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The distribution, abundance and movement of the adult whelk *Buccinum undatum* (L. 1758) in South Wales, UK

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In collaboration with the Fisheries and Conservation Science Group

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The distribution, abundance and movement of the adult whelk *Buccinum undatum* (L.) in South Wales, UK

Abstract

The population parameters of the edible common whelk (*Buccinum undatum*) were investigated in Oxwich Bay and Swansea Bay, South Wales, UK, from June to July 2014. A fisheries catch analysis and mark-recapture study to estimate abundance were conducted, in collaboration with a commercial fisher. *B. undatum* abundance, Total Shell Length (TSL), and Catch Per Unit Effort (CPUE) were determined, with bycatch, depth, temperature and habitat type recorded. Abundance, TSL and CPUE were analysed from different pot types and colours, as well as a range of pot soak times, with the percentage of undersized *B. undatum* identified. To validate the mark-recapture study, laboratory experiments assessed the retention rate of tags and simulated the effect of handling disturbance (tagging, rolling and air exposure) on the ability of *B. undatum* to be recaptured. The population abundance in each bay was estimated using the Lincoln-Petersen Index, and *B. undatum* density determined based on the area created from the release and recapture points. Conservative estimates of movement were calculated using the minimum and daily distance travelled. A total of 8,377 *B. undatum* were measured, with abundance, TSL and length-frequency distribution significantly different between bays, 16 - 106 mm TSL in Oxwich Bay and 20 - 86 mm TSL in Swansea Bay. As part of the mark-recapture study, 11,528 *B. undatum* were tagged and released, with an 18.3 % recapture rate at Oxwich Bay and 12.0 % at Swansea Bay. The overall percentage of undersized *B. undatum* caught below the 45 mm Minimum Landing Size (MLS) was considerably higher at Oxwich Bay compared Swansea Bay, with discards of 12.3 % at Oxwich Bay and 2.4 % discarded at Swansea Bay.

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Acronyms

ANOVA = Analysis of Variance

CPUE = Catch Per Unit Effort

DD = Decimal Degrees

FCSG = Fisheries and Conservation Science Group

EFF = European Fisheries Fund

EU = European Union

GPS = Global Positioning System

MLS = Minimum Landing Size

SE = Standard Error

1. INTRODUCTION

The edible whelk (*Buccinum undatum* L.) is a neogastropod mollusc, commonly distributed in North Atlantic shelf waters and Arctic Oceans (Golikov, 1968; de Vooys & van der Meer, 2010) (Fig. 1). *B. undatum* is the largest edible marine gastropod in North Atlantic waters, capable of reaching a maximum shell length of 120 mm, and has a variable morphology (Palsson et al, 2014). *B. undatum* is found in depths of three to 600 m in open seas, and occurs on a range of substrata (Valentinsson et al, 1999; de Vooys & van der Meer, 2010). *B. undatum* is an opportunistic feeder, as it is both a predator and scavenger, feeding mainly on carrion, including fish and shellfish (de Vooys & van der Meer, 2010). Many marine predators and scavengers have well developed chemosensory abilities, enabling them to detect and locate prey, and other food sources using water-borne signals (Bailey & Laverack, 1966; Sutterlin, 1975; Crisp et al, 1978; Miller 1978). This is advantageous in fishing for some fish, crab, lobster, and whelk species, as they can be caught using baited traps, commonly referred to as pots (Himmelman, 1988). *B. undatum* has a relatively low level of fecundity as it displays direct development (Hancock, 1963; Martel et al, 1986; Kideys et al, 1993). *B. undatum* is considered to be a 'K' selected species, due to its low fecundity, long maturation time and long life span. The opportunity for dispersal is limited due to the absence of a planktonic larval stage and being sedentary in adulthood (Hancock, 1963; Martel et al, 1986; Morel & Bossy, 2004). As a result, localised populations are formed with limited gene flow (Gendron, 1992), rendering the species susceptible to over-fishing and localised extinction (Morel & Bossy, 2004).

