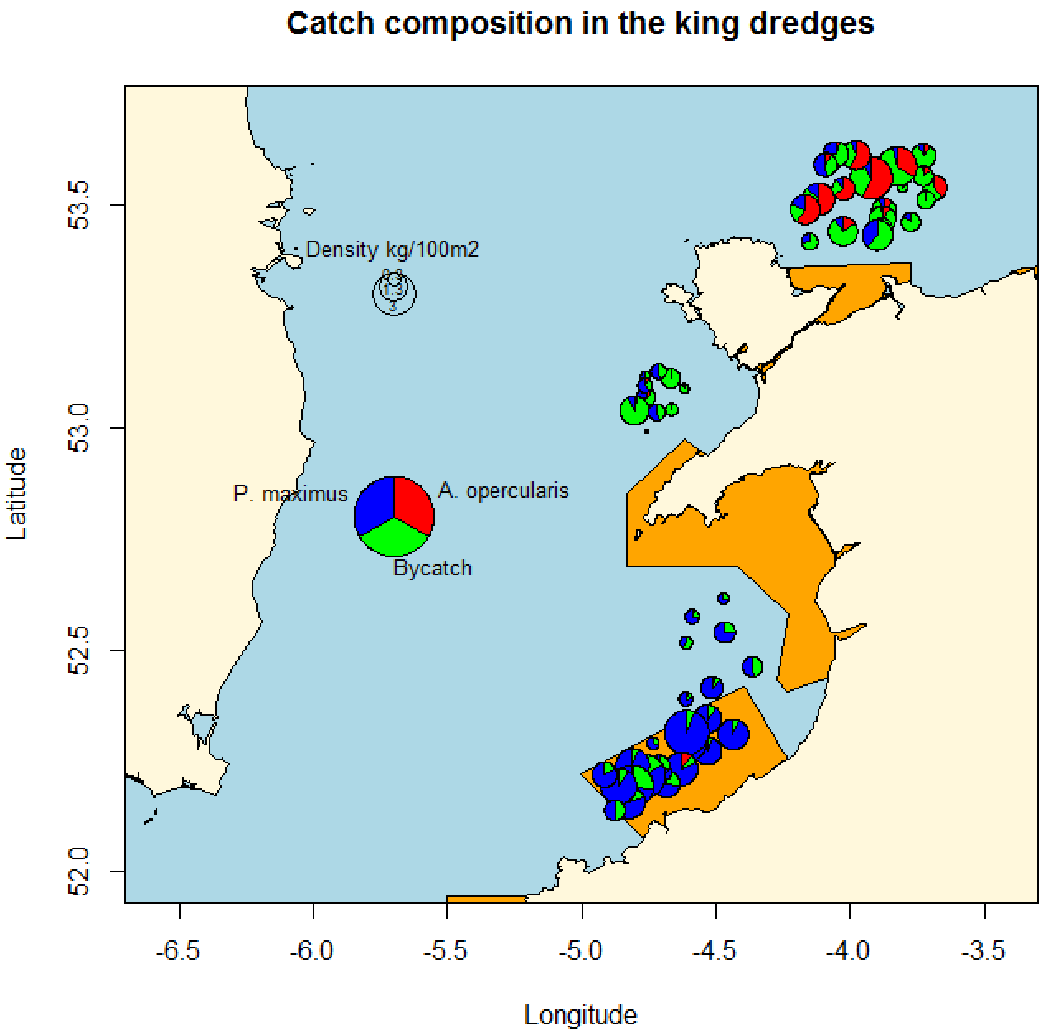


Figure 14. Catch composition in king scallop dredges. Size of circle indicates total biomass of catch (kg/100m^2). Blue indicates the proportion of the target species *P. maximus* in the catch, red indicates the proportion of queen scallops *A. opercularis* and green indicates the proportion of bycatch in the total catch.

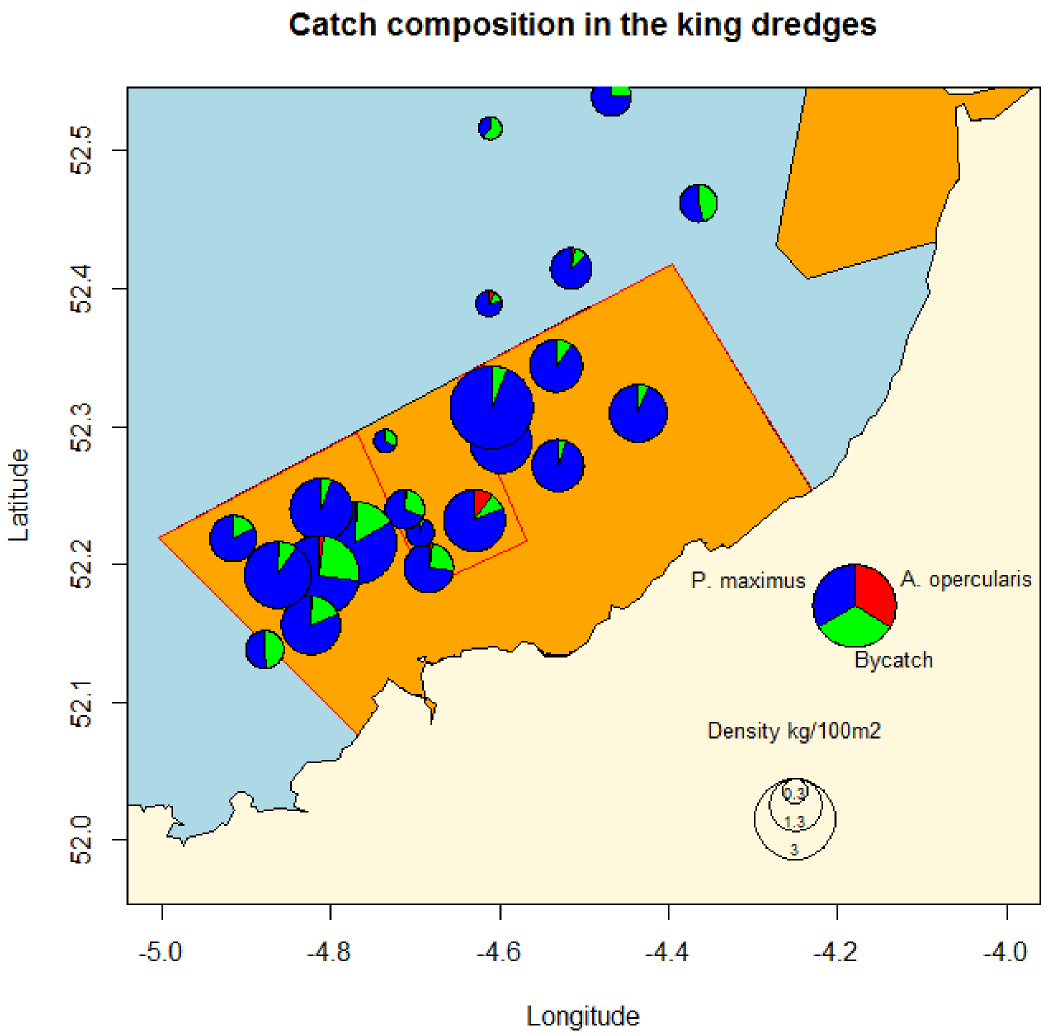


Figure 15. Catch composition of king scallop dredges in Cardigan Bay. Size of circle indicates total density of catch (kg/100m^2). Blue indicates the proportion of the target species *P. maximus* in the catch, red indicates the proportion of queen scallops *A. opercularis* and green indicates the proportion of bycatch in the total catch.

In the king dredges, the bycatch biomass was 0.04 (± 0.02) in the open area of the SAC and 0.08 (±0.1) kg/100m^2 in the closed area. In the queen dredges, the bycatch biomass was 0.12 (±0.08) in the open area of the SAC and 0.19 (±0.16) kg/100m^2 in the closed area. The species composition of the bycatch between the three main grounds varied significantly (Anosim results, r^2=0.45, p=0.001). The MDS plot showed that Cardigan Bay clustered separately from the other areas (Figure 16).

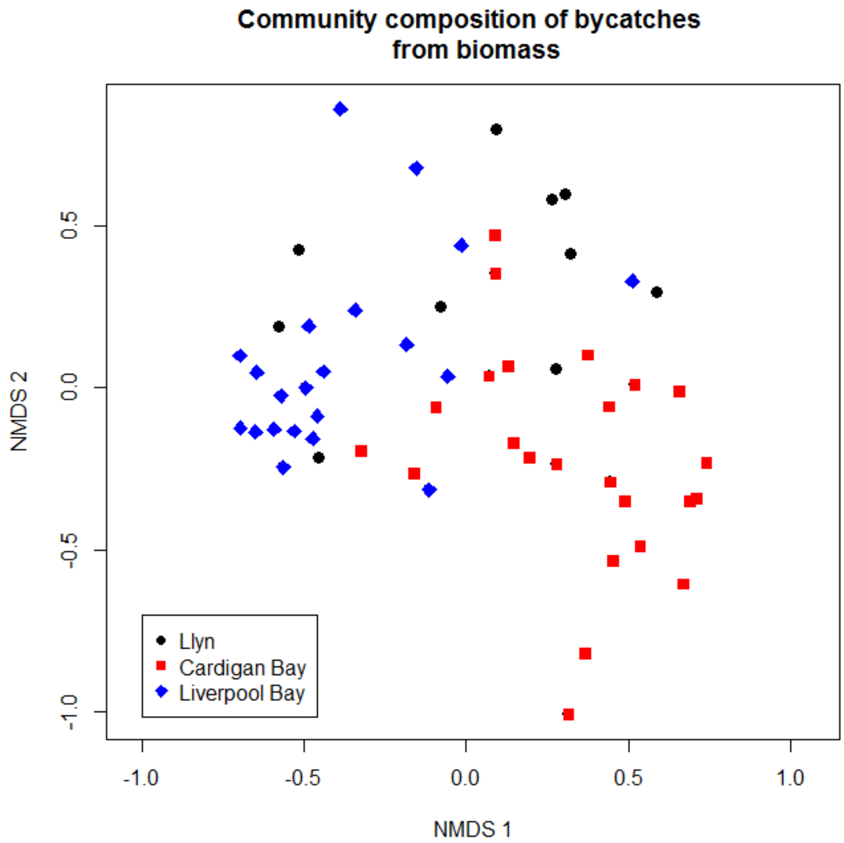


Figure 16. MDS plot representing the community composition of the bycatch from king scallop dredges in three areas traditionally fished for king scallops.

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.

A high number of the species caught at most sampled sites in Liverpool Bay were relatively rare in Cardigan Bay and the Llyn Peninsula. These species included *Adamsia carciniopados*, *Alcyonium digitatum*, *Aphrodita aculeata*, *Colus gracilis*, *Ciona intestinalis*, *Eurynome sp.*, *Hyas spp.*, *Hydrallmania spp.*, *Inachus sp.*, *Modiolus modiolus*, *Neptunea antiqua*, *Ophiocomina nigra*, *Ophiothrix fragilis*, *Ophiura albida*, *Pagurus prideauxi*, *Psammechinus miliaris*, *Psidia longicornis*, *Spatangus purpureus*, *Tubularia indivisa*.

