Cyfoeth Naturiol Cymru
Natural Resources Wales

Skomer MCZ
Scallop Survey 2016

M. Burton, K. Lock, P. Newman & J. Jones.

NRW Evidence Report No 196

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- Securing our data and information;
- Having a well-resourced proactive programme of evidence work;
- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us; and
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Yn 2016 cynhaliwyd arolwg o boblogaethau cregyn bylchog mwyaf (*Pecten maximus)* yn Ardal Gadwraeth Forol (AGF) Sgomer am y 5ed tro ers 2000. Mae casglu cregyn bylchog "trwy unrhyw ddull" yn anghyfreithlon o fewn AGF Sgomer ers 1990.

Archwiliwyd 60 trawstoriad arolygu o fewn AGF Sgomer gan 35 o wirfoddolwyr, gan gasglu 2534 *P. Maximus*. Mesurwyd hwy, cyn eu dychwelyd yn fyw i'r AGF.

- O fewn AGF Sgomer amcangyfrifwyd fod y dwysedd cymedrig *P. maximus* yn 35 / 100m^2. Mae'r ffigwr hwn saith gwaith mwy na'r ffigwr a gyfrifwyd yn 2000. Yr uchafswm dwysedd *P. Maximus* yn 2016 oedd 62/100m^2.
- Gwelwyd tystiolaeth gadarn fod niferoedd da o *P. maximus* ifanc wedi ymuno â'r boblogaeth, yn enwedig ers 2012.
- Roedd y strwythur oedran yn amrywio'n sylweddol rhwng safleoedd gwahanol, ond gwelwyd fod y dosbarth oed cymedrig yn dod yn ieuengach gydag amser.
- Roedd cynnydd ym mhresenoldeb ewin mochyn (*Crepidula fornicata*) ymledol, gan goloneiddio 2.6% o *P. maximus.*

Mae'r canlyniadau'n awgrymu bod yr is-ddeddfau sy'n gwarchod y *P. maximus* o fewn AGF Sgomer wedi bod yn effeithiol, gan alluogi i'r boblogaeth gael eu hadfer o'r dwyseddau isel iawn a gafwyd cyn eu penodiad.

Byddai'n ddefnyddiol cymharu'r canlyniadau gydag ardaloedd eraill y tu allan i'r AGF, yn lleol yn ogystal ag o weddill y DU.

Prin iawn yw'r wybodaeth ynglŷn â tharddiad y *P. maximus* ifanc sy'n ymuno â'r boblogaeth, ac ymhle mae'r larfae yn sefydlu yn y pen draw. Ychydig iawn o gregyn rhwng 1-2 blwydd a gafwyd yn ystod yr arolygon hyn. Efallai bod angen dull gwahanol a safleoedd gwahanol er mwyn canfod y recriwtiaid ieuengaf yma.

2. Executive Summary

In 2016 a survey of the population of the King scallop (*Pecten maximus*) at Skomer Marine Conservation Zone (MCZ) was repeated for the 5th time since 2000. The removal of King scallops "by any means" has been prohibited within the Skomer MCZ since 1990.

A team of 35 volunteers completed 60 scallop survey transects within the Skomer MCZ. They collected 2534 *P. maximus* which were all measured and released, alive, back into the MCZ.

- The average density of *P. maximus* within the Skomer MCZ was estimated to be 35 / 100m^2. This is a 7 fold increase since 2000. Densities pre-designation (1984) are estimated at around 1-1.2/ 100m2. The maximum density of *P. maximus* in 2016 was 62 / 100m^2.
- There was strong evidence of good recruitment of young *P. maximus* into the population especially since 2012.
- Age structure was variable between sites but the modal age class appears to be getting younger with time.
- There was an increase in the occurrence of the invasive slipper limpet (*Crepidula fornicata*) with 2.6% of *P. maximus* being colonised.

These results show that the byelaws protecting *P. maximus* within the Skomer MCZ have been effective in allowing the population to recover from very low densities found before designation.

It would be useful to compare the results to other areas outside the MCZ both locally and in the rest of UK.

Little is known about where recruits come from and where larvae end up settling. Hardly any 1 to 2 year *P. maximus* are found in any of the surveys. A different method and search area may be required to find these youngest recruits.

3. Skomer MCZ Scallop (*Pecten maximus*) Survey 2016

3.1. Introduction

Pecten maximus (Linnaeus, 1758), the King scallop, is found in the Skomer Marine Conservation Zone (MCZ). The *P. maximus* population in Skomer MCZ has been protected since July 1990 upon designation of the, then, Marine Nature Reserve (MNR).

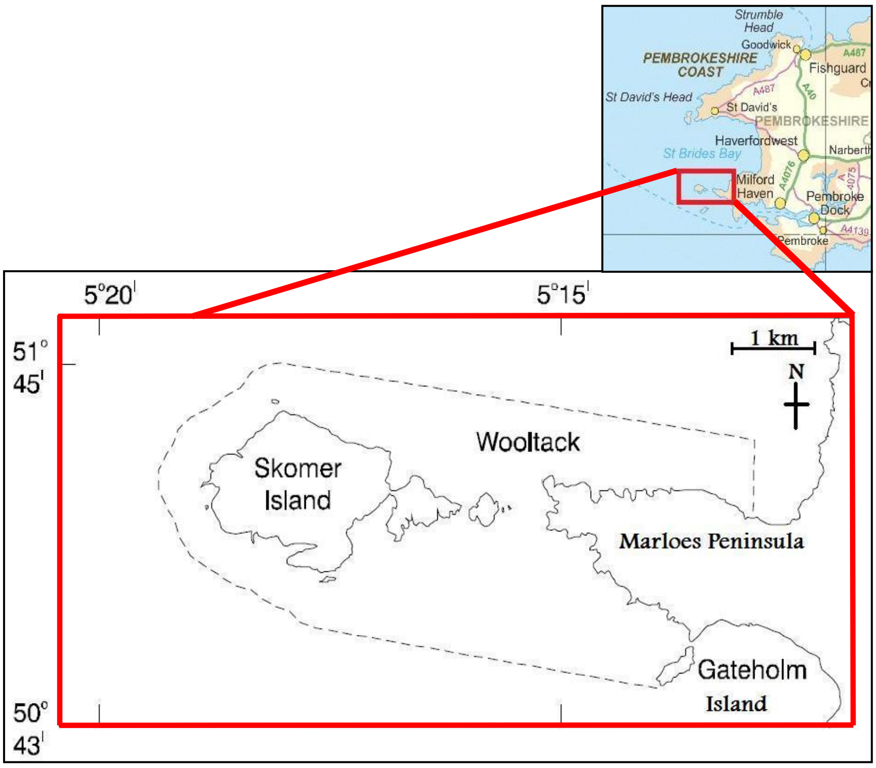
South Wales Sea Fisheries Committee (SWSFC) byelaws numbers 27 and 28 (Appendix 1) prohibited the use of dredges or beam trawls as well as the removal of *P. maximus* and *Chlamys opercularis* (now *Aequipecten opercularis*) from the Skomer MCZ by any means.

On 1 April 2010, the implementation of the Marine and Coastal Access Act 2009 in Wales had the effect that the two Sea Fisheries Committees in Wales were abolished and their duties and functions taken on by Welsh Government.

The Skomer MCZ byelaws originally created by the South Wales Sea Fisheries Committee were among those adopted by the Welsh Government and continue to be in force.

Seabed protection outside the MCZ was further enhanced by the introduction of the Scallop Fishing (Wales) Order 2010, which has prohibited dredging for King scallop within 1 nautical mile of the Welsh coast.

Figure 1. Map indicating (dashed line) the boundary limits of the Skomer Marine Conservation Zone. Map adapted from Rogers, 1997. Scale map from Ordnance Survey.



Prior to designation as a Marine Nature Reserve in 1990 the sea bed around Skomer was dredged commercially for scallops and scallops were collected by divers.

Bullimore (1985) reviewed the *P. maximus* survey data that were available from the MCZ between 1979 and1984 and assessed the status of the population at that time. These surveys estimated extent of habitat suitable for *P. maximus* in Skomer MCZ, *P. maximus* density, age frequency distribution and first year growth bands and annual growth rates for individuals. These results suggested very low densities of scallops of 1 to 1.2 scallops / 100m^2 (Lock, 2001 & Bullimore 1985).

Repeat surveys have been carried out in an attempt to monitor recovery of the population since the creation of the SWSFC bylaw in 1990. The survey of *P. maximus* in 2000 was carried out by a team of volunteer divers guided by MCZ staff and established the field methods at three survey sites. In 2004 the survey was repeated at the same three sites and established a further four sites (Luddington *et al* 2004). These field methods were used at the seven sites in the surveys of 2008, 2012 and again in 2016.

Survey results in 2000 showed an increase in *P. maximus* density compared to the 1984 survey data. The 2004, 2008 and 2012 surveys showed a continuation of this trend, with an overall increase in *P. maximus* density. Two spat collectors were deployed in 2005 and 2006, but only a single *P. maximus* spat was found. Further collectors were deployed in 2012 (Apr- Sep) but no *P. maximus* spat were found. In 2012 a survey area was set up outside the boundary of the MCZ in an area known to have been dredged in 2008.

Crepidula fornicata, the slipper limpet is a non-native species first introduced to the UK in the late 1800s from America. It lives in groups, forming curved chains of up to 15 animals attached to stones and shells mainly in mixed sediment habitats. Its UK northern limit of distribution is in Pembrokeshire and it is abundant in the Milford Haven Waterway where its invasive nature competes with and displaces other filter-feeders like oysters and mussels (Bohn 2012). It was first found in the Skomer MCZ during the 2008 survey when 2 individuals were found attached to a *P. maximus* shell. It has also been found attached to scallop shells in all subsequent surveys.

3.1.1. Survey objectives

This survey aimed to establish the current status of the *P. maximus* population in Skomer MCZ and compare the results to previous surveys. It also aimed to repeat the study area outside of the Skomer MCZ boundary where scallop dredging occurred in 2008.

