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The size at maturity for the common whelk, *Buccinum undatum* in Welsh waters, with an industry perspective on minimum landing sizes

Jodie A. Haig, Julia R. Pantin, Harriet Salomonsen, Lee G. Murray & Michel J. Kaiser

School of Ocean Sciences, College of Natural Sciences, Bangor University

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Summary

The size at maturity for common whelks sampled in Welsh waters between 2013 and 2014 varied over small spatial scales. Sites 8-10 miles from each other had populations of whelks with very different length frequencies and size at maturity. This presents some difficulties when assessing whelk populations as management units. Further complicating the issue is the seasonal variation in maturity estimates. Using visual estimation methods for maturity introduces some error during seasons when gonads are not active (and thus do not contain eggs or sperm for visual assessment). The potential for overestimating the proportion of immature whelks increases outside of the reproductive season. We observed that the peak season for identifying gonad development was autumn, after this spent whelks may be considered immature and further a decrease in feeding means that catchability of mature whelks is lower. We investigated the length frequency from all sites to determine the impact a minimum landing size (MLS) change would have on whelk fishermen. The vastly different size structure of populations means that a change to MLS will disproportionately affect fishers, one fisher would see a 50% loss of annual income from a MLS change.

Introduction

The common whelk, *Buccinum undatum* (Linnaeus, 1758) is a neogastropod mollusc, common in the subtidal waters of the North Atlantic shelf waters (de Vooys and van der Meer 2010) and is considered to be a boreal species. *B. undatum* is a predator and scavenger in water depths between three and 600 m (ref); their keen chemosensory abilities enable them to detect carrion from within a 111 - 585 m^2 area (Himmelman 1988) which enables them to be caught in baited traps. *B. undatum* is gonochorous; however, females can suffer from imposex (the growth of male sexual organs) when exposed to certain marine pollutants such as TriButyl Tin (TBT), causing infertility (Mensink *et al.* 1996a,b). *B. undatum* typically display distinct seasonality to breeding periods. Spawning occurs in the UK between November and January (Kideys *et al.* 1993; French 2011), but all year round in Swedish and Danish waters (Valentinsson 2002) and in autumn in Canadian waters (Martel *et al.* 1986; Himmelman and Hamel 1993).

Reproduction is controlled by the release of pheromones by the female, which attract males and induces copulation (Martel 1985). Females may store sperm for up to eight weeks until the eggs are ready to fertilise, the eggs then pass from the ovary past the seminal receptacle before they are encased in the capsule gland (Fretter and Graham 1994). Females produce approximately 140 eggs per egg mass, which are within capsules that are cemented to solid structures. Multiple females can contribute to a single egg mass, each one laying eggs onto anothers egg mass (Martel and Larrivee 1986).

There is a commercial fishery for *B. undatum* in the United Kingdom where fishers use baited traps ("pots") connected together on a long line ("string"). An early publication on whelks states that large quanities were usually on sale in London, though they were not often eaten in the north of England (Dakin 1912). Dakin (1912) also comments that in Scotland and the Isle of Man, they were referred to as "buckies" or "coxen" in Heligoland. English fishermen were referred to as "coxen clappers" on account of them breaking open the whelks for use as bait.

Consistent fisheries records did not begin for whelk until 1995 and since then annual landings have increased each year. Today, whelks are fast approaching the third most important shellfish fishery in Wales; and in 2013 whelk landings were almost 5,000 tonnes (estimated at around £3.6million; MMO, 2014). The demand from Asian and European markets for whelk has increased (Fahy *et al.* 2000) and as other fisheries decline or experience restrictions in Welsh waters a displacement of effort into the whelk fishery is expected. Currently there is limited management for *B. undatum* populations in Welsh waters. The size at maturity (Table 1), length frequency and genetic structure of *B. undatum* populations has been shown to vary over small spatial scales (Weetman *et al.* 2006; Shelmerdine *et al.* 2007; McIntyre *et al.* 2015); thus highlighting the need for fine scale spatial biological data on this species .

Table 1. Results from published literature for the minimum landing size and the size at maturity of *Buccinum undatum* using various methods and sampling months. Methods include: Gonad, differentiation of the digestive whorl; PL, penis length method; GSI, gonadosomatic index; Gametes, microscopic examination for the presence of sperm or oocytes.

Location	L_{50} Male	L_{50} Female	Method	Months	MLS	Reference
England	46.4-76.2	44.8-77.8	Gonad	Jan - Mar	45	(Hancock and Urquhart 1959; McIntyre *et al.* 2015)
Ireland	63.2-83.2		PL		50	(Fahy *et al.* 2000)
Canada	49-76	60-81	PL / GSI	Apr & May	70	(Santarelli 1985; Gendron 1992)
Iceland	45-75		PL	May & Sep	45	(Gunnarsson and Einarsson 1995)
Sweden	53.5-71.9	51.5-71.5	Gametes	Oct to Nov	45	(Valentinsson *et al.* 1999)

Throughout EU the legislated minimum landing size (MLS) is 45mm total shell length (TSL). In the Shetland islands, industry were concerned with the sustainability of whelk fishing and raised the MLS to 75 mm within a 6 mile limit of the island (Shelmerdine *et al.* 2007). Similarly on the Isle of Man and Jersey and the Channel Isles, the MLS is set to 75 mm TSL (Kideys *et al.* 1993; Morel and Bossy 2004, respectively).

The whelk fishery is considered “data poor” with little knowledge of stock status. Early unpublished research suggests that the current MLS is too low to protect brood stocks in Wales. We investigated the seasonal and regional variation of size at maturity with regard to the length frequency distribution of *Buccinum undatum* stocks in Welsh waters. We then presented the results to the fishers involved in the study and discussed a number of potential management scenarios that may result from the research. The survey was aimed at gauging industry support for different management measures and also to identify the potential impact that management measures will have on individual fishermen.

Methods

Fisheries dependent sampling

Permits were obtained to allow four fishermen dispensation to land the total contents of two pots each per month for 13 months (including all bycatch and undersized animals) for the purpose of scientific research. Two "scientific pots" were provided to four fishermen fishing out of ports in north, mid and south Wales, UK (Figure 1). Pots were 36 litre "Fish-tec" or "stand-up" pots weighted with lead (diameter 320 mm and height 350 mm). Drainage holes existed in the base of the pot and were 30 mm in diameter, to allow water and mud to escape during hauling. Fishermen were asked to attach the pots to a string of their own pots and to provide monthly samples for thirteen months ($n_{samples}$ = 26 per port). The datasheet provided to the fishermen requested the following data: date, latitude and longitude of pot haul, bait type and soak time.

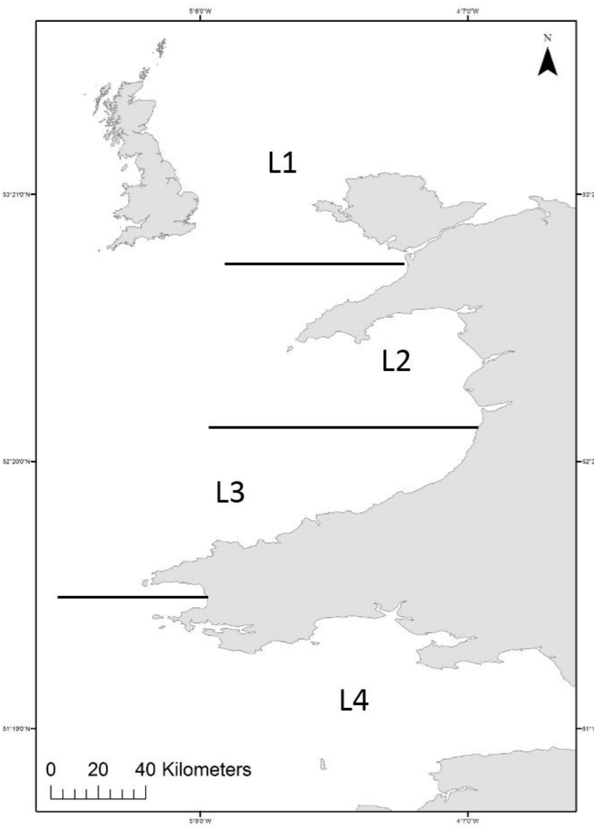


Figure 1. Left). Map of Wales, United Kingdom showing the four regions where whelk (*Buccinum undatum*) samples were collected in 2013 and 2014; Right) science whelk pot attached to a string of fishing pots.

Laboratory methods

Whelks were kept frozen and defrosted prior to dissections. All whelks were weighed wet, and shell morphometrics were recorded (total shell length and minimum and maximum widths to the nearest mm). A total of 30, randomly chosen whelks (with operculum) were selected from each pot sample (60 whelks per monthly sample per location) for further analysis. Whelks without the operculum were excluded from the random sampling procedure. Each whelk was weighed whole and then the animal was carefully removed from the shell and photographed. Total shell length was measured (mm) with Vernier callipers and a shell damage index was assigned (Table 1).

The damage index was designed to identify whelks that might have experienced enough damage to divert energy away from reproduction and into repair. It will also provide an index of damage which will relate to the possibility of operculum loss, as whelks regrow the operculum this will be vital information for future aging research on these samples.

Table 1. Damage index assigned to common whelk shells (*Buccinum undatum*) by visual estimation.

Damage index	Description
1	No damage
2	Small chips in lip of shell
3	Medium damage to shell, evidence of recent or previous trauma or a hole in the shell, damage no greater than 1/3 of shell width
4	Extensive recent or previous damage to shell, damage greater than 1/3 of shell width and likely subsequent operculum loss
5	Completely crushed, will likely not recover

The whole body was weighed before removing the digestive whorl (containing the gonad) to obtain the wet weight.

