Determination of the Abundance and Population Structure of *Buccinum undatum* in North Wales

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Declaration

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This dissertation is being submitted in partial fulfilment of the requirement of the M.Sc. in Marine Environmental Protection.

The dissertation is the result of my own independent work / investigation, except where otherwise stated.

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Abstract

A mark-recapture study and fisheries data analysis for the common whelk, *Buccinum undatum,* was undertaken for catches on a commercial fishing vessel operating from The fishing location, north Wales, from June-July 2014. Laboratory experiments were conducted on *B.undatum* to investigate tag retention rates and behavioural responses after being exposed to a number of treatments. Thick rubber bands were found to have a 100 % tag retention rate after four months. Riddling, tagging and air exposure do not affect the behavioural responses of *B.undatum*. The mark-recapture study was used to estimate population size and movement. 4007 whelks were tagged with thick rubber bands over three tagging events. An overall recapture rate of 3.29 % was achieved which yielded a mean population size of 11,319,410 over a 26 km^2 area. The mean minimum distance travelled by *B. undatum* over 24 hours was 111.3 m. The total shell length of 9041 whelks was measured during five sampling days. Total shell length was found to vary significantly with pot colour, pot type, depth, and habitat. On average 3.16 kg of whelks were landed per pot. Catch per unit effort varied significantly with depth, with the shallower depths having lower catch per unit efforts. Over the five sampling days 32.56 % of the whelks caught were undersized (less than 45 mm total shell length). Out of the total number of whelks caught 2.93 % was bycatch, 59.62 % of this were netted dog whelks (*Nassarius reticulatus*).

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I would like to thank all of the people who helped and supported me with this research project.

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Abbreviations

TSL	Total shell length
MLS	Minimum landing size
CPUE	Catch per unit effort
MSY	Maximum sustainable yield
GIS	Geographical information system

Introduction

The aim of this thesis is to collect baseline data on the population structure and ecology of the marine gastropod *Buccinum undatum* off the Llyn Peninsula, north Wales*.* Gastropods are an extremely diverse taxonomic class within the phylum Mollusca (McArthur and Harasewych, 2003). Gastropod species vary in behaviour, feeding, reproductive cycle, and favoured habitat making generalities between them hard to find. Marine gastropods were first recorded from the Late Cambrian period; there are now approximately 30,000 known species. *Buccinum undatum*, also known as the "common whelk", is one of the largest marine gastropods. It is the most abundant species of gastropod mollusc inhabiting the North Atlantic (Kideys et al., 1993). *B. undatum* has a pointed spiral shell with a white/yellow body flecked with black (Figure 1). The body consists of a ventral foot and head with two tentacles, the eye spots are located on the top

Figure 1: Photograph of a tagged *Buccinum undatum* out of the water with its siphon extended © Zara Turtle

of the tentacles. The operculum acts as a trap door, closing the shell, and is made of a calcareous material. *B. undatum* must make full use of its sensory organs; including its olfactory organs (sense of smell), statocysts (balance sensor), eyes and mechanoreceptors (which respond to mechanical pressure or distortion) (Chase, 2001) because it has no hearing. The siphon is used to draw water into the mantle cavity and over the gills; this both supplies the gills with water (to extract oxygen) and enables the whelks to "taste" the water for the presence of food. To feed, *B. undatum* use their radula; this has very small teeth and is used for cutting food before it enters the oesophagus. *B. undatum* have a life span of about 10 years and can grow to a total shell length (TSL) of 110 mm (Hayward and Ryland, 1995). They are usually found between the sublittoral zone and the continental shelf edge and have been observed to live on a variety of substrata;

including coarse and muddy sand, rocks, and gravel. *B. undatum* inhabit colder waters with a salinity of 20-30 ppt. In water temperatures greater than 12 ^{o}C they become stressed, lying on their backs (Himmelman, 1993). Due to differences in diet or habitat preference older whelks have been found to inhabit deeper waters, whereas younger whelks are found in shallower waters (Valentinsson et al., 1999). *B. undatum* are regarded as a K-selected species as they are late maturing, slow growing, and have a low fecundity (French, 2011). This puts populations at risk of overfishing as recovery rates are slow. When in search of food the maximum distance a whelk has been recorded travelling in one day is 50 metres (Pardo and Johnson, 2004). Due to their limited movement *B. undatum* populations are expected to have a low inter-population connectivity, reducing the gene flow between whelk populations. This will further reduce their recovery rate from over-exploitation.

Diet

To detect food *Buccinum undatum* "smell" the water by inhaling the seawater into their siphon and across sensitive chemo-receptors (Gendron, 1992). They have been observed to move at speeds of up to 10 cm per minute whilst in search of food (Gendron, 1992). *B. undatum* are both predators and opportunistic feeders (Morissette and Himmelman, 2000), feeding on molluscs, polychaetes, echinoderms, small crustaceans, and mussels (Valentinsson et al., 1999). Food availability and prey species varies for whelks in different habitat types. In a study of the stomach contents of *B.undatum* in the northern Gulf of St Lawrence, Canada, fragments of urchins, polychaetes and amphipodes were found in the stomach of whelks from sandy sediment. Whereas decapod crustaceans and fish eggs were the most common prey found in the stomach contents of whelks from rocky habitats (Himmelman, 1993).

Reproduction

The reproductive cycle of *Buccinum undatum* varies in timing and duration, depending on the location and therefore water temperature (Heude-Berthelin et al., 2011) as seen in Table 1. When the water reaches approximately 10 ^{o}C female whelks release pheromones into the water to attract male whelks (Kideys et al., 1993). Whelks mate by copulation and the eggs are fertilised internally. Female whelks accumulate the sperm cells from a number of males until external conditions are at their most favourable. On average female whelks produce up to 2,000

Table 1: Time of mating and egg laying of *Buccinum undatum* in Europe (French, 2011), Canada (Heude-Berthelin et al., 2011) and Northern Gulf (Himmelman, 1993)

Location	**Mating Period**	**Eggs Laid**
Europe	Autumn	December-January
Canada	Late spring	Early autumn
Northern Gulf	May-June	June-August

egg capsules, each one protecting up to 3,000 eggs (Hancock, 1963). However only one percent of the individuals hatch from each capsule (Smith and Thatje, 2012). Development to a juvenile stage (3.0 mm in size) is intra-capsular and takes between three to eight months, including seven ontogenetic stages. Not all eggs develop into larvae and the first veligers to develop consume the surrounding "nurse" eggs in the capsule. The larvae use these nurse eggs as nutrition. It is estimated that only one percent of eggs from each egg capsule successfully develop into juveniles (Heude-Berthelin et al., 2011). Female *B. undatum* expend six times more energy than male *B. undatum* during the reproductive cycle. Females can lose up to 10.5 % of their body mass during reproduction, compared to a 1.6 % loss of body mass in males (Martel et al., 1986). Females use the bulk of their energy to produce the protective egg capsules to enclose their eggs before laying them (Brokordt et al., 2003). This considerable loss in energy reserves compromises their escape responses, leaving the female *B. undatum* vulnerable to predation.

Growth

Growth rate of *Buccinum undatum* varies with geographic location but has generally been found to be a slow process. *B. undatum* have been observed to grow approximately 2.5 cm in their first year (and decreasing amounts in the consecutive years) in south east England (Hancock, 1963). Geographic variation in growth rates leads to corresponding differences in total shell length (TSL). For example *B.undatum* measured off the Shetland Isles had a mean TSL of 76 mm, whereas *B.undatum* measured off the south coast of England had a mean TSL of 54 mm (Shelmerdine et al., 2007). This makes the setting of a single minimum landing size for *B. undatum* can be problematic. Any minimum landing size that is set, will disproportionally affect fishermen across Europe. Shell thickness and repair affect the growth rate of whelks. When the shell of a whelk is damaged a large amount of energy is needed to repair it, causing a decrease in the whelks' growth and movement. Growing a thicker shell will also reduce their growth rate but will provide better protection from predators.

Predators

Starfish, decapods, cod, dogfish, and humans are the common predators of adult *Buccinum undatum* whereas the larvae are predated by sea-urchins. Both juvenile and adult whelks have been observed to effectively identify and escape predators (Rochette et al., 1995). The common whelk has developed a number of dynamic escape responses when threatened by the predatory asteroid *Leptasterias polaris.* These include rapid flight (respective for a whelk), shell rocking, foot contortions, and burrowing (Rochette et al., 2001). *B. undatum* also have physical adaptations to protect from predators such as a thicker shell and outer lip, strong sculpture with low spire, and a narrow aperture. These features strengthen their shell and reduce the probability of being crushed by crabs or fish.

Fisheries

Buccinum undatum have been commercially fished since the 1940s for food and bait. Current global whelk landings have an annual value of over £7 million in 2007 (French, 2011) and consist of catches from Ireland, Belgium, Iceland, France, Canada, and the United Kingdom (Shelmerdine et al., 2007). In England and Wales whelk landings were worth over £10 million in 2012 (Lawler, 2014). Over the last 20 years an increased demand from commercial markets in the Far East, has resulted in a dramatic increase in landings (French, 2011). This can be seen in the landings data from 1985-2011 in the North Sea, North West Scotland, Northern Ireland, and Irish Sea (Figure 2). The levels of local stock and the condition of the market influence the

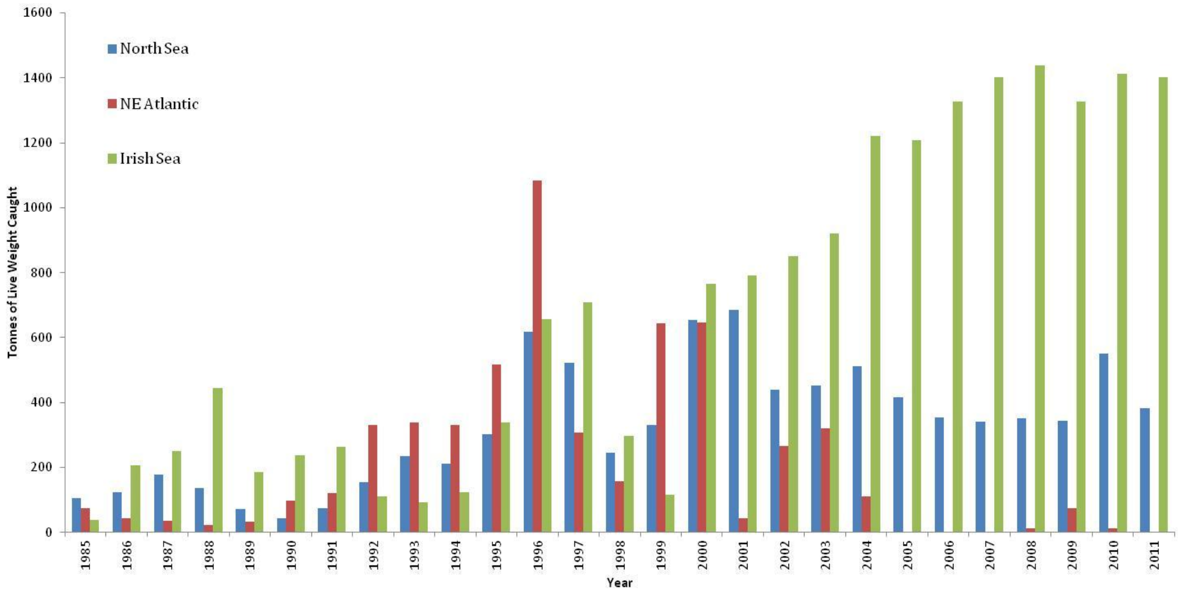


Figure 2: Landings data sourced from ICES from 1985-2011, in the North Sea, North West Scotland, Northern Ireland, and Irish Sea

expansion or depletion of a whelk fishery. Whelk traps, commonly known as pots, (Figure 3) have a netted entrance with a quick-release toggle. The net prevents the whelks from escaping and helps to keep the catch from escaping during stormy conditions. The holes in the side of the pots provide an escape route for undersized whelks and allow excess mud and water to drain from the pots during hauling. Whelk pots are relatively inexpensive (£7-25 each) making it comparatively cheap to get involved in a whelk fishery; this results in large fluctuations in the fishing fleet numbers.