The species specifically caught at the Llyn Peninsula included *Ascidian spp.*, *Botryllus schlosseri*, *Eledone cirrhosa*, *Raja naevus*, *Polychaetes*, *Sertularella gayi*, *Suberites sp.* The only species that characterized Cardigan Bay were spider crabs *Maja squinado*, brown crabs *Cancer pagurus*, the dog cockle *Glycymeris glycymeris* and the Norway cockle *Laevicardium crassum*. The ground was therefore mostly distinguished by the very low abundances and diversity of bycatch 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 110mm compared to 107mm in Liverpool Bay and 128mm 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 more even distribution across the size classes found in Liverpool Bay and the Llyn Peninsula with much lower densities (Figure 17). Scallops caught were on average 4 year old in Cardigan Bay and Liverpool Bay, while scallops off the Llyn Peninsula were on average 6 year old (Figure 18).

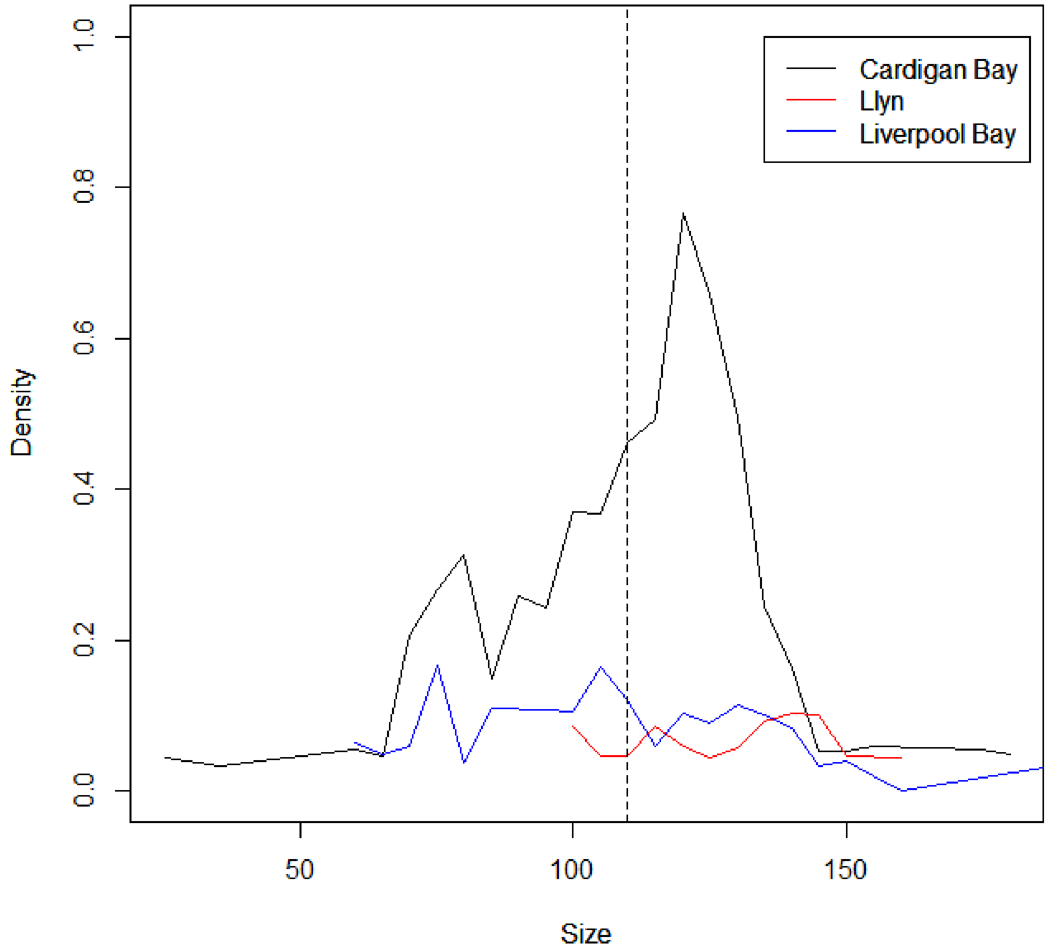


Figure 17. Size distribution of king scallops caught in queen dredges from the three different fishing grounds. Density is in number of individuals/100m^2. Size is in mm. The dashed line is the MLS, 110mm.

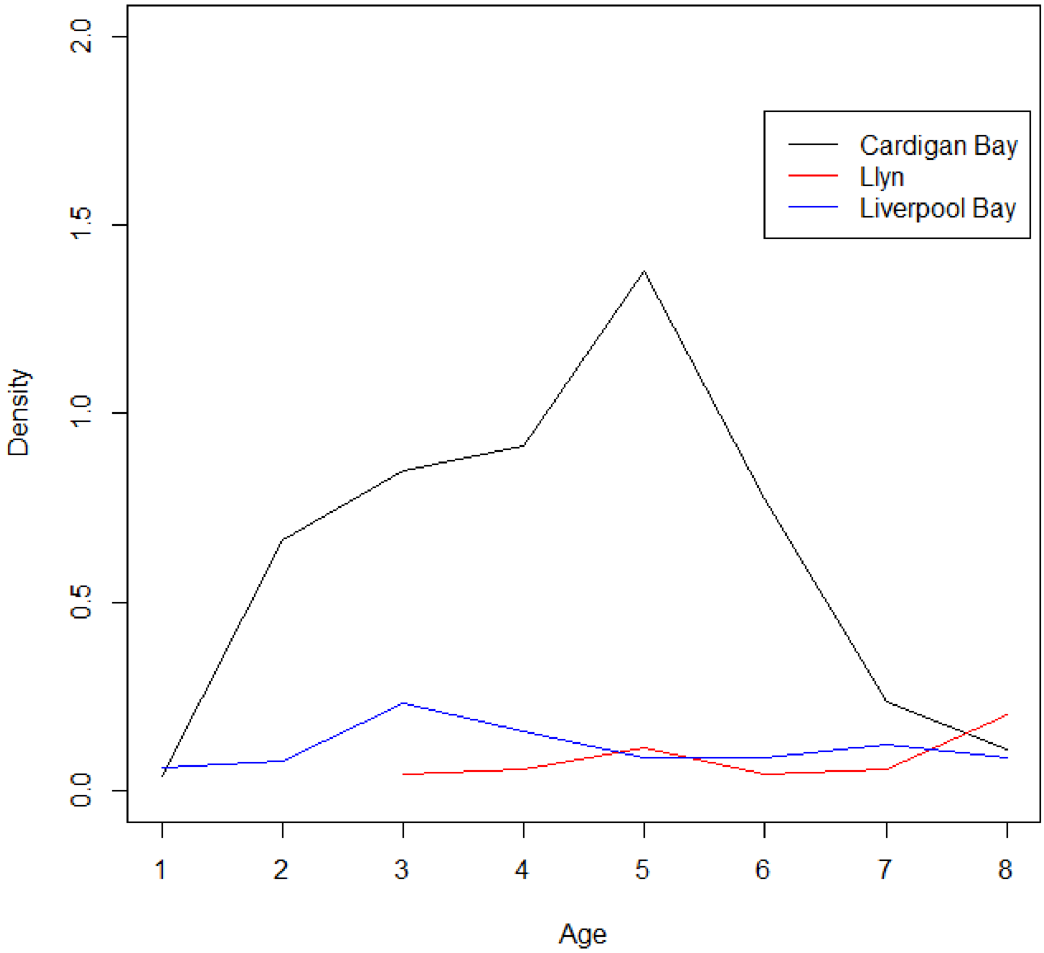


Figure 18. Age distribution of king scallops from the three different fishing grounds. Density is in number of individuals/100m^2. Age is in years.

There were also some major differences in size and age between the closed and open areas in Cardigan Bay. The average size in the closed area of the SAC is 118mm vs. 99mm in the open area of the SAC and the average age in the closed area is 5 compared to 3 in the open area (Figure 19). This was probably due to the presence of older scallops up to age 8+ in the closed area while very few scallops reached above age 5 in the open area i.e. older individuals have been fished out. Note that there appeared to be very few 2 and 3 year old scallops, <110mm, in the closed area of the SAC.

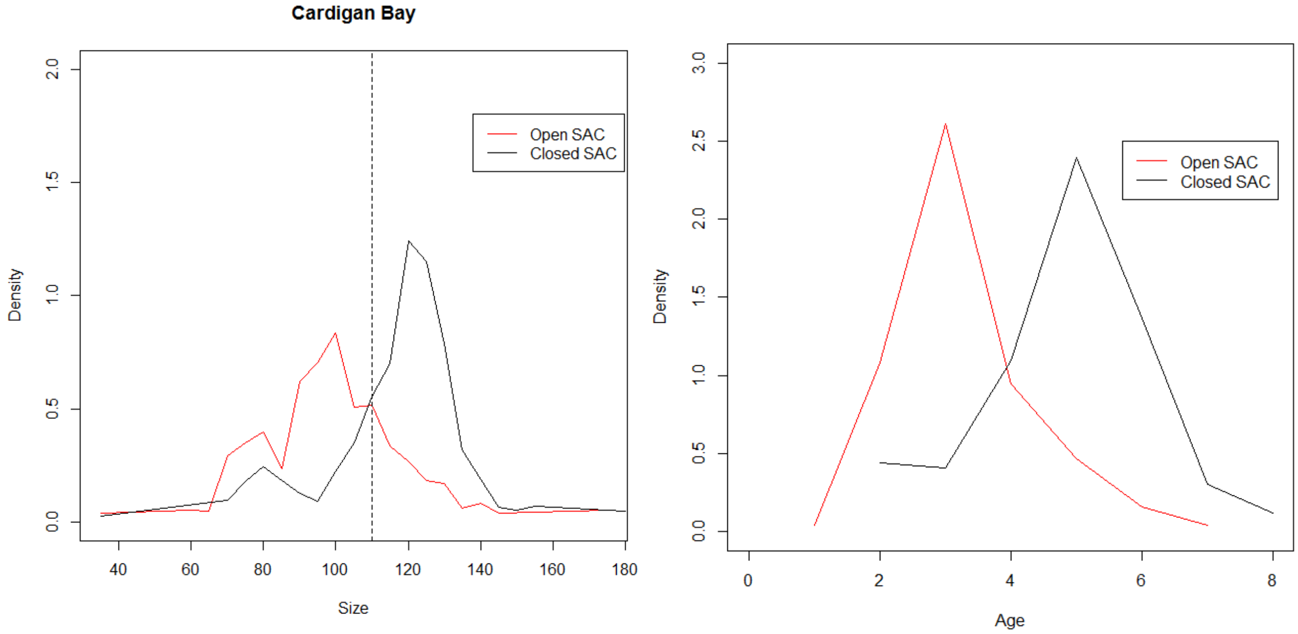


Figure 19. Size and age distribution of kind scallops sampled from queen dredges in Cardigan Bay SAC. Comparison between open and closed areas. Density is in number of individuals/100m^2. Size is in mm and age is in years.

There were very low levels of smaller, younger scallops recruiting to the grounds of Liverpool Bay and Llyn Peninsula, whereas Cardigan Bay showed higher numbers of pre-recruits (defined here as scallops under MLS, i.e. <110mm), especially in the closed area (Figures 20 and 21). There was a major difference in the number of pre-recruits between the closed and open areas of the SAC, mostly due to one site sampled in the bottom right corner of the open box (Figure 21). The density of pre-recruits in the open area of the SAC was 3.3 (± 3.2) /100m^2 and 0.94 (± 0.84)/100m^2 in the closed area and was significantly different (Anova, df=17, F=6.74, p=0.02).