Sex and maturity determination and gonadosomatic index

Gonadosomatic index (GSI) is used as an index of reproductive activity using the following formula:

$$GSI = \frac{\text{whole body weight}}{\text{digestive whorl}} \times 100$$

Sex was determined by the presence of a penis, and penis length (mm) was recorded. Maturity stage was assigned by observing the differentiation of the digestive whorl (Figure 2, Table 2).

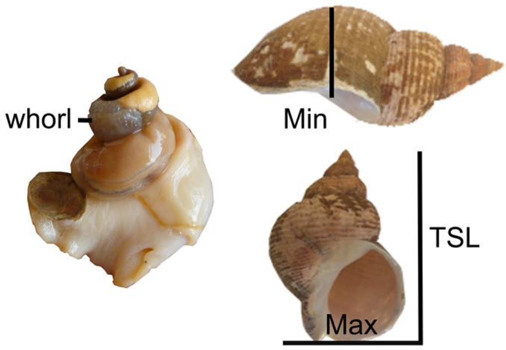


Figure 2. An adult female whelk extracted from the shell showing the differentiated digestive whorl containing yellow eggs (left) and the total shell length (TSL) and minimum and maximum angles that whelk shells are measured at.

Table 2. Maturity stage assessment of the whelk *Buccinum undatum* using basic visual methods.

Stage	Description
Immature	No differentiation in digestive whorl
Beginning to mature	Differentiation in the digestive whorl, possibly a visible vas deferens in males
Mature	Differentiation in the digestive whorl obvious, visible vas deferens in males

Size at maturity analysis

All statistical analyses were run in R (R Core Team 2014). Maturity stage data was converted to binary form (immature = 0 and mature = 1). Population estimates for size at maturity were estimated using a logistic regression model (Roa *et al.* 1999) reformulated by Walker (2005) to produce:

$$P(l) = P_{MAX}(l + e^{-\ln(19)\left(\frac{l-\beta 1}{\beta 2-\beta 1}\right)})^{-1}$$

Where *P(l)* is the proportion of the population mature at TSL; β1 and β2 are curve parameters corresponding to L_{50} and L_{95} respectively, and P_{MAX} is the asymptote. Parameters were estimated using a generalised linear model with a logit link function and binomial error structure. Confidence intervals were added by bootstrapping the generalised linear model (runs at 10,000). The significance of the fitted models were tested by comparing the deviance explained relative to the null model using chi-squared tests. The base R code was constructed by Alastair V Harry and is available online (Harry 2013). The data was subset by sex, season (northern hemisphere) and location for all analyses.

Whelk management survey for fishers

A survey was designed as a pilot measure to capture fisher's response to the whelk research results and to gauge the impact of various possible management measures. The proposed management changes do not in any way indicate proposals from the Welsh government. This survey was conducted on the four fishers engaged in this study and is available for use as a potential guide for future fisher surveys (Appendix 1).

Results

A total of 5,080 whelks were caught and measured over the duration of the project; 1,659 of those were dissected and maturity was successfully determined. The research officially began in May 2013 though some earlier samples were obtained from south Wales (Table 3). Data collection was opportunistic and gaps occurred in the data when fishermen were not able to fish due to inclement weather, boat repairs or because they changed fishing gear to target another species. Geographical reference information from the datasheets completed by the fishers identified two distinct sub-areas (or fishing patches) within each location. To maintain the fishers' commercial confidentiality the locations and sub-areas are not revealed here.

Table 3. The total number of whelks (*Buccinum undatum*) caught with the two scientific pots in each month for each location fished in Wales. L1, north Wales; L2, north mid-Wales; L3, south mid-Wales; L4, south Wales

	2013											2014				
		Spring			Summer			Autumn			Winter			Spring		
Location	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
L1				91		87		68	152	212			57			112
L2				66	140	158	183		75	64					69	332
L3				257	365	182	168		53	128	38		88	27		
L4	132	220		54	156	129		155	173	372	139	261				112

Size at maturity (sex, location, site)

Maximum likelihood estimates of the size at maturity (L_{50}) predicted by the binomial logit GLM ranged between 51 mm to 76 mm TSL (Table 4). Data was sufficient to run similar ogive analyses for each sex at each location (Figure 2), even though the site samples had wider confidence intervals and all analyses were highly significant when tested against the null model (Figure 3 & 4, Table 4).

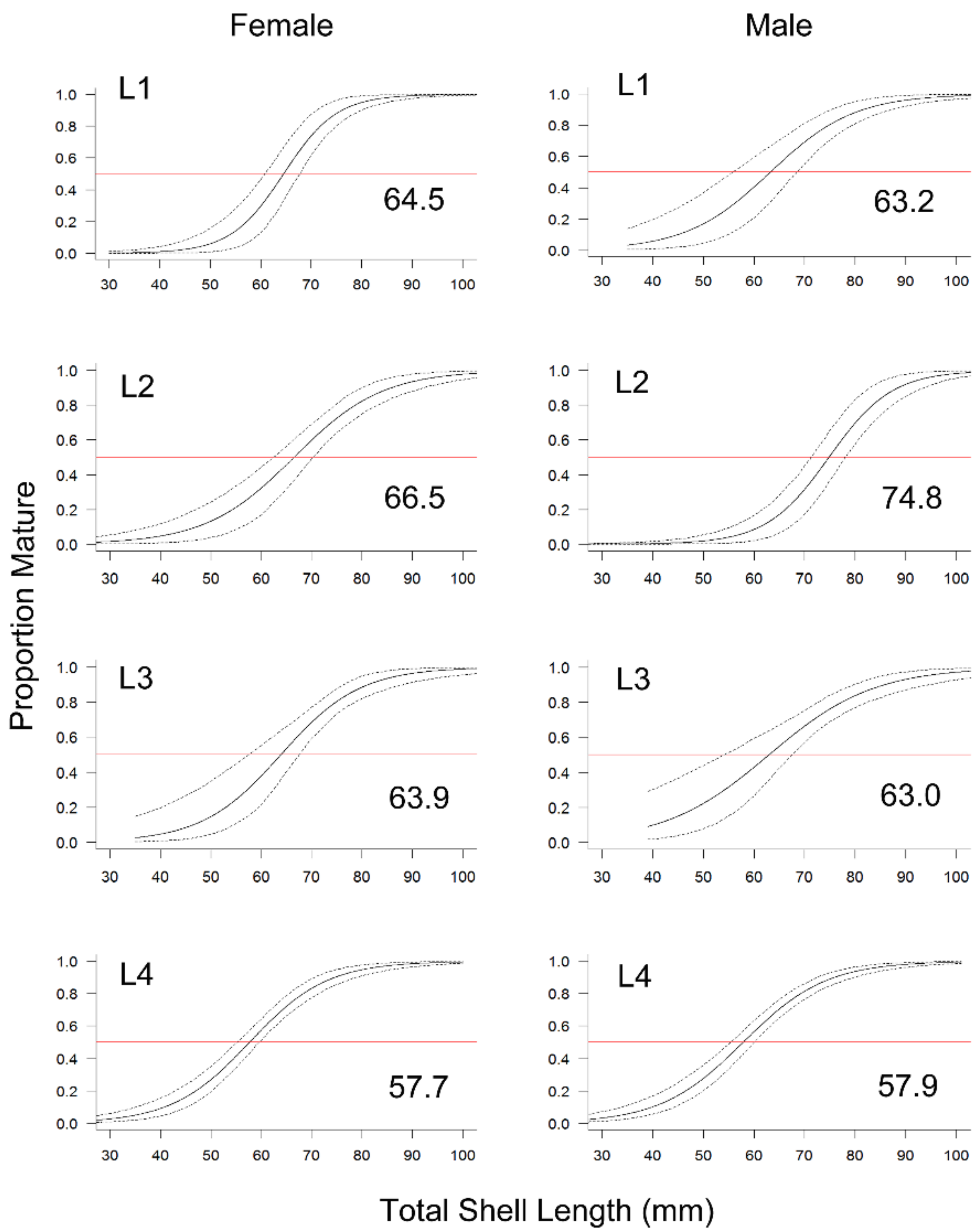


Figure 3: Maturity ogive of model fit for female and male whelk (*Buccinum undatum*) from Wales. L1, north; L2, north mid- Wales; L3, south mid-Wales, L4 south Wales. The proportion where 50% of sampled whelks were found mature is marked by the horizontal line and displayed in the bottom right corner of each figure.