Figure 3: Picture of a whelk pot used by common whelk fishermen in Swansea, South Wales © Georgia Robinson

Fisheries Management

The aim of fisheries management is to maintain a sustainably high yield. A maximum sustainable yield (MSY) approach can be used to manage fish stocks. The MSY is the highest yield of a fish stock that can continuously be landed over a long period of time without resulting in a negative impact on the stocks abundance. However, this method has not proven to be effective as 88 % of fish stocks in Europe are currently being overfished (Froese et al., 2011). Successful fisheries management should be based on an ecosystem approach. This approach attempts to take into account the interactions between biotic, abiotic, and human components, however this is often not easy due to the environmental complexity. Currently the whelk stocks are not fished at a MSY. Instead, Annex XII of EU regulation 850/98 has imposed a minimum landing size (MLS) of 45 mm TSL for *Buccinum undatum* (Shelmerdine et al., 2007). Whelk fishermen use riddles (Figure 4) to remove any whelks under the MLS from their catch. The MLS is usually determined by estimating the size at which at least 50 % of the fished stock have reached sexual maturity (L_{50}). However, L_{50} measurements have been found to vary greatly depending on water temperature, and therefore location (Shelmerdine et al., 2007). The development of highly efficient fishing methods and equipment, and the increase in market demand from the Far East, will begin to have a negative impact on whelk populations in the UK (Nicholson and Evans, 1997). Larger whelks inhabit deeper waters so UK whelk fisheries

Figure 4: Riddle used to discard undersized whelks (under 45 mm total shell length) (French, 2011)

(which fish inshore, within 12 nautical miles) are more likely to target younger, smaller whelks. This may result in growth overfishing, where the mean size of the whelks landed is smaller than the ideal size that would produce a maximum sustainable yield.

Welsh Fisheries Management

Buccinum undatum are the third most valuable landed species in Wales with average annual values of £2,536,863 in 2013. European Union and the United Kingdom's national legislations have recently requested proof that fisheries are at safe biological limits and are not having a negative impact the environment. At present the available data for Welsh fisheries is limited, which has significant implications for effective fishery management.

Tag-Recapture

The first recorded tagging attempt was by a Roman officer named Quintus Pictor in 218 B.C., who used thread to mark a bird's leg. Tagging studies on the ecology and biology of fish populations have been used since 1945. They can be used to study the movement and growth of individuals, as well as estimating population sizes. The Lincoln-Petersen method, a "two-sample model", is the simplest capture-recapture model. A number of individuals from the targeted population are captured, tagged, and then released. The number of tagged individuals recaptured is used to estimate the population size at the time of the mark-recapture study. For the Lincoln-Petersen method the following assumptions must be met:

- The population is closed; there is no change in population size during the investigation
- There is no loss of tags; 100 % retention rate of tags
- Marked and unmarked individuals have the same mortality rates
- Marked individuals mix randomly with unmarked individuals
- Marked and unmarked individuals are independent; each has the same probability of being caught in the second sample

The Jolly-Seber method (1965) is a "K-sample" model in which the individuals are distinctly marked and there are multiple recapture sessions. The same conditions as with the two-sample model must still be met. It can be used to estimate survival rate, capture probability, and the number of new individuals immigrating into the population as well as the population size. Table 2 shows the advantages and disadvantages for using capture-recapture techniques (Henry and Jarne, 2007). The common whelk population density over a certain area can be calculated

Table 2: Advantages and disadvantages for the use of capture-recapture techniques

Advantages	Disadvantages
Providing conditions are met, population estimates can be very accurate	Requires large sampling effort
Useful for populations with restricted ranges	Not suitable for highly mobile populations
Permanent tags allow long-term analysis	Repeated capture-recapture can be stressful for the animals
	High percentage (≥50%) of the population needs to be marked to obtain accurate estimates
	Number of capture sessions needs to be high (minimum 4-8) to obtain accurate estimates

using underwater cameras, pot sampling, diving, and mark-recapture experiments (Kideys, 1993). Estimations using mark-recapture experiments and underwater cameras have been found to give overestimates for population density whereas pot sampling and diving methods gave comparable results. When marking animals the tags should have a high retention rate, be reliable, and have no impact on the individual. There have been a number of studies which have involved marking hard-shelled gastropods, including *Buccinum undatum.* A variety of tags have been used including gouache paint, car body paint, glued plastic markers, thin and thick rubber bands, zip ties, and plastic tags inserted through a drilled hole in the shell. When choosing a suitable tagging method for *B. undatum* there are two problems to consider (Henry and Jarne, 2007). Firstly, if paint marks or glue have not dried sufficiently before the whelks are released back into the water it can lead to a poor tag retention rate, resulting in the population size being overestimated. Plenty of space and time is needed for these methods, neither of which will be possible when tagging is taking place on a commercial fishing vessel. Secondly, the tag/mark should not affect the survival probability of the whelk. Survival rate could be reduced by chemical compounds diffusing into the porous calcium carbonate shell, or if relatively bulky or heavy tags impairing the whelks' movement. The tag retention rate and the affect the tag has on the whelk should therefore be quantified before the study.

Aims and Hypotheses

There is currently no published data on the abundance of the common whelk in Wales, so the aim of this project was to collect baseline data on the local abundance, biology and ecology of *Buccinum undatum*.

Observation: Studies have shown that larger whelks are found further offshore and size of whelks varies with habitat due to diet preferences.

> H_1: Total shell length of *Buccinum undatum* varies between habitat types and depth ranges
>
> H_0: Total shell length of *Buccinum undatum* will be similar between habitats and depth ranges

Observation: Smaller whelks live in higher densities.

> H_2: The higher the catch per unit effort the larger the percentage of undersized whelks present
>
> H_0: There will be no change in percentage of undersized whelks present with varying catch per unit effort

Observation: When whelk pots have a long soak time the catch per unit effort will start to decrease due to small whelks escaping, resulting in fewer undersized whelks being caught.

H_3: Longer soak times will result in lower catch per unit effort and a smaller percentage of undersized whelks being caught

H_0: Catch per unit effort and percentage undersized will not vary with increased soak time

Observation: Fishers have observed catching more whelks in white coloured pots

H_4: Catch per unit effort will be highest in white pots

H_0: Catch per unit effort will not vary between white and blue coloured pots

Observation: Whelk prey on rocky sediments consists of decapods crustaceans whereas whelk prey on sandy sediments consists of urchins and amphipodes.

H_5: Percentage bycatch will vary with habitat type

H_0 Percentage bycatch will not vary with habitat type

Objectives

The following objectives will be used to investigate these hypotheses:

- Determination of length-frequency data and catch per unit effort of a whelk fishery off the Llyn Peninsula in north Wales
- Abundance and movement estimates using mark-recapture methods

To assess the tag retention rate and affect of tagging on individual whelks the following studies were undertaken in the laboratory:

- Tag retention study
- Study of the behaviour of whelks after simulated tag-recapture

Materials and Methods

Practical Methods

Sampling at sea took place on-board the 32 ft mono-hull commercial vessel out of north Wales. This vessel fishes with 25 strings with 20 pots per string and eight hours were spent at sea each day. Spider crab and dog fish were used as bait and the soak time typically ranged for 24-72 hours, dependent on weather conditions.

Figure 5: Photograph of the commercial fishing vessel (removed)

Figure 6: Sampling location out North Wales (removed)

Fisheries Data

Fisheries data was collected over five days during June and July 2014. All whelks measured were taken, un-riddled, from the first blue and white pots from every other string. The total shell length (TSL) was measured to the nearest millimetre, from the siphonal canal to the tip of the apex using callipers (Figure 7). After measuring, any by-catch present was recorded and

Figure 7: Measuring total shell length (mm) of *Buccinum undatum* using callipers © Zara Turtle

returned to the sea along with any whelks under the minimum landing size of 45 mm. A GoPro Hero3 drop down camera was used on the same strings that sample pots were collected from to look at the habitat types across the area. The temperature was recorded through June and July using a Tiny Tag 2 temperature logger attached to one of the pots.

Laboratory Experiments

Tag Retention Study

During March, 60 common whelks were caught in the Menai Strait and placed into a holding tank in the School of Ocean Sciences, Bangor University. To test tag retention rate these whelks were tagged with thick rubber bands (Figure 8) and kept in an 83 L tank circulated with sea-

Figure 8: Photograph of a common whelk used in the tag retention study tagged with a thick rubber band © Zara Turtle

water from the Menai Strait. The whelks were inspected twice a week for four months, the number of dead whelks and the number of tags lost was recorded.

Behavioural Response to Tagging and Riddling

In a separate experiment, to test how long it would take the whelks to right themselves after being tagged and inverted, sample whelks were exposed to one of five different treatments. 70 whelks were caught in the Menai Strait and placed into three 83 L holding tanks in the School of Ocean Sciences, Bangor University. The tanks were circulated with sea-water from the Menai Strait. The distribution of whelks and treatments between the three tanks can be seen in Table 3. The control group were left in the tank. Treatment 1 whelks were tagged with neutral coloured thick rubber bands under the water. Treatment 2 whelks were removed from the tank, shaken in a box for one minute (to simulate being riddled) then tagged with yellow thick rubber bands before being

Table 3: The number of whelks used in each treatment and in each tank to study how long it would take the whelks to right themselves after being tagged and inverted

	Control	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Total Number of Whelks
Tank 1	4	5	5	4	5	23
Tank 2	5	5	4	5	4	23
Tank 3	5	4	5	5	5	24

returned to the tank. Treatment 3 whelks were removed from the tank, shaken in a box for one minute, tagged with blue thick rubber bands, left in a bucket exposed to air for one hour then returned to the tank. Treatment 4 whelks were removed from the tank, shaken in a box for one minute, tagged with red thick rubber bands, left in a bucket exposed to air for three hours then returned to the tank. The experiment was timed so that all of the whelks were returned to the tank at the same time. On return to the tank all of the whelks (including the control group) were turned onto their backs and the time taken for them to right themselves was recorded. This experiment was repeated on a separate occasion using 55 whelks, 12 whelks were used in each treatment group. 24 hrs after this experiment was completed the whelks were moved to the middle of the tank and crab bait was placed at the other end. The time taken for the whelks to reach the bait was recorded.