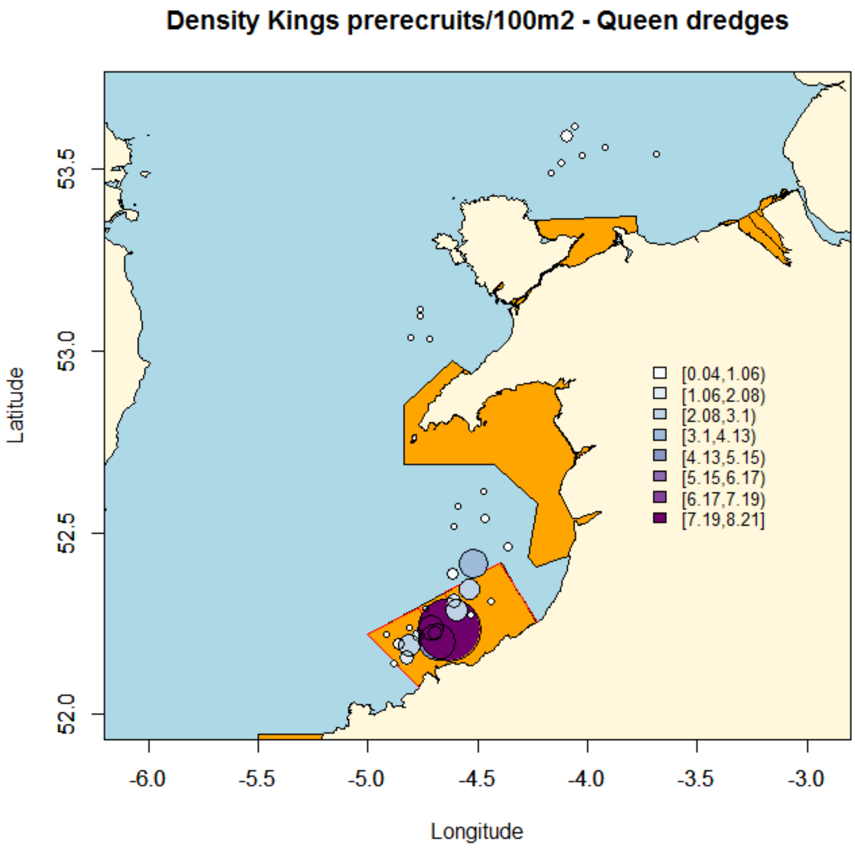


Figure 20. Densities of pre-recruit (<110mm) king scallops at three fishing grounds in Welsh waters.

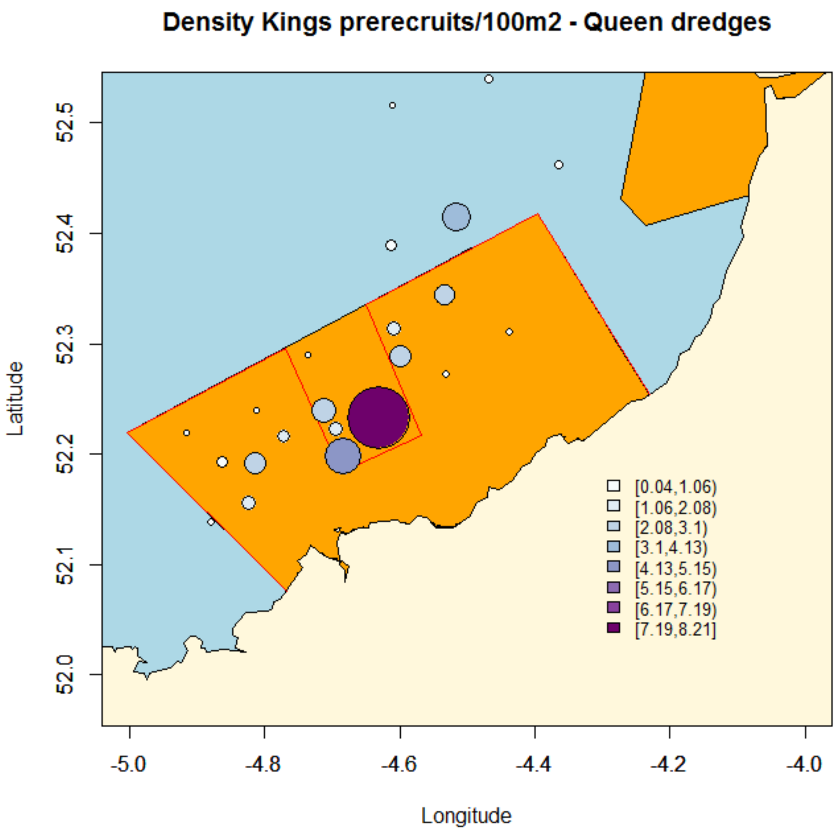


Figure 21. Densities of pre-recruit (<110mm) king scallops in Cardigan Bay SAC.

b) Growth rates

The growth rates of king scallops are similar at the sites sampled off the Llyn Peninsula, in the Liverpool Bay and Cardigan Bay (Figure 22).

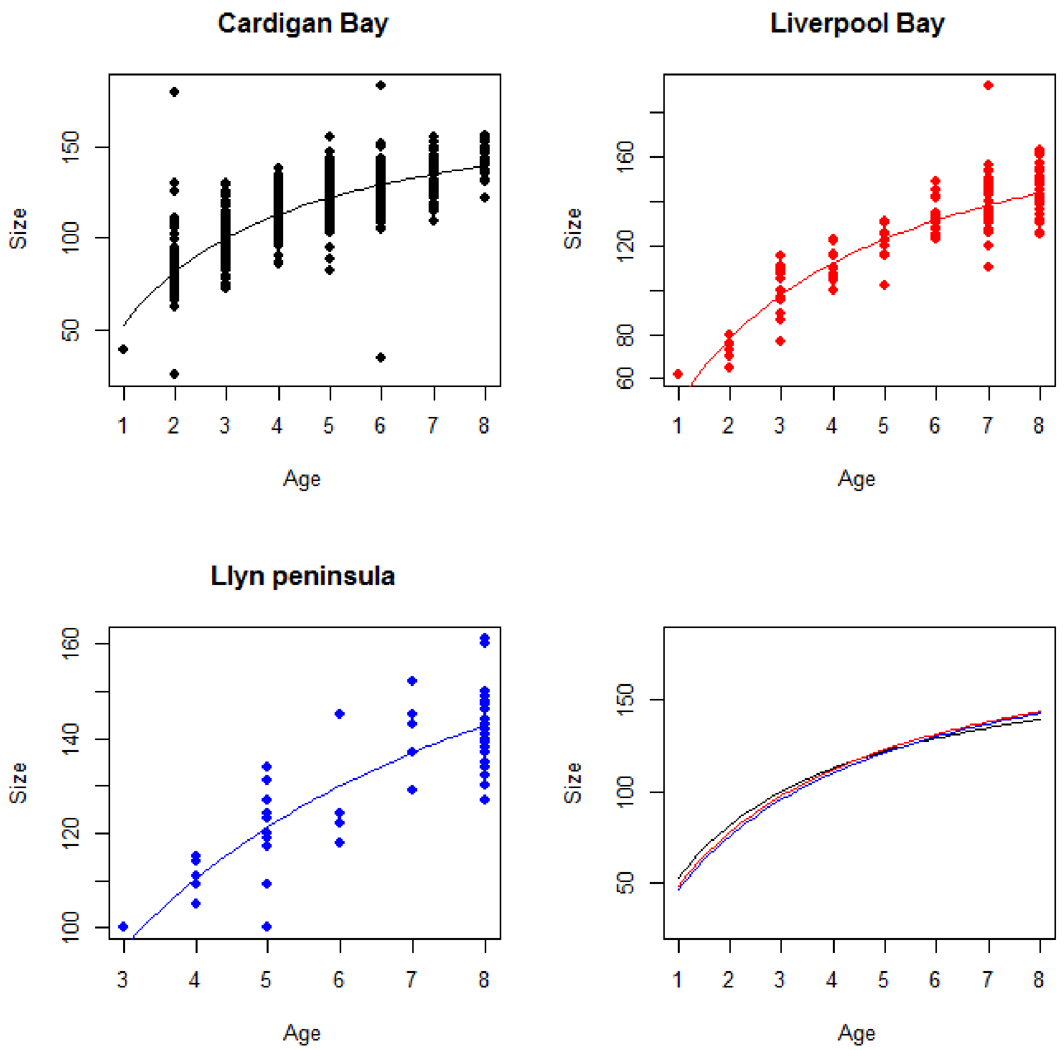


Figure 22. Growth curves of the 3 areas sampled, i.e. Cardigan Bay, Liverpool Bay, Llyn Peninsula. The bottom right panel is for comparison of the growth rates between areas, the black, blue and red curves represent Cardigan Bay, Liverpool Bay and Llyn Peninsula respectively.

c) Weight and reproductive status

- Meat weight- length relationship

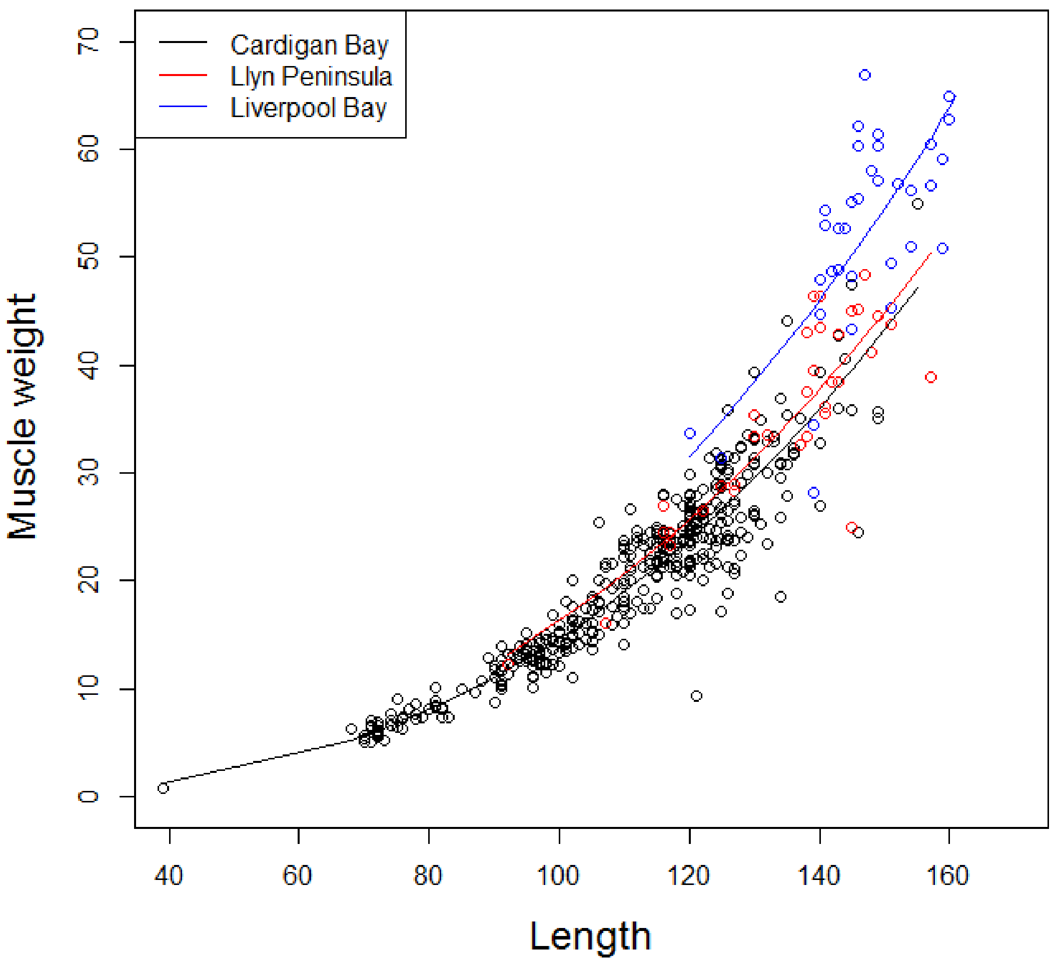


Figure 23. Length-weight (mm-g) relationships for Cardigan Bay, Liverpool Bay and Llyn Peninsula.