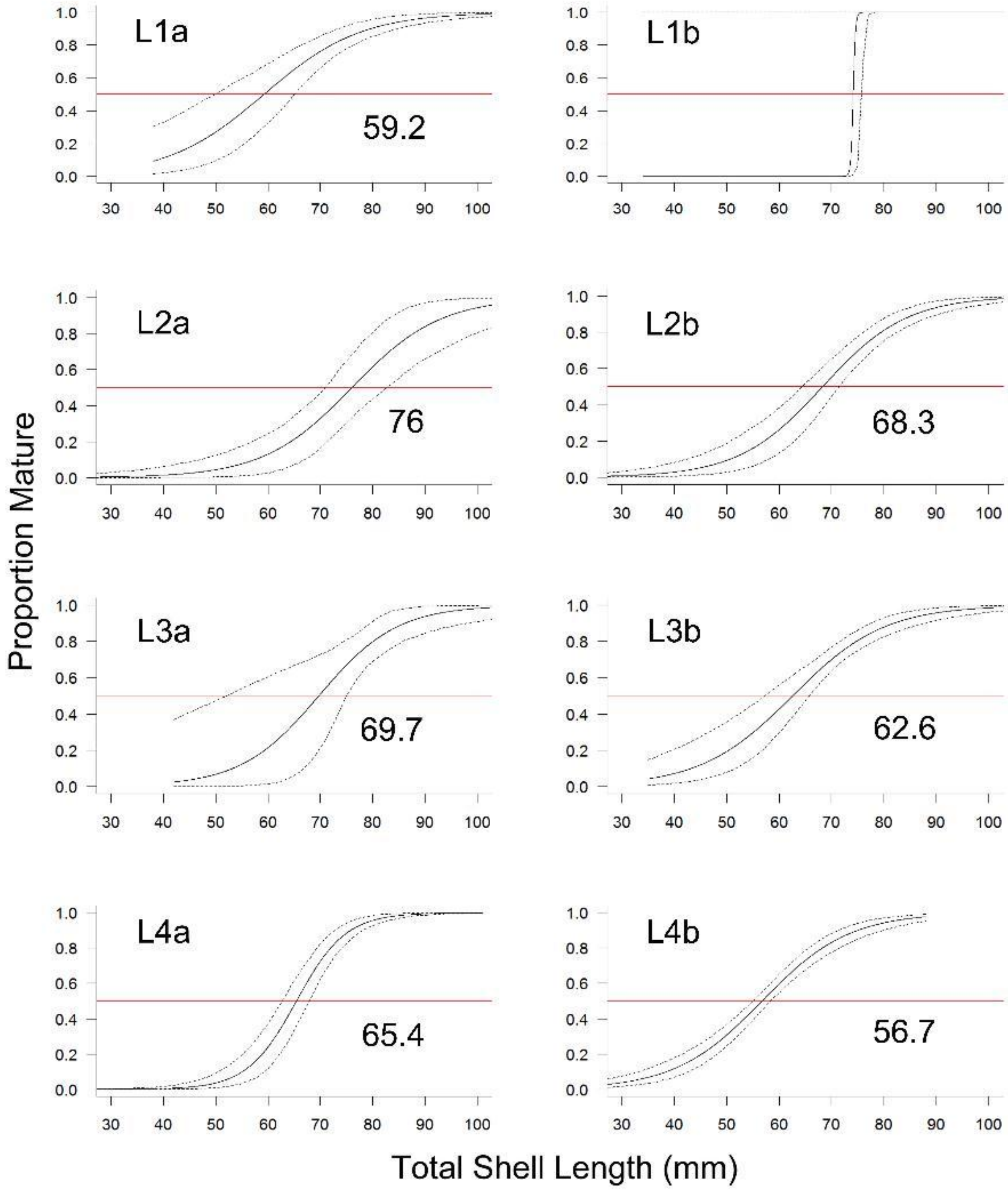


Figure 4: Maturity ogive of model fit for female and male whelk (*Buccinum undatum*) from sites within each Welsh location. Two locations were sampled from each locationL1a and b, north Wales; L2 a and b, north mid-Wales; L3 a and b, south mid-Wales, L4 a and b, south Wales. The number in the bottom right of each figure is the total shell length (mm) at which 50% of sampled whelks were found mature (L_{50}).

Table 4. Summary statistics and size at maturity (L50) for each sex, location and season for the common whelk, *Buccinum undatum,* populations collected from Welsh waters in 2013 - 2014. TSL, total shell length; L50, the TSL where 50% of the sampled population were found to be mature; Lower and Upper CI, bootstrap for 95% confidence intervals (runs = 10,000).

Data	Sub-sample	Total number caught	Sampled for maturity	Min TSL	Mean TSL	Max TSL	Lower CI	L_{50}	Upper CI
Females	Summer	834	210	22	68.1	110	56.4	60.4	63.8
	Autumn	745	230	25	63.9	102	63.1	66.2	69.4
	Winter	361	207	25	63.5	106	54.5	57.5	60.2
	Spring	746	205	13	64.3	113	52.6	57.8	61.9
	L1	441	178	30	75.1	111	60.8	64.5	67.8
	L2	571	160	13	59.2	107	62.0	66.5	70.2
	L3	708	173	35	74.2	113	57.7	63.9	67.5
	L4	966	341	15	57.9	100	55.5	57.7	59.6
Males	Summer	734	211	12	69.8	111	57.1	61.7	65.3
	Autumn	707	257	27	65.7	104	59.9	63.0	66.0
	Winter	353	182	29	62.4	120	55.9	59.8	63.2
	Spring	600	157	13	65.4	118	57.2	63.1	67.9
	L1	338	130	35	74.8	120	55.7	63.2	68.6
	L2	512	137	13	61.9	112	71.3	74.8	78.3
	L3	598	174	39	74.5	111	54.5	63.0	67.8
	L4	946	366	12	60.7	101	55.5	57.9	60.0

Seasonality proportion mature

Mature whelks were found in all months throughout the sampling period (Fig 5). The proportion of mature whelks from a sampled population did not vary between the sexes overall, though an ANCOVA revealed variation with season ($F_{3, 1651} = 16.82$, $p \leq 0.001$) and as an interaction between sex and season ($F_{3, 1651} = 5.62$, $p<0.001$). Tukey post hoc testing identified a peak in the proportion of females in autumn (p adj ≤ 0.001) which was also significantly greater than the proportion of mature males sampled in autumn (p adj = 0.05).

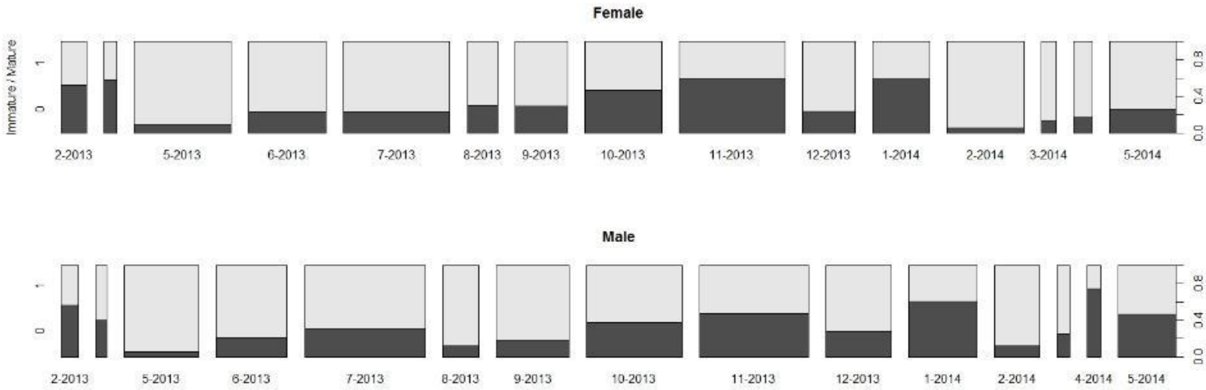


Figure 5. The proportion of male and female *Buccinum undatum* that were found mature in each sampling month between February 2013 and May 2014.

Seasonality in Gonadosomatic Index

The gonadosomatic index (GSI) was higher for females than males (ANOVA, $F_{1,\,1557}$ = 172.93, $p < 0.001$) in all seasons (ANOVA, $F_{3,\,1557}$ = 46.71, $p < 0.001$), and was different between locations (ANOVA, $F_{3,1557}$ = 23.66, $p < 0.001$). No significant difference was found between the individual seasons; however, when paired, a post-hoc Tukey test identified autumn and spring as significantly different from winter and summer for both sexes (p adj ≤ 0.001). In both sexes this resulted in an increase in GSI in autumn and spring (Figure 6).

Most whelks experienced some damage between category two and three, the amount of damaged found on the whelk shell did not significantly influence the GSI; however only one individual was found with damage 5 and 11 whelks with damage category 4.

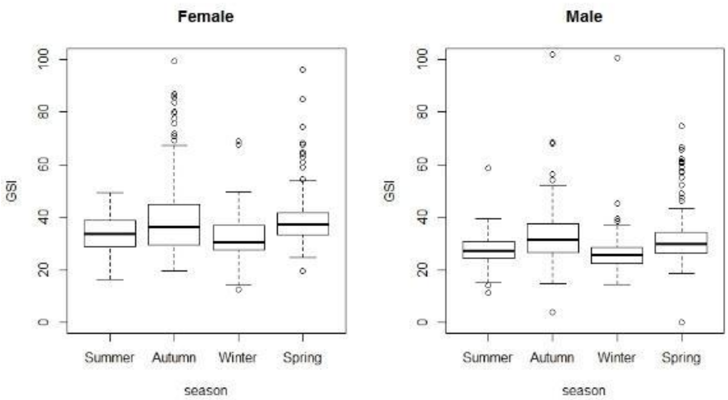


Figure 6. Gonadosomatic index for male and females whelks (*Buccinum undatum*) in each season sampled from Welsh waters between 2013 and 2014. Figure 7 displays a monthly breakdown of this data.

The visual inspection of the gonadosomatic index showed similar monthly patterns for each sex from each location (Fig 7). The increase in autumn was distinct in September and October and the increase in spring was evident in March and May samples for both sexes.