Fig. 1. The edible common whelk (*Buccinum undatum* L.) caught using bated pots in England, UK. Image obtained from Lawler and Vause (2009).

1.1 Biology

1.1.1 Feeding and nutrition

As a predator, *B. undatum* uses chemoreception to detect and locate prey, as well as other food sources (Bailey & Laverack, 1966; Sutterlin 1975; Crisp et al, 1978; Miller 1978). These prey items include polychaete and sipunculid worms, crustacea, mollusca, eggs, small echinoids and barnacles. *B. undatum* is also a scavenger, feeding on moribund and dead animals (Blegvad, 1915; Hunt, 1925; Nielsen, 1975; Taylor & Taylor, 1997). The diet of *B. undatum* may be seasonally influenced, as deposit-feeding polychaetes are available all year round, whereas suspension feeders display seasonal patterns of abundance (Taylor & Taylor, 1997).

1.1.2 Growth

B. undatum can grow up to 120 mm in TSL and 60 mm in width, with the shell covered in a relatively thick periostracum and encrusting organisms. The shell has seven to eight whorls, with the last whorl representing 70 % of its height (Fig. 1) (Ager, 2008). *B. undatum* is a long-lived and slow-growing species, with continued shell growth that decreases over its lifespan (Kideys et al, 1993). Geographical differences in TSL and growth rates have been detected over relatively short ranges (Shelmerdine et al, 2007). *B. undatum* typically has a life span of up to ten years (Santarelli et al, 1986), but may live longer than this (Gendron, 1992; ten Hallers-Tjabbes, 1993). Gendron (1992) estimated that *B. undatum* in the Gulf of St. Lawrence, Eastern Canada, attained sexual maturity between five ad seven years of age, and can live up to 12 years, based on the examination of operculum annuli (Fig. 2).

Fig. 2. *Buccinum undatum* operculum with a coin of 24 mm diameter shown for scale. Lines show examples from four of the growth rings. Image obtained from Shelmerdine et al (2006).

1.1.3 Reproduction

The reproductive cycle and general biology of *B. undatum* have not been examined in detail since Dakin (1912), Fretter (1941, 1953), and Johansson (1957) described the anatomy, histology and function of the reproductive organs, with Hancock (1960; 1967) reporting on aspects of *B. undatum* biology in English waters. European populations of *B. undatum* mainly breed during autumn and winter (de Vooys & van der Meer, 2010). In the Northern Hemisphere *B. undatum* is thought to have a distinct annual reproductive cycle, with a single major egg-laying period in the autumn (Valentinsson, 2002). *B. undatum* mate at different times of the year, depending on the geographical location, therefore the timing is likely to be dependent on sea temperature. Although Thorson (1946) concluded that *B. undatum* in Swedish and Danish waters spawned throughout the year, recent studies have indicated that there is a distinct annual breeding cycle, as is the case for the majority of high-latitude marine invertebrates (Valentinsson, 2002). In the Gulf of St. Lawrence, Eastern Canada, mating occurs from May to June and egg-laying from late May to August (Martel et al., 1986; Himmelman & Hamel, 1993). South of the Isle of Man in the Irish Sea, egg laying has been reported to occur from late December to January (Kideys et al, 1993). In South Wales, females are thought to lay their eggs from November to January (French, 2011 M. Sc. thesis).

Female *B. undatum* attract males using pheromones, once the water temperature has reached approximately 9 - 12 °C (Hancock, 1967; Kideys et al, 1993). Female *B. undatum* mate with several males and accumulate the sperm, undergoing internal fertilisation when environmental conditions are optimal (Kideys et al, 1993). Eggs contained in capsules are laid on hard substrata, with both the trochophore and veliger larvae stages developing inside the egg capsules (Fig. 3) and embryos consuming the nurse eggs during intracapsular development (Fretter & Graham 1984; Valentinsson, 2002). Three to eight months later juveniles emerge from the capsules, and begin life on the benthos (Fretter & Graham 1962; Martel et al, 1986).