For the same length, the meat weight is higher in Liverpool Bay than at the Llyn Peninsula or in Cardigan Bay (Figure 23). This observation was statistically tested and found to be highly significant (r^2=0.94, p<0.001). The relationship between shell weight and length was different at the Llyn Peninsula compared to the other 2 grounds, with shells being on average heavier for a given length (r^2=0.95, p=0.002). The gonads were heavier for a given length at the Llyn Peninsula and in Cardigan Bay than in Liverpool Bay (r^2=0.76, p<0.001).The tissue weight was no different between the 3 grounds (r^2=0.93, p<0.001). The individual scallop weight was lowest in Cardigan Bay SAC (r^2=0.96, p<0.001) (Figure 24).

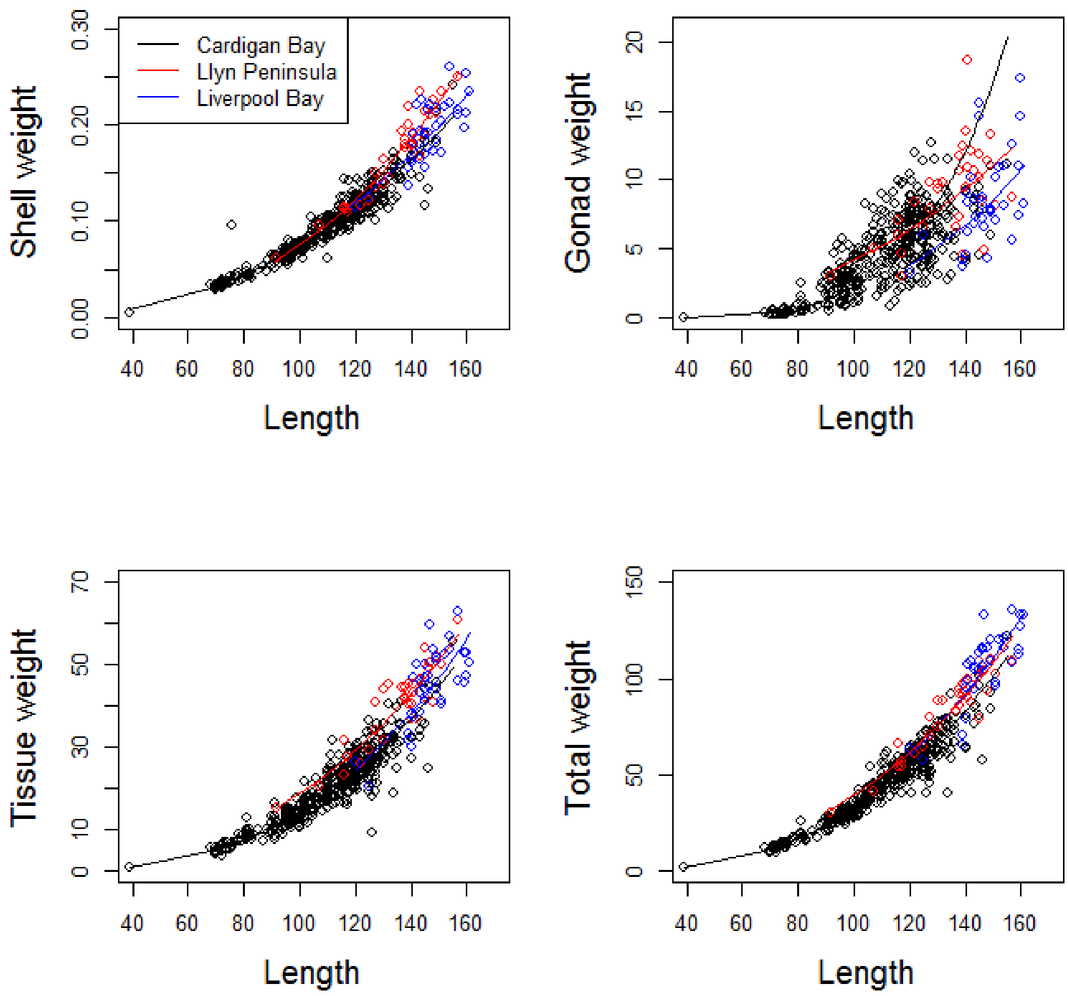


Figure 24. Length-weight (mm-g) relationships for shell, gonad, tissue and overall weight for Cardigan Bay, Liverpool Bay and the Llyn Peninsula.

- Meat weight- total weight relationship

Across all ages, the meat weight:total weight ratio was lowest at the Llyn Peninsula, followed by Cardigan Bay, followed by Liverpool Bay (Figure 25). This reflects the previous results that the overall weight is lowest in Cardigan Bay and meat weight the highest in Liverpool Bay.

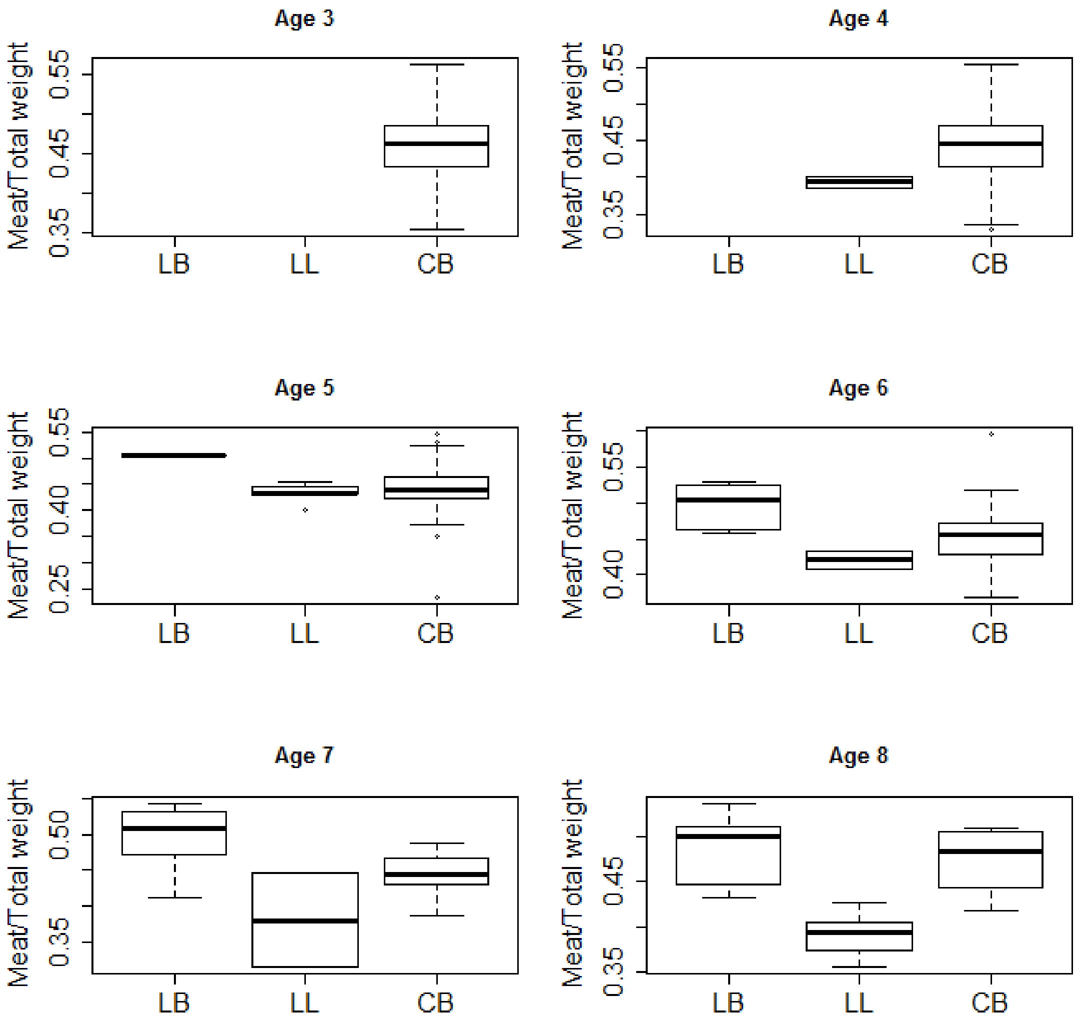


Figure 25. Meat to total weight ratio for Cardigan Bay (CB), Liverpool Bay (LB) and the Llyn Peninsula (LL) in the four main age groups caught by the fishery.

- Gonad status

There was a range of gonad stages between the three grounds. Liverpool Bay and the Llyn Peninsula presented very distinguishable patterns compared to Cardigan Bay (Figure 26). Most of the scallops in Cardigan Bay were at stage 5, filling up, almost ready to spawn with very few scallops in earlier stages. At the Llyn Peninsula and in Liverpool Bay scallop gonads showed two peaks. Half of the scallops in Liverpool Bay were at stages 3-4, half way to filling up after spawning, and half of them were at stages 6-7, ready to spawn and spent, i.e. empty just after spawning. At the Llyn Peninsula, scallop gonads were one stage behind the Liverpool Bay ones. Half of them were at stages 1-2, just starting to fill up after spawning while the other half was at stages 5-6, almost ready to ready to spawn.