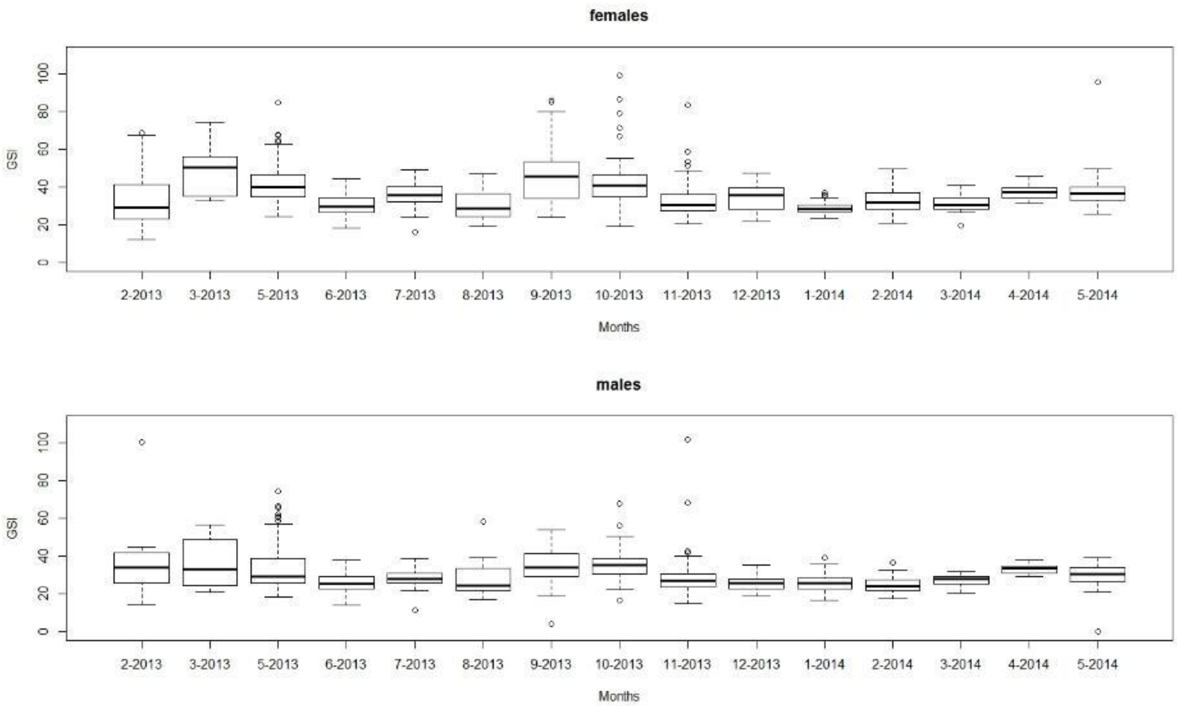
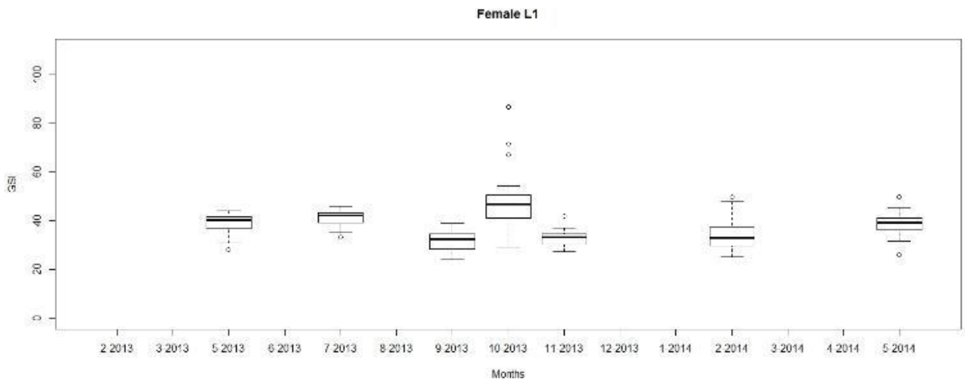
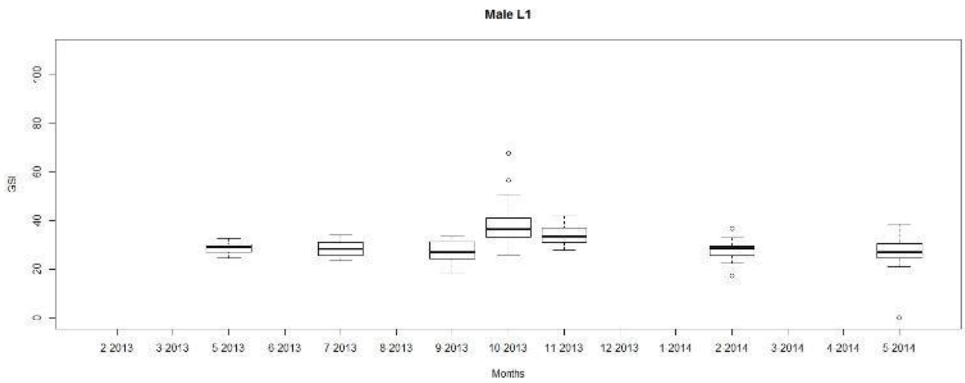
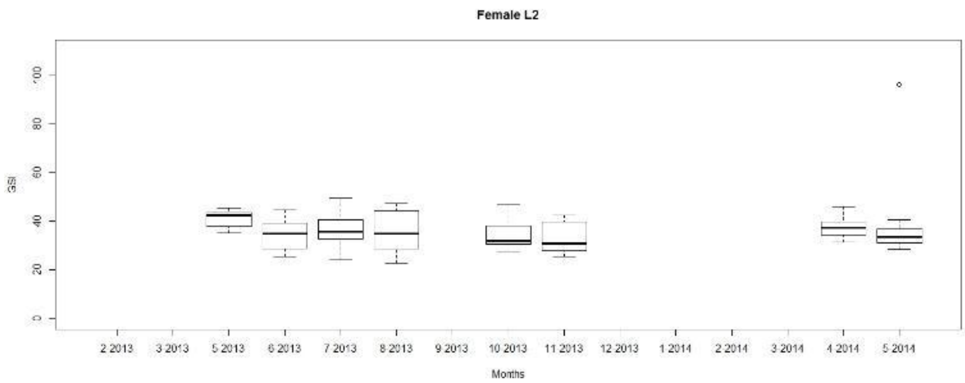


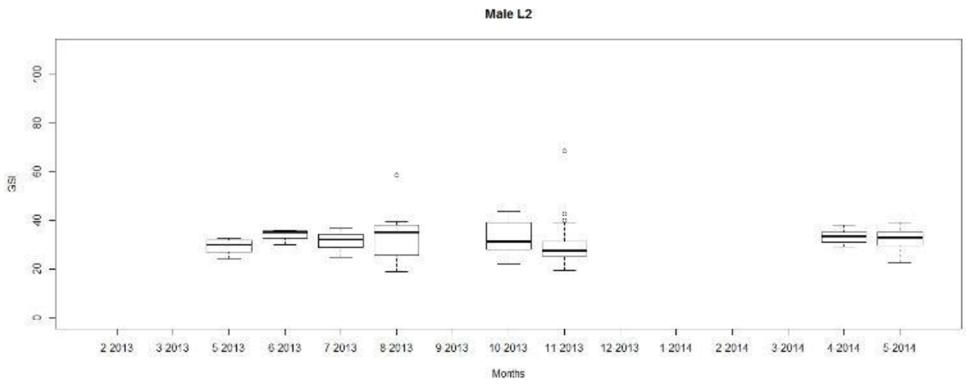
Fig 7. Monthly pattern of gonadosomatic index for males and female (*Buccinum undatum*) from all locations.

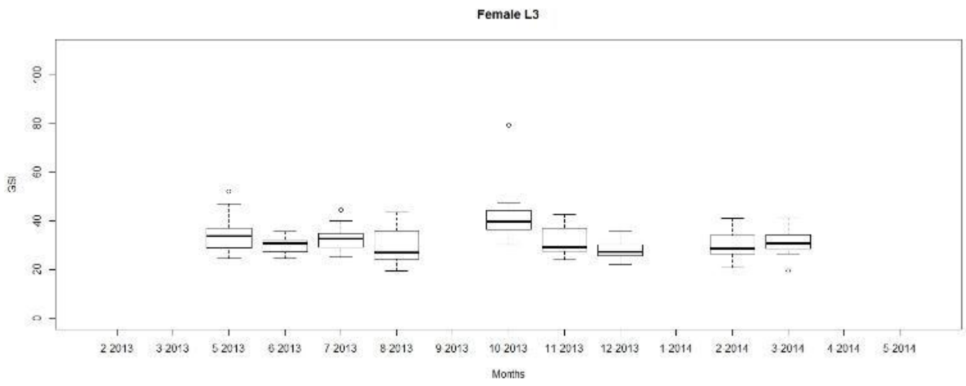
When the data were analysed for variation between months for each location, month was found significantly different for locations L1, L3 and L4 but not L2 (Figure 8). Within each location a TukeyHSD test found that October differed significantly for sites L1 and L3 and the GSI for many months varied for L4, most notably May and September.