Abundance Estimates

Tagging events took place over four days during June and July on-board'. The types of pots used are shown in Figure 9. Tagging data for each day is shown in Table 4. Only whelks

Figure 9: Photograph of a black whelk pot used by whelk fishermen in Swansea © Zara Turtle

above the MLS (45 mm) were tagged and the bands were applied either by hand or using a lobster bander. The locations in which they were released and re-captured were recorded and illustrated using Arc-Map GIS.

Table 4: Tagging event data

Date	Number of whelks tagged	Number of pots used	Colour of tag
17/06/2014	1043	6	Blue
18/06/2014	879	4	Neutral
30/06/2014	962	6	Yellow
15/07/2014	1123	7	Green

Data Analysis

Statistical analysis was conducted using R software (R Core Team, 2014) or PRIMER (Clarke and Gorley, 2006). All data was tested for normality (Fox and Weisberg, 2011) and homogeneity (Sandrini-Neto and Camargo, 2014) before a statistical test was chosen.

Fisheries Data

The total shell length (TSL) was used to construct a length frequency histogram. A Mann-Whitney test was used to determine any significant differences in TSL between pot colours and between pot types. Length frequency histograms have been used to illustrate the TSL of whelks present in normal and scientific pots. Kruskal-Wallis tests were used to analyse any significant differences in TSL between depth and between habitat types (Girdaudoux, 2013). A linear regression was used to relate changes in TSL with depth.

ANOSIM was used to compare variation in catch per unit effort (CPUE) with soak time and depth. The CPUE data was twice square-root transformed before one-way ANOVAs were used to test for significant differences between different coloured pots and between pot types. The CPUE data was square root transformed before a one-way ANOVA was used to test for significant differences between habitat types.

The number of undersized whelks was used to calculate an overall percentage of undersized whelks discarded. A linear regression was used to relate changes in the percentage undersized whelks with catch per unit effort. The percentage of undersized whelks was calculated separately for each pot colour and pot type. A Mann-Whitney test was used to analyse differences in percentage undersized whelks with pot type. A one-way ANOVA was used to test for significant differences in percentage of undersized whelks between habitat types. A power analysis was used to determine the sample size required for each habitat type to detect an effect of a given size with a given degree of confidence. ANOSIM was used to compare variation in the percentage of undersized whelks with depth and soak time.

The proportion of bycatch of the total catch was calculated and a list of the species caught was made. Mann-Whitney tests were used to test for significant differences in percentage bycatch between pot colours and pot types. A one-way ANOVA was used to test for significant differences in percentage by-catch and habitat type. The species composition of bycatch at each depth range was graphically analysed. ArcMap was used to illustrate the distribution of percentage of bycatch over the fishing area using graduated colour markers.

Study of Behavioural Responses

The tag retention rate after a four month period was calculated. Box plots were created to display the time taken for the whelks to right themselves after being inverted and the time taken for the whelks to respond to bait. Kruskal-Wallis tests were used to detect any tank effects and to determine any significant differences in response times between treatments.

Abundance Estimates

ArcMap was used to illustrate the positions of release and recapture for each coloured band. These maps were used to calculate the mean minimum distance travelled for each band colour. The percentage of recaptures was calculated for each colour band, as well as an overall recapture rate. Due to the blue band and neutral band tagging events being on consecutive days they have been treated as one tagging event. Abundance estimates were calculated using the Lincoln-Petersen model (Eqt 1). The abundance estimates for the blue and neutral tagging event

$$\boldsymbol{N = \frac{MT}{R}}$$

Equation 1: Lincoln=Petersen Model, where N= total population size; M=number of individuals marked initially; T=total of individuals in second sample; and R= number of marked individuals on recapture

and the yellow tagging event were calculated using a three week period after the initial tagging and release. The abundance estimate for the green tagging event was calculated using a one week period after the initial tagging and release because the fishermen relocated their fishing efforts after this date. The area of the main fishing zone was estimated by drawing a polygon round the release and recapture points on ArcMap. Using the abundance estimates and the area of the main fishing zone the density of whelks present was determined.

Results

Fisheries Data

Total Shell Length

A total of 9041 whelks were measured during five sampling days. The length-frequency histogram of the whelks measured during the sampling period is presented in Figure 10. The

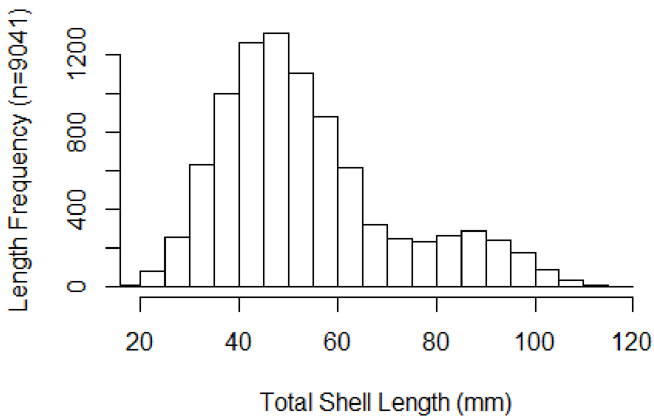
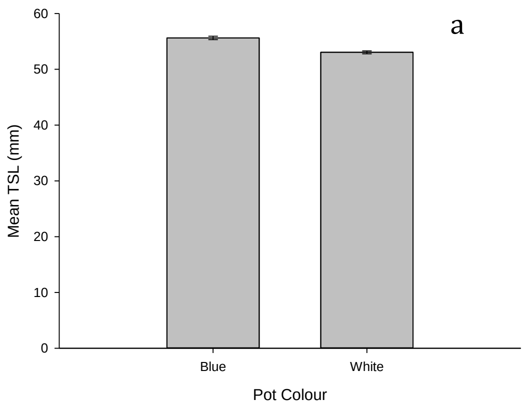


Figure 10: Length-frequency histogram of the *Buccinum undatum* measured in north Wales sampling area. Each class size represents 5 mm.

mean total shell length (TSL) was 54.6 mm and the largest and smallest whelks were measured at 119.00 mm and 10.00 mm respectively. There was a significant difference in median TSL between blue and white pot colours (Mann-Whitney W=8688007, n_1=3463, n_2=4629, $P<0.05$) (Figure 11) and between scientific and normal pot types (Mann-Whitney W=3249889, n_1=949, n_2=8092, $P<0.05$) (Figure 12), both of which show bimodal distributions.



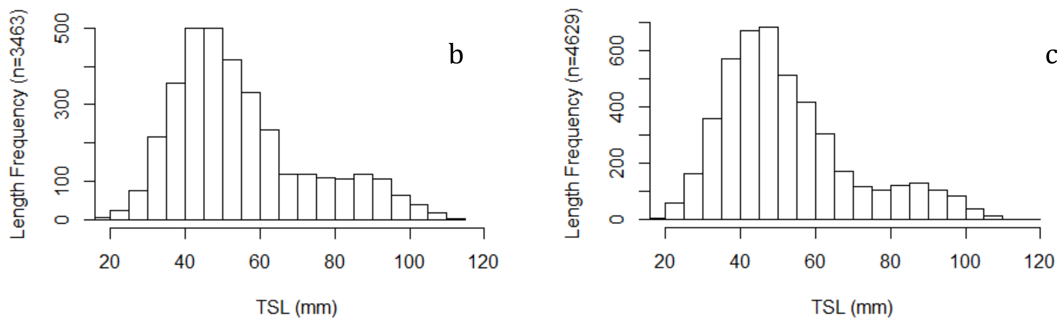


Figure 11: a) Bar chart with standard error bars illustrating mean total shell length (mm) for blue and white pot colours from the north Wales sampling area. b) Length frequency histogram for whelks caught in blue pots from the north Wales sampling area. Each class size represents 5 mm. c) Length frequency histogram for whelks caught in white pots from the north Wales sampling area. Each class size represents 5 mm.

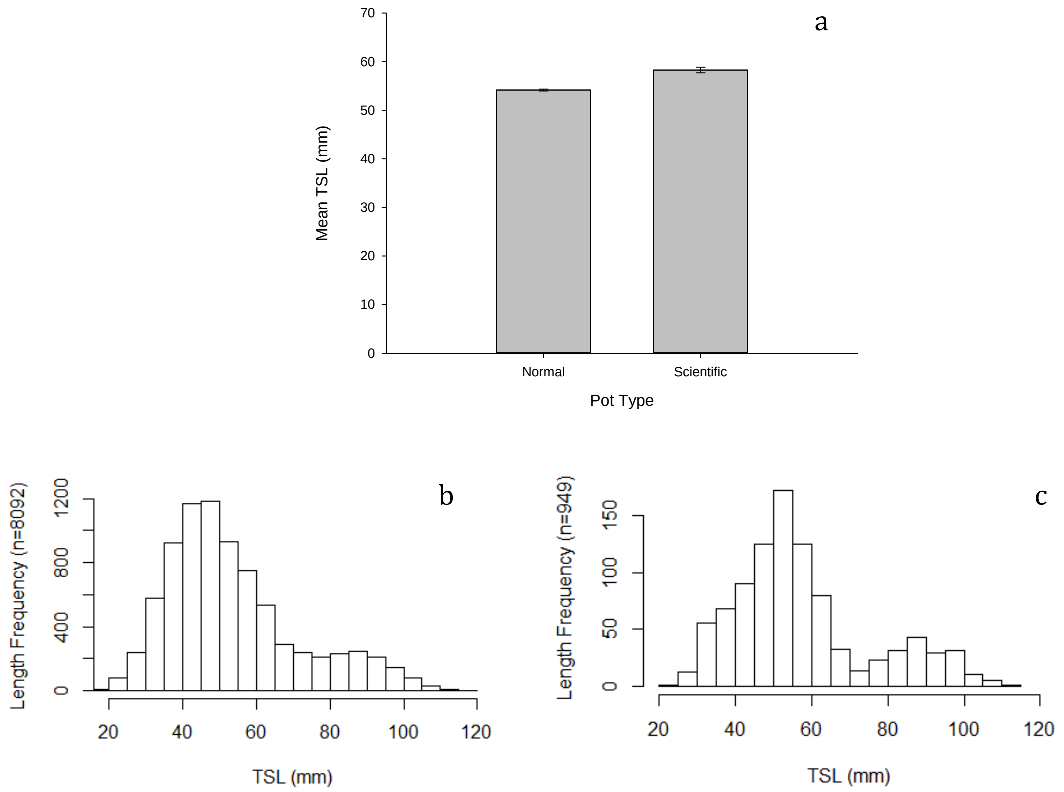


Figure 12: a) Bar chart with standard error bars illustrating mean total shell length (mm) for normal and scientific pot types from the north Wales sampling area. b) Length frequency histogram for whelks caught in standard pots from the north Wales sampling area. Each class size represents 5 mm. c) Length frequency histogram for whelks caught in scientific pots from the north Wales sampling area. Each class size represents 5 mm.