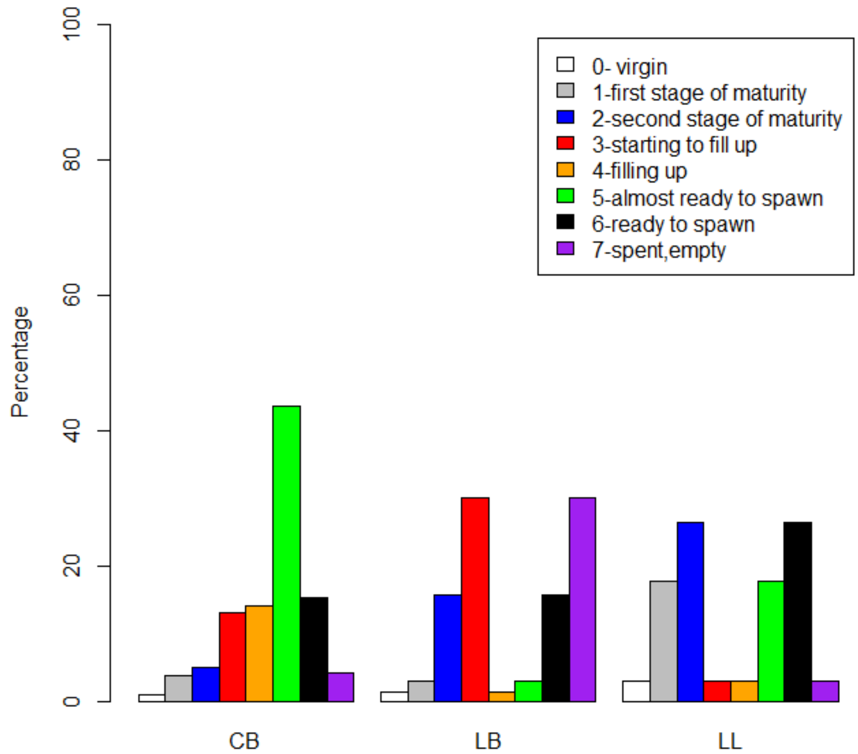


Figure 26. Gonad status in the three fishing grounds, Cardigan Bay (CB), Liverpool Bay (LB) and the Llyn Peninsula (LL).

The pattern in Cardigan Bay was mostly due to data from the closed area. In the open area the gonads were mostly between stages 3 and 5 (Figure 27).

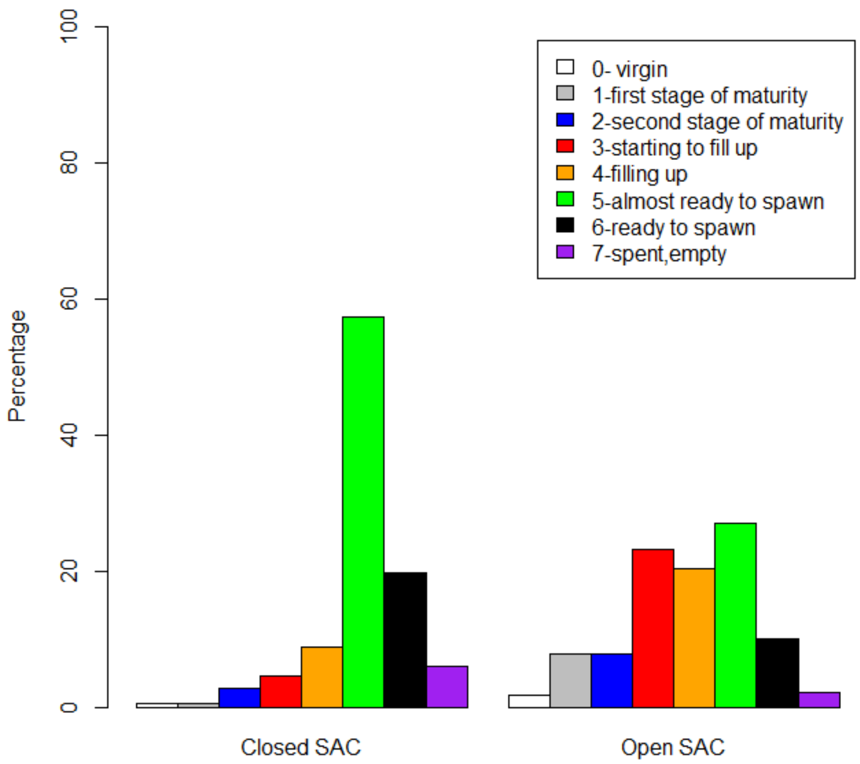


Figure 27. Gonad status in Cardigan Bay (CB), open vs closed area

7- Comparison of 2012 and 2013 stock status surveys

a) Queen scallop *Aequipecten opercularis* densities (number/100m^2)

In queen dredges:

		Under MLS		Above MLS	
		2012	**2013**	**2012**	**2013**
Liverpool Bay		1.7 (±4.2)	0.2 (±0.3)	6.4 (±4.8)	5.6 (±7.3)
Llyn Peninsula		0.06 (±0.1)	0.03 (±0.05)	0.1 (±0.2)	0.3 (±0.5)
Cardigan Bay	Inside closed SAC	0 (±0)	0.03 (±0.08)	0.07 (±0.1)	0.2 (±0.3)
	Inside open SAC	0 (±0)	0.03 (±0.04)	0.6 (±0.8)	0.9 (±1.5)
	Outside SAC	0 (±0)	0.02 (±0.04)	0.02 (±0.04)	0.2 (±0.3)

There is no obvious difference between 2012 and 2013 for queen scallops, except for the lower number of undersize animals caught in 2013 compared to 2012 in Liverpool Bay. Generally, the other averages are comparable and the variability within grounds is equally high, with Liverpool Bay remaining the main ground for the species.

b) King scallop *Pecten maximus* densities (number/100m^2)

In queen dredges:

		Under MLS		Above MLS	
		2012	**2013**	**2012**	**2013**
Liverpool Bay		0.06 (±0.08)	0.2 (±0.3)	0.3 (±0.4)	0.3 (±0.2)
Llyn Peninsula		0.03 (±0.1)	0.03 (±0.03)	0.2 (±0.3)	0.2 (±0.2)
Cardigan Bay	Inside closed SAC	0.9 (±0.8)	0.9 (±0.8)	4.2 (±1.8)	5 (±2.6)
	Inside open SAC	1.2 (±0.6)	3.3 (±3.2)	1.2 (±0.5)	1.4 (±1.1)
	Outside SAC	0.7 (±0.5)	0.7 (±1.1)	0.4 (±0.3)	0.8 (±0.5)

In king dredges:

		Under MLS		Above MLS	
		2012	**2013**	**2012**	**2013**
Liverpool Bay		0.02 (±0.04)	0.07 (±0.1)	0.3 (±0.3)	0.2 (±0.3)
Llyn Peninsula		0 (±0)	0.03 (±0.03)	0.2 (±0.2)	0.2 (±0.2)
Cardigan Bay	Inside closed SAC	0.8 (±0.7)	0.4 (±0.4)	3.9 (±1.5)	4.1 (±2.9)
	Inside open SAC	0.6 (±0.5)	1.6 (±1.5)	0.9 (±0.3)	0.9 (±0.3)
	Outside SAC	0.3 (±0.2)	0.2 (±0.2)	0.5 (±0.3)	0.5 (±0.5)

The estimates of scallop densities, both under and above MLS, are similar between 2012 and 2013. Cardigan Bay remains the main scallop ground. The scallop densities estimated from the dredges show that the densities of scallops caught in the closed area of the Cardigan Bay SAC are about 4 times higher than the densities caught in the open area of the SAC. The number of undersize scallops remains low in the closed area compared to the open area, which seems to have seen a patchy increase in number of undersize scallops in 2013 as opposed to the closed area in which the number of undersize scallop may have decreased in patches.

c) Bycatch analysis (from queen dredges)

		Abundance (number/100m^2)		Biomass (kgs/100m^2)	
		2012	**2013**	**2012**	**2013**
Liverpool Bay		14.4 (±8.5)	8.5 (±5.3)	0.3 (±0.2)	0.5 (±0.3)
Llyn Peninsula		2.3 (±1.6)	3.3 (±3.8)	0.1 (±0.07)	0.2 (±0.1)
Cardigan Bay	Inside closed SAC	1.6 (±0.7)	2.5 (±1.8)	0.1 (±0.06)	0.2 (±0.2)
	Inside open SAC	1.8 (±1.0)	1.8 (±1.2)	0.05 (±0.05)	0.1 (±0.08)
	Outside SAC	0.7 (±0.9)	1.1 (±0.5)	0.09 (±0.04)	0.1 (±0.07)

The abundance and biomass of bycatch was consistent between 2012 and 2013. The highest level of bycatch was found in the Liverpool Bay, followed by the Llyn Peninsula and the three areas of the Cardigan Bay. There may have been an increase in bycatch at the Llyn Peninsula and in the closed area of Cardigan Bay SAC in 2013. Note that *Alcyonium digitatum*, dead man's fingers, were removed from the comparison because they were not always counted and weighed during the 2013 survey.

Species richness could not be compared as the number of tows varied between areas and surveys. In general, species number increases with number of tows up to a certain point, which has not been determined here.

d) Population dynamics

a. Size, age distribution and mortality rates

There has been a shift in the age and size structure of the stock between 2012 and 2013, most visible in the Cardigan Bay area, where it mirrors the distinct management measures of this prolific scallop ground (Figures 28 & 29). In the closed area, in 2012, most of the scallops caught in the queen dredges were above 110mm, as is still the case in 2013 with an increase in length of 5 to 10mm. The age structure reflects this growth in length (Figures 28 & 29). However, the percentage of undersize scallops is relatively low.

In the open area, there has been an increase in the proportion of small scallops, under MLS, which is also reflected in the age structure of the stock (Figures 28 & 29). Outside the SAC, the age and size structure mirrors the open area of the SAC. In Liverpool Bay and at the Llyn Peninsula, the patterns are less clear, due to the lower densities of scallops observed.