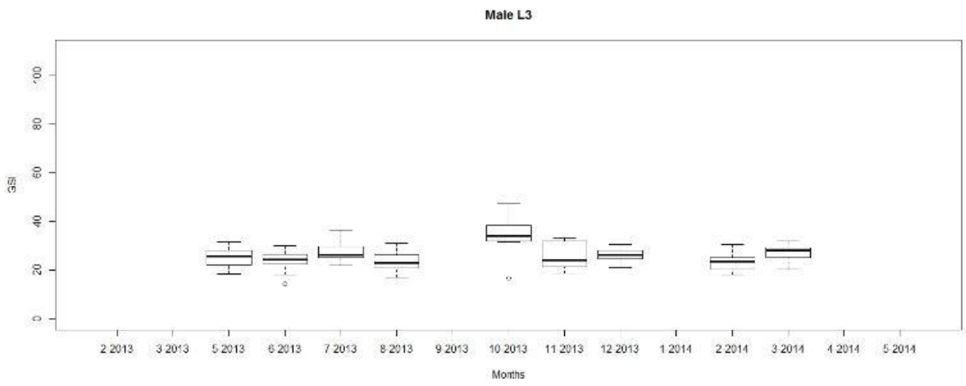







Male L2
GSI
Months
2 2013
3 2013
5 2013
6 2013
7 2013
8 2013
9 2013
10 2013
11 2013
12 2013
1 2014
2 2014
3 2014
4 2014
5 2014


Female L3
GSI
Months
2 2013
3 2013
5 2013
6 2013
7 2013
8 2013
9 2013
10 2013
11 2013
12 2013
1 2014
2 2014
3 2014
4 2014
5 2014


Male L3
GSI
Months
2 2013
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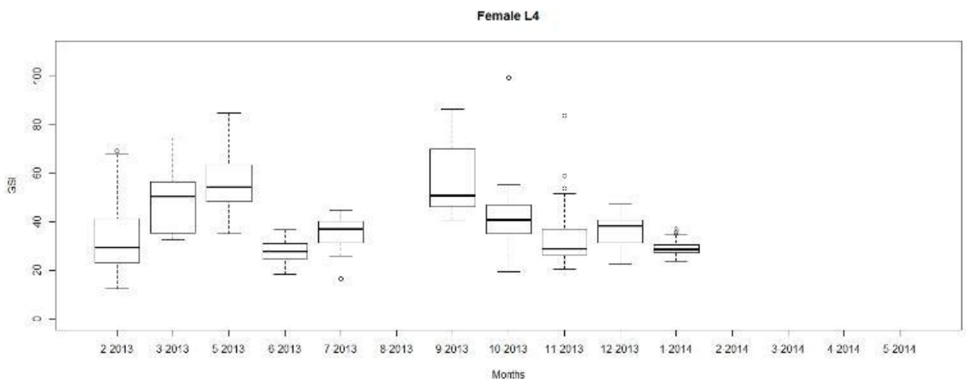
Female L4
GSI
Months
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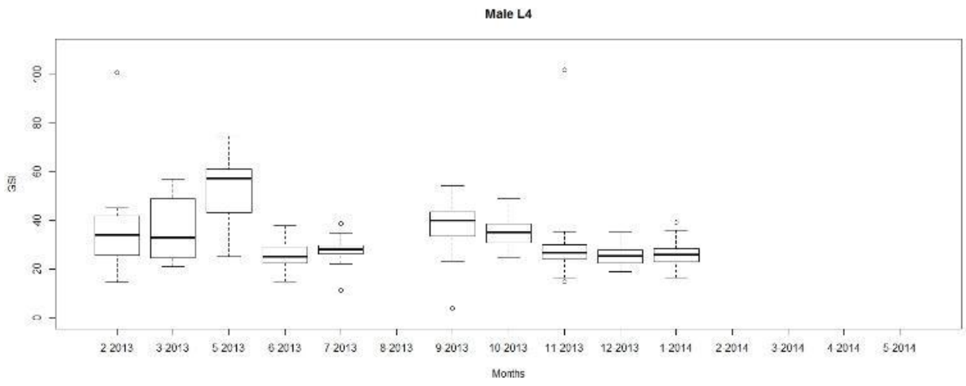

Figure 8. The Gonadosomatic index for *Buccinum undatum* males and females for each month, from each location sampled in Wales between February 2013 and May 2014.

The pattern of differentiation seen in the digestive whorl was used to identify if a peak in GSI was resulting from an increase weight due to feeding or gonad development. When plotted for each sex it was clear that the time in which samples showed the most gonad development was in autumn, and predominantly in October (Fig. 9).

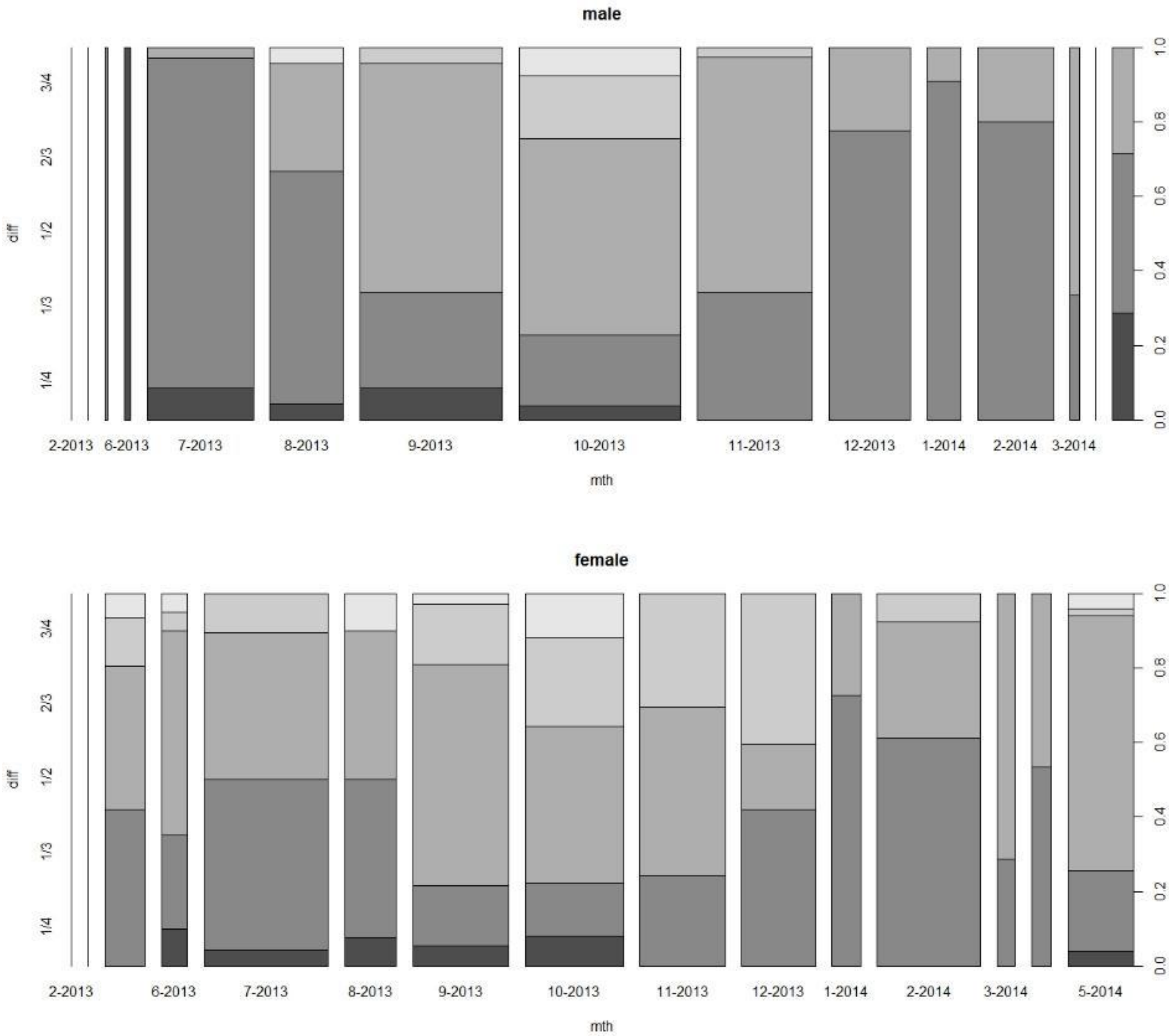

Figure 9. The proportion of the digestive whorl that shows differentiation and gonad development for *Buccinum undatum* for each sex, at each sampled location in Wales between February 2013 and May 2014.

Seasonality in size at maturity

An analysis of covariance between the L_{50} values for sex, location and season (Figure 10) were all found to vary significantly, both individually and as interactions between each of the parameters.

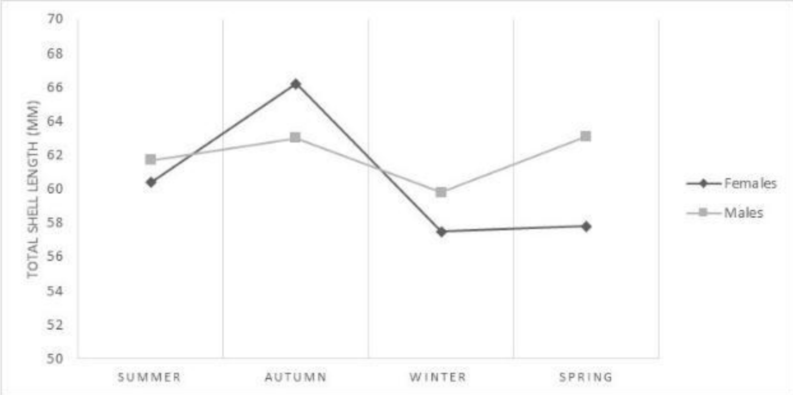

Figure 10: Mean seasonal distribution of L_{50} using visual estimates of maturity for male and female *Buccinum undatum*.

Using morphometric features to indicate maturity in males

Male whelk maturity was also assessed using a morphometric index of penis length to total shell length; where whelks with a penis length greater than 50% of the total shell length were considered mature (Gendron 1992). PL_{50} was estimated and compared to the L_{50} from observations of the gonad. The morphometric method estimated maturity at size ranges well above the gonad method (Table 5).

Table 5. A comparison between morphometric and gonad estimates of population maturity for the whelk *Buccinum undatum*. The morphometric measurement was the PL_{50} (the total shell length at which 50% of the population are mature using a morphometric indicator of relative penis length).