Fig. 3. Female *Buccinum undatum* laying an egg mass, UK. Image obtained from Lawler (2013).

1.2 Ecology

1.2.1 Distribution and abundance

To assess the abundance and distribution of *B. undatum* by using their attraction to baited pots, it is most useful to refer to their recruitment as the size at which juveniles are recruited to the fishery; once they have reached a size where they can be fished. The distribution and abundance of populations in a community is controlled by dispersal, competition, predation, parasitism, physical disturbance and facilitation (Roughgarden et al, 1988). Although the maximum range of a species may be determined by environmental factors such as temperature, salinity, dissolved oxygen and substratum, the complexity of the interaction between biological and physical factors makes it difficult to identify the dominant influence on a community, with likely variation geographically and temporally. *B. undatum* are thought to have localised populations, with the extent of their dispersal and the connectivity between populations poorly understood, despite the commercial importance of the species

(Weetman et al, 2006). Genetic analysis of *B. undatum* has suggested asymmetric migration between inshore and offshore locations of bays and inlets, where the water chemistry is likely to differ predictably (Weetman et al, 2006).

B.undatum is commonly found off all British coasts, on muddy sand, gravel and rock, as well as occasionally in brackish waters, down to depths of 1200 m (Ager, 2008). However, in Swedish waters, *B. undatum* is generally found on soft bottoms at depths ranging from five to 600 m (Valentinsson, 1999). *B. undatum* can only survive in temperate or cold sea temperatures, with temperatures over 29 ^{O}C proving fatal (Gowanloch, 1927). *B. undatum* struggle to survive in low salinity levels (Russell-Hunter & Russell-Hunter, 1963), tolerating salinities down to 20 ‰ (de Vooys & van der Meer, 2010), and is not well adapted for the intertidal zone (ten Hallers-Tjabbes et al, 1996).

B. undatum has restricted scope for dispersal, and is unlikely to undertake migrations, due to the absence of a planktonic larval phase and limited movement in its adult stage (Hancock, 1967). Underwater observations using SCUBA indicated that *B. undatum* were capable of travelling a distance of up to 50 m per day, at average speeds ranging from 8.3 cm min^{-1} to 11.4 cm min^{-1} (5 ^{O}C water temperature) (Himmelman, 1988).

1.2.2 Predation

B. undatum is predated by invertebrate species such as crabs, lobsters, and starfish, as well as teleost and elasmobranch species (Thomas & Himmelman, 1988; ten Hallers-Tjabbes et al, 1996). *B. undatum* displays escape responses such as rapid flight, shell rocking and foot contortions, when attacked by predators or in response to chemodetection to the polar six-rayed starfish (*Leptasterias polaris* Müller & Troschel, 1842) (Harvey et al, 1987; Rochette et al, 1996; Rochette et al, 1997). In North Wales, the common starfish (*Asterias rubens* L.) is one of the main predators of *B. undatum*, with *B. undatum* responding to its presence using violent contortions of the foot (Feder, 1963; Mackie et al, 1968; Wantanabe, 1983; Ramsay & Kaiser, 1998).

1.3 Buccinum undatum fisheries

1.3.1 Relevance of Buccinum undatum fisheries

Belgium, France, Iceland, Ireland and the UK are the main European countries to exploit *B. undatum* (Dakin, 1912; Hancock, 1967; Shelmerdine et al, 2007), with a *B. undatum* fishery also existing in Eastern Canada (Villemure & Lamoureux, 1974; Martel et al, 1986). *B. undatum* populations have declined in several parts of the North Sea (Cadée et al, 1995; ten Hallers-Tjabbes et al, 1996). A successful *B. undatum* fishery existed in the Dutch Wadden Sea in the 1920s and 1930s, but began declining in the 1920s and has been locally extinct since 1991 (Cadée et al, 1995). The main causes of the decline are thought to be the effects of overfishing, chemical pollution, especially by TBT antifouling paints, and mortality as a result of beam trawling (Cadée et al, 1995; Ten Hallers-Tjabbes et al, 1996).