TSL varied significantly with depth (χ^2_4=218.210, P<0.05) (Figure 13). Whelks caught at 15-17 m depth were significantly larger than those caught at other depths (Table 5). There was no linear relationship between TSL and depth (P=0.767, $R^2<0.1$). TSL also varied significantly between each habitat type ($\chi^2_2=195.05$, $P<0.05$) (Figure 14).

Table 5: Total shell length data for each depth range

Depth (m)	Number of Whelks Measured	Mean (mm)	+/- SD	Minimum TSL (mm)	Maximum TSL (mm)
12-14	294	50.1	0.8	10	94
15-17	503	60.5	0.7	18	110
18-20	3017	53.6	0.3	18	119
21-23	2393	54.5	0.3	17	115
24-26	1256	48.8	0.4	20	115

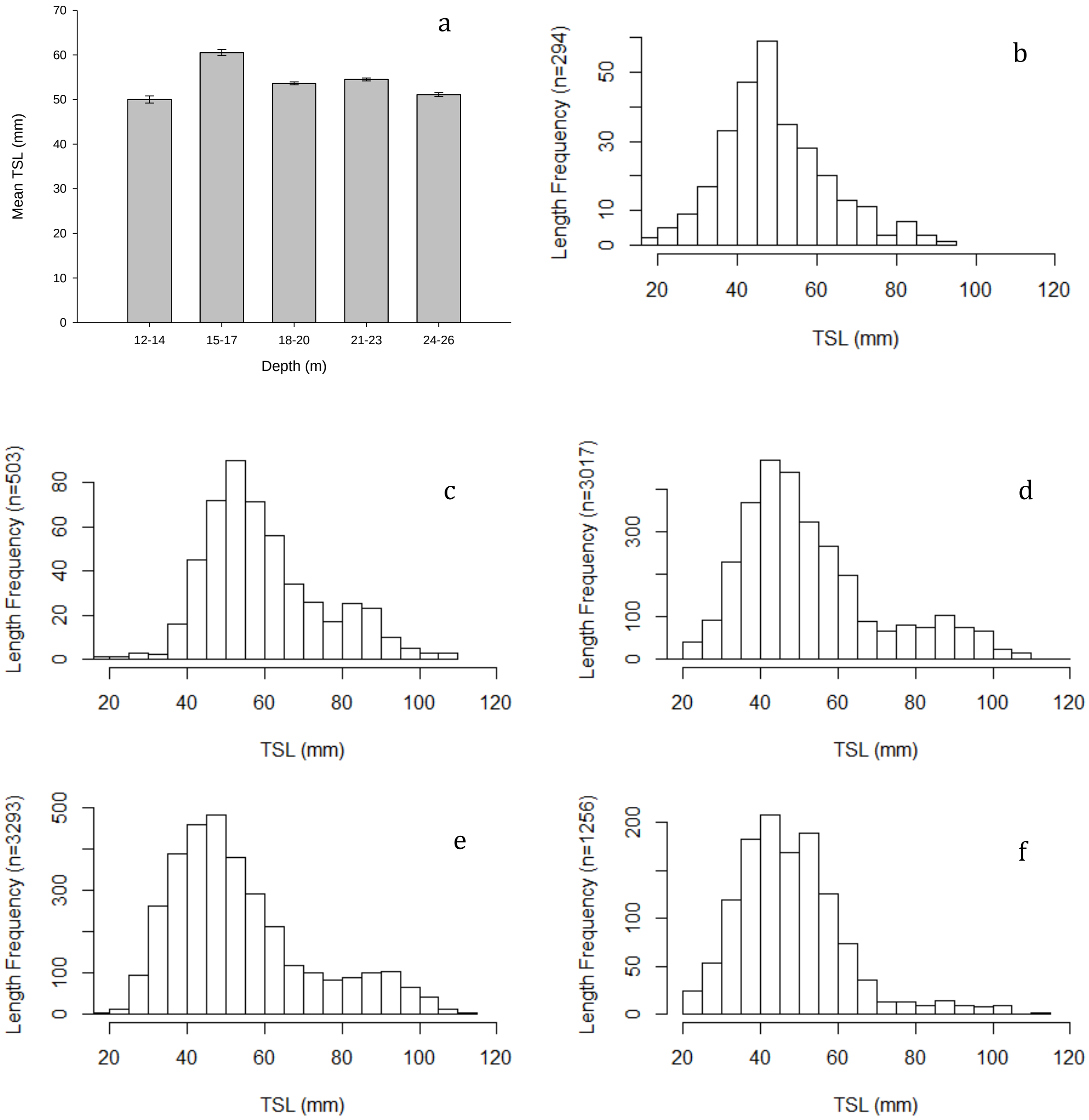


Figure 13: a) Bar chart with standard error bars illustrating mean total shell length (mm) for each depth range from the north Wales sampling area. b) Length frequency histogram for whelks caught at 12-14 m depth from the north Wales sampling area. Each class size represents 5 mm. c) Length frequency histogram for whelks caught at 15-17 m depth from the north Wales sampling area. Each class size represents 5 mm. d) Length frequency histogram for whelks caught at 18-20 m depth from the north Wales sampling area. Each class size represents 5 mm. e) Length frequency histogram for whelks caught at 21-23 m depth from the north Wales sampling area. Each class size represents 5 mm. f) Length frequency histogram for whelks caught at 24-26 m depth from the north Wales sampling area. Each class size represents 5 mm.

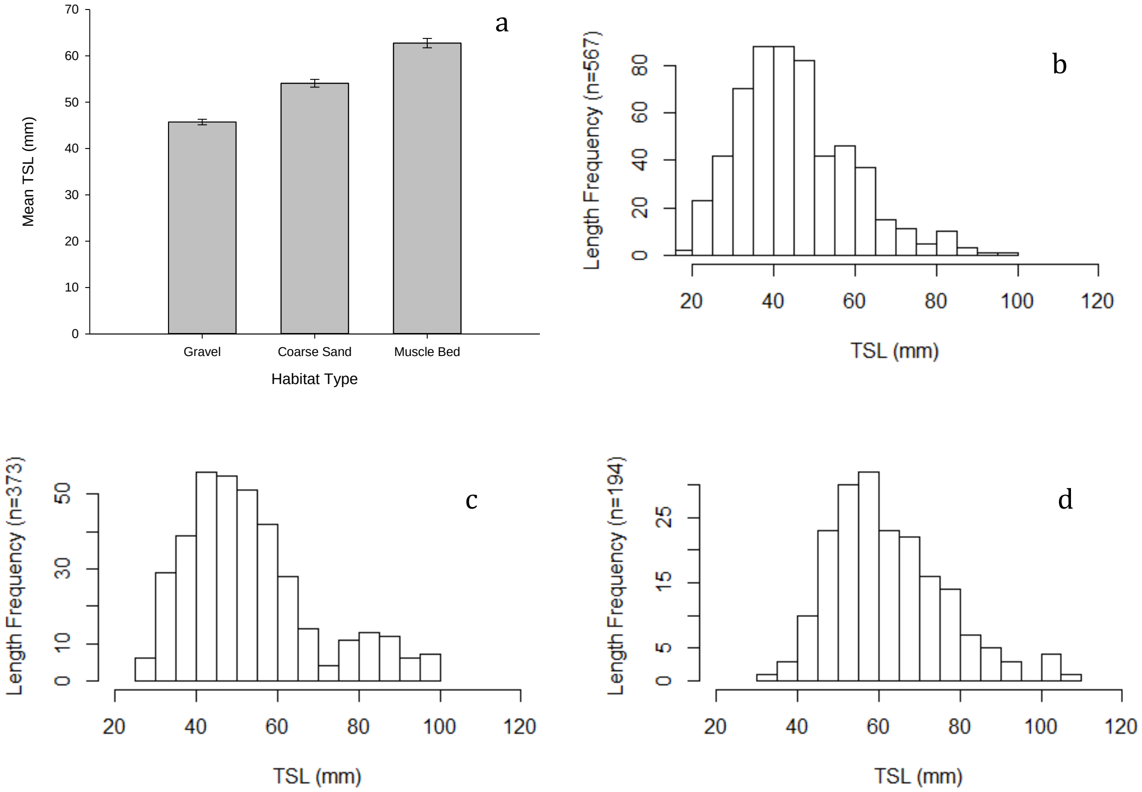


Figure 14: a) Bar chart with standard error bars illustrating mean total shell length (mm) for each habitat type from the north Wales sampling area. b) Length frequency histogram for whelks caught on gravel from the north Wales sampling area. Each class size represents 5 mm. c) Length frequency histogram for whelks caught on coarse sand from the north Wales sampling area. Each class size represents 5 mm. d) Length frequency histogram for whelks caught on a muscle bed from the north Wales sampling area. Each class size represents 5 mm.

Catch per Unit Effort

The mean number of whelks caught per pot was 105, this equates to 3.16 kg per pot. The catch per unit effort (CPUE) in June and July showed no variation with time or temperature. There were no significant differences in CPUE between soak times (ANOSIM R=0.004, P=0.369). One-way ANOVAs revealed there were no significant differences in CPUE between pot colours ($F_{(1,75)}$=0.281, P=0.598), pot types ($F_{(1,81)}$=2.540, P=0.115) or habitat types ($F_{(2,5)}$=0.251, P=0.787).

CPUE varied significantly with depth (ANOSIM R=0.073, P=0.033) (Table 6) with the shallower depths having lower CPUEs. From Figure 15, *b* was significantly different to *c*, *d*, and *e* whilst *a* was significantly different from *e*.

Table 6: Significant results from an ANOSIM pair-wise comparison for catch per unit effort between depth ranges (non-significant results excluded)

Pairwise Test	P
15-17 - 18-20	0.039
15-17 - 21-23	0.004
15-17 - 24-26	0.015
12-14 - 24-26	0.016

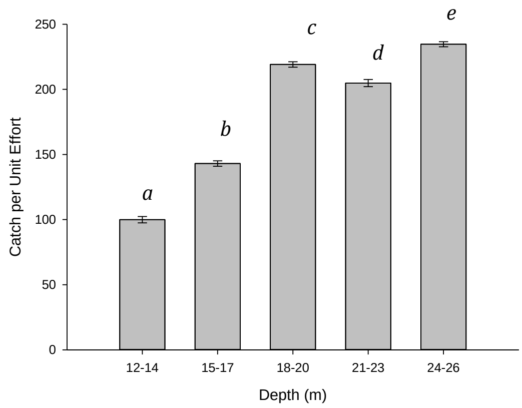


Figure 15: Bar chart with standard error bars illustrating the catch per unit effort in the north Wales sampling area from each depth range

Undersized Whelks

Over the five sampling days 32.6 % of the whelks caught were undersized (less than 45 mm total shell length). The percentage of undersized whelks per pot can be predicted from the CPUE by the following formula: y=0.001x+0.706, R^2=0.079. There was no significant difference in the percentage of undersized whelks between blue and white pot colours, having 30.9 % and 36.1 % undersized whelks respectively. 33.9 % of the whelks caught in normal pots were undersized whereas 21.6 % of the whelks caught in the scientific pots were undersized, although this is a larger variation than for between pot colours the median percentage undersized for each pot type did not vary significantly (Mann-Whitney W=237.5, n_1=77, n_2=5, P=0.388). There was no significant difference found in percentage undersized between habitat types ($F_{(2,3)}$=2.749, P=0.21), however when the data was displayed graphically there seemed to be a large amount of variation (Figure 16). The lack of significant difference may have been due to the small sample sizes. Power analysis, conducted with R software using the pwr package developed by

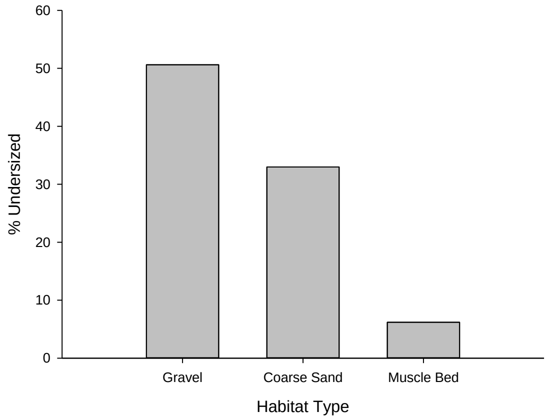


Figure 16: Bar chart illustrating the mean percentage of undersized whelks caught in the north Wales sampling area on each habitat type

Stephane Champley, used the effect size, significance level, and power to determine that at least 21 samples for each habitat type would be needed to be able to detect any significant effects with confidence. Percentage undersized varied significantly between depth ranges (ANOSIM R=0.171, P<0.05) (Table 7). From Figure 16, *c* varied significantly with *a, b* and *e* whilst *d* varied significantly with *e*.