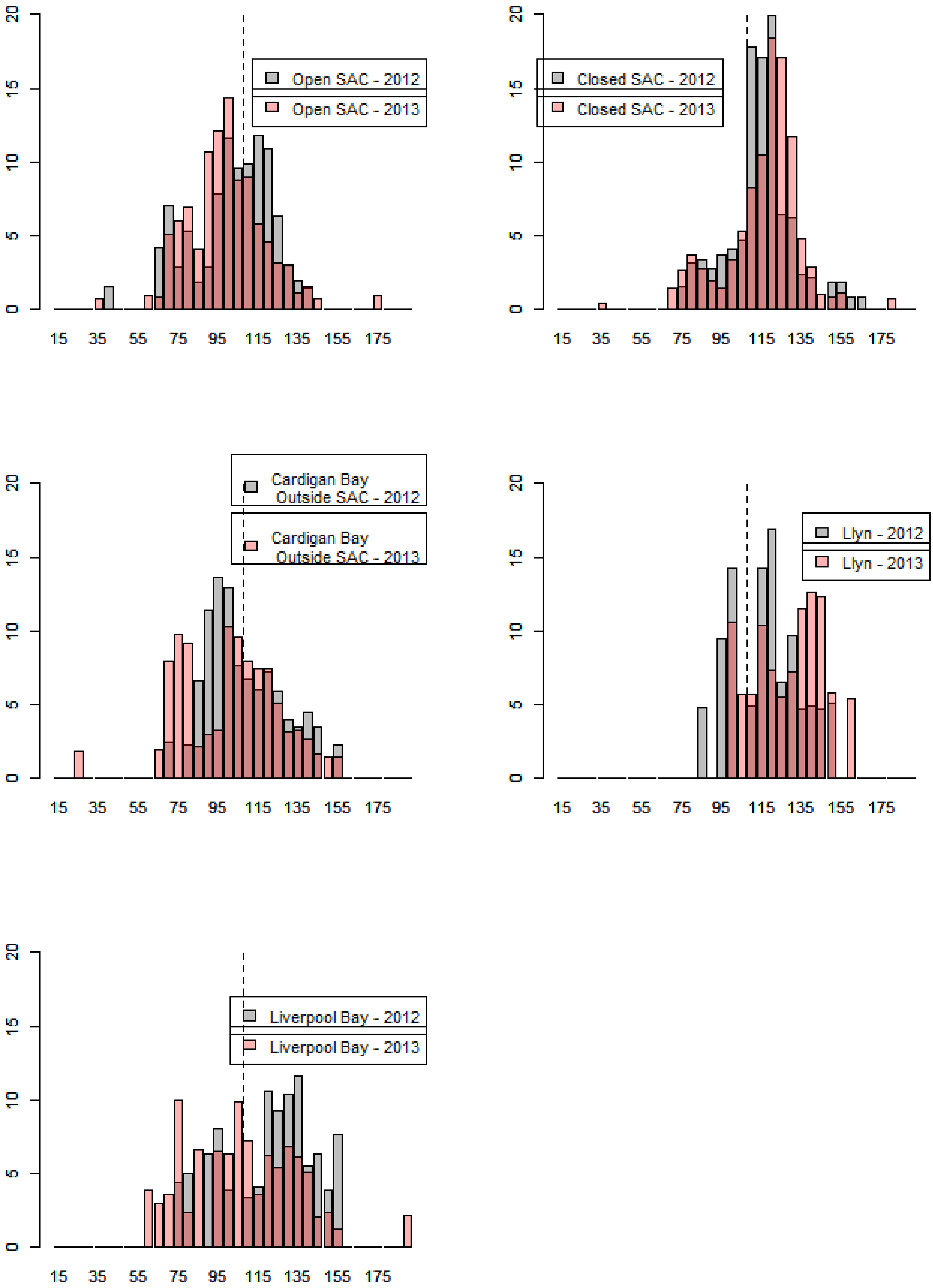


Figure 28. Size distribution on each fishing ground (the vertical line represents the minimum landing size (MLS) 110mm)

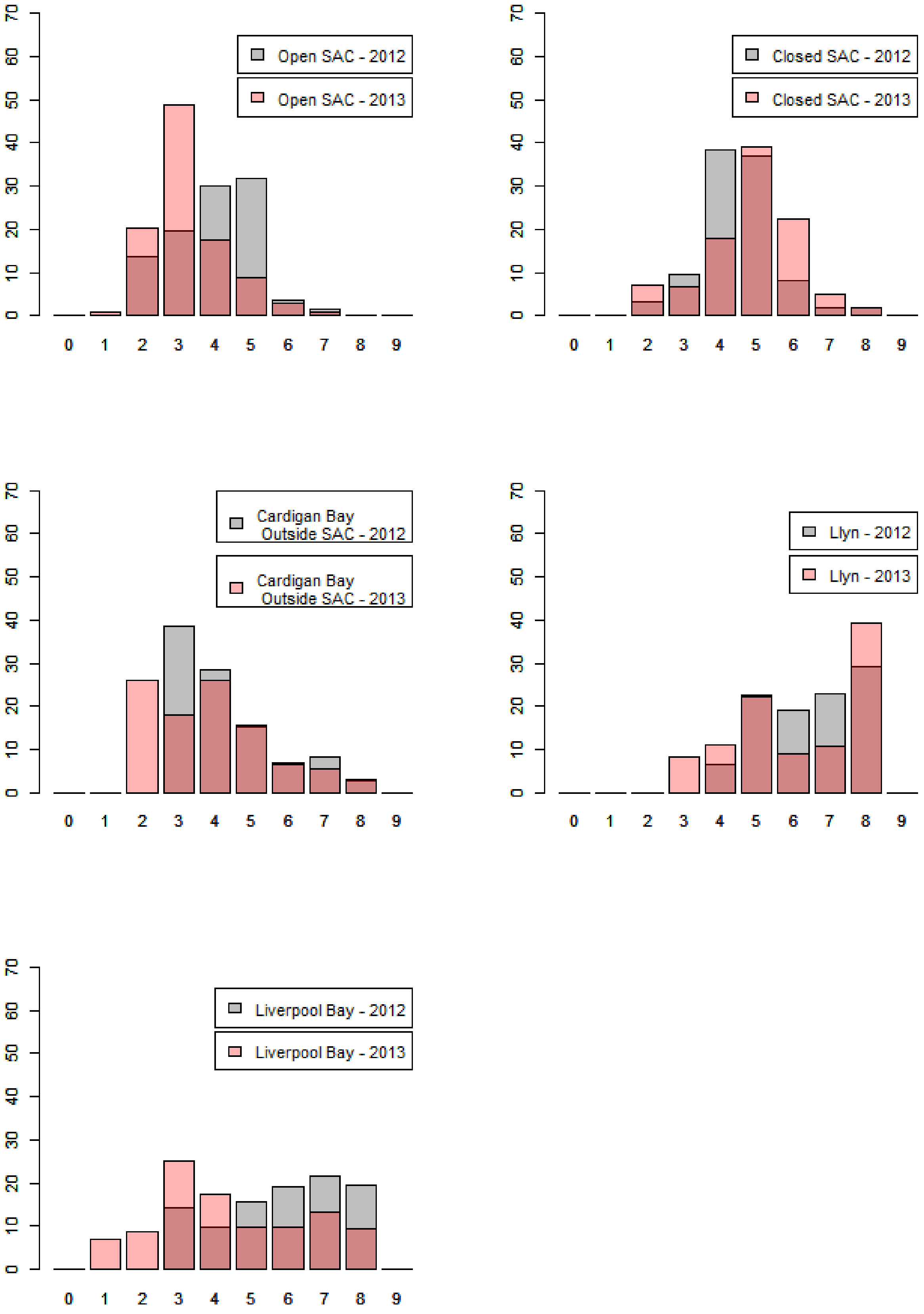


Figure 29. Age distribution on each fishing ground

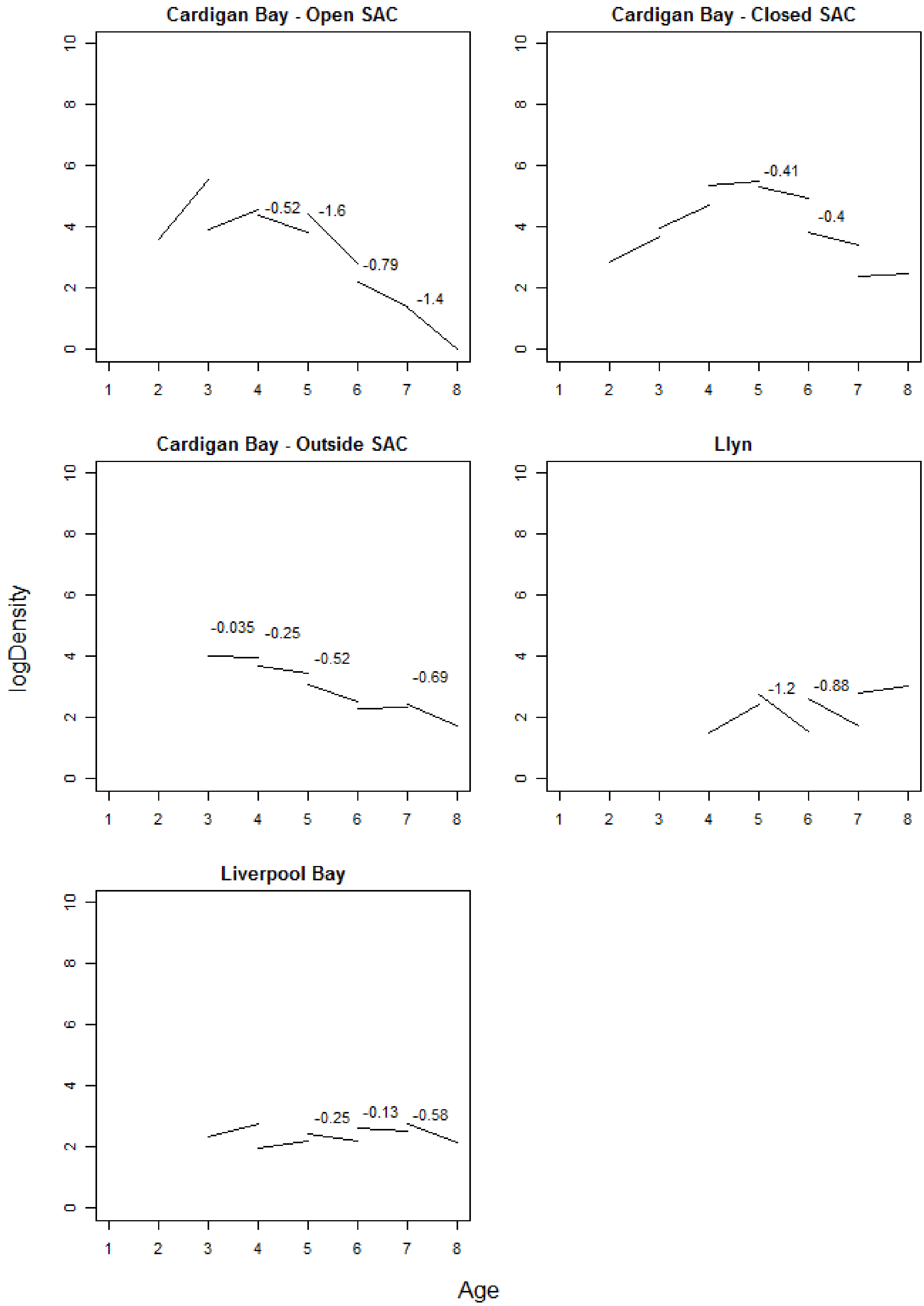


Figure 30. Catch-curve analysis - Mortality at age on each fishing ground, following the cohorts between 2012 and 2013

Since the stock has been sampled for two consecutive years, it is now possible to obtain a first estimate of mortality by following the cohorts (catch-curve analysis, Figure 30). The analysis reveals that 4 year old scallops may not be fully recruited to the fishery yet, hence a low to positive mortality estimate Z. The most reliable estimate of mortality Z is obtained for age group 5. Indeed, the scallops appear fully recruited to the fishery then and the numbers at age 5 and 6 remain high enough to limit the variability in their estimation. Older scallops are scarcer and more difficult to estimate accurately with a limited number of tows.

Z at age 5 is highest in the open area of the SAC, where fishing effort is known to be highest (Z=1.6). It is about 4 times the mortality in the closed area of the SAC, where Z=0.41. In the closed area Z is the natural mortality. From this it is possible to estimate F, the fishing mortality, in the open area of the SAC, which is F=1.19, corresponding to about 3 times the natural mortality. Outside the SAC, Z at age 5 is lower, Z=0.52, reflecting a lower F and possibly a lower M which could be linked to the lower bycatch level, and thus less predation, found there compared to inside the closed area of the SAC. At the Llyn Peninsula, Z was also high, Z=1.2, while it was relatively low in the Liverpool Bay, Z=0.25, where the scallops are not the main target species.

b. Growth rates

Overall, size at age did not vary significantly between 2012 and 2013 in Cardigan Bay and Liverpool Bay (Figure 31). Some variation was observed at the Llyn Peninsula where the scallops appeared larger for the same age in 2013.