In the UK, fisheries landings began being recorded in 1986, although data were not consistently recorded until 1995, when European Union legislation made this compulsory (MMO, 2014). The *B. undatum* fishery in the UK is increasing, partly due to the development of markets in South Korea (Morel & Bossy, 2004; Fahy et al, 2005), as there is no market for *B. undatum* as a food source in the UK. *B. undatum* landings in England and Wales were worth over £13.3 million at first sale in 2013, and in excess of £3.6 million for Wales in the same year (MMO, 2014). In the last two decades, *B. undatum* fisheries have become an increasingly viable income for some crab and lobster fishers, as catches and prices have declined for those fisheries. Lawler & Vause (2009) reported that in Sussex, England, *B. undatum* fishing had sometimes occurred during winter, outside of the traditional *B. undatum* season, to supplement fishers' income.

1.3.2 Buccinum undatum fishery in Wales

Historically, the *B. undatum* fishery in Wales has existed on a small scale for food and bait. In the last decade, Wales has seen an increase in *B. undatum* landings, to almost 5,000 tonnes in 2013, becoming the third most important fishery in Wales (MMO, 2014) (Fig. 4). *B.undatum* landings in Wales for 2014 appear to be on a similar scale to that of 2013, based on landings up until August 2014. However, no baseline data currently exists for the *B.undatum* fishery in Wales.

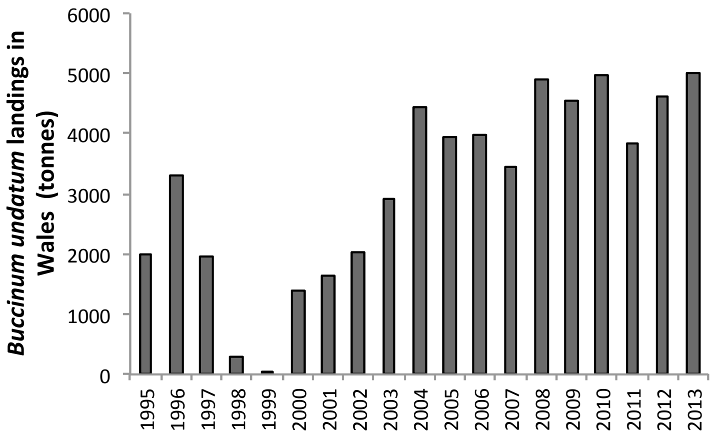

Fig. 4 The annual weight of *Buccinum undatum* landings (tonnes) to Welsh ports, UK, from 1995 to 2013 (MMO, 2014). The 1997 Korean financial crisis caused the *Buccinum undatum* market to collapse and landings to Welsh ports to fall to its lowest level recorded, before recovering to some of the highest levels recorded in 2013.

For decades, a small UK market existed for *B. undatum* supported by a small-scale fishery. By the 1990s, Pacific whelk species had been depleted, creating a market for *B. undatum* in Asia, causing landings to Welsh ports to increase over 10-fold between 1994 and 1995 (Fahy, 2001). However, the 1997 Korean financial crisis caused the *B. undatum* market to collapse and landings to Welsh ports to fall to the lowest level recorded (Morel & Bossy 2004) (Fig. 4). Recovery of the Asian market attracted fishers back to the fishery, and landings have now increased to some of the highest levels recorded (MMO, 2014) (Fig. 4). Over-reliance on the South Korean market causes fishers to be concerned about future market instability (Fahy et al, 2000).