Table 7: a) Significant results from an ANOSIM pair-wise comparison for percentage of undersized whelks between depth ranges. Unsignificant results not included. b) Percentage undersized data for each depth range.

a

Pairwise Test	P
12-14 - 18-20	0.05
15-17 - 18-20	0.008
18-20 - 24-26	0.005
21-23 - 24-26	0.045

b

Depth (m)	Number of Pots Sampled	Mean (%)	Minimum (%)	Maximum (%)
12-14	2	33.245	32.857	33.632
15-17	4	10.237	7.087	13.333
18-20	14	25.779	4.839	61.628
21-23	15	22.636	0.000	76.829
24-26	4	27.610	2.899	49.906

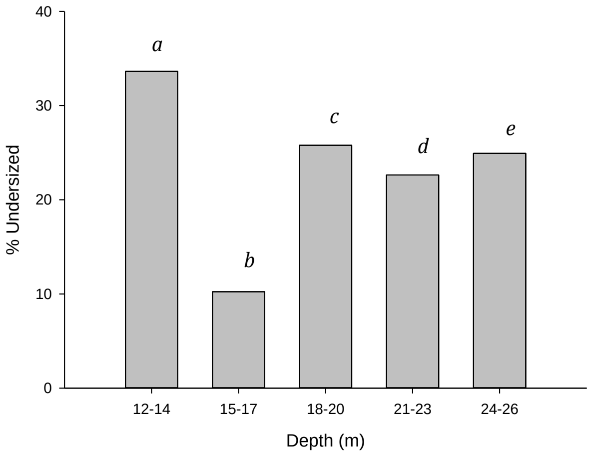


Figure 17: Bar chart of the percentage of undersized whelks caught in the north Wales sampling area from each depth range

Significant differences were found in percentage undersized between each soak time (ANOSIM R=0.870, P<0.05) (Table 8) (Figure 18).

Table 8: Percentage undersized data for each soak time

Soak Time (hrs)	Number of Pots Sampled	Mean (%)	Minimum (%)	Maximum (%)
24	19	24.027	0.000	61.628
42	8	16.750	4.839	38.585
78	12	27.319	1.351	76.829

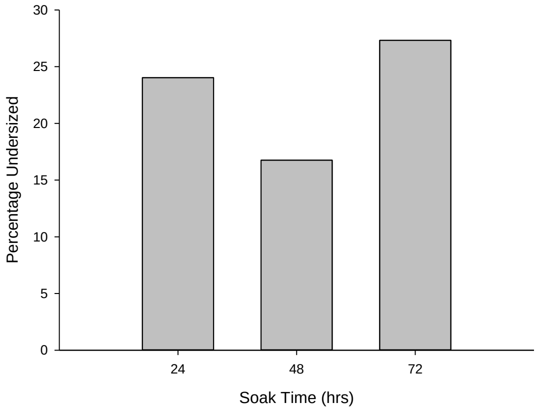


Figure 18: Bar chart to illustrate the percentage of undersized whelks caught in the north Wales sampling area after each soak time (hrs)

Bycatch

Out of the total number of whelks caught 2.93 % was bycatch, 59.62 % of this were netted dog whelks (*Nassarius reticulatus*). The composition of bycatch was been split into three taxa groups: marine gastropods, decapods crustaceans, and echinoderms (Figure 19). The

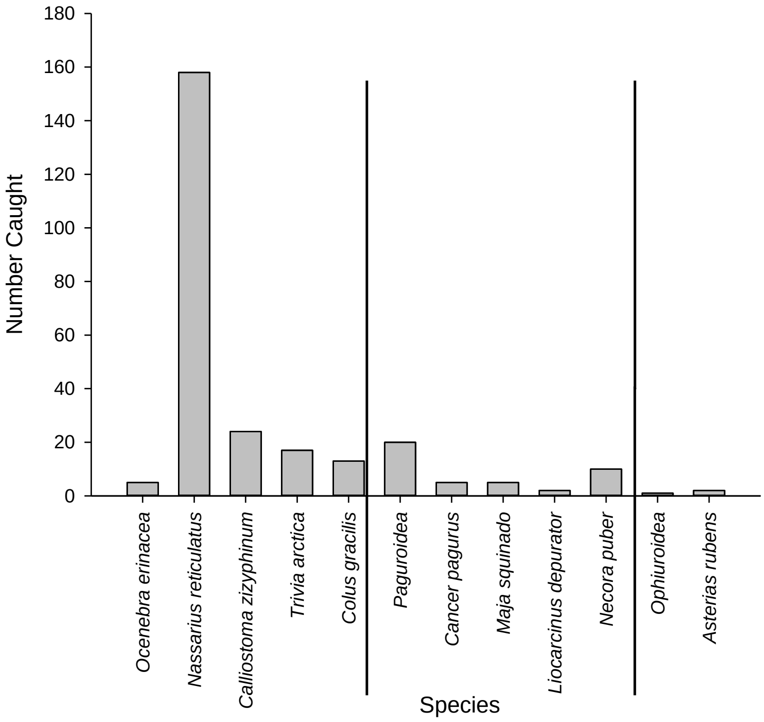


Figure 19: Species composition of bycatch caught over the sampling area in north Wales

distribution of the percentage bycatch caught is illustrated in Figure 20 and the percentage of each taxa present on every habitat type is shown in Table 9. The gravel habitat had the highest percentage bycatch present (64.7 %) followed by the muscle bed (23.5 %) and the coarse sand habitat had the least percentage bycatch present (11.8 %). There was no significant difference

Figure 20 removed

Figure 20: Map showing the percentage of bycatch caught at each sampling point across the sampled north Wales area

Table 9: Percentage bycatch present on each habitat type

	Gravel	Coarse Sand	Muscle Bed
Marine Gastropods	45 %	100 %	88 %
Decapod Crustaceans	55 %	0 %	12 %
Echinoderms	0 %	0 %	0 %

in the median percentage bycatch between pot colours (Mann-Whitney W=840, n_1=37, n_2=40, P=0.301) or between pot types (Mann-Whitney W=324, n_1=77, n_2=6, P=0.096), however this may be due to the small sample size for the scientific pots (Figure 21). A one-way ANOVA analysis did not show any significant differences in percentage bycatch between habitat types

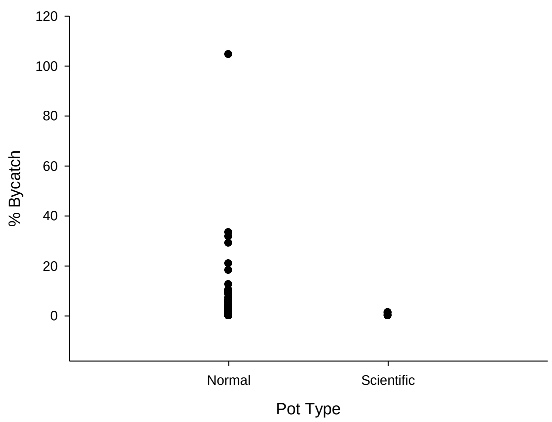


Figure 21: Scatter plot of percentage bycatch caught in the north Wales sampled area from each normal and scientific pot sampled

($F_{(2,5)}$=1.645, P=0.283). The species composition of bycatch caught at each depth range is shown in Figure 22, again the bycatch was split into three taxa groups: marine gastropods, decapod crustaceans and echinoderms. Significant differences were found in percentage bycatch caught

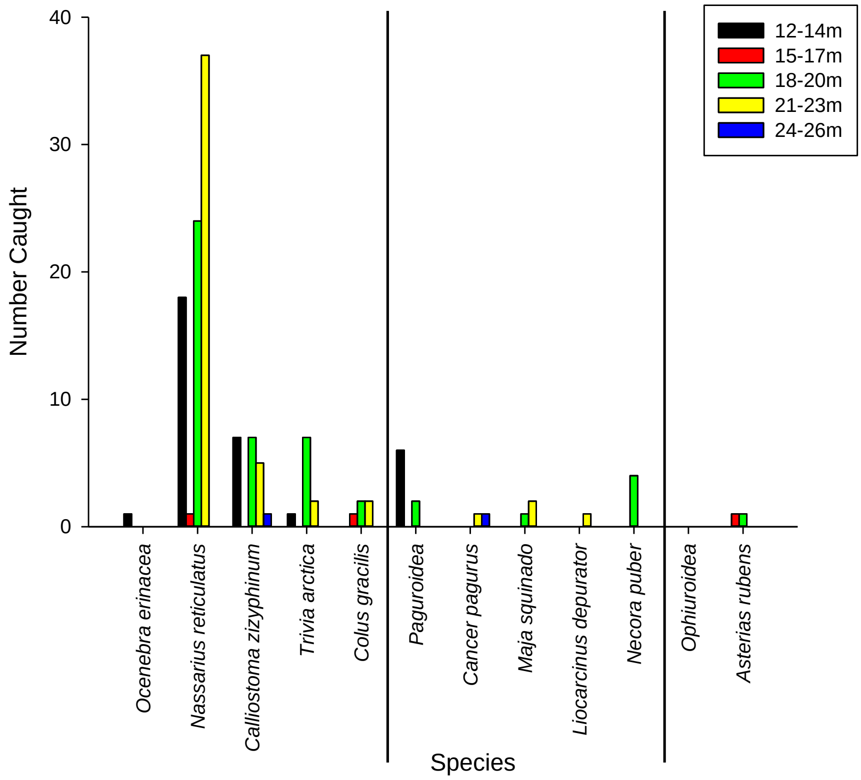


Figure 22: Species composition of bycatch caught in the north Wales sampling area at each depth range

between the depth ranges 15-17 m - 24-26 m (P=0.029), and 18-20 m - 24-26m (0.044). However, as a whole no significant difference was found between percentage bycatch caught and depth (ANOSIM R=0.06, P=18.9).