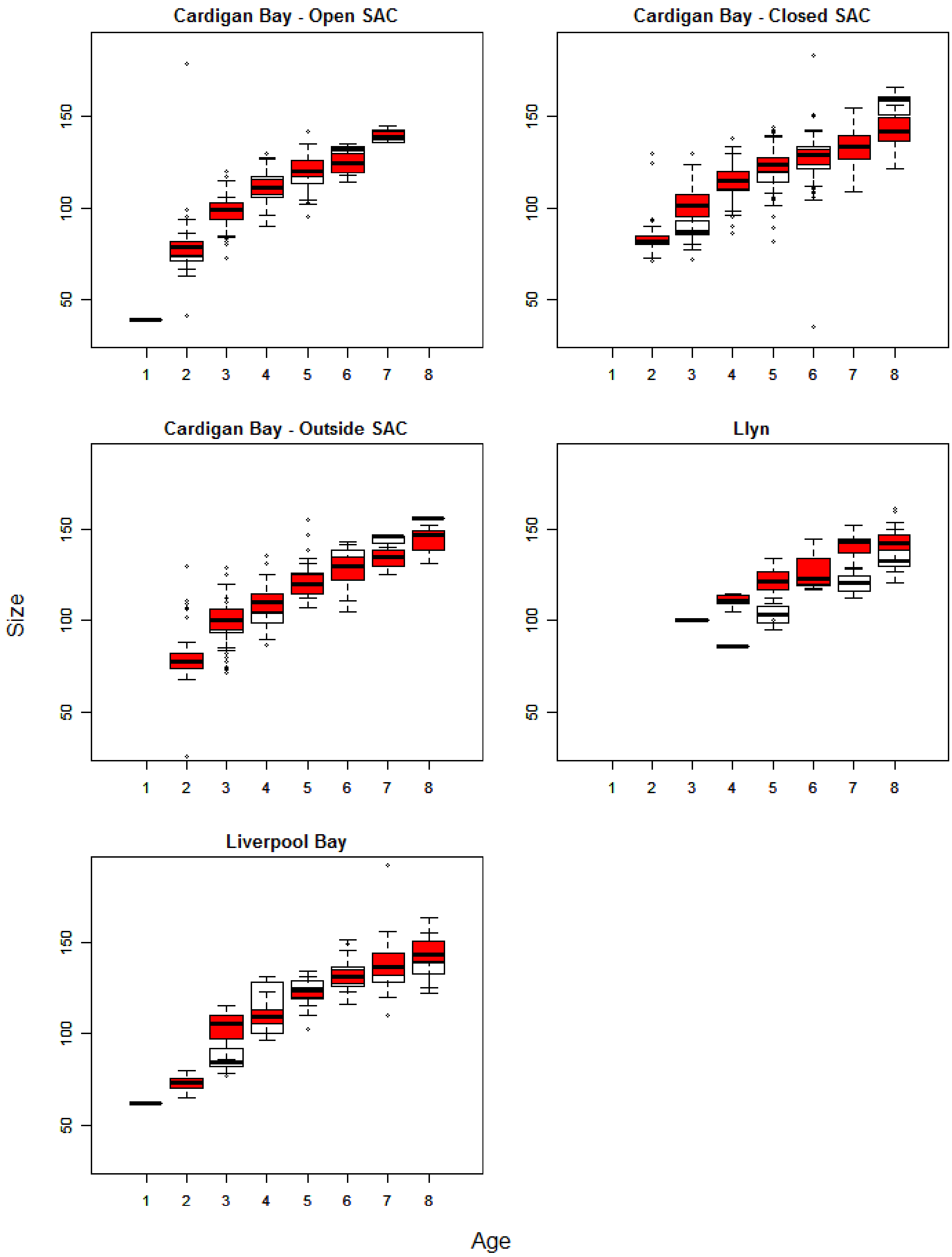


Figure 31. Size at age on each fishing ground. Red is 2013 and white is 2012.

c. Weight and reproductive status

No information on weight was recorded in the open area of the Cardigan Bay SAC or outside the SAC in 2012. Therefore, only the closed area, the Llyn Peninsula and Liverpool Bay were compared. Overall, weight at age did not vary significantly between 2012 and 2013 in the closed area of the Cardigan Bay SAC (Figure 32). Muscle weight was lower in 2013 at the Llyn Peninsula and higher in Liverpool Bay. The variation in gonad weight increased in 2013 but no other clear pattern emerged (Figure

33). The main difference between 2012 and 2013 regarding the gonads was the gonad status (Figures 26 and 27). In June 2012, gonads were all at stages 3 and 4, with no difference between areas whereas in July-August 2013 there was a clear distinction between grounds.

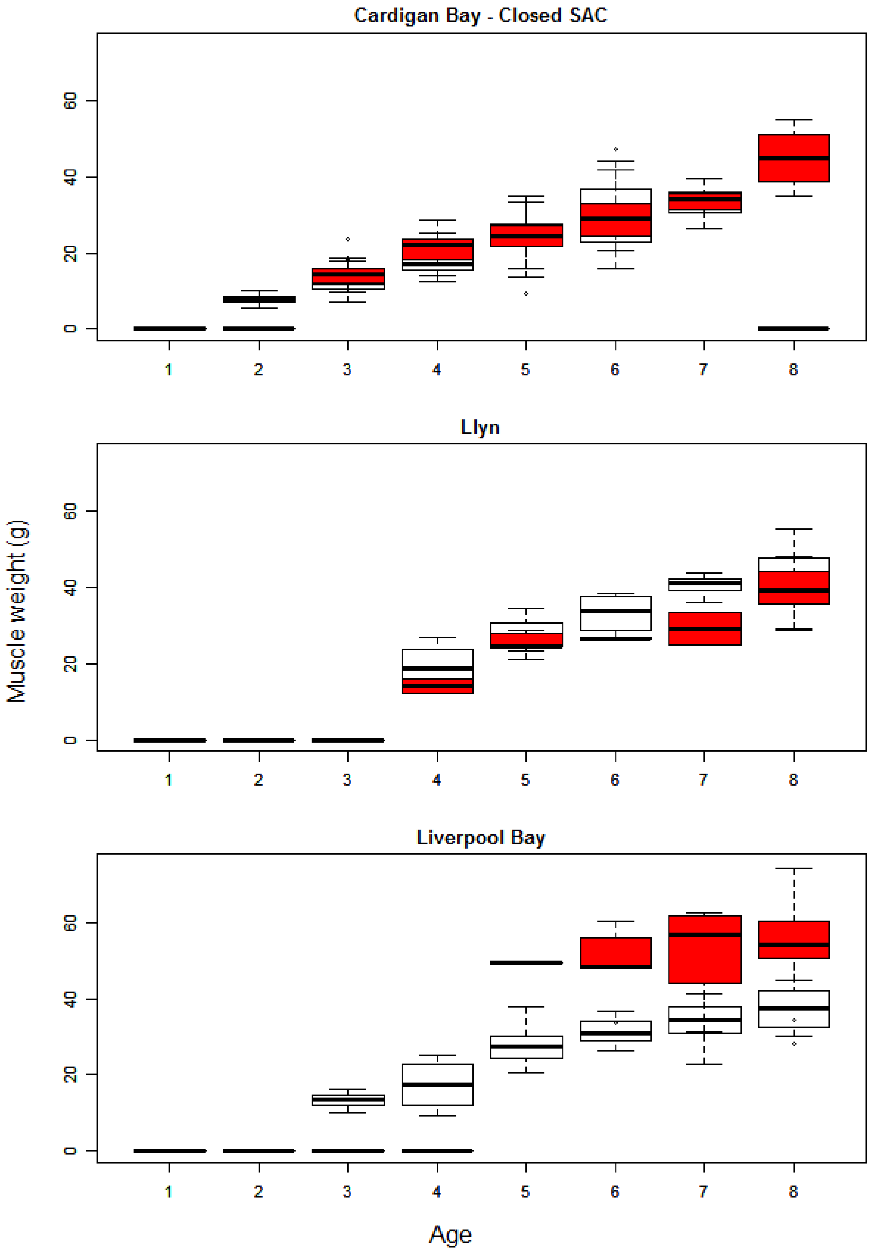


Figure 32. Muscle weight at age on each fishing ground. Red is 2013 and white is 2012

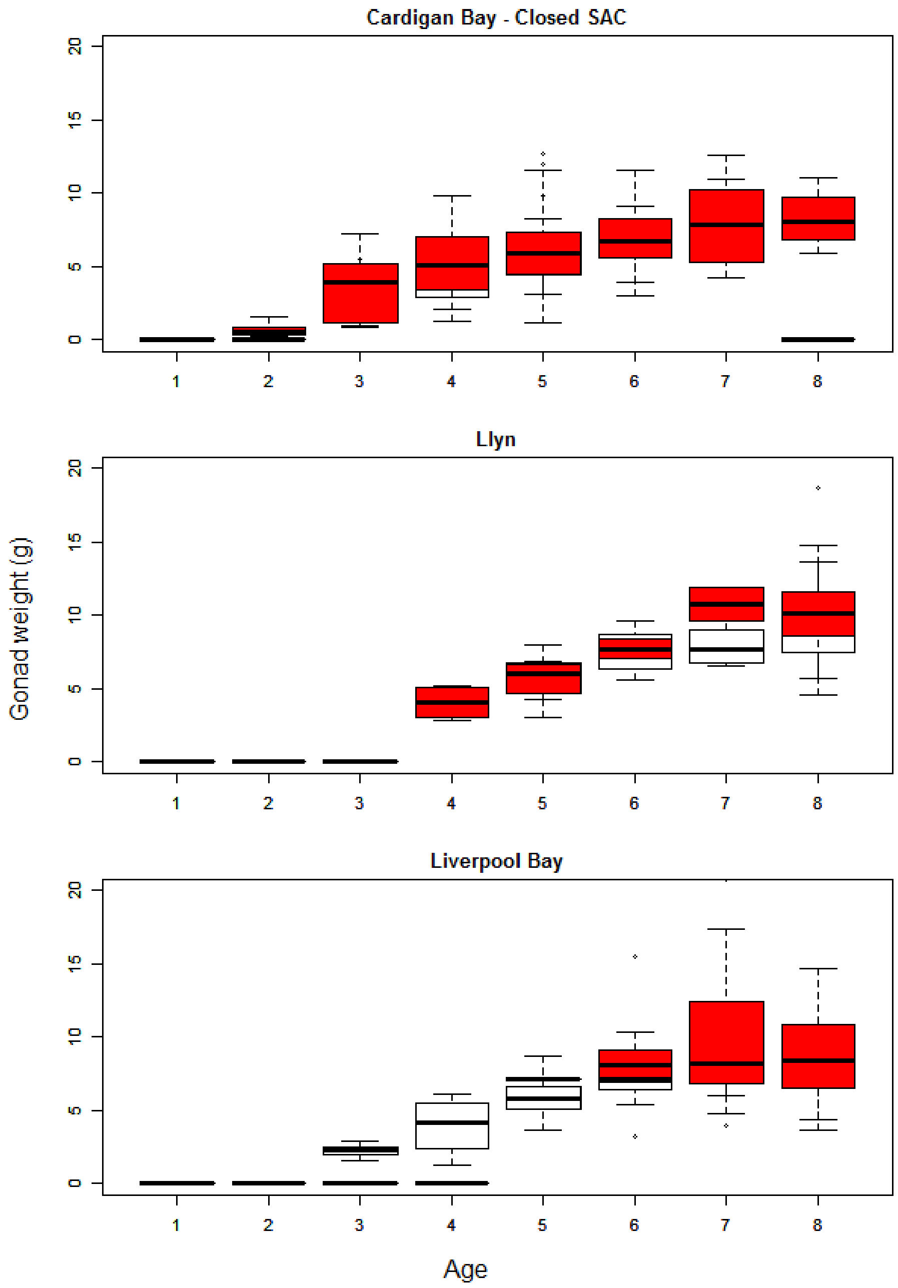


Figure 33. Muscle weight at age on each fishing ground. Red is 2013 and white is 2012.