1.3.3 Current regulations and management

In 2006, the European Union Whelk Conservation of Stocks Order (S. I. 237 of 2006) set the Minimum Landing Size (MLS) at a TSL of 45 mm (Browne, 2006). This stipulated that it was an offence to have on board, transport, or offer for sale *B. undatum* below this size. Although the order stated that sub-sized animals should be carefully handled and returned immediately to the water, regulation is not necessarily enforced. The use of baited pots does not discriminate against size, unlike net mesh size for finfish. Some ports have recorded landing of up to 50 % of *B. undatum* below the MLS (Browne, 2006). This makes size regulation an important conservation tool to maintain sustainable *B. undatum* fisheries.

1.3.4 *Species vulnerability*

Aspects of *B. undatum* biology make it susceptible to growth- and recruitment-overfishing (Lawler & Vause, 2009). These biological characteristics include its slow growth, late age at first reproduction, absence of a planktonic larval stage and a sedentary adult stage (Richardson et al, 2005). The vulnerability of *B. undatum* to overfishing, and the recent increase in fishing effort, necessitates that a conservative management approach be taken to ensure the sustainability of stocks. This has recently become more relevant in Wales, due to policy responsibility for fisheries having been devolved to the Welsh Government in 2011.

The lack of enforcement of the 45 mm TSL minimum landing size for *B. undatum* set by the EU, and the open access status of the fishery in Wales encourages an opportunistic harvesting approach by fishers. *B. undatum* fishers are not incentivised to conserve stocks due to past experience and unpredictability of the resource (Richardson et al, 2005). In 2004, Richardson et al (2005) assessed attitudinal differences between 18 skippers/owners of licensed *B. undatum* fishing vessels, operating from the inshore commercial fishery in Wales, UK. The *B. undatum* fishery being restricted to predictable and well-defined fishing grounds (Agrawal, 2001; Janmaat, 2005) may be considered an incentive for the conservation of the fishery (Richardson et al, 2005). However, apart from mobile gear fishers, the *B. undatum* fishers interviewed felt less strongly about the need for stock conservation than all other sectors, namely the crustacean, line/net and transient fishers. Although a number of the *B. undatum* fishers acknowledged that they could be fishing too many pots, this was condoned by other fishers doing the same.

In Jersey, UK, a *B. undatum* fishery was set up in 1996, where none had previously existed. A significant difference was seen in catch per unit effort (CPUE) at fished and non-fished sites, with fished sites having a lower CPUE than non-fished (Morel & Bossy, 2004). Concern over the sustainability of *B. undatum* fisheries led to the Sussex Sea Fisheries Committee, England, conducting an investigation in 2009/2010 to inform management decisions. On 1st April 2013 the Kent and Essex Inshore Fisheries and Conservation Authority (IFCA) district introduced a new byelaw for hobby and commercial fishers, with permits now issued for between 10 and 300 pots (IFCA, 2013).

1.3.5 Fishing methods

B. undatum is caught using baited pots, which are tied together to form a string of pots (Fig. 5a). There are typically 20 – 50 pots per string, with fishers commonly having a total fleet of 500 pots when commercial vessels are up to 10 m in length (Dr Jodie Haig personal communication, April 2014). As fishers deploy multiple strings of pots, these can be placed in the various locations known by fishers to have a high abundance of *B. undatum,* usually for a duration or 'soak time' of 24 hours. Moulded plastic pots specifically designed for catching *B. undatum* can be purchased from £42 each, but are also made more economically by fishers, using modified plastic fuel containers weighted with cement (WG, 2014). Pots designed to lay on their longest edge are referred to as 'lay down' pots, while those that lay on their short edge are known as 'stand up' pots. A survey of *B. undatum* fishers in Wales suggests that lay down pots baited with a mixture of edible brown crab (*Cancer pagarus* L.), or spider crab (*Macrocheira kaempferi* Temminck, 1836), and catshark spp. (family: Scyliorhinidae) is most successful (Dr Jodie Haig, personal communication, April 2014), although different types of bait have been used effectively in the past (Hancock, 1967). The commercial static gear used in inshore waters generally fishes very cleanly, with low bycatch abundance (Lawler & Vause, 2009). To comply with the 45 mm MLS, catch is passed over a 25 mm riddle, an onboard sieving device (Fig. 5b). A bucket positioned underneath the riddle retains the undersized *B. undatum* so they can be returned to the water, while *B. undatum* of 45 mm or above are collected in bags for landing.