Laboratory Experiments

Tag Retention Study

After four months of the tag retention experiment the thick rubber bands had a 100 % tag retention rate.

Behavioural Response to Tagging and Riddling

From the first study of behavioural responses no tank effect was found between the three tanks (χ^2_2=0.184, P=0.668). There was no significant difference in the time taken for the whelks to right themselves after inversion between treatment groups (χ^2_4=7.881, P=0.096) (Figure 23).

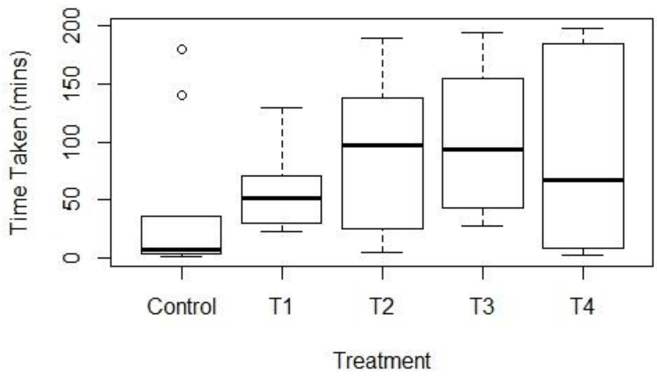


Figure 23: Box plot to illustrate the time taken for the whelks to right themselves after being inverted. Control-Whelks were inverted under the water.
T1-Whelks were tagged under the water then inverted.
T2-Whelks were removed from the tank, shaken in a box for 1 minute, tagged, and then returned to the tank.
T3-Whelks were removed from the tank, shaken in a box for 1 minute, tagged, left in a bucket exposed to air for 1 hour and then returned to the tank.
T4- Whelks were removed from the tank, shaken in a box for 1 minute, tagged, left in a bucket exposed to air for 3 hours and then returned to the tank.

After three hours whelks from each of the treatment groups, apart from treatment 4 whelks, had responded to the bait (Figure 24). The response to bait did not significantly differ between these treatments (χ^2_3=4.609, P=0.203).

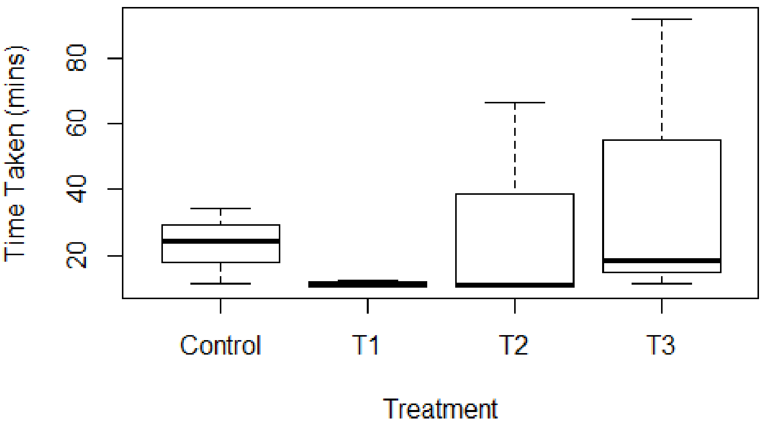


Figure 24: Box plot to illustrate the time taken for the whelks to respond to crab bait.
Control-Whelks were inverted under the water.
T1-Whelks were tagged under the water then inverted.
T2-Whelks were removed from the tank, shaken in a box for 1 minute, tagged, and then returned to the tank.
T3-Whelks were removed from the tank, shaken in a box for 1 minute, tagged, left in a bucket exposed to air for 1 hour and then returned to the tank.
T4 whelks have been excluded as no animals responded within 3 hours.

Abundance Estimates

The positions of release and recapture for the blue, neutral and yellow banded whelks are illustrated in Figure 25. GPS coordinates could not be recorded for the release of the green banded whelks so these are not included. Overall there was a recapture rate of 3.29 %. The mean minimum distance travelled for each of these colours are displayed in Table 10. Three

Table 10: Mean minimum distance travelled by the blue, neutral, and yellow banded whelks

Colour Band	Mean Minimum Distance Travelled (m)	+/- SE
Blue	282.3	45.1
Neutral	107.8	20.3
Yellow	94.3	17.0

yellow banded whelks, which were recaptured 24 hrs after being released, travelled a minimum distance of 111.34 m. Table 11 shows the whelk abundance and density estimates for each tagging event. On average, the whelk population is estimated to be 11,319,410 over a 26 km^2 area.

Table 11: Abundance and density estimates of the whelk population in North Wales

Colour Band	Abundance	95% Confidence Limits	Denisty (whelks per m^2)
Blue and Neutral	14656908	14560606 - 14671756	1.774
Yellow	15734219	15686172 - 15782549	1.653
Green	3567102	3547600 - 3586817	7.290

Figure 25 removed

Figure 25: Maps illustrating the release and recapture points of each coloured tag over the sampled north Wales area

Discussion

Total Shell Length

During June and July 2014 9041 *Buccinum undatum* were sampled from The fishing location, north Wales giving a good sample size for determining the whelk population structure. The overall mean TSL in this study was 54.6 mm (range 10-119 mm, SE ± 0.19). The mean TSL for whelks sampled from normal pots was 54.1 mm (range 10-119 mm, SE ± 0.20) and 58.3 mm (range 24-115 mm, SE ± 0.59) for scientific pots. These values are much smaller than the mean TSL obtained by the *Buccinum undatum* sampled in the same area using the scientific pots during June and July 2013 (66.47 mm, range 22-110 mm). This may be due to the use of *B.undatum* from scientific pots only, where the smaller whelks can escape from the larger holes in the bottom of the pot. The recent smaller mean TSL value could be a result of fishing pressure on the area if the larger whelks are being removed by the fishing effort. This can be seen from the monthly mean TSL taken from the same area using scientific pots in 2013 (Figure 26) where the mean TSL has decreased throughout the year. This could be an example of growth overfishing,

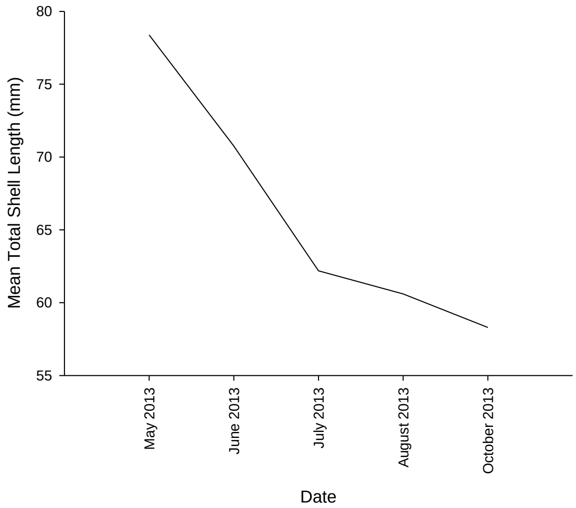


Figure 26: Mean total shell length variation of *Buccinum undatum* caught in scientific pots from May-October 2013

this occurs when the mean size of the whelks caught is smaller than the size that would produce the maximum yield. Growth overfishing can lead to recruitment overfishing where the adult whelk population is depleted to a point when it doesn't have the reproductive capacity to replenish itself. The current mean TSL for the sampled area is also smaller than the mean TSL for Camarthen Bay, south Wales (67.4 mm, range 19-111 mm) measured in 2011 (French, 2011) and the mean TSL for the Shetland Isles (84.1 mm, range 39-122 mm) measured in 2006 (Shelmerdine et al., 2007). The *B. undatum* fishery off the Shetland Isles has only been in operation for 30 years, making it a comparatively new fishery. This may explain its high mean TSL. *B.undatum* measured in south England in 2006 (54.3 mm, range 31-86 mm) (Shelmerdine et al., 2007) and in 2009 (49.4 mm, range 8-102 mm) (Lawler, 2009) had a similar mean TSL to those measured in north Wales 2014 but had a much smaller range of sizes. The relatively small TSL in south England may be because the *B.undatum* fishery has been in operation for a much longer period i.e. since 1947. As well as fishing pressure there are a number of factors which influence the TSL of marine molluscs. Shell growth requires energy so food availability is a limiting factor for TSL (Moran et al., 1984). Areas in which the TSL is low could indicate high levels of intra or inter-specific competition for food resources or poor habitat areas which yield low prey numbers. The presence of predators can cause marine molluscs to produce a thicker shell for protection, decreasing the total shell length at age (M. Nakota, 2000). The temperature and salinity of the water can alter the metabolism and shell magnesium incorporation of marine molluscs. Fluctuations in water temperature and salinity can also alter the calcium carbonate solubility, saturation state, and equilibrium needed for shell growth (Waldbusser et al., 2010). Areas with warmer water temperatures and higher salinities will have more calcium carbonate available for shell growth (because it is less soluble in warmer water), resulting in marine molluscs have a higher growth rate and larger total shell lengths. Wave action has been found to alter the shell formations of the dog whelk, *Nucella lapillus* (Crothers, 1983). In areas of high wave action, such as exposed headlands, the shell edges are battered when the whelks roll along the sea bed, causing them to form short, squat shell shapes with small total shell lengths. Dog whelks inhabiting sheltered areas were found to have elongated shells with greater total shell lengths. However after finding exceptions to this theory Crothers concluded that wave action would not be the sole influence on shell shape and length. For example, elongated shell length could be an adaptation to avoid desiccation; dog whelks with longer total shell lengths are able to retain far more water within their shell than shorter dog whelks. There are a number of trade-offs that take place which can affect shell growth and total shell length. It could be assumed that a thicker, shorter shell will provide greater protection from predators and that when a whelk shell is damaged it must use a large amount of energy to repair it. This can cause a decrease in growth. However the trade-off between repair and shell growth has been observed to have the opposite effect. Experiments on *Nucella ostrina* (collected from Bodega Head in California) found that damage to the shells resulted in increased growth (Figure 27). However this

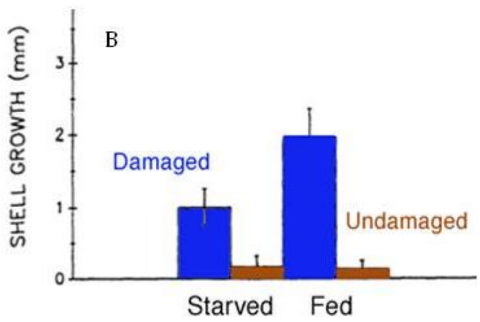


Figure 57: Effect of starvation and shell damage on shell growth in *Nucella ostrina* (collected from Bodega Head in California)

experiment was conducted under laboratory conditions for only 34 days and was not repeated. Therefore the reproductive period and varying sea water temperatures would not be taken into account.