DISCUSSION

State of Scallop stocks

The results of the scallop survey showed that there were some considerable differences between the three main fishing grounds sampled. The first obvious finding is that the abundance of king scallops *P. maximus* above MLS were much higher in the Cardigan Bay open area of the SAC (1.4 (±1.1) individuals/100m^2 from queen scallop dredges) than at the Llyn Peninsula (0.2 (±0.2) individuals/100m^2 from queen scallop dredges) and in the Liverpool Bay (0.3 (±0.2) individuals/100m^2 from queen scallop dredges). The low abundance of scallops in the Liverpool Bay and at the Llyn Peninsula and its potential explanations (larval supply, mortality causes, habitat availability) have been discussed in length in the 2012 scallop stock status report (Lambert et al. 2012). With respect to Cardigan Bay, the abundance of king scallops over MLS caught in the queen scallop dredges in 2013 was over three times higher within the closed area of the SAC (5 individuals/100m^2) than in the open area (1.4 individuals/100m^2). It is important to note that the mean estimates of abundance will differ depending on the sampling gear used (see results and discussion below).

The only area where queen scallops occurred with a high abundance was in Liverpool Bay. Abundance of queens over the MLS was estimated to be 5.6 (±7.3) individuals/100m^2 (based on catches in queen scallop dredges). In Cardigan Bay, queen scallops were found at very low abundances (between 0.2 and 0.9 ind/100m^2).

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 the representative sampling of very small scallops (age 1-2). However, at age 4, scallops have on average started to reach the size targeted by the dredges.

At the Llyn Peninsula, there was no difference in king scallop densities between the 2012 and 2013 surveys. However, no site was sampled inside 3nm due to the high density of strings of lobster and crab pots in the area, making it difficult to tow a dredge or a video camera. Another method of sampling may have to be considered for this area, such as using a drop down camera. In Liverpool Bay, a higher number of undersize scallops were caught in the dredges in 2013 compared to 2012. The average age has also decreased from 6 to 4 years old, and the average size from 122mm to 107mm.

High abundance of age groups 3 to 5 were sampled in the open area of the Cardigan Bay SAC while older king scallops (7+) were rare. This pattern suggests that older individual have been removed by the fishery. Data from 2012 suggested that there were many undersize scallops in the Cardigan Bay SAC compared to the other grounds, and this remained true in 2013, with an increase in undersize scallop densities in the open area (in patches, as there is a high variability between tows). In the closed area, the densities of undersize scallops do not appear to have changed significantly. In both years around 0.9 scallops/100m^2 were caught in the queen dredges. This number is relatively low compared to the open area so it is a possibility that the low number of small scallops in the closed area (under 110mm and under age 4) is the result of spatial competition with the high density of large scallops (video estimates of over 0.5 scallop per m^2 in some patches).

If the average number of undersize scallops has not changed in the closed area, the size and age structure of the population has, however, changed. Scallops have become larger in the closed area, by about 10mm. The majority of scallops caught in the queen dredges in 2012 was just above 110mm and is now around 120mm. Those scallops are around 5 year old. The number of 4 year old is however lower than last year, suggesting that scallops are getting older but that there has been a poor recruitment following this peak of high density. In the open area, the opposite pattern is observed. The peak of scallop densities that was above 110mm in 2012 is now around 100, 10mm less and under MLS. The scallops are on average one or two years younger compared to last year. This could reflect the poor recruitment of the cohort of age 4, which is the age-group corresponding to an average size of 110mm. Scallop of the age 5+ groups are likely to have been fished out during the 2012-2013 fishing season. It is possible that a relatively low abundance of scallops will be available to the fishery in November 2013 since the majority are still 10mm or more below the MLS at the beginning of August, and the number of oversize scallops caught in the dredges is on average $0.9/100m^2$ (same as in 2012). This is a very low density and might be an issue in terms of long term economic viability of the fishery, although this remains to be investigated. On the other hand, the number of oversize scallops could be greater in 2014 due to the relatively high number of undersize scallops caught in the open area. However, we do not know yet what proportion of undersize scallops is caught in the queen (or king) dredges, which makes it difficult to make any prediction at this early stage. Also, the patchy nature of the scallops' distribution, as reflected in the high standard deviation around the estimates of densities, adds to the complexity of predicting the recruitment to the fishery. Some additional survey work in 2014 should help to improve our understanding of the population dynamics of the stock and the effects it has on the fishery.

In the Cardigan Bay SAC, the dynamics of the population should be considered alongside the management in place as it appears to have a direct visible impact on the age and size structure of the stock. Indeed, it is clear that the part of the stock which is protected is composed of older and larger scallops in 2013 compared to 2012 while the part of the stock which is not protected is composed of smaller and younger scallops. Some further investigation is required to understand the consequences of such spatial management, especially in the context of the sustainability of the fishery. There is still a list of questions to answer, such as: Is there enough recruitment in the closed area to sustain the scallop population across the whole SAC? Are older scallops better or worse spawners? If the reproductive output of old scallops is poor, would rotation be a viable option for the fishery and the stock? If the reproductive output of old scallops is better than young ones, what is the explanation for the small number of scallops around 110mm in the open area of the SAC?

King scallop growth, gonad and meat status and mortality

In 2013, no difference in overall growth was observed between the 3 grounds but there was a slight difference in the muscle meat:size ratio. King scallops in Liverpool Bay had larger meat weights. Across all ages, the meat weight:total weight ratio was lowest at the Llyn Peninsula, followed by Cardigan Bay, followed by Liverpool Bay.

The gonad status was very different between the 3 grounds in 2013, while no difference had been observed in June 2012. In all areas, in June 2012, over 90% of the gonads were recovered from the previous spawning event but had not yet filled ready for the next spawning event. They were at stages of maturity called stages 3 and 4. In July-August 2013, two offset peaks were observed at the Llyn Peninsula and in Liverpool Bay. The first peak was around the “filling-up” phase (stages 2-4) and the second peak was around the “filled up- almost ready to spawn-spent” phase (stages 5 to 7). In the Cardigan Bay, the scallops were mostly around the “almost ready to spawn” phase (stage 5). This observation has got several implications. First of all, for the fishery, the yield will depend on the status of the gonads (the roe). It would therefore be interesting to understand how quick is the transition between gonad stages and what causes those differences between grounds. Another implication is the connectivity between or within sub-populations. Depending on when the scallops spawn the larvae might be transported in different directions. Since it is hardly feasible to track larvae in the water column, understanding which factors affect the gonad development and trigger a spawning event would allow us to use modelling techniques to try and predict where the larvae will settle. The implications for management are obvious as managing a self-recruiting population or a source or sink population will be very different.

Following cohorts between 2012 and 2013 allowed us for the first time to estimate the mortality rate of scallops in Welsh waters. Since scallops do not appear to be fully recruited to the fishery before age 5 and since they are getting quite sparse on fished grounds after age 7, we only compared estimates for the age group 5 to 6. The mortality rate Z_{5-6} was 4 times higher in the closed area compared to the open area of the SAC. In the open area, the mortality estimated, $Z_{5-6}=0.4$, was the natural mortality, $M_{5-6,}$ since the area has not been fished since 2009. If M_{5-6} is the same in the closed and open areas then the fishing mortality F_{5-6} is equal to 1.2. This corresponds to a very high exploitation rate, E_{5-6}, meaning that the fishing mortality F compared to the total mortality Z is very high, $E_{5-6}=F_{5-6}/ Z_{5-6}=0.75$, meaning that 75% of mortality was due to fishing. However, this is only considering the open area as a separate unit. Since $F_{5-6}=0$ in the rest of the SAC, if the whole SAC (open and closed) is considered as a stock unit and if we consider that 75% of the stock is unfished, then $E_{5-6=}$ (1.2*25% + 0*75%)/1.6=0.2. Further investigation is required to assess whether an exploitation rate of 0.2, i.e. 20% of mortality due to fishing, is sustainable. However, this does not take account of the sedentary nature of the stock. Fishery indicators, which are widely used for fish stocks, have to be interpreted with caution in the context of spatial management of a scallop stock.

Z_{5-6} was lower outside the SAC than in the open area of the SAC ($Z_{5-6}=0.52$), reflecting a lower fishing mortality and possibly a lower natural mortality, which could be linked to the lower bycatch level found there compare to inside the closed area of the SAC. At the Llyn Peninsula, Z_{5-6} was also high, $Z_{5-6}=1.2$, while it was relatively low in Liverpool Bay, $Z_{5-6}=0.25$, suggesting a low natural mortality compared to Cardigan Bay and the Llyn Peninsula as well as a low fishing mortality as king scallops are not the main target species there.

By-catch levels and environmental context

As in 2012, the amount of bycatch retained in the dredges in Liverpool Bay was higher and more diverse than at the Llyn Peninsula, which was also higher and more diverse than in Cardigan Bay. The biomass caught remained low at all fishing grounds with averages of less than 0.5kg per 100m^2. Again as in 2012, Liverpool Bay showed a very diverse and rich fauna with many fragile species such as the purple sea urchin *Spatangus purpureus*, which seems to indicate that this area has not been highly impacted by fishing in recent years.

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 catches in Cardigan Bay were mostly ‘clean’, consisting mainly of the target species *P. maximus*. There was also no significant difference between the bycatch in the closed and open area, which seems to indicate that despite over 4 years of closure there has been little change with respect to this component of the benthic fauna. This finding concurs with some of our latest work where we similarly could not detect any differences between the open and closed areas (Sciberras et al. 2013, Albrecht 2013). This suggests that the impact of the fishery on the ecosystem in the closed area would be limited regarding the living biota currently 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.

Assessment of sampling equipment

The relationships between still, video and dredge estimates of queen and king scallop densities were good and better in 2013 than in 2012 even though some variance remained. This variance is linked to habitat types as it is more difficult to see scallops when they are buried in softer sediments and also due to the patchiness of scallop beds as the dredge and video tows were not exactly overlapping.

The still images seemed to give very high estimates of queen scallop densities compared to what was caught in the dredges (over 25 times higher). This is, however, probably an artefact as no still images were taken on the main queenie ground (as the camera broke during the survey). The relationship is therefore only based on very low queen scallop densities. In 2012 we calculated a relationship of the order of one to ten, i.e. one queen scallop in the queen dredge corresponded to ten on the seabed. GoPro videos were, however, recorded in 2013 and showed a relationship of one to ten with the queen dredges. For the king scallops, the estimates obtained from the still images were 2.85 times higher than the estimates obtained from the GoPro videos and 4.85 times higher than the estimated from the queen dredges. This difference between the stills and video estimates remains unexplained. It is probably due to the difference in area covered with each method (ca. 13m^2 for the stills compared to ca. 280m^2 for the GoPro). The GoPro estimates are therefore likely to be more realistic but, on the other hand, the quality of the still images is much higher. Further work has to be conducted to find out with certainty which method captures the best estimate of the true scallop density.

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