a) **b)**

Fig. 5 a) Lay down *Buccinum undatum* pots ready to be deployed onboard 'Danny Buoy', used to conduct survey work in Oxwich Bay and Swansea Bay, South Wales **b)** The 25 mm riddle (gap width) used in the *B. undatum* fishery to separate those below a 45 mm Total Shell Length (TSL), to comply with the Minimum Landing Size (MLS) onboard 'Danny Buoy', Swansea, South Wales. A riddle was not used as part of the fisheries catch analysis, and *B. undatum* for the mark-capture study were assessed for size by eye.

1.4 Mark-recapture to estimate abundance

1.4.1 Mark-recapture

Mark-recapture methods can be used to obtain an estimate of population size for a given species, when it is not practical to count all the individuals in a population (Lockwood & Schneider, 2000). A sample of the population is captured, tagged and then released. A later sample of the population is captured and counted, where the number of tagged individuals in the second sample should be proportional to the number of tagged individuals in the population as a whole. Dividing the number of tagged individuals from the initial tagging event, by the proportion of tagged individuals in the second sample, provides an estimate of total population size (Lockwood & Schneider, 2000). Mark-recapture methods used to estimate abundance assumes that, instantaneous rates of mortality, exploitation and recruitment are constant. As *B. undatum* is sedentary, the fishery can be considered as a closed population. The Lincoln–Peterson Index can be used for closed populations, where visits to the study area are close enough in time so that no animals die, are born, immigrate or emigrate between visits (Lockwood & Schneider, 2000).

1.4.2 Mark-recapture examples

In the laboratory, *B. undatum* tagged with thick rubber bands had a 100 % retention rate after two months, performing better than alternative tagging methods (unpublished data, Haig, 2013). The tagging of *B.undatum* using rubber bands can be successful in field experiments, provided that the study is short term (Himmelman, 1988; Kideys, 1994). In September 2009, a mark-recapture study was conducted to assess two *B. undatum* fisheries in potting surveys off the Sussex coast, Eastern English Channel, UK (Lawler & Vause, 2009). Rubber bands were used to tag *B. undatum* and the feasibility of using this methodology to assess exploitation rates and population size was investigated. As the survey was carried out in September, outside of the fishing season for *B. undatum*, this resulted in very low catch rates. To compensate for this, the natural population was supplemented with *B. undatum* from an adjacent area that was not part of the survey area. The survey was successful in conducting the mark-recapture experiment for *B.undatum* tagged with rubber bands, but the data obtained did not reflect that of a natural population.

Field studies conducted by Himmelman (1988) indicated that *B. undatum* were more readily recaptured using traps in experiments where greater care had been taken not to make them stressed. *B. undatum* captured and tagged by divers, had a better recapture rate than those that had been removed from the water to be tagged. This was true in four out of six release sites, despite all sites being the same for both groups (Himmelman, 1988). This suggests that the removal of experimental *B. undatum* from the water may impair their typical behavioural responses. This may affect the ability of *B. undatum* to detect, locate and travel to baited pots, reducing their ability to be recaptured.

1.5 Aim

The project aims to estimate the population parameters of *Buccinum undatum* in two inshore locations, Oxwich Bay and Swansea Bay, South Wales, UK, as no baseline data currently exists for Wales. The fieldwork involves collaboration with a commercial fisher to conduct a fisheries catch analysis, and a mark-recapture study to estimate *B. undatum* abundance and movement. Laboratory experiments will assess the effect of handling on the ability of *B. undatum* to be recaptured. Research will be undertaken in line with the objectives of the European Fisheries Funded project: Sustainable Fisheries Resources in Welsh waters.