Survey objectives:

1. To determine the density of *P. maximus* at selected sites;

2. To determine *P. maximus* population dynamics: age distribution and size distribution and growth rates;

3. To compare results with previous surveys;

4. To record the invasive species, *Crepidula fornicata*, the Slipper limpet;

5. To resurvey the study site in St Brides Bay (outside of the Skomer MCZ boundary).

3.2. Method

3.2.1. Site selection

Since 2004 seven fixed sites have been established following reconnaissance dives to assess their suitability as *P. maximus* survey sites. Each site position has a recorded GPS position and was marked with a buoyed sinker for the duration of the survey.
In 2012 a new site was established in St Brides Bay to act as a study site outside of the MCZ. This site was relocated in 2016.

Pecten maximus is deemed a "sensitive species" exempt from general data release so the exact locations of these sites cannot be published in this report.

3.2.2. Diving field method

In 2000 a method suitable for volunteer divers was established and this has been repeated in the 2004, 2008, 2012 and 2016 surveys.

Survey transects are conducted from each site marker, following compass bearing directions: N, NE, E, SE, S, SW, W and NW where topographic features allow. Survey transects are completed by divers working in buddy pairs. Each pair is equipped with a surface marker buoy (SMB), a compass, net bags, a torch and a 50m tape.

The divers attach the tape measure to the fixed marker on the seabed and swim together laying out the tape for either 50m or 30m on an agreed compass bearing. The scallops are then collected with one diver positioned on either side of the tape. The divers search for all *P. maximus* found in a 2m wide corridor on either side of the tape, giving a total width of 4m, collecting the animals into net bags. This is repeated by swimming back along the tape collecting any *P. maximus* missed during the first pass. The divers return to the boat with the collected *P. maximus* where they are kept alive in labelled buckets of clean aerated seawater.

At some sites it is not appropriate to complete full 50m transects due to changes in benthic substrate and in these cases transects are omitted or reduced. At sites where high densities are found, transects are reduced to 30m in length. On completion of every dive the direction, length and width of each transect is recorded to document any variation in the survey area.

The 2016 survey was conducted in good visibility and 50m X 4m wide transects were possible at most sites.

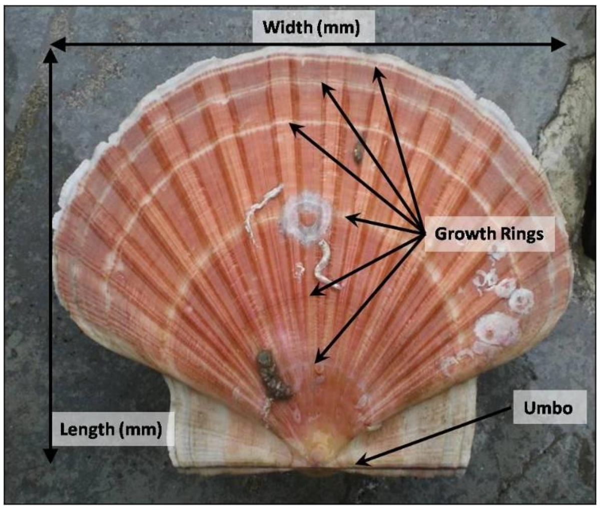
3.2.3. Field recording on the surface

- On the boats part of the flat side of each *P. maximus* shell is cleaned using a scrubbing brush until the series of growth rings are clearly visible.
- Length and width measurements are recorded. Growth rings are measured from the umbo (hinge line) to each annual growth check ring on the flat valve, as shown in figure 2.
- Each *P. maximus* is marked with a filed notch 2-3mm into the edge of the hinge to ensure that no scallop is measured twice during the survey (after the

four-year survey interval notches from previous surveys are far less obvious and cannot easily be mistaken for “current year” notches).

- Once all the *P. maximus* from each transect have been measured, recorded and marked they are returned alive to the sea in the area immediately surrounding the site marker buoy from which they have been removed.
- During subsequent transects any *P. maximus* collected bearing a notch is omitted from further recordings.

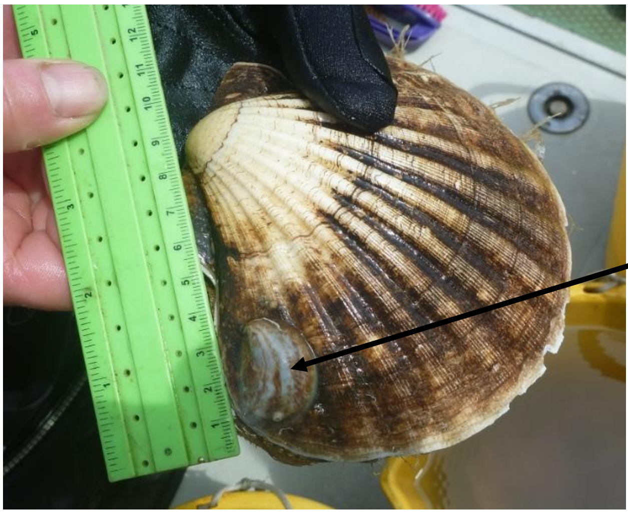
Figure 2. Length and width dimensions measured and the position of the annual growth rings relative to the umbo of the shell.



3.2.4. Recording *Crepidula fornicata*

All *P. maximus* that are brought to the surface are inspected carefully for the presence of *C. fornicata*. Care is taken to remove encrusting barnacles so that the numbers of *C. fornicata* can be counted. Any *C. fornicata* that are found are destroyed by desiccation followed by disposal to domestic composting bin and not returned to the sea.

Figure 3 Recording *Crepidula fornicata*



Crepidula fornicata attached to underside of *P. Maximus* shell

3.2.5. St Brides Bay study site

In 2012 reconnoitre dives were completed at several sites in St Brides Bay to assess the suitability as a *P. maximus* survey site. The depth of the sites was a dictating factor as areas greater than 20-25m greatly reduced dive survey time. A site was established and its position was recorded using GPS. This site was relocated in 2016 and surveyed by the MCZ staff. The initial relocated site was not the same habitat as recorded in 2012, and scallop densities were low. A second site was found 200m away with a more suitable habitat and both sites were surveyed in 2016.

3.3. Results

In 2016 60 transects were completed from 7 sites within the Skomer MCZ and a further 8 transects were completed at 2 sites in St Brides Bay close to the 2012 position.

Skomer MCZ (Table 1):
Total number of scallops counted - **2534**
Total area surveyed - **8620 m^2**
Number of scallops with *Crepidula fornicata* - **58**

St Brides bay site:
Total number of scallops counted - **86**
Total area surveyed - **1280 m^2**
Number of scallops with *Crepidula fornicata* - **1**

Table 1. Survey effort at Skomer MCZ.

Year	*P.maximus* Total	Survey Area M^2	MCZ Transects completed	Notes
1984	36	N/A - Timed searches	10	Not a comparable method. Density estimate of 0.01 Scallops / m^2
2000	155	3400	17	Only 3 sites surveyed
2004	1292	11120	63	7 sites surveyed including the 3 from 2000
2008	1661	9780	61	As 2004
2012	913	3480	49	As 2008 but with poor visibility so transect area was reduced. St Brides survey site added
2016	2534	8620	60	As previous surveys. Good visibility. St Brides survey repeated

3.3.1. Density of Scallops

Comparable data exist for scallop density in the MCZ from 2000 onwards but an estimate of density for 1984 can also be made (see Lock 2000).

In 2000 only 3 sites were completed, 7 sites were completed in the following surveys.

For the production of this report data from previous surveys has been reanalysed to ensure consistency in how the densities are calculated:

All notched *P. maximus* have been removed from the density counts.
P. maximus with erroneous measurement data have been included in the density counts but not in the size/ age class analysis.
Extra transects on which *P. maximus* were counted but no biometric data was measured have been included in the density counts.
Zero transects (no *P. maximus* found) have been included in the density count.

There are different methods of calculating the overall average for the whole of the Skomer MCZ area (Table 2):

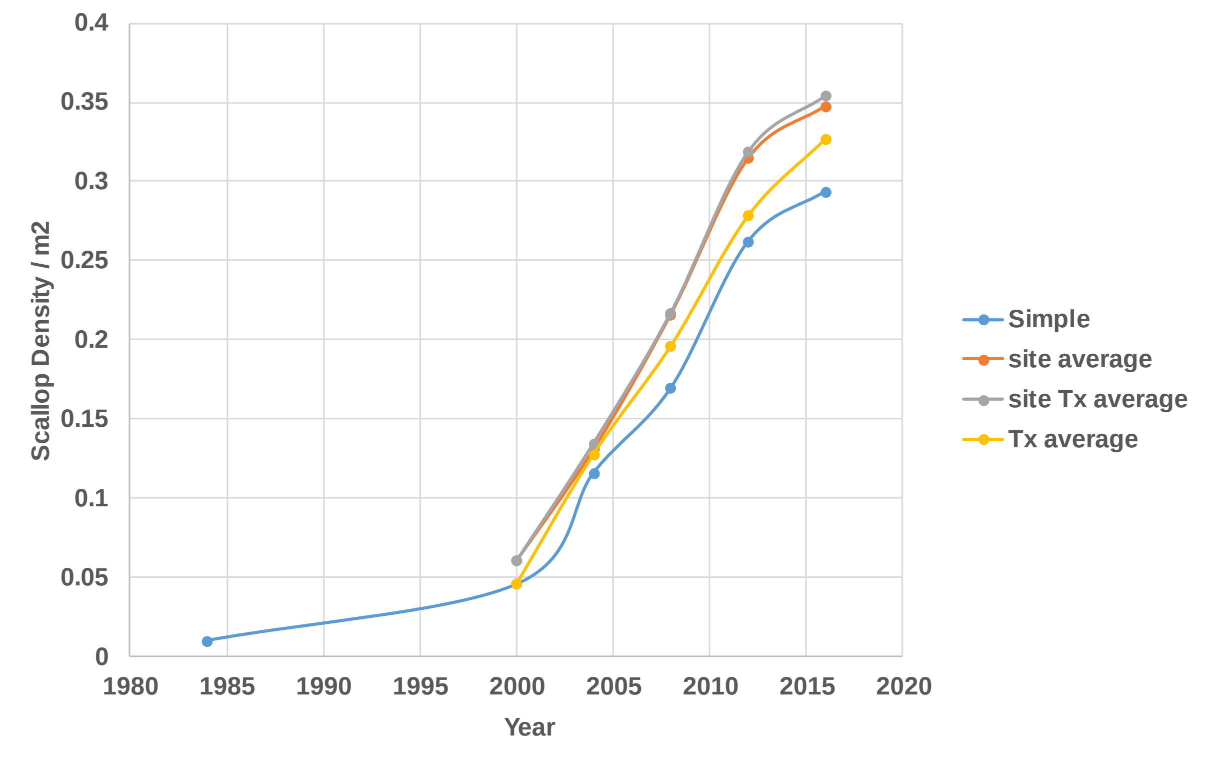
1. Simple average = Total number of *P. maximus* / total area surveyed.
2. Simple site density average = total number of *P. maximus* at each site / total area surveyed at each site. Then average these to get an annual average.
3. Site transect density average = calculate a density for each transect at each site then average these densities. Then average the 7 site densities to get an annual average
4. Transect average for whole MCZ = calculate densities for all transects completed that year and then average these.