Location	Gonad L_{50}	Penis PL_{50}	Upper CI	Lower CI
L1	64.3	71.5	75.04	67.11
L2	70.4	82	84.94	79.15
L3	63.3	78.5	81.94	75.03
L4	57.8	67	69.27	64.78

To determine if male penis length is an effective indicator of male maturity an iterative search procedure was used with the following linear model: $TSL \sim PL*I(x<c)+x*I(x>c)$, where * is main effects and interactions for both variables, TSL is the total shell length, PL is the penis length and c is the breakpoint at which lowest mean standard error value was obtained for each iteration (Crawley 2007). For pooled morphometric data for all sampled males, an inflection was identified at 65 mm TSL using penis length (Figure

11).. This estimate was only slightly higher than the L_{50} for all pooled males using the gonad assessment method (61.8 mm TSL).

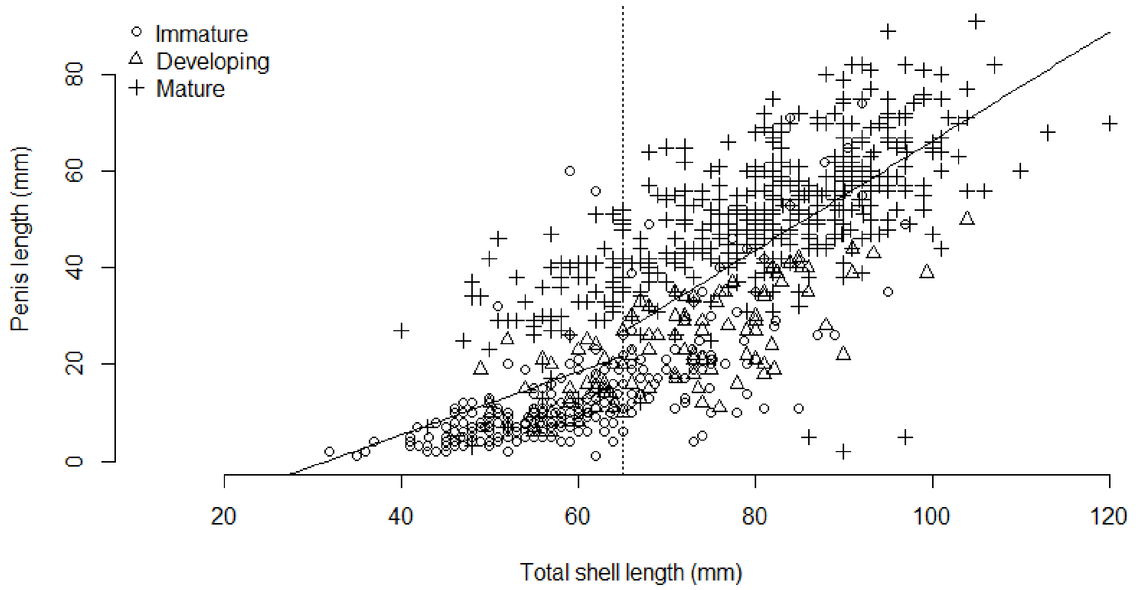

Figure 11. Inflection point based on morphometric variance between iterative tests on linear models of penis length and total shell length for the whelk *Buccinum undatum*. The dotted vertical line highlights the inflection value with the lowest mean standard error (65 mm TSL). Maturity stage determined from visual estimates is shown.

Length frequency and size at maturity.

The length frequency distribution (Figure 12) was analysed using an analysis of covariance with sex, season and location. Total shell length varied significantly with sex ($F_{1, 5042}$=6.90, p<0.01), season ($F_{3, 5042}$=35.71, p<0.001), and location ($F_{3, 5042}$=377.56, p<0.001); and a significant interaction was revealed between location and sex ($F_{3, 5042}$=4.23, p<0.01) and location and season ($F_{8, 5042}$=324, p<0.001), but not between sex and season.

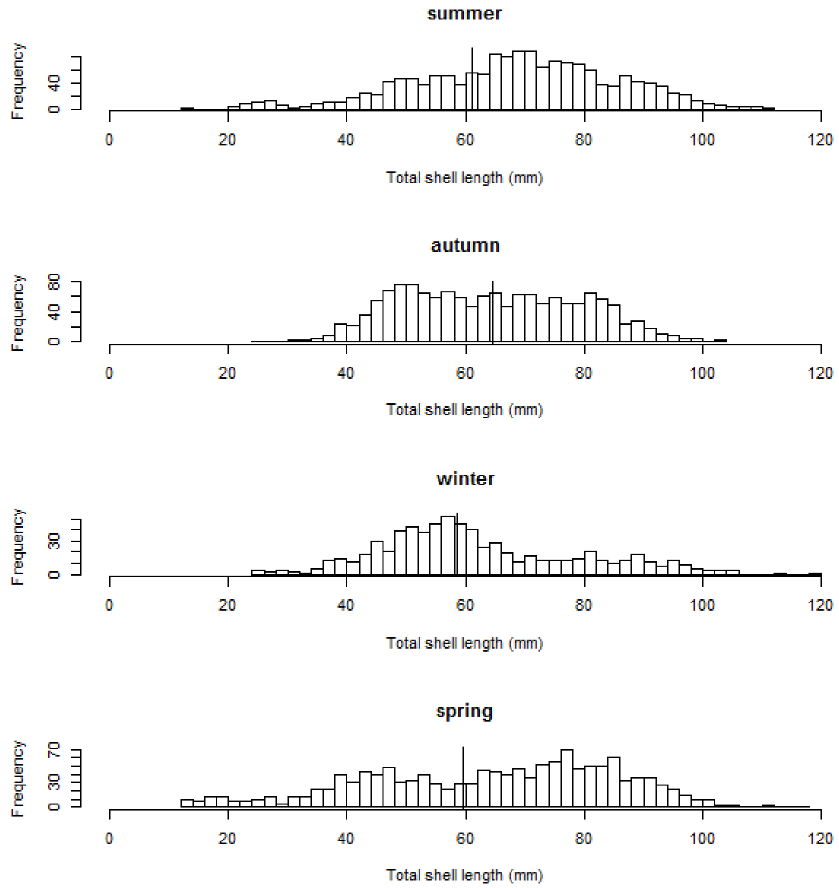

Figure 12: Seasonal total shell length distribution of *Buccinum undatum* for all locations in Wales. The vertical solid line indicates the value of L_{50} estimated for each season on data pooled by location.

The total shell length distribution varied between locations ($F_{3,5073}$=349.9, p<0.001) and also sites ($F_{7,4732}$=264.6, p<0.001; Figure 13). The percentage of animals caught between the minimum landing size of 45 mm TSL and L_{50} ranged from 7-58 % for sites (Figure 13).

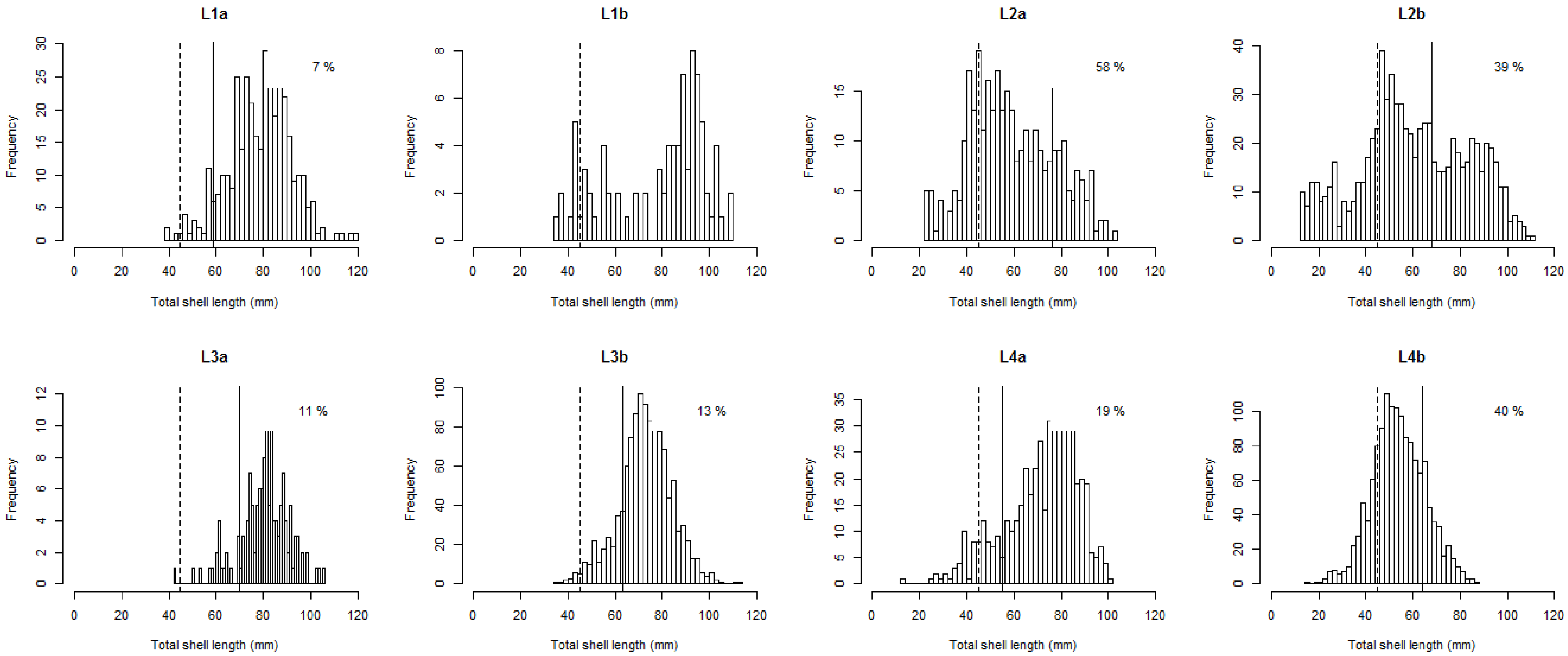

Figure 13: Total shell length distribution of all samples of *Buccinum undatum* from sites in Wales. Solid line indicates L_{50} for the site and the dashed line indicates current minimum landing size of 45 mm total shell length. The value shown is the percentage of the catch between MLS and the L_{50} value for the individual sites. Site L1b did not have sufficient data to produce an L_{50} and so no value is shown on this figure.