Length Frequency

The length-frequency histogram (Figure 10) of the *Buccinum undatum* sampled in June and July shows a bimodal distribution with a large range in total shell length (TSL). The size range with the largest representation is between 40-45 mm. Another much smaller peak can also be seen between 80-85 mm. *B.undatum* sampled from scientific pots in the same area during June and July 2013 (Figure 28) had a multimodal distribution with three distinct cohorts (represented by vertical lines). The first cohort ranges from 20-35 mm, the second from 35-75 mm and the third

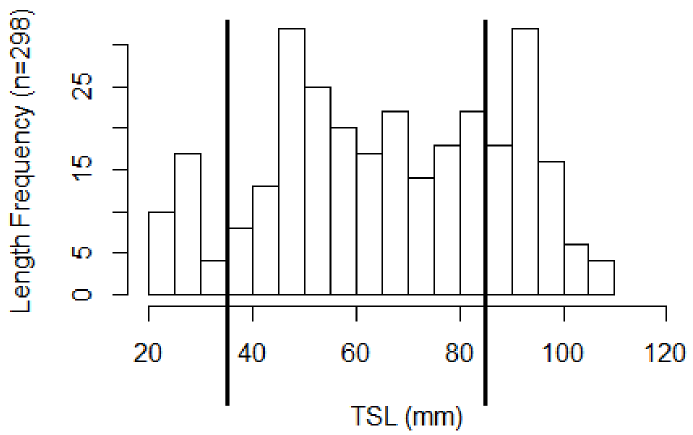


Figure 28: Cumulative length frequency histogram of whelks caught from scientific pots in the north Wales area during June and July 2013. Each class size represents 5 mm. (J. Haig, unpublished data)

from 75-105 mm. The bi and multi modal distributions observed could be due to sexual differences, age classes, environmental effects, genetic effects or social interactions (Thorpe, 1977). The length frequency histograms plotted for each sex separately showed similar distributions so the multimodal distribution pattern is not due to sexual differences. An example of an environmental effect would be if some larval whelks were dispersed onto a favourable habitat. A favourable habitat would give them protection and provide good food resources so the larval whelks here would grow more rapidly than subordinate individuals. The difference between the bi and multi modal distributions could be due to the use of scientific pots only in the 2013 samples. The holes in the bottom of the scientific pots are larger than the holes in the side of the normal pots, allowing smaller whelks to leave the pot. However if the scientific pots are full the small whelks will not be able to reach the holes in the bottom of the pot to escape. In general, it is thought that every one mm increase in hole size results in a 1.5-3 % reduction in the percentage of undersized whelks caught (Kent and Essex IFCA, 2014).

Depth

Total shell length was found to vary significantly with depth. Larger whelks were found in shallower water depths (mean 60.5 mm at 15-17 m) than smaller whelks (mean 48.8 mm at 24-26 m). Pots hauled from the deeper waters (24–26 m) had the highest percentage of undersized whelks (27.6 %). These findings oppose a previous theory that larger whelks are found offshore whilst smaller whelks remain inshore (Valentinsson et al., 1999). In contrast, whelks sampled in Camarthen Bay (French, 2011) had larger total shell lengths in depths between 26-30 m (mean TSL 71.8 mm) whereas the smaller whelks were found between 21-25 m depth (mean TSL 63.3 mm). Some studies have shown that shell growth shows no variation with depth (Hanson et al., 1988) meaning that the differences between north and south Wales populations could be due to other limiting factors such as habitat type. Whelks will have to balance food availability with ideal water temperature, and therefore depth. Although habitats with better food sources may be located at greater depths the water temperature here may be too cold for the whelks to function affectively.

Habitat Type

Total shell length was found to vary significantly with habitat type, with larger *Buccinum undatum* being caught on the muscle beds. The gravel habitat yielded the smallest whelks with only 8 % of whelks measuring over 65 mm TSL. Larger *B. undatum* will be able to feed on the muscles whereas the smaller whelks would feed off smaller prey such as urchins and polychaetes found on sandy and gravel substrate. Food availability is a limiting factor for shell growth. Experiments on *Nucella ostrina* (collected from Bodega Head in California) found that whelks which were starved had a lower growth rate than fed whelks (Figure 29). Catch per unit effort was lowest over the muscle bed, suggesting that larger whelks are more sparsely populated and smaller whelks live in higher densities. The muscle bed is part of an area which is closed to scallop trawling. The shells of whelks which inhabit trawled areas could be damaged by the trawling gear. A study on the affect of beam trawling on the common whelk observed that only 40 % of the whelks caught with a beam trawl survived and that shell repair took up to six weeks (Mensink et al., 2000). This suggests that whelks on the coarse sand or gravel habitat which are damaged by trawling gear will have a smaller TSL as more energy is put in to shell repair. Although there was no significant difference found between percentage of undersized whelks and habitat type the graphical illustration showed the gravel habitat to have the highest percentage of undersized whelks and the muscle bed to have the smallest percentage of undersized whelks. This was thought to be due to the small sample sizes (n=3 for each habitat type). Results of the power analysis concluded that 21 samples would be needed for each habitat type to detect any significant effects with confidence.

Catch per Unit Effort

On average, during June and July in the north Wales sampling area, 3.16 kg *Buccinum undatum* were caught per pot. This is comparable with landings data from south Wales (2.65 kg per pot) (French, 2011) and Jersey (3.3 kg per pot) (Morel and Bossy, 2004), implying that CPUE is consistent between the locations I have cited. CPUE data from a Swedish *B.undatum* fishery (Valentinsson et al., 1999) reported much lower landings of 1.3 kg per pot. This could be due to colder water temperatures or fishing over unsuitable habitat.

Soak Time

In this study the CPUE did not vary significantly with soak time whereas in the whelk fishery in Sweden it was found that CPUE increased with lengthened soak time (Valentinsson et al., 1999). Contrary to this, an assessment of the common whelk fishery in the southwest Irish Sea (Fahy et al., 2000) found that the CPUE fell with increased soak time (Figure 29). This is usually the case in areas with strong tidal currents. Increased soak time in areas of strong currents results in gear becoming tangled and pots rolling over, allowing the whelks to escape. The smell of the bait will rapidly dissipate in a strong current; this will have two main affects. Firstly, over time whelks will not be able to sense the bait resulting in fewer whelks entering the pot. Secondly, *Cancer pagurus* (the edible crab) which is a common predator to the common whelk will not enter the pot whilst it can smell crab bait. Once the smell has dispersed the crabs will enter the pot in search of their whelk prey.

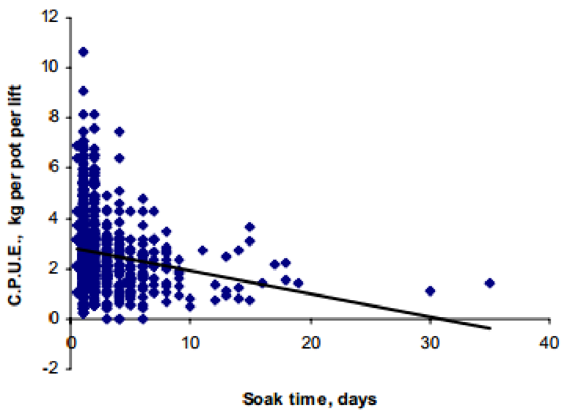


Figure 29: Change in catch per unit effort against soak time in the common whelk fishery of the south Irish Sea (Fahy et al., 2000)

Depth

CPUE varied significantly with depth during June and July in the north Wales sampling area, with CPUE being poorest in shallower depths (mean of 73 whelks caught per pot at 12-17 m) and greatest in the deeper depth ranges (mean of 201 whelks caught per pot at 24-26 m). This is comparable to the variation in CPUE in Sweden (Valentinsson et al., 1999) where CPUE was highest between 25-30 m and lowest between 10-15 m. An opposite trend was reported in south Wales (French, 2011) where CPUE was highest between 16-20 m depth and least between 26-30 m depth. The variations in CPUE between north and south Wales could again be due to differences in habitat type. CPUE might be low in shallower waters if there are more small whelks present because many of them may be undersized and will have to be returned.

Percentage Undersized

Over the sampling period in north Wales 32.56 % of the *Buccinum undatum* caught were below the minimum landing size (45 mm). In south Wales (French, 2011) the percentage of undersized whelks caught was considerably lower with 3.55 % undersized. This implies that there is still a strong recruitment of smaller whelks in the north Wales area whilst the whelk fishery in south Wales could be in danger of becoming unsustainable. However the difference could also be due to the south Wales sampling only taking place in one bay, smaller juvenile whelks could be present further along the coast. Percentage of undersized whelks varied with soak time, the longest soak time (72 hrs) yielding the highest percentage of undersized whelks. Alternatively it could be expected that an increase in soak time will result in a reduction in the number of undersized whelks caught. This is because the bait will be used up and the whelks will start to try and leave the pot. The smallest whelks will be able to escape through the holes in the side of the pot resulting in a small percentage of undersized whelks when the pot is hauled. This was the case with the study of the common whelk fishery in the southwest Irish Sea (Fahy et al., 2000), however disruptions caused by poor weather conditions and relocation of the gear made any relationships between percentage undersized whelks and soak time hard to interpret.

Bycatch

Although there is little data available in published literature on the bycatch of other fisheries, whelk fisheries are generally very clean with low bycatch numbers. In the sampled area in north Wales 2.93 % of the catch was bycatch, made up of marine gastropods, crustaceans, and echinoderms. The netted dog whelk (*Nassarius reticulatus*) comprised 59.62 % of the total bycatch caught. They were caught over all habitat types, constituting for 35 % of the bycatch on gravel habitat, 25 % on coarse sand and 50 % on the muscle bed. Percentage bycatch in the whelk fishery in Sweden was 12.42 % out of the total weight with the main bycatch being *Neptunea antique,* making up 10 % of this (Valentinsson et al., 1999).

Laboratory Experiments

Tag Retention Study

To make it possible to calculate accurate abundance estimates using the tag-recapture technique the tag retention rate had to be determined. Other studies (such as Himmelman, 1988) used rubber bands for their tagging but had not reported any tag retention data. Henry & Jarne, 2007 compared a number of tagging methods for *Buccinum undatum* including car body paint, nail varnish, gouache paint, and glued plastic markers. The whelks were returned to their natural environment and proportion of tag loss was calculated on recapture. The gouache paint and car body paint had 0.041 and 0.066 mean proportion of loss respectively with the proportion of loss for the gouache paint being dependent on colour. The glued plastic markers had the lowest mean proportion of loss, 0.015 over 57 days. Although the glued plastic markers had a high retention rate, and would enable individual markings, it was unpractical to use them whilst on the fishing boat. The whelks would need to be dried before the tag was applied and the glue would need space and time to set before they were returned to the water. A study using embossing tape tags (Kideys, 1994) had a 100 % tag retention rate after the whelks were kept in laboratory conditions for one year. However, holes need to be drilled into the shell of the whelk to apply this tag, again making it unpractical for use on whelk fishing boats. An unpublished study by J. Haig (Bangor University) investigated the tag retention rate of zip ties, thin and thick rubber bands, and glued plastic markers on *B. undatum* over a two month period. 20 % of zip-tie tags and 16 % of thin band tags were lost whereas thick bands and glued plastic markers had 100 % retention rate. It is because of this that we chose to further investigate the retention rate and use of thick rubber bands for tagging *B. undatum*. They could be applied by hand or using a lobster bander and were not found to deteriorate over the study period.