Table 2 Density of *P. maximus* / m^2 for the whole MCZ 1984 – 2016

Year	Simple	Simple Site density average	Transect Site density average	All Transect average
1984	0.01	*na*	*na*	*na*
2000	0.05	0.06	0.06	0.05
2004	0.12	0.13	0.13	0.13
2008	0.17	0.22	0.22	0.20
2012	0.26	0.31	0.32	0.28
2016	0.29	0.35	0.35	0.33

If the sampling effort (area surveyed) was identical for all transects and all sites in each year then the different annual averages would agree but because sampling effort has varied there is a slight discrepancy depending on how the overall average is calculated (Fig. 4).

Figure 4 Overall density (*P. maximus* / m^2) for the whole MCZ 1984 – 2016



The trend is the same whichever method is chosen to calculate the annual average density. The graph shows a steep increase in density since 2000 with an indication that the rate of increase is reducing in 2016. The simple average is always the lowest estimate of density and suggests similar densities between 2012 and 2016. The density estimated in 2016 is about 7 times greater than the density estimated in 2000.

Each method for calculating the annual density average has its own pros and cons;

- Simple Average: easy to understand but it is just a number and cannot be tested statistically. Result is highly dependent on how the sampling effort is split between the different sites.

- Simple site density average: has the effect of adjusting for differences in transect area within each site. It can be tested and you can choose which sites to include when testing between years.

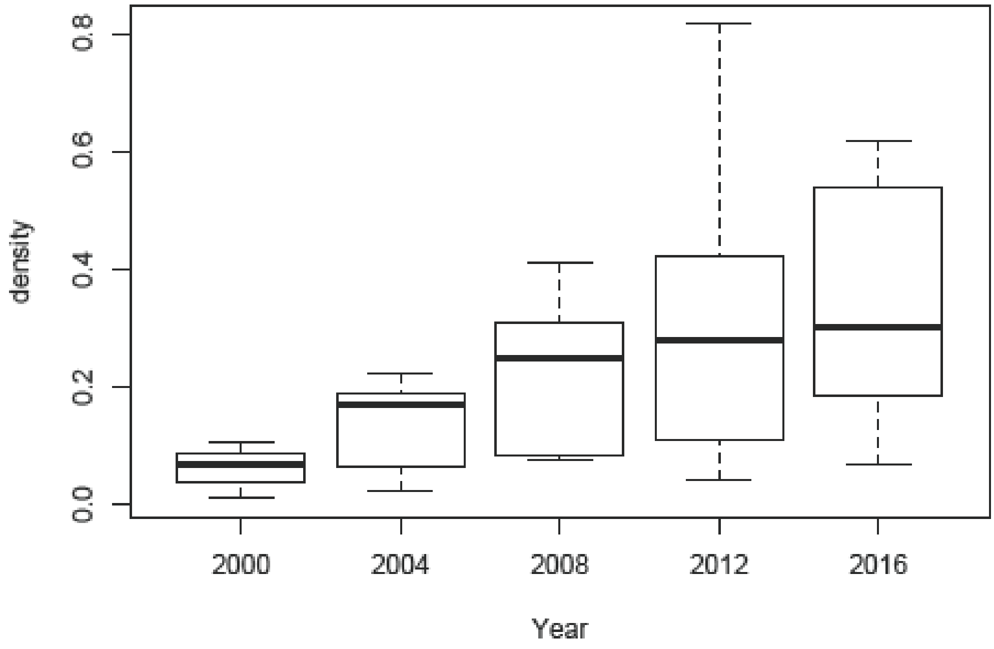
- Site Transect density: similar results to the "Simple site density average", small discrepancies are down to variation in effort between transects (i.e. transect area can vary sometimes). This same method can be used to test for differences between sites as well as between years.

- Transect average for whole MCZ: this ignores which site the individual transects come from and treats the whole MCZ as 1 area. If all sites had similar densities / distributions then this may be valid but the results for each site (section 3.3.2) show that there is a lot a variation between sites. Not a recommended way of producing an annual average density estimate. The increased sample number (n) has the effect of increasing the power of a chosen statistical test but really this is pseudo replication.

Statistical testing on scallop density between years.
The density data are not normally distributed (a Shapiro-Wilk normality test W =0.838, p – 1.8e-10) even after transforming the data (log(X+1), Square root(X+1) and $(X+1)^2$).
Parametric tests are, therefore, unsuitable for the density data.

Non-parametric tests were therefore considered. Figure 5 represents a graphic description of the non-parametric properties of the data.

Figure 5. Box plot of Medians, quartiles, mins & max values for 2000 – 2016 (All scallop average site density values).



Non parametric alternatives were conducted using the R (version 3.2.2) stats package.

Test for differences in density between the years:
2004 – 2016 have a consistent set of sites. Were all the sites to show consistent densities and trends over time then 2000 could also be included but density and response over time is highly variable (see section 3.3.2) so 2000 has not been included.
A ***Kruskal-Wallace test*** on scallop density vs. year (2004 – 2016) on the 7 simple site densities for each year was not significant (KW chi^2= 4.6322, d.f. = 3, p-value = 0.2008 ns
A ***Mann-Whitney – U test*** between 2004 and 2016 was significant at 6% (W = 9.5, p-value = 0.06363).

With only 7 samples per year there was not enough power to detect changes in density between years.

When the individual transect data results were used for testing instead of the site averages (n increased from 7 to 60) then there was enough power to detect changes in transect average density between years.
A ***Kruskal-Wallace test*** on scallop density vs. year (2004 – 2016) for individual transect data gave a significant difference between the medians– (KW chi^2= 28.8, df3, p=2.45 e^{-10}).
Mann-Whitney – U tests between the years show that 2016 is significantly different (W = 881.5, p=3.4 e^{-7}) to 2004 and 2008 but not to 2012.

In order to include the data from 2000 site 1, 2 and3 were selected from the data and analysed separately, again using individual transect results.
A ***Kruskal-Wallace test*** on scallop density vs. year (2000 – 2016 just sites 1-3) for individual transect data gave a significant difference between the medians– (KW chi^2= 24.2, df4, p=7.2 e^{-10}).
Again - ***Mann-Whitney – U tests*** between the years show that 2016 is significantly different (W=1, p=0.033) to 2000, 2004 and 2008 but not to 2012.

3.3.2. Density of scallops at individual sites

The annual density results show an increasing trend in *P. maximus* density, however this trend is not uniform across the individual sites. There is a lot of variability in how each site responds over time (see Figure 6). The lowest density in 2016 was found at Site 3 (0.07/m^2) with the highest density found at sites 2 and 6 (0.62/m^2)

Site 1: has slowly changed since 2004. Density in 2016 was 150% higher than in 2000 (60% higher than 2004).

Site 2: shows a steady year on year increase. Densities in 2016 are now 500% higher than those in 2000.

Site 3: Low densities of scallops found in 2000. There has been little change since 2008 but density in 2016 is now 600% higher than in 2000.

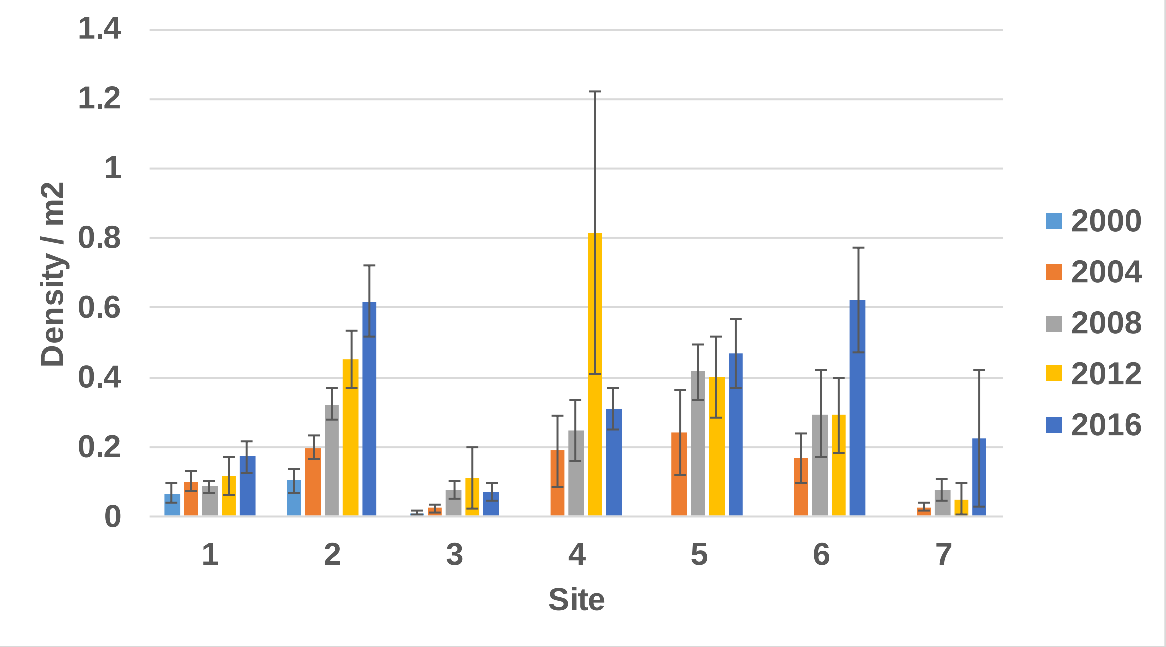
Site 4: 2012 stands out as a high-density year. 2016 density is 60% higher than 2004.