1.6 Hypotheses

H_1: *B. undatum* length-frequency distribution, abundance, TSL and CPUE will be significantly different when Oxwich Bay and Swansea Bay are compared.

H_2: *B. undatum* abundance, TSL and CPUE will be significantly different among depth, pot colour (abundance and TSL only) and soak time at both Oxwich Bay and Swansea Bay, and between lay down and scientific pots at Oxwich Bay.

H_3: *B. undatum* percentage undersized will vary between Oxwich Bay and Swansea Bay, depth, pot type, pot colour and soak time.

H_4: *B. undatum* tagged using thick rubber bands will retain their tags for four months, under laboratory conditions.

H_5: *B. undatum* disturbed to simulate handling (tagged, rolled and exposed to air) will have recovery times to righting and feeding that are not significantly different to the control group, under laboratory conditions.

2. METHODS

2.1 Fieldwork

2.1.1 Survey area

The survey was carried out in two neighbouring bays, forming part of the Gower Peninsula in Swansea, South Wales, UK (Fig. 6). Oxwich Bay is a large, moderately exposed sandy bay, forming part of a National Nature Reserve with nearby sand dunes and a wetland site. Sampling predominantly took place to the East of Oxwich Bay, near Three Cliffs Bay, with sediment ranging from fine to muddy sand (Admiralty chart 1161). Surveys conducted in 1980 suggested that the littoral zone in Oxwich Bay had high densities of the sea potato (*Echinocardium cordatum* Pennant, 1777) and razor clam (*Ensis siliqua* L.) (Bishop & Holme, 1980). Swansea Bay is a shallow industrialised embayment, and considerably larger than Oxwich Bay, extending from Port Talbot to the Mumbles Peninsula. The sediment in Swansea Bay is thought to consist of fine to gravelly sand (Admiralty chart 1161), and the bay is exposed to prevailing south-westerly winds (Davies, 1998). Swansea Bay is currently a proposed site for a tidal lagoon development, which will be a source of renewable energy, selected based on the 10.5 m tidal range in the bay (Tidal Lagoon, 2014). The project has been in the feasibility stage since 2011, with the area extensively surveyed after that time.

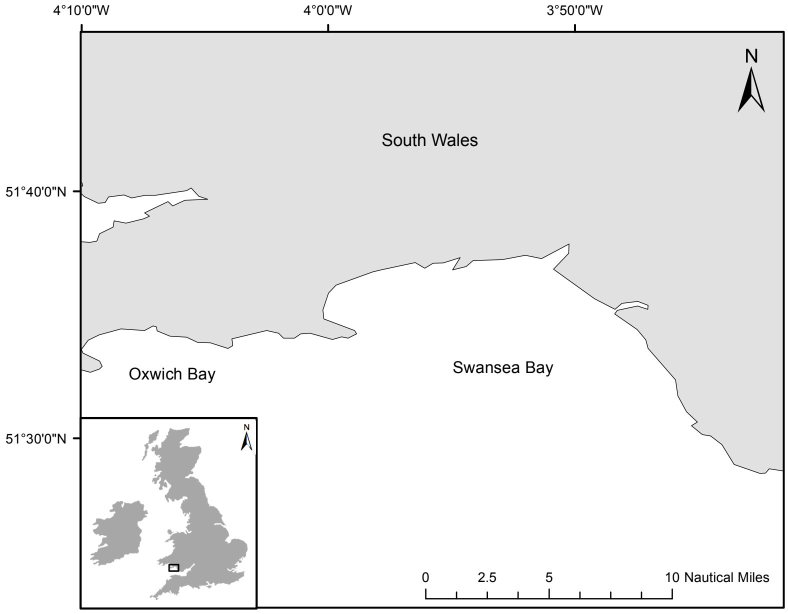

Fig. 6 Survey areas in South Wales, Oxwich Bay and Swansea Bay, where *Buccinum undatum* fisheries catch analysis was conducted from 24th June – 25th July 2014, and the mark-recapture study from 10th – 25th July 2014. *B. undatum* were fished using baited pots in water depths of 0.9 – 11.8 m chart datum, with the tide ranging from 0.4 - 6.6 m during fieldwork.