Whelk management survey results

Riddling and MLS

Three of the four fishers grade their catch with riddles of 20,22 & 25 mm riddles, depending on where and when they are fishing and what the catch size is. Some fishers had undertaken length/width measurements of whelks to assure that their riddles were effective for eliminating undersize whelks. All fishers said they would support a mandatory requirement to riddle catch.

Three of the four fishers supported an increase in MLS suggesting increases of 50 and 75 mm ("the same as the Isle of Man"). One fisher suggested a decrease in MLS to 40 mm. The idea of a pan-Wales approach to MLS was only supported by one fisherman with others responding that it was "too complex" to comment on, or that we should have a north / south split in MLS. An increase in MLS to 70 mm would not result in fishers changing grounds, though it would influence the number of days at sea for some fishers. Two fishers said that no change in days at sea would occur, one fisher said he would increase effort between March and August and another fisher said he would lose 100% of his days at sea between October and March if an increase to 70 mm MLS was brought in. This loss in fishing days would not be offset by increased effort in other months or a change in area as weather inhibited fishing in other areas over the months between October to March. All fishers responded that they were not able to increase landings of other target species in response to any loss in whelk landings.

Effort control

All fishers supported the idea of opening discussions on a pot limitation scheme, with three of four strongly supporting a cap on the number of pots. The following effort management measures were mentioned: capping the number of pots per licence, by boat size, by historical fishing allocation, and by number of crew. All fishers maintained that they have a CPUE cut off that allows them to "rest" grounds to ensure they are productive later in the season, or in the following year. Two fishers expressed concerns about large fishing operations, where large boats fish "around the clock". These large boats are perceived to have a much lower CPUE cut off point and could potentially be fishing well below sustainable levels. Half the fishers support a separate whelking licence, with two fishers suggesting different pot allowances for inside and outside the six nautical mile limit to protect inshore fisheries for small artisanal fishing operations.

Closed seasons for spawning

A closed season for whelks would not effect fishers that also prosecute scallops, for which there is an open season from November to May each year. All fishers were effected by closed seasons between August and November (to protect breeding whelks) but only two were effected by closed seasons between January and February (to protect laying females). One fisher commented that laying whelks were self protecting, in that they not feed and so are not caught during this season.

Discussion

An assessment of morphological methods to determine maturity

Males have been considered mature if the penis is at least as long as 50% of the total shell length (Santarelli 1985) which was originally based on early observations of male maturity (Koie 1969) and has been continually used to either confirm or identify male maturity for *B. undatum* (Martel *et al.* 1986; Gendron 1992; Fahy *et al.* 2000; McIntyre *et al.* 2015). For this study a total of 16 male whelks between 51 and 97mm TSL had no differentiation in the digestive whorl and thus were classed as immature, though they had a penis index greater than 50% and so according to the literature, were mature. There was no discernible seasonal pattern when large immature whelks were detected, as they were found in all seasons and all locations, they did not have extensive damage, nor were there any obvious signs of disease (evident from a mottled pattern in the gonad).

We used an iterative process on a linear model to detect changes in morphology influenced by the onset of maturity. Our initial test on penis length detected an inflection point at 65mm TSL, which was similar to the pooled value of L_{50} using the visual assessment of the gonads (61.8 mm TSL). These results confirm that a penis length that is 50% of total length is a reasonable method of identifying mature males that do not display typical gonad differentiation.

Other studies have found that PL_{50} closely resembles L_{50} (McIntyre *et al.* 2015); though PL_{50} consistently overestimated maturity in our dataset. As there is no detailed methodology for measuring a whelk penis, it is possible methods are not consistent between studies. Further, seasonal estimates of L_{50} vary, inhibiting direct comparisons between some studies.

GSI and seasonal variations in maturity

Welsh populations of *Buccinum undatum* displayed a significant increase in gonadosomatic index (GSI) in autumn and a decrease in winter suggesting that spawning occurs with the onset of winter. Two sites showed significantly greater GSI values in October and one in September. These results together with the pattern of gonad differentiation identify August to October as an annual peak in gamete production for Welsh whelk populations in 2013. Similar patterns were observed in gonad weight of *B. undatum* from the south-west Irish sea where gonads were heaviest in autumn and lightest at the end of winter (Fahy *et al.* 2000). The marked decrease in GSI together with the increased number of observations of egg casings attached to pots and also washed up along Welsh shorelines through winter indicate spawning occurs a few months after the peak in gonad activity. The spring peak in GSI was not as obvious, an only significant at the most southerly location, in February, March and May for both sexes. The fisher reports an increase in CPUE during these months at L4, as whelks being feeding after a winter lull.

The estimation of L_{50} varied in a similar pattern to GSI, which an increase in L_{50} detected in autumn and spring. This suggests that the visual method of estimating L_{50} introduces a seasonal error. The inability to accurately assign maturity in some seasons, for example when *B. undatum* females were in a recovery phase or when males were storing sperm would underestimate the number of mature whelks, thus shifting the curve to the x and xestimating the size at maturity. Given the seasonal nature of reproduction, the ideal season to visually assess size at maturity is when the majority of individuals display maximum gonad differentiation, which for Welsh populations is in autumn (September to November). In other seasons it may be necessary to incorporate other indicators for maturity (such as penis length) or to undertake histology to confirm visual assessments. Other sources of error may arise from the capture method (baited pots), if egg-laying whelks cease to feed during winter the proportion of mature females may be underestimated. This can be seen in the length frequency patterns, as there is an increase in the proportion of immature cohorts caught in winter samples, though an even distribution of mature and immature samples in autumn.

Regional variation in size at maturity

Regardless of seasonal fluctuation in estimates of maturity, it is clear that the size at which *B. undatum* become mature varies over small spatial scales for Welsh, English (McIntyre *et al.* 2015) and Canadian (Gendron 1992) populations. Our assessment of populations in autumn was limited due to access to samples during this time, nonetheless it was possible to determine size at maturity for two of the four populations (autumn L_{50} L1 = 65.1 mm TSL; L4 = 62.3 mm TSL). That whelk size at maturity is regionally variable presents some difficulties for management of *B. undatum* stocks. The length frequency and size at maturity for each of the eight sites varied significantly, with differences seen at spatial scales of less than eight miles (data not shown to maintain confidentiality). The proportion of whelks between the current MLS of 45mm TSL and the L_{50} varied with each location; between 7 - 58% of the catch from the scientific post were immature. It has been argued that the scientific pots have a different catchability to the majority of gear fished in the industry, with the “Fish-tec” pots having a “cleaner” haul (less undersize and bycatch), if this is true we would expect that the industry catches of immature whelks to be even greater than those caught in the science pots. Regardless of the science pot catchability, it is clear that the current MLS does not protect brood stocks in Welsh waters. The persistent removal of immature whelks exposes whelk populations to growth overfishing, whereby the removal of whelks under size at maturity interferes with a maximum yield per recruit, this is the result of fewer animals are reaching maturity prior to being caught.

The Welsh government are currently considering appropriate management options for whelk stocks. The *B. undatum* fishery is “data poor” and for both Wales and England, stock assessments are not available to inform total allowable catch limits (McIntyre *et al.* 2015). Gear restrictions and closed seasons are management options that are available as a method of managing *B. undatum* stocks. Under a hypothetical increase of the MLS to 70mm TSL landings would be disproportionately effected in different regions of Wales. Our total annual catches under 70mm TSL varied from 37% in the north to 67% in the south. At the site scales 11% of catches at L3a were under 70 mm TSL compared to 90% at site L4b. An increase in MLS would not result in a change of fisher’s behaviour for those engaged in this study, either by displacing effort into other areas, or onto other target species.

Fishers displayed considerable concern on displaced effort from other fisheries into the whelk sector. Whelk fishing is comparatively cheap to enter into and with decreased landings and increased restrictions in other fishing sectors an expected increase in whelk effort is expected. With no effort controls and unmanaged latent effort the future sustainability of whelk fishing is at risk. Fishers were most open to the idea of effort control (as opposed to closed seasons or minimum landing sizes) to manage the whelk fishery.

The future for whelk fisheries science

Research is currently being undertaken to develop more accurate methods of aging whelk, and also to determine the growth rates for *B. undatum* under different environmental scenarios (personal communication Philip Hollyman, Bangor University). The results from these studies are important for stock management as they will inform a time line for expected stock recoveries. Further, the combination of accurate aging techniques and size at maturity research will build a better demographic picture of whelk sub-populations and potentially highlight areas of optimum growth or important juvenile habitats in Wales. This research, together with a comprehensive maturity protocol (Hollyman and Haig in prep) should allow for better comparative and more collaborative whelk fisheries science in the future.

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Appendix 1. Format of the survey undertaken with fishers in 2015

Management scenarios for the common whelk (*Buccinum undatum*) fishery in Welsh waters

Socio-economic survey questionnaire

Fisheries and Conservation Science Group, Bangor University

Interviewer: ____________________________

Interviewee: ____________________________

Date: ___ / ___ / _____

Time: ____:____

Location: ____________________________

Home port: ____________________________

Terms used.