Site 5: A large increase between 2004 and 2008 which has then stabilised. In 2016 density was 90% higher than in 2004.

Site 6: Large increase in 2016 with density now 270% higher than in 2004.

Site 7: A large increase found in 2016, but this must be treated with caution as it is due to a single transect result.

Figure 6. Individual site density changes (*P. maximus* / m²) 2000 – 2016 with 95% confidence intervals.



Site	Average	S.E.	95% Error
1	0.17	0.02	0.05
2	0.62	0.05	0.10
3	0.07	0.01	0.03
4	0.31	0.03	0.06
5	0.47	0.05	0.10
6	0.62	0.08	0.15
7	0.22	0.10	0.20

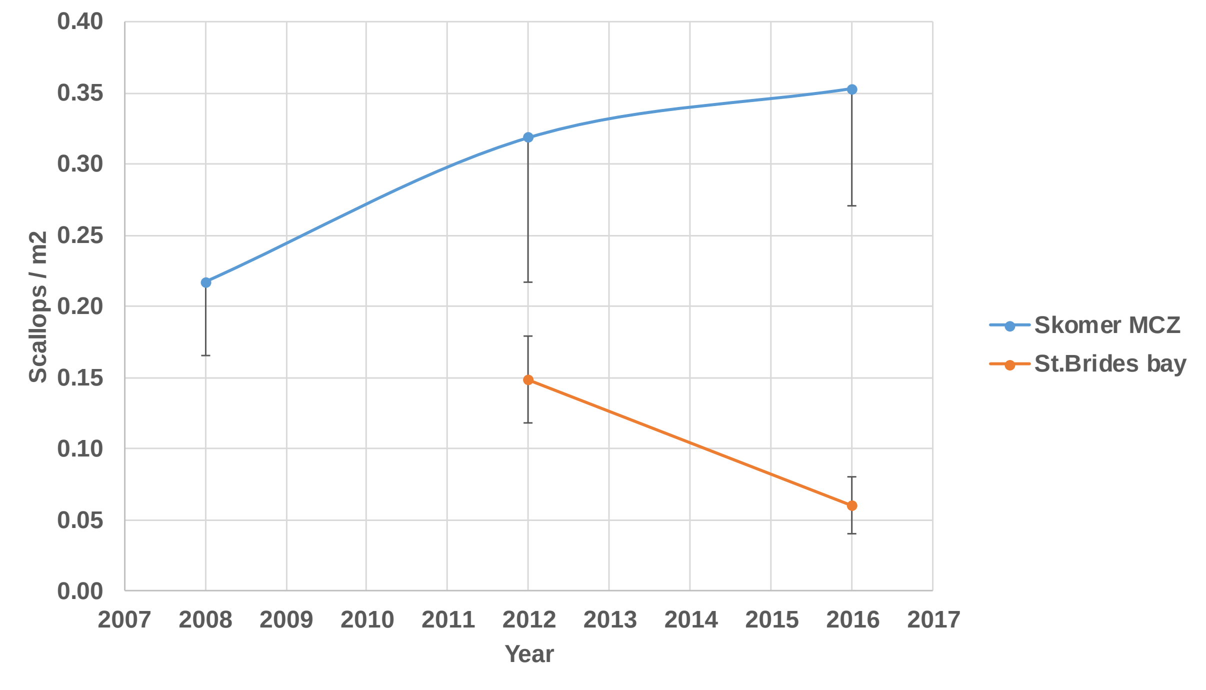
Density results are highly variable between sites and years suggesting a clumped distribution of *P. maximus* across the MCZ. This gives rise to large variances around the averages. Density does not change uniformly across all of the sites surveyed in the MCZ. This suggests that certain sites have the suitable habitat required to promote settlement and growth of *P. maximus* whilst other sites are not as suitable (assuming there is no significant removal of *P. maximus* and mortality is uniform across all sites).

St Brides Bay.

In 2012 and 2016 surveys were carried out outside the MCZ in St Brides bay. Due to a change in habitat between 2012 and 2016 the site was changed during 2016. Due to lack of data, transect results from both 2016 sites were used to calculate the St Brides Bay site average.

In 2012 the average density was 0.15 *P. maximus* / m^2. This dropped in 2016 to 0.06 *P. maximus* / m^2 (Figure 7.)

Figure 7. Density of *P. maximus* inside and outside the MCZ boundary 2012 & 2016 (SE error bars)



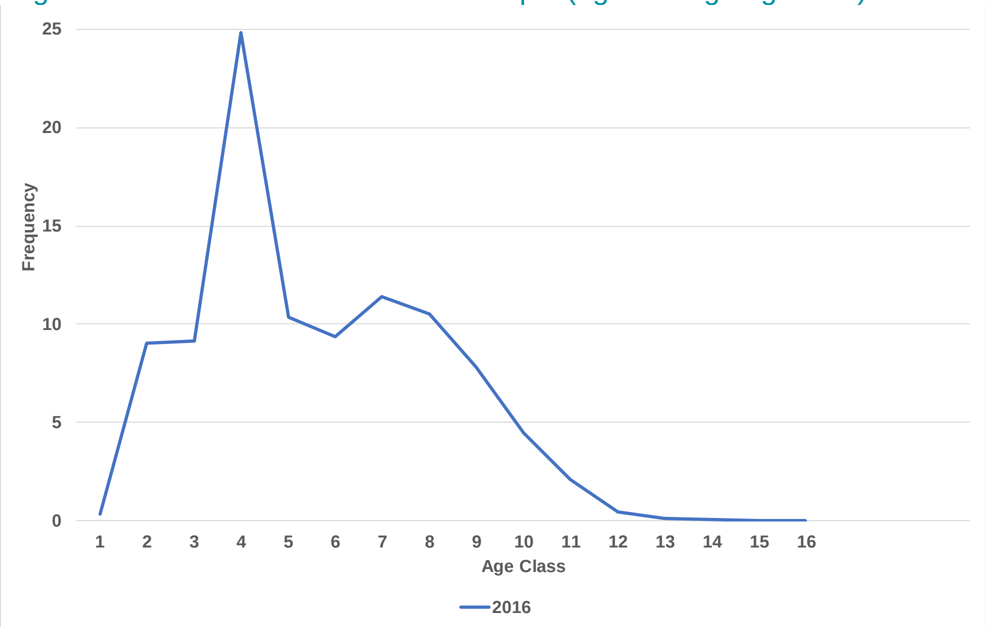
There is not enough of a time series to interpret trends at this site but densities are lower than those found within the MCZ boundary.

3.3.3. Size and Age Structure

Individuals were measured and aged. Two methods were used to estimate age.

1. Age estimation from growth ring counts (Fig. 8).

Figure 8. Age structure of 2016 *P. maximus* sample (aged using ring count).

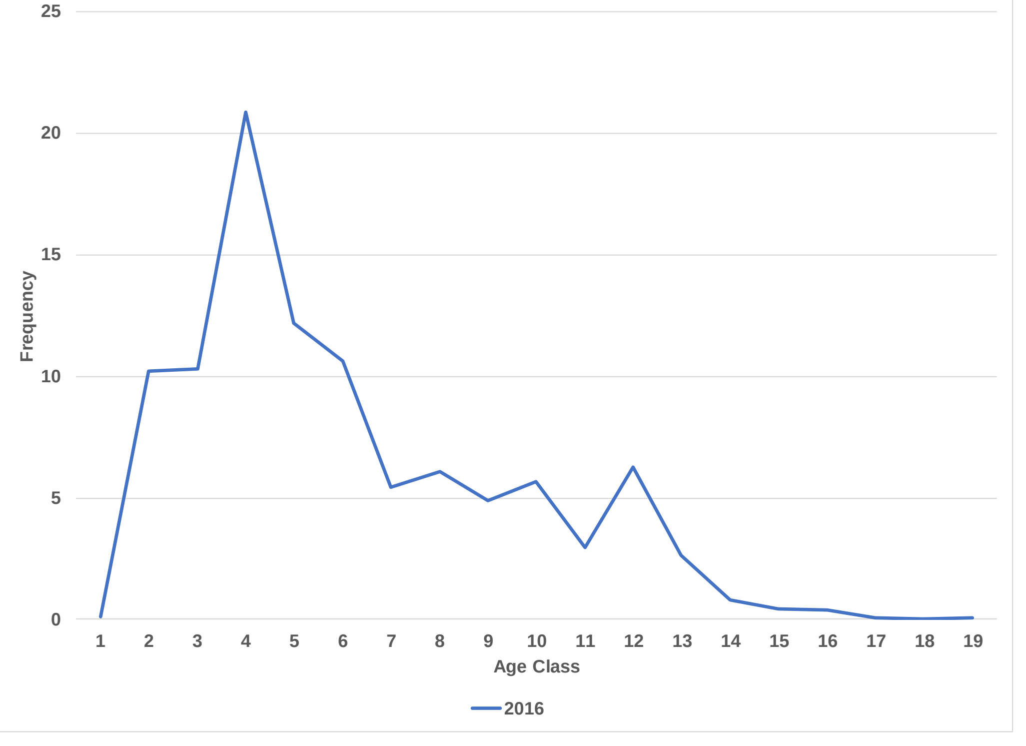


The age 4 size class is strongly represented, suggesting good recruitment in 2012. Older *P. maximus* are difficult to age by counting the age rings, because beyond a certain age the rings on the shell are very close together and hard to differentiate. For this reason this method is probably only accurate in estimating age up to the 7th or 8th age class.