Behavioural Response to Tagging and Riddling

The study of behavioural responses was conducted to ensure that the tagging process would not affect the likelihood of them being recaptured. As no significant difference was found in turn over times between treatment groups after the whelks were inverted, it can be assumed that tagged whelks will be able to right themselves if they become inverted after being returned to the water. Very few of the whelks (12 out of 55) responded at all to the addition of crab bait to the tank. Out of the whelks which did respond there was no significant difference in the time taken for the whelks to approach the bait between treatments, however none of the "treatment 4" whelks responded to the bait within three hours. As the whelks were not left out of the water for more than one hour after tagging on the fishing boat it is unexpected that there will be an unequal probability for tagged and untagged whelks entering baited pots. The lack of response to the bait could be due to the poor water flow in the tank, the whelks might not have been able to smell the bait. A study into the movement of whelks (Himmelman, 1988) found that whelks generally responded to baited pots within six hours. If the response to bait experiment was to be run again a longer time could be given for the whelks to respond.

Abundance Estimates

Prior to undertaking the study I was unsure how many whelks we would be able to tag and whether there would be any recaptures at all. For successful population modelling it is suggested that the tagging effort should aim to tag 10 % of the population and that the recapture rate should be at least 10 % of those tagged. The overall recapture rate for this study was 3.29 %. The recapture rate could be influenced by the fishermen temporarily moving strings out of the release area (to look for better fishing grounds). The mark recapture study on the common whelk that took place in Sussex also reported very low and variable recapture numbers. Due to the low catch rate they used pre-marked whelks from an adjacent site to supplement the release numbers (Lawler, 2014).

Movement

It is believed that *Buccinum undatum* are sedentary and have limited daily movement (up to 50 m a day when in search of food) (Himmelman, 1988). Research on the movement of the common whelk in the Gulf of St Lawrence recorded average movements of 2.2-9.2 m in less than six hours (Sainte-Marie, 1991). A study on the knobbed whelk, *Busycon carica* (which can grown up to 305 mm in total shell length), observed much lower daily movements which varied significantly with gender. For male knobbed whelks the mean distance travelled per day was 1.6 m whereas females had a mean daily movement of 2.6 m (Shalack, 2007). Using Arcmap software it is estimated that three yellow banded whelks travelled a minimum distance of 111.34 m in 24 hours during this study, this is over twice the expected amount. If the whelks had been individually marked it would have been possible to determine a mean distance travelled from the released population.

Population Density

The estimated density of the common whelk present in the north Wales fishing area is much higher than the density calculated for the common whelk in Swedish waters (Valentinsson et al., 1999). The mean density calculated in this study was 3.57 m^2 whereas the density of whelks in Swedish waters ranged from 0.06-0.13 whelks per m^2. This could be due to the water temperature being much lower in Swedish waters or the habitat being much less favourable. Research into the density of *Buccinum undatum* off Douglas, Isle of Man between 1989-1990 used four different methods to estimate whelk density. The mark-recapture experiment and underwater camera method gave overestimations for density whereas density estimates from pot sampling and diving gave comparable results. The overall mean whelk density estimated from pot sampling ranged from 0.08-0.38 whelks per m^2 (Kideys, 1993).

Conclusions

H_1: Total shell length of *Buccinum undatum* varies between habitat types and depth ranges

H_0: Total shell length of *B. undatum* will be similar between habitats and depth ranges

Conclusion: Total shell length was found to vary significantly between habitat types and depth ranges. *B. undatum* caught on the muscle beds had greater total shell lengths than those caught on gravel or coarse sand. Larger whelks were found in shallower water depths than smaller whelks.

H_2: The higher the catch per unit effort the larger the percentage of undersized whelks present

H_0: There will be no change in percentage of undersized whelks present with varying catch per unit effort

Conclusion: No significant relationship was found between CPUE and percentage of undersized whelks caught. However CPUE was lowest over the muscle bed, where the larger whelks were caught, implying that larger whelks are less densely populated.

H_3: Longer soak times will result in lower catch per unit effort and a smaller percentage of undersized whelks being caught

H_0: Catch per unit effort and percentage undersized will not vary with increased soak time

Conclusion: No significant variation in catch per unit effort was found with increased soak time.

H_4: Catch per unit effort will be highest in white pots

H_0: Catch per unit effort will not vary between white and blue coloured pots

Conclusion: Catch per unit effort did not vary significantly with pot colour

H_5: Percentage bycatch will vary with habitat type

H_0: Percentage bycatch will not vary with habitat type

Conclusion: No significant difference was found in percentage bycatch and habitat type, but this may be due to the small sample sizes. Graphically it was shown that gravel habitat had the highest percentage bycatch present whereas the coarse sand habitat had the least percentage bycatch present.

Future Studies

Better recapture rates may be obtained by tagging a greater number of whelks. This would require an increase in time and effort spent tagging on the fishing vessel. The whelks could be marked with depth tags to enable better analysis of the movement of whelks between depth ranges. If the whelks had been individually marked the Jolly Seber model could have been used for the population size estimates. Other estimations such as survival rate, capture probability and the number of individuals immigrating into the population could also have been calculated using the Jolly Seber model. Permanent marker pen could be used to individually mark each thick rubber band. It would have to be done prior to the tagging events on the fishing vessel to allow the ink to dry and to save time. Although there are a number of improvements that could be made to this study the data collected so far, and long term data outside the timescale of this thesis, has provided excellent data as a pilot study.

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Appendices

Appendix A - Catch per Unit Effort data for depth

Depth (m)	Number of Pots Sampled	Mean CPUE	+/-SD	Minimum CPUE	Maximum CPUE
12-14	4	73.250	25.519	22	140
15-17	7	71.857	29.200	4	178
18-20	26	116.077	21.871	11	401
21-23	27	109.000	20.103	17	537
24-26	8	200.750	27.469	109	303

Appendix B – One-way ANOVA

Used to analyse:

- Percentage undersized with depth
- Percentage undersized with habitat type
- Percentage bycatch with habitat type
- CPUE with habitat type
- CPUE with pot colour
- CPUE with pot type
- CPUE with depth

```
#set up where to find files

setwd("C:/Users/Owner/Documents/Work/DISSERTATION")

getwd()

#import relevant file

undervsdepth<-read.table("% undersized vs depth.csv",header=TRUE,sep=",")

str(undervsdepth)

#check for normaility

#test with shapiro

shapiro.test(undervsdepth$undersized)

#data not normal

#try sqrt transforming data

undervsdepth<-cbind(undervsdepth,sqrt(undervsdepth$undersized))

fix(undervsdepth)

#test with shapiro

shapiro.test(undervsdepth$sqrtundersized)

#data normal

#test for homogeneity

bartlett.test(sqrtundersized~Depth,data=undervsdepth)

#data passes test

#one way anova between habitat types

anovadata<-aov(sqrtundersized~Depth,data=undervsdepth)

summary(anovadata)

#test which depths are significantly different

TukeyHSD(anovadata)
```

Appendix C – Power Test

```
#power test

pwr.anova.test(k=3,n=,f=0.4,sig.level=0.05,power=0.8)
```

Appendix D – Mann-Whitney U Test

Used to analyse:

- Percentage undersized with pot type
- Percentage bycatch with pot colour
- Percentage bycatch with pot type
- TSL with pot type
- TSL with pot colour

```
#set up where to find files

setwd("C:/Users/Owner/Google Drive/Work/DISSERTATION")

getwd()

#import relevant file

undervstype<-read.table("% undersized vs pot type.csv",header=TRUE,sep=",")

str(undervstype)

#check for normaility

#test with shapiro

shapiro.test(undervstype$Under)

#data not normal

#try sqrt transforming data

undervstype<-cbind(undervstype,sqrt(undervstype$Under))

fix(undervstype)

#test with shapiro

shapiro.test(undervstype$sqrtunder)

#data not normal

#try sqrt sqrt transforming data

undervstype<-cbind(undervstype,sqrt(undervstype$sqrtunder))

fix(undervstype)

#test with shapiro

shapiro.test(undervstype$sqrtsqrtunder)

#data not normal, only two factors, so use non parametric test

wilcox.test(Under~Type,undervstype)
```

Appendix E – Kruskal-Wallis Test

Used to analyse:

- Percentage undersized with soak time
- Percentage bycatch with depth
- TSL with depth
- TSL with habitat type

```
#set up where to find files

setwd("C:/Users/Owner/Documents/Work/DISSERTATION")

getwd()

#import relevant file

bycatchPvsdepth<-read.table("Bycatch vs depth.csv",header=TRUE,sep=",")

str(bycatchPvsdepth)

fix(bycatchPvsdepth)

#check for normaility

#test with shapiro

shapiro.test(bycatchPvsdepth$BycatchP)

#data not normal

#try sqrt transforming data

bycatchPvsdepth<-cbind(bycatchPvsdepth,sqrt(bycatchPvsdepth$BycatchP))

fix(bycatchPvsdepth)

#test with shapiro

shapiro.test(bycatchPvsdepth$sqrtbycatchP)

#data still not normal

#try sqrt sqrt transforming data

bycatchPvsdepth<-cbind(bycatchPvsdepth,sqrt(bycatchPvsdepth$sqrtbycatchP))

fix(bycatchPvsdepth)

#test with shapiro

shapiro.test(bycatchPvsdepth$sqrtsqrtbycatchP)

#data still not normal so use non parametric test

#Test with Kruskal Wallis test

kruskal.test(BycatchP~Depth,data=bycatchPvsdepth)
```

```
#which depths vary significantly from each other

kmc<-kruskalmc(BycatchP~Depth,bycatchPvsdepth,probs=0.05)

print(kmc)
```

Appendix F – Descriptive Statistics

```
#descriptive stats for TSL for pot colour

Mean_Potcolour1<-aggregate(TSL..mm.~Pot.colour,data=TSL,mean)

Median_Potcolour1<-aggregate(TSL..mm.~Pot.colour,data=TSL,median)

sd_Potcolour1<-aggregate(TSL..mm.~Pot.colour,data=TSL,sd)
```

Appendix G – Length Frequency Histograms

```
#set up where to find files

setwd("C:/Users/Owner/Documents/Work/DISSERTATION")

getwd()

#import TSL fisheries analysis

TSL<-read.table("Nefyn TSL R.csv",header=TRUE,sep=",")

str(TSL)

#histogram of TSL for length-frequency distribution

hist(TSL$TSL..mm.,main=NULL,xlab="Total Shell Length (mm)",ylab="Length Frequency (n=9041)",breaks=20,xlim=c(20,120))
```

Appendix H – Box Plots

```
#set up where to find files

setwd("C:/Users/Owner/Documents/Work/DISSERTATION")

getwd()

#import turn over times

TOT<-read.table("Turning over times.csv",header=TRUE,sep=",")

#look at table to see what needs to be turned into a factor

str(TOT)

#make tank a factor

TankF<-factor(TOT1$Tank)

#connect tank factor to table now called TOT2

TOT2<-cbind.data.frame(TankF,TOT1)

#make box plot of time taken to turn over

boxplot(TOT2$Time~TOT2$TreatmentF,main="Time Taken for Whelks to Right Themselves",xlab="Treatment",ylab="Time Taken (mins)")
```