TSL Total shell length

MSL Minimum landing size

L_{50} The size at which the sampled population is found to be 50% mature. Considered the size at onset of maturity.

Fisher to be presented with the most current research data on the size at maturity of *Buccinum undatum* in Welsh and English waters prior to interview.

Riddling and minimum landing size (MLS)

1. Do you currently riddle your whelk catch?

Yes ☐

No ☐

2. If yes, what size riddle to you use?____
3. If you riddle above 45 mm why?____

____

4. Do you support a mandatory requirement to riddle whelk catches on-board?

Yes ☐

No ☐

Reason:____

____

5. Would you support an increase in MLS for whelks?

Yes ☐

No ☐

6. Based on recent scientific evidence that whelk maturation is regionally variable (and that L_{50} is between 51 and 76 mm TSL for Wales (Bangor University) and between 44.8 and 77.8 mm for England (CEFAS)) do you think that a **pan-Wales MLS** is a reasonable option?

Yes ☐

No ☐

Comment:____

____

7. Given the recent scientific evidence (that L_{50} is between 51 and 76 mm TSL for Wales (Bangor University) and between 44.8 and 77.8 mm for England (CEFAS)) **what do you think is a reasonable MLS** for Wales? ___________________________________ (mm TSL).

MANAGEMENT SCENARIOS

Increase in MLS

If the MLS increases to **70 mm** (currently a purely hypothetical scenario) in order to protect stocks, how would your:

8. **Fishing practice change?**

Temporal change (+ / - number of fishing days) of the gears used now and expected gear in the future. E.g. current 40 pots all months future 40 pots only in Jan after MLS change. *For example, current gear (whelk pots) decreased -10 fishing days in April and May with a subsequent increase in lobster pots to make up for the change. Future gear is an anticipated change in the gear type e.g. changing to trawling instead of whelking.*

Current gear	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
Whelk												
Lobster												
Future gear	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***

Spatial & temporal fishing behavioural change (new/different fishing grounds)

9. What percentage of your current fishing days with whelk pots will be located on a different ground as a result of a MLS change? *(Just indicate how many days more on new grounds)*

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
%												

10. On average, are these new grounds at the same distance from your home port of the actual grounds?

Yes ☐

No ☐

11. If not, how many miles (on average) are they closer or further from the port with respect to current grounds?

_______________________ miles (+ / -)

12. Are these new grounds already exploited for whelks?

Yes ☐

No ☐

13. Are these new grounds already exploited for other species?

Yes ☐

No ☐

If yes then which species____

14. Can you estimate how much will the fishing pressure increase on these new grounds? *(if not % then number of fishers present on the patch now and expected number in the future under the management scenario)*

___________ %

15. **Business COSTS change (+/-)?**

Fuel costs _________% Crew share _______% Total crew _______%

Bait costs _________% Maintenance _______%

Investments (fishing gears) _________%

16. **Business LANDINGS change (in kg/t)?**

Please indicate the variation (**% of kg/t**) by species and if this variation will occur during some specific months or if it will occur in general during all year long (overall).

Species	**+/- %**	**During specific months (indicate the months)**	**Overall**
e.g. whelk e.g. crab	4 tonne +8 tonne		Overall Overall

Other changes/comments?

____
____
____
____
____
____
____
____
____
____
____
____
____

Effort control (Pot limitation)

17. Approximately how many pots do you have?

Crab/Lobster: _______

Prawn: _______

Whelk: _______

18. Do you think that industry needs to begin discussions on pot-limitation schemes?

Yes ☐

No ☐

Reason:____

____

____

19. Do you support the idea of capping fishing effort in the Welsh whelk potting sector?

Yes ☐

No ☐

Reason:____

____

____

20. What do you think would be the most equitable form of effort control for **number of pots**? (circle)

- Commercial Pots per licence (an even number for all licences)
- Historical fishing allocation (based on the number of pots you have previously fished)
- Crew- based allocation (more crew = more pots)
- Boat-length based allocation (bigger boats = more pots)
- Other:____

21. Do you think that there should be a separate licence to fish for whelk?

Yes ☐

No ☐

Reason:____

Closed season for spawning

If a two month closure was introduced (again a purely hypothetical scenario) in order to protect spawning stock, how would your:

22. Fishing **practice** change for any given month?

TEMPORAL CHANGE (+ / - number of **fishing days**) of the gears used now and expected gear in the future. E.g. Your future fishing days may change as a result of

Current gear	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
Whelk												
Lobster												
Future gear	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***
whelk												

23. Business **LANDINGS** change (in **kg/t**)?

Please indicate the losses that a closed season would result in (**% or kg/t**) by species. And will this loss be compensated for by increased landings in other months or increase landings of another species.

Species	**+/- %**	**During specific months (indicate the months)**	**Overall**
whelk	_____ tonne loss	September / October	

Other changes/comments?

____

____

____

____

____

____

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____

Appendix 2. Summary statistics for total shell length, L50 and L95 for the whelk *Buccinum undatum* populations collected from Welsh waters in 2013 - 2014. Summaries were made for pooled data, then sub-divided by sex, season and location. TSL, total shell length; CI, confidence interval.

Data		**Min TSL**	**Mean TSL**	**Max TSL**	**L50**	**Upper CI**	**Lower CI**	**L95**	**Upper CI**	**Lower CI**
All	All data	12	66	120	**60.6**	62.3	58.9	90.1	88.7	82.1
Sex	Females	13	65	113	**60.6**	62.2	58.8	85.3	89.1	82.1
	Males	12	66	120	**61.8**	63.6	59.8	90.1	93.9	86.4
Season	Summer	12	69	111	**61**	63.7	58.2	85.4	90.5	80.9
	Autumn	25	65	104	**64.5**	66.4	62.3	91.7	97.5	86.8
	Winter	25	63	120	**58.6**	60.7	56	83.9	89.9	78.2
	Spring	13	65	118	**59.7**	62.8	56.2	87.1	92.2	82.3
Location	L1. North Wales	30	75	120	**64.3**	67.4	61.4	83.4	87.8	78.7
	L2. North Mid-Wales	13	60	112	**70.4**	72.9	67.6	93.7	99.1	88.6
	L3. South Mid-Wales	35	74	113	**63.3**	66.4	58.5	90.2	97.8	84.6
	L4. South Wales	12	59	101	**57.8**	59.2	56.1	81.2	84.9	77.8
L1	Summer	34	79	110	**74.1**	NA	NA	74.8	NA	NA
	Autumn	30	66	102	**65.1**	70.4	60.4	87.1	103.6	72.8
	Spring	43	87	118	**64.1**	NA	NA	64.8	NA	NA
L2	Summer	22	64	110	**68.4**	74.8	61.1	92.9	106.6	81.0
	Spring	13	57	112	**60.8**	66.9	92.6	84.7	92.6	76.2
L3	Summer	35	71	111	**64.6**	NA	NA	76.3	NA	NA
	Autumn	54	81	104	**77.4**	129.3	15.9	106.0	405.9	-92.4
	Winter	42	82	106	**60.0**	240.7	-44.5	81.0	112.0	61.3
	Spring	40	75	113	**64.1**	70.6	41.6	80.9	94.3	68.9
L4	Summer	12	69	101	**52.3**	57.7	39.0	74.7	89.0	61.8
	Autumn	25	61	100	**62.3**	66.0	58.3	85.4	93.6	78.1
	Winter	25	55	82	**57.4**	60.7	54.1	80.0	97.3	70.0
	Spring	15	55	95	**53.1**	57.9	45.2	64.7	73.3	51.6
Sub-location	L1a	38	79	120	**59.2**	65.1	47.8	86.5	93.6	79.9
	L2b	22	60	104	**76**	82.5	70.9	101	118.3	87.5
	L2b	13	61	112	**68.3**	71.6	64.2	91.9	98.3	86
	L3a	42	81	106	**69.7**	75.2	55.5	91.7	108.7	82.8
	L3a	35	74	113	**62.6**	65.8	57.6	88.3	96.5	82.3
	L4a	12	72	101	**65.4**	68.1	62.9	79.3	82.4	75.5
	L4b	15	54	88	**56.7**	58.4	55	81.2	88.3	75.9
Females	Summer	22	68	110	**60.4**	64.1	56.4	83.5	90.4	77.2
	Autumn	25	64	102	**66.2**	69.1	63.2	95.7	106.6	88.2
	Winter	25	64	106	**57.5**	60.2	54.2	79.3	86	72.2

	Spring	13	64	113	**57.8**	61.8	52.7	78.7	83.9	73.8
	L1	30	75	111	**64.5**	67.8	61.1	80	85	73.4
	L2	13	59	107	**66.5**	70.2	62	92.3	101.7	85
	L3	35	74	113	**63.9**	70.2	62	87	101.7	85
	L4	15	58	100	**57.7**	59.7	55.6	80.3	86.3	74.8
Males	Summer	12	70	111	**61.7**	65.2	56.5	87.3	94.6	80.7
	Autumn	27	66	104	**63**	65.9	59.9	88.6	95	83
	Winter	29	62	120	**59.8**	63.1	55.9	88.8	100.1	79.5
	Spring	13	65	118	**63.1**	68	57.1	96	106	87.5
	L1	35	75	120	**63.2**	68.2	55.9	87.7	95.9	80.2
	L2	13	62	112	**74.8**	78.2	71.5	93.1	99.6	86.6
	L3	39	75	111	**63**	67.6	54.5	93.4	106.7	84.6
	L4	12	61	101	**57.9**	60.1	55.5	82	87.4	77.4