2. Age estimation from overall length (Fig 9).

Because of the uncertainty of accurately measuring growth rings on older scallops an average annual growth rate was derived from that year's actual measured growth rates for all scallops of the age range 8 and over (see Table 3). This growth rate was then used to calculate theoretical overall length of scallops at age eight and over for the specific year.

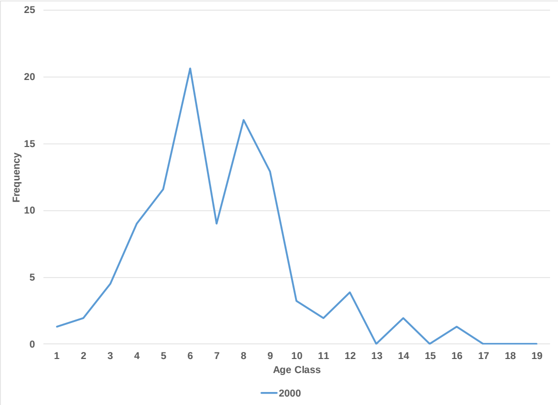
Figure 9. Age structure of 2016 *P. maximus* sample (aged using estimated age from overall length).



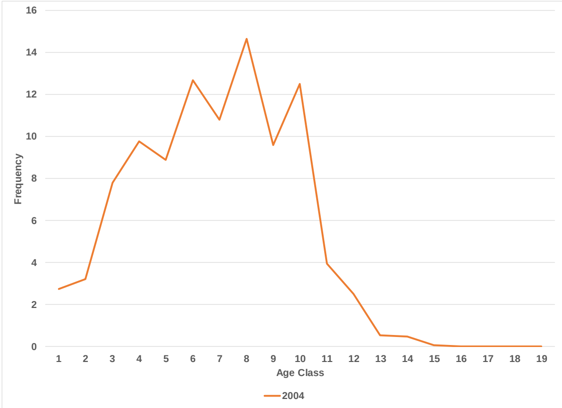
This method is more consistent than the ring count method. It removes some of the user error and provides a more consistent comparison between different surveys. The results (Fig 9) show that class 4 age class is also strong, but the tail extends out to 16-year-old scallops.

Figure 10. Age structure of *P. maximus* 2000 - 2016 (aged using estimated age from overall length for that year's data).

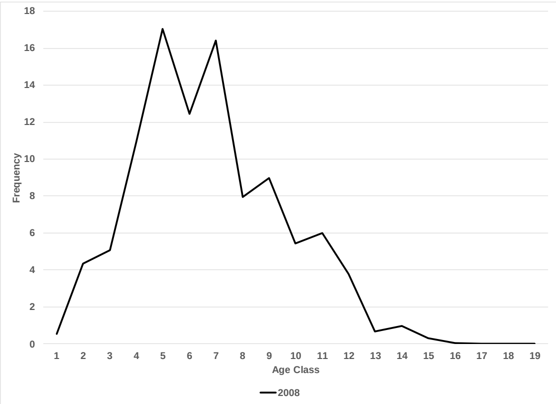
Year 2000



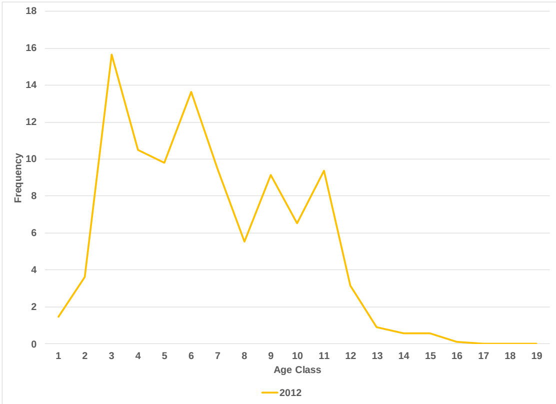
Year 2004



Year 2008

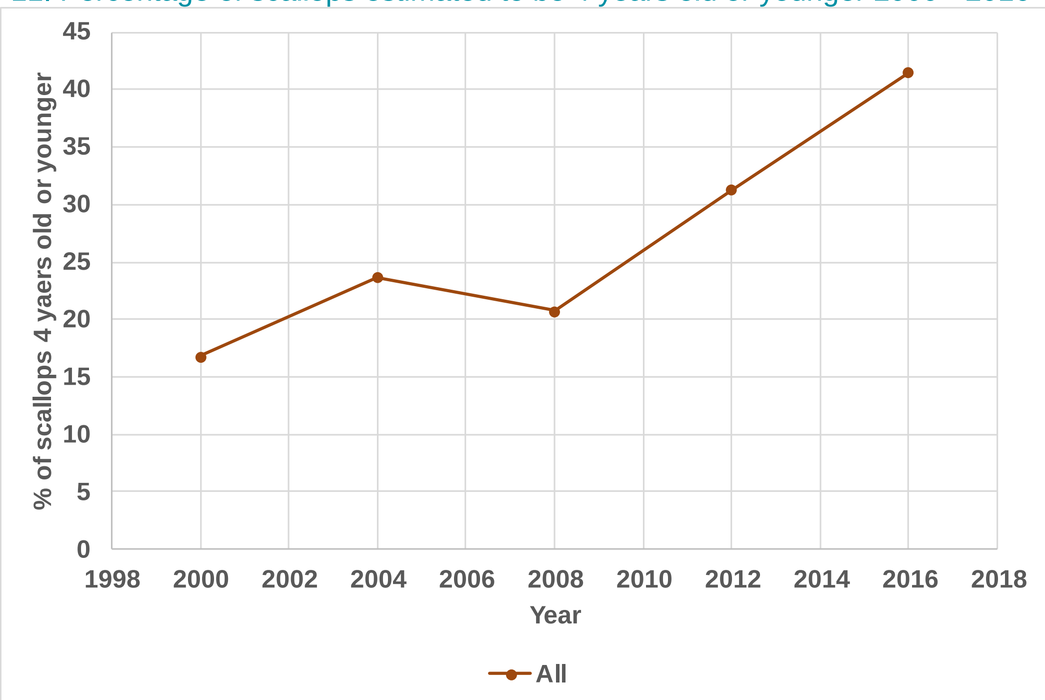


Year 2012



In 2000 there were only 150 *P. maximus* to measure so these data may not be comparable to estimates from the following years. Since 2004 there seems to be a shift of the modal size class towards younger *P. maximus* (Figs 10 and 11).

Figure 11. Percentage of scallops estimated to be 4 years old or younger 2000 - 2016



Without supporting information about recruitment and survival rates it is difficult to interpret these results but it would be useful to compare these results to other populations around the UK.

Age class structure at individual sites.

The age structure of the scallops found at each individual site was calculated and compared between sites and years.

Figure 12. % frequency of each age class (1-19) calculated for each site **2016** (Density found in 2016 marked on for each site for reference)

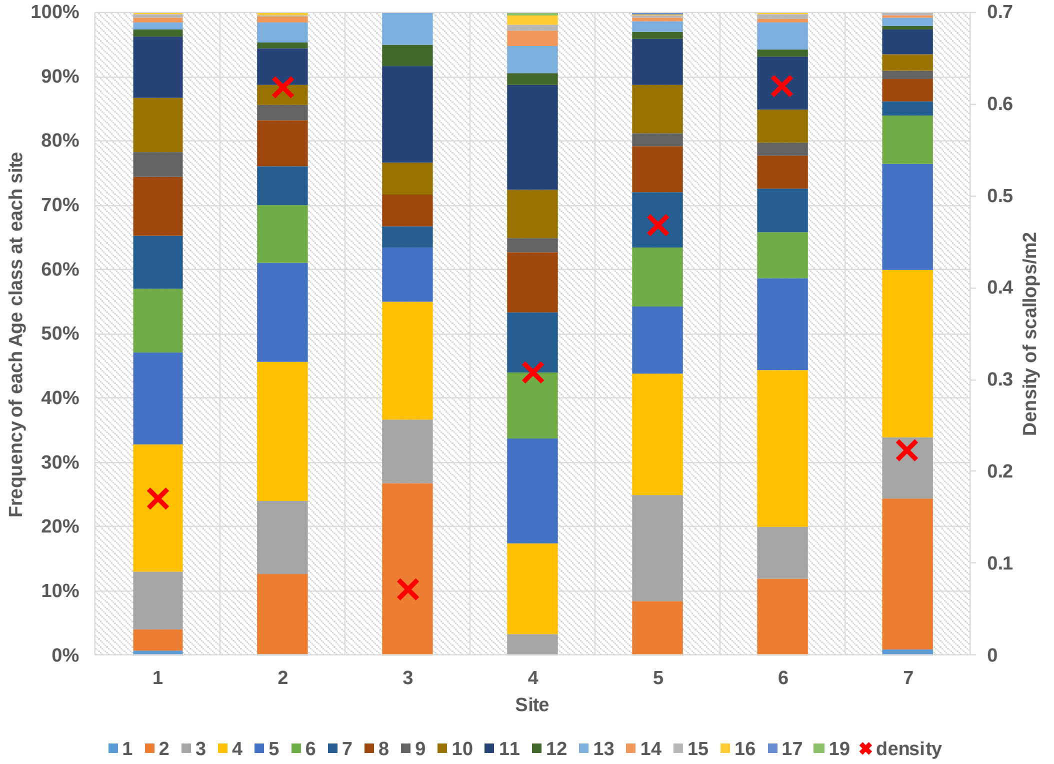
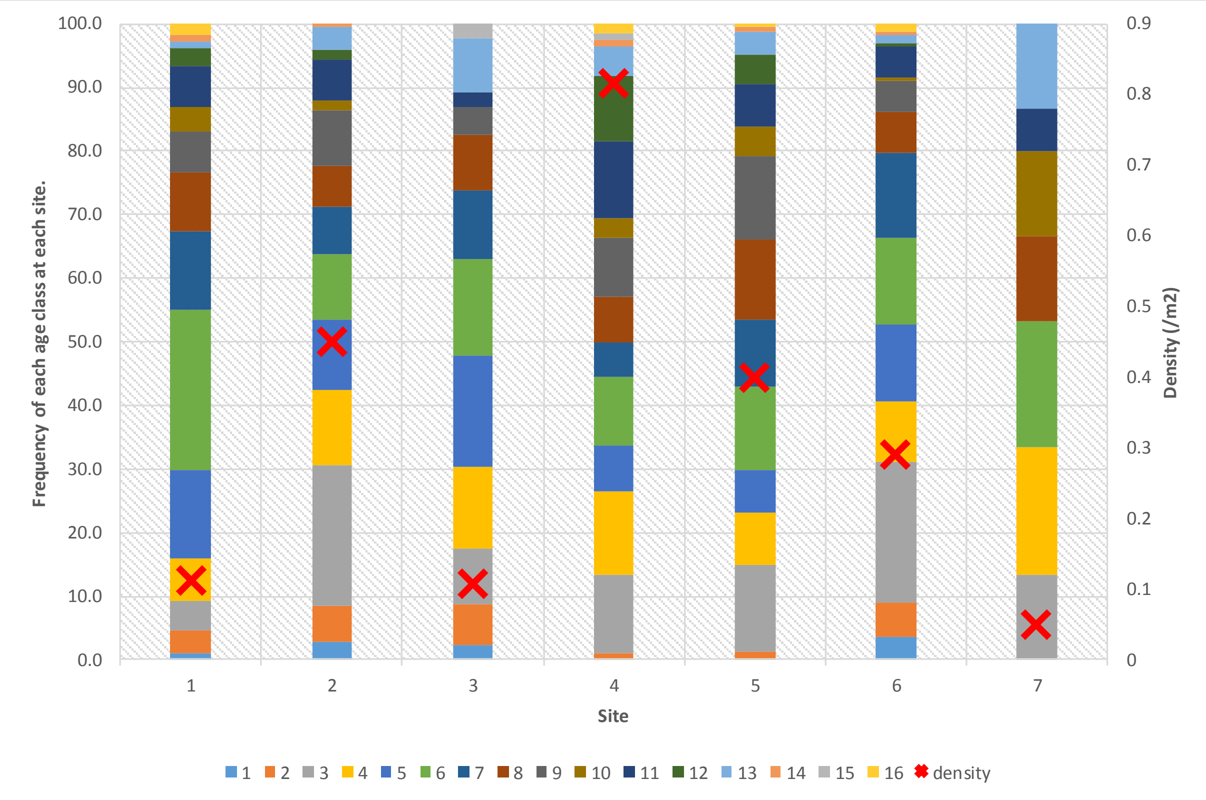


Figure 13. % frequency of each age class (1-19) calculated for each site **2012** (Density found in 2012 marked on for each site for reference)



This is a lot of information to interpret on a single graph. A simple summary of the main messages;
Age structure is not uniform across all sites, for example site 4 and site 7 show considerable differences; site 7 is comprised of 60% age 4 *P. maximus* or younger while over 80% of *P. maximus* at site 4 are aged 5 or older. The density of *P. maximus* at these 2 sites is not significantly different.

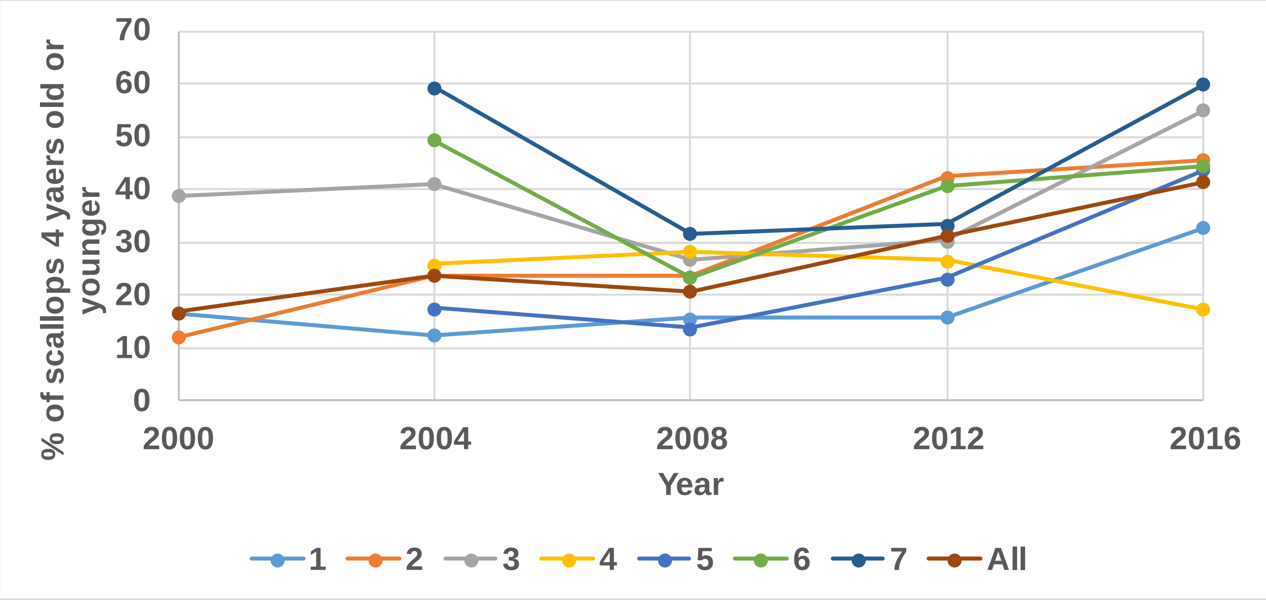
Age structure is similar to the findings for the density results i.e. there is no continuity between sites. This makes interpreting changes between years even harder; for example the high density found at sites 2 and 6 in 2016 coupled with the high proportion of younger *P. maximus* (45% age 4 or younger) will shift the overall proportion of younger *P. maximus* for the whole of the 2016 data.

Comparing the same sites between 2016 and 2012 also shows no consistent trends. To see if there are any trends across all the years (2004 to 2016) correlation tests were conducted between recruitment levels since the last survey (i.e. number of *P. maximus* aged 4 or younger) vs :

a) Density at site in the present survey
b) Density at site in the previous survey
c) Change in density at the site (either as a ratio or as a subtraction of present survey to previous survey)

None of these tests produced a significant correlation (Spearman's rank correlation test p>0.05) and none of them produced a consistent pattern across all the years; positive correlations in 1 year would give negative correlations in other years.
With only 7 sites the power of these tests is low but the lack of consistency suggests that there is no link between where *P. maximus* recruit and density of *P. maximus* (either present, previous or as a measure of change).

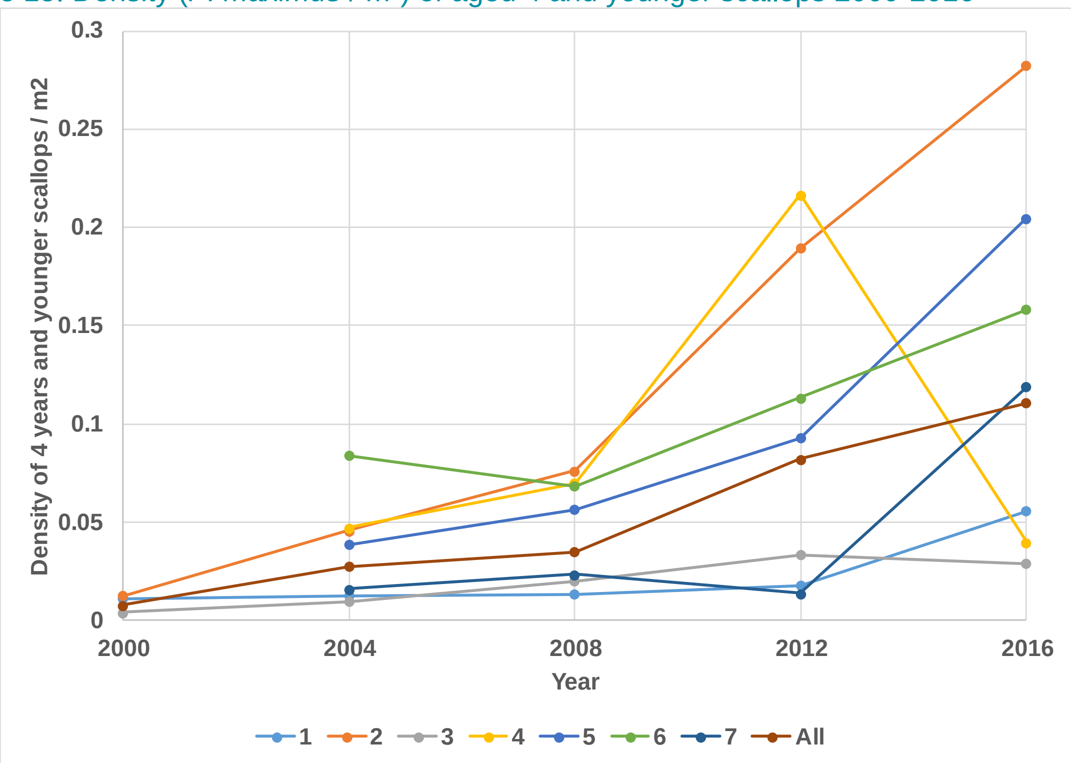
Figure 14. % of *P. maximus* 4 years old and younger at each site 2000 – 2016.



The proportion of *P. maximus* <= 4 years old at each site gives a variable picture of change over time depending upon the site.

Rather than using the percentage of <= 4 Year olds, the density (/m^2) of *P. maximus* <= 4 Years old can be calculated. This shows a clearer picture of increasing trend since 2008 at all sites except site 4. This will be linked in part to the overall increase in density of all *P. maximus* but it is also down to an increase in the proportion of <= 4 year olds in the whole population.
Site 4 (yellow line Fig 15) had a dramatic rise in density in 2012 followed by a drop in density in 2016. It would appear that there has been only little recruitment at site 4 in the last 4 years. This contrasts with all the other sites (except site 3) which have seen an increase in <= 4 Year olds.

Figure 15. Density (*P. maximus* / m^2) of aged 4 and younger scallops 2000-2016



The average % change in overall density (all ages) between 2012 and 2016 was +66%.
The average % change in density of <= 4 year old scallops was + 150%.
These young *P. maximus* have increased at over twice the rate of the older *P. maximus* which is what would be expected in a growing population with healthy recruitment. Due to the relatively long period the larvae spend in the water column (20 – 40 days Salomonsen *et al.* 2015) this high level of recruitment may not necessarily be coming from the resident population.

Very few 1-2 year old individuals are ever found at the survey sites. It could be that they are too small to be easily seen by the divers or they may be inhabiting a different habitat before moving onto the main beds as they grow older.

Growth rates

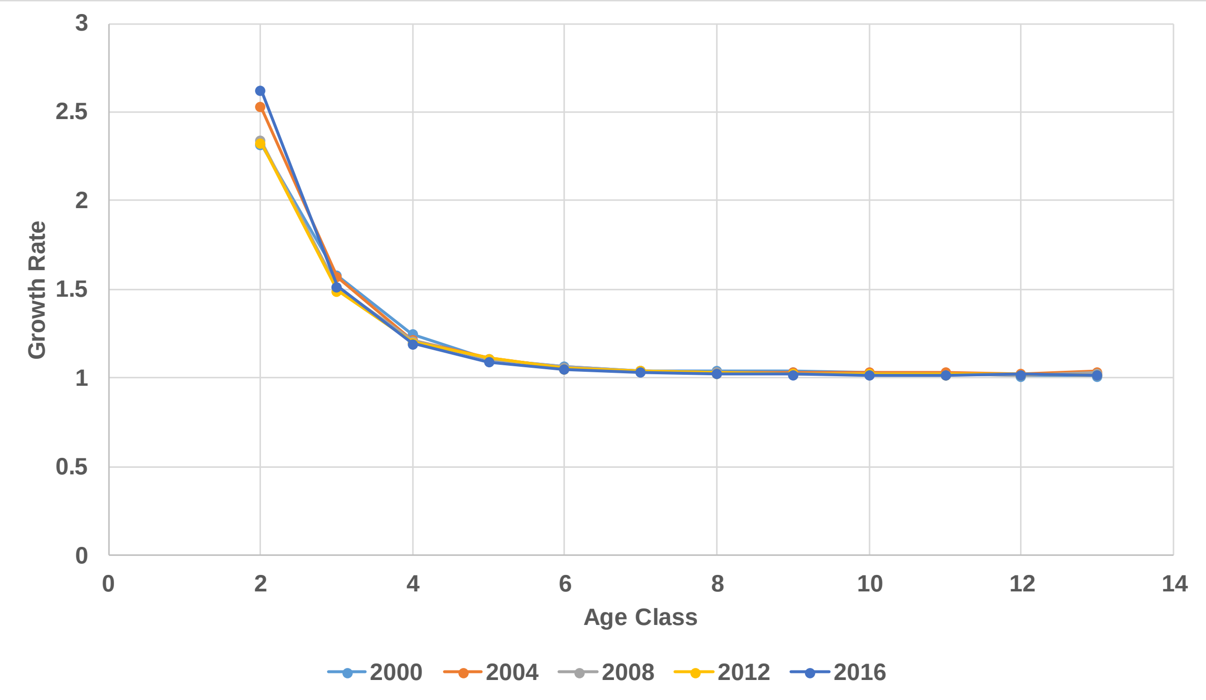
The rate of change in size can be calculated between each age class to show how growth varies as *P. maximus* ages. These can be compared between years (Table 3).

Size at t/size at t+1 = proportional change in size

Table 3. Growth rates between age classes (2000 – 2016) with associated 95% confidence limits

Year	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13
2000	2.3199	1.5808	1.2505	1.1077	1.0659	1.0425	1.0403	1.037	1.029	1.0233	1.0132	1.0143
2004	2.53	1.5699	1.2171	1.1119	1.059	1.044	1.0349	1.0319	1.0317	1.0337	1.0255	1.038
2008	2.3396	1.5146	1.2121	1.1056	1.0623	1.042	1.0327	1.027	1.0233	1.0225	1.0174	1.0314
2012	2.3276	1.4945	1.2031	1.1141	1.0559	1.0404	1.0311	1.0274	1.0258	1.0218	1.0194	1.0184
2016	2.6265	1.5157	1.1955	1.0934	1.0517	1.0343	1.0254	1.02	1.0164	1.0157	1.0205	1.0154
	95% CI											
2000	0.1155	0.0449	0.0245	0.0107	0.0092	0.006	0.0066	0.0071	0.0062	0.0118	0.0059	0
2004	0.0894	0.0316	0.0102	0.0143	0.0027	0.0023	0.0018	0.002	0.0029	0.0084	0.0043	0.0168
2008	0.0324	0.0117	0.0071	0.0038	0.0031	0.0027	0.0021	0.0023	0.0037	0.0034	0.0034	0.0177
2012	0.0455	0.0149	0.0099	0.0278	0.0031	0.003	0.0025	0.0046	0.0047	0.0098	0.0076	0.0128
2016	0.0309	0.0091	0.0043	0.0029	0.0017	0.0012	0.001	0.0009	0.0008	0.0017	0.0086	0.0045

Figure 16. Graph of changes in growth rates with age (2000 – 2016)



All years show a similar pattern of growth rate, with rapid growth in years 2 and 3 then slowing down in 4 and 5 and almost stopping by age 6 (Fig 16).

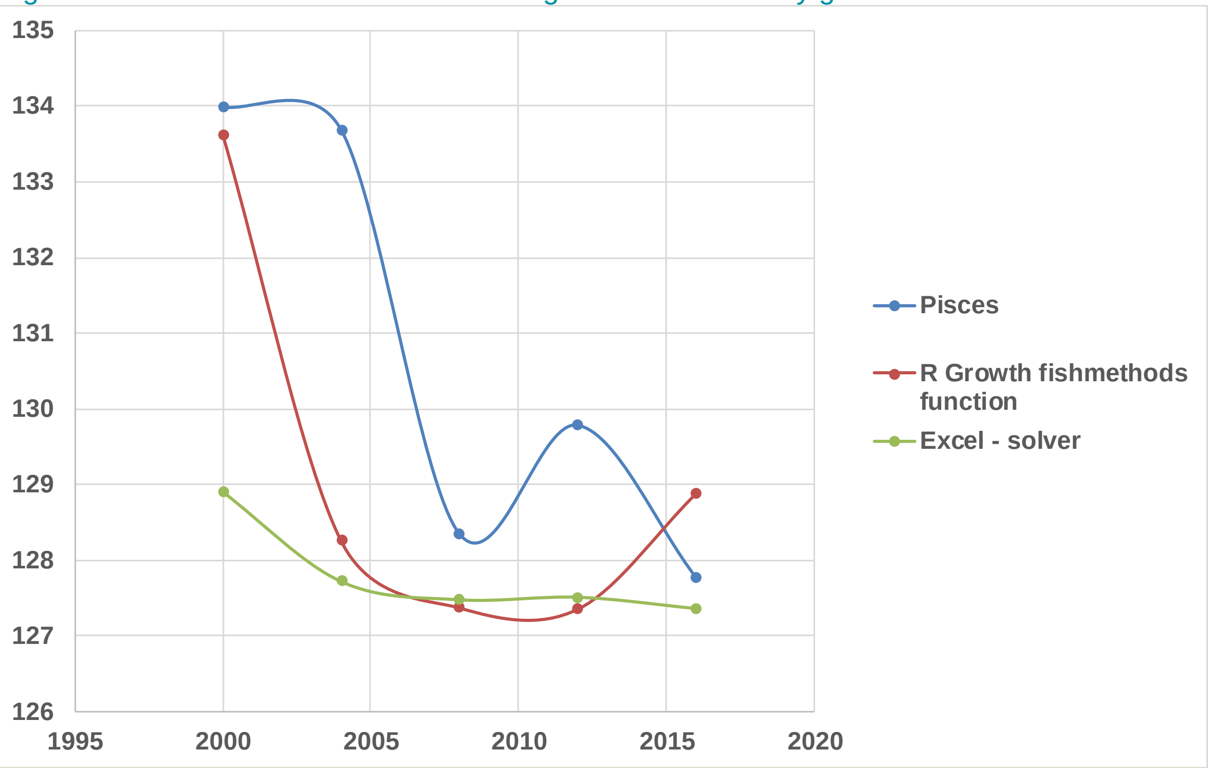
The 1st - 2nd growth ring shows the only possible significant difference but this could be compounded by a double spawning event resulting in variable 1st growth ring measurement.

The double spawning event may not be as pronounced some years (due to environmental factors) therefore the growth rate between 1 to 2 years will depend upon how much growing time the young *P. maximus* has in its first year. Spring spawned *P. maximus* will have more time to grow than scallops spawned in the late summer. The most recent study into spawning times for *P. maximus* in Wales (Salomonsen *et al.* 2015) suggests a double spawning event ; one in spring and a second in late summer with continuous, low level of spawning in between. Times of spawning are variable between geographical areas and are effected by genetics and the environment (Salomonsen *et al.* 2015), they are therefore subject to change.

Von Bertallanffy growth curves.

Growth Curves can be calculated from the age and size data. The von Bertallanffy growth equation has been successfully used to describe the growth of many marine organisms. If a von Bertallanffy curve can be fitted to the data the equation allows for estimates of growth coefficients:

Figure 17. Different methods for calculating the von Bertallanfy growth coefficient L_∞



Pisces - Growth II Pisces Conservation Software
R – using the “fishmethods” package growth function
Excel – using “solver” and least summed squares of difference

These coefficients would show if the growth characteristics of P. maximus had changed over the 16-year period.

3 methods were used to fit curves to the averaged growth data but there was not enough consistency in the results to allow for reliable analysis (Fig 17).

Crepidula fornicata
All *P.maximus* shells were checked for the presence of the non-native limpet *Crepidula fornicata*. Individuals found were counted and then removed from the *P. maximus* shell and destroyed.

Figure 20. Numbers and % of *P.maximus* found with *Crepidula fornicata* 2012 & 2016

	Scallops with *C.fornicata*			
Site	**2012**	**%**	**2016**	**%**
1	0	0	13	2.73
2	2	0.9	19	3.20
3	0	0.0	5	6.49
4	0	0.0	0	0.00
5	1	0.6	5	1.27
6	2	1.2	10	2.07
7	0	0.0	6	2.60
St Brides	1	0.6	1	1.16
Total	**6**		**59**	
MCZ average %		**0.4**		**2.6**

2016 saw an increase in the number of sites where *C. fornicata* was found and an increase in the % of *P. maximus* found with *C. fornicata*.

3.4. Discussion

3.4.1. Density

The trend of increasing *P. maximus* density is clear, no matter how the overall density is calculated (for instance 0.05/m^2 in 2000 rising to 0.35m^2 in 2016 making a 7 fold increase in both the simple site density average and the site transect average). The high variances associated with these densities make statistical testing difficult without falling foul of pseudo replication.

The values themselves match well with other *P. maximus* density studies; Beukers-Stewart (2005) has the most comparable methods where diver swum transects (from an area of seabed closed to dredging in the Isle of Man) estimated scallop densities of 0.05/m^2 in 1989 rising to 0.2/m^2 in 2002.

There have been some recent (2012 and 2013) stock estimates from Cardigan Bay in a fished and closed area of the Cardigan Bay SAC (Lambert et. al.2013). Dredges were used to estimate *P. maximus* density but video and stills cameras were also used to assess the efficiency of the dredges.
Estimated *P. maximus* densities from dredges gave 0.06/m^2 in the closed area and 0.04/m^2 in the fished area. These appear much lower than the densities from the MCZ but dredge density estimates will be much lower when compared to diver estimates. Lambert et.al. 2013 suggests that if the still camera trials are a true estimate of density then dredges are about 20% efficient.
Adjusting the dredge estimates (x 5) gives densities of 0.3/m^2 (closed area) and 0.2/m^2 (fished area) and these are similar to the Skomer MCZ results.

Both of these studies show highly patchy distributions of *P. maximus*, as seen in the Skomer MCZ. It would appear that *P. maximus* has a highly clumped distribution on small and large scales.

It would be useful to compare the Skomer MCZ results with a range of locations in the UK with different fisheries management techniques.

Density at individual sites.
There are some significant differences in *P. maximus* density between the 7 sites and all of the sites show a different response in density change over time. *P. maximus* settlement, growth and mortality must vary significantly between the sites. That may be due to environmental conditions at the sites and / or due to random recruitment / mortality events. There are no data available on annual settlement rates and there has been no success with the use of spat collectors in previous years to provide information on settlement rates.

Only site 2 shows a consistent increase in density over time. Site 2 is within a few hundred metres of sites 5 and 6. There is no real difference in the habitat type found at site 2 compared to sites 5 and 6 and it is quite similar to site 7. However these sites do show quite different responses over time, this suggests random or non-measured factors are affecting *P. maximus* density.

Site 3 consistently has the lowest densities. It has potentially good scallop habitat, but it is shallower than the other sites and it has been suggested (survey divers pers.

comm.) that scallop density increases with depth away from the survey location at site 3, indicating that depth has an influence on habitat selection by scallops.

Site 4 had a dramatic increase in density in 2012 which has been followed by a significant decrease in 2016. The raw data and field sheets from 2012 have been checked to ensure the data has been accurately recorded and that there was no obvious change in the method used at that site in 2012. There is no obvious error or methodological explanation for these dramatic changes. The density of young *P. maximus* does suggest that there has been poor recruitment at site 4 in the last 4 years which would explain some of the drop in density in 2016. The huge rise in density in 2012, however, is not matched by a rise in the proportion of young recruits (see Fig 12). The density of young recruits is high, but so is the density of all the age classes; the proportion of year 4 or less scallops is 26% in 2012 and is similar to the proportions found in 2008 and 2004. So the 2012 result remains difficult to explain, it would need a large immigration event of a range of *P. maximus* ages. *P. maximus* can move but usually only when provoked and adult *P. maximus* are not know to move *en- masse*. The authors suggests that the 2012 density result is treated with caution.

At site 7 the proportion of young recruits in 2016 was 60%, and this was coupled with a significant rise in density. The large rise in 2016 is down to a single transect result from a dense area of scallops (0.8 /m^2 compared to an average of 0.12 /m^2 for all the other transects), again demonstrating the highly clumped dispersion of scallops.

3.4.2. Size, Age class and growth rate

Age class

The age structure of the sampled population differs between sites and between years. It also differs at each site over time, therefore there is no consistent pattern.

There is an increase in the proportion of younger *P. maximus* (year 4 or less) with time. The increase in density of these young scallops is faster than the overall increase in density, therefore it would appear to be driving the increase in density at most of the sites. This suggests good recruitment in recent years. 2012 would appear to have recruited a lot of *P. maximus* into the 2016 population.

Site 4 would be the exception where the proportion of year 4 or less *P. maximus* has remained constant at around 27% since 2004 and then dropped in 2016 to 17%. The density however has changed significantly in that time, it would appear that factors other than recruitment are contributing to density changes at this site.
With a 4 year spacing between surveys it is hard to follow cohorts through and estimate survival.

The low numbers of 1-2 year old *P. maximus* may need further investigation. Surveys in Lamlash Bay in the Isle of Arran (Howarth 2011) found *P. maximus* of this age group settling onto seaweeds in the shallows. This is a habitat which is not surveyed for *P. maximus* in Skomer MCZ and it would be worth expanding the methodology to look for young recruits in other habitats.

P. maximus planktonic larvae remain in the water column for at least 21 – 40 days before settling out (Salomonsen 2015). This means that larvae can be transported a long way from the release site. There are strong tidal currents around west Wales's coast and it is not known where recruits into the Skomer MCZ population come from. Likewise we do not know where the larvae produced at Skomer end up settling.

3.4.3. Von Bertallanfy growth curves

Due to the lack of consistency in the results no reliable conclusions can be drawn. The growth rate curves (Figure 16) suggest little change in the 16-year period.

3.4.4. Crepidula fornicata

Although numbers are low *Crepidula fornicata* would appear to be increasing within the *P. maximus* population in Skomer MCZ. *P. maximus* must provide a suitable substrate for settlement and could provide stepping stones for the spread of *C. fornicata* from the high densities found in the Milford Haven estuary.

3.5. Conclusions

The population of *P. maximus* within the boundary of the Skomer MCZ would appear healthy and increasing.

- The density of *P. maximus* has increased 7 fold in the 16 year survey period with a suggestion that this increase is now slowing down.
- There is strong evidence of good recruitment into the Skomer MCZ population but it is unclear whether these recruits are from the resident population or from further afield.
- Density and recruitment are variable between years and sites.

3.6. Recommendations

- Continue with the same methodology, next survey due in 2020.
- Collate and analyse the data pre 2000 in more detail to look for changes in growth rates over a longer time period.
- Look in more detail at the methods for fitting von Bertallnafy growth curves.
- Compare the Skomer MCZ results to other studies on *P. maximus* around the UK.
- Survey other habitats for the presence of young (1-2 year old) *P. maximus*.

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5. Appendices

5.1. Appendix 1 Inshore Fishery Legislation – Skomer

BYELAW 27. PROHIBITED AREA FOR USE OF DREDGES AND BEAM TRAWLS - SKOMER

No person shall use in fishing for sea fish any fishing dredge or any beam trawl within the area detailed below.

From the northern point of Gateholm Island due North to the mainland. From the southern point of Gateholm Island a straight line in a direction of 278^{o}(T) to a position 2.75 cables due south (T) of the western extremity of the Mew Stone thence 2.75 cables off the mainland shore of Skomer around the west coast of the Island to a position 2 cables due north (T) of the Garland Stone, thence a straight line in a direction of 098^{o} (T) to a position 51^{o}44.5'N,05^{o}13'W, thence due south (T) to the mainland coast.

BYELAW 28. PROHIBITED AREA FOR SCALLOP FISHING - SKOMER

No person shall fish for, take or land any scallop of the species *Pecten maximus* or of the species *Chlamys (now Aequipecten) opercularis* from the area detailed below.

From the northern point of Gateholm Island due North to the mainland.

From the southern point of Gateholm Island a straight line in a direction 278^{o} (T) to a position 2.75 cables due south (T) of the western extremity of Mew Stone, thence 2.75 cables off the mainland shore of Skomer around the west coast of the Island to a position 2 cables due north (T) of the Garland Stone, thence a straight line in a direction of 098^{o} (T) to a position 51^{o}44.5'N,05^{o}13'W, thence due south (T) to the mainland coast.

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