2.1.2 Fishing vessel

Survey work was conducted onboard the commercial fishing vessel 'Danny Buoy' (Fig. 7) in Swansea, South Wales, during alternate weeks from 10th June – 25th July 2014. The inshore vessel is a 10 m Cygnus 33 catamaran, with twin inboard Ford 90 horsepower diesel engines and forward wheelhouse, equipped primarily for the pot fishing of *B. undatum*. The first of the four weeks at sea were used to conduct the mark-recapture study, and the remaining three to conduct a fisheries catch analysis. Recapture data were recorded by the fisher from 16th June – 25th July 2014. *B. undatum* were caught using baited pots from two survey areas in South Wales, Oxwich Bay and Swansea Bay. Oxwich Bay was visited in the morning and Swansea Bay in the afternoon, with an approximate travel time of 45 minutes between sites.

Fig. 7 The commercial fishing vessel 'Danny Buoy' used to conduct *Buccinum undatum* fisheries catch analysis and a mark-recapture study to estimate abundance Swansea, South Wales from 10th June – 25th July 2014.

2.1.3 Fishing gear

Fishing gear comprised 13 strings and 554 pots, with 30 – 52 pots per string (Table 1). Pots were positioned 20 m apart on each string, with a total string length of 600 – 1,560 m depending on the number of pots (Fig. 8a). Seven strings were located at Oxwich Bay and hauled each day (Monday to Friday), while six strings were located at Swansea Bay, with between two and four strings fished daily.

Table 1
The location and number of strings and pots used to conduct the *Buccinum undatum* fisheries catch analysis and mark-capture study in Oxwich Bay and Swansea Bay, South Wales, from 10th June – 25th July 2014. Four 36 litre round, stand up scientific pots were attached to the end of four strings in Oxwich Bay, South Wales. * scientific pot attached to sting. String numbers 6 and 13 do not exist. (No. = numbers).

Bay	String no.	No. pots per string	No. strings per bay	No. pots per bay
Oxwich	1	50	7	311
	2*	30		
	3*	30		
	8	50		
	12	50		
	14*	49		
	15*	52		
Swansea	4	30	6	243
	5	30		
	7	50		
	9	43		
	10	45		
	11	45		
Total			**13**	**554**

Strings typically had a soak time of 24 – 48 hours, with soak times occasionally up to seven days at Swansea Bay due to logistical reasons. Strings hauled on a Monday at both Oxwich Bay and Swansea Bay had a soak time of 48 hours, due to the fisher not working at weekends. The fleet mainly comprised lay down pots (Fig. 8a), with four scientific pots (Fig. 8b) attached to the end of pot strings in Oxwich Bay (Table 1).

a) **b)**

Fig. 8 *Buccinum undatum* pots used to conduct survey work onboard the fishing vessel in Oxwich Bay and Swansea Bay, South Wales **a)** A 25 litre lay down pot with the mesh drawn closed and holes in the side visible, used to encourage *B. undatum* to detect bait and for water drainage and **b)** a round, stand up 36 litre scientific pot attached to the end of four strings of pots in Oxwich Bay, South Wales.

Scientific pots were 36 litre round 'Fishtec' stand up pots, and had been used as part of a previous study conducted by the Fisheries and Conservation Science Group, and used in the present study to compare abundance and Total Shell Length (TSL) to lay down pots. Lay down pots made up 99 % of the fleet, with 76 % 25 litre in capacity, while scientific pots represented the remaining 1 % of the fleet (Table 2).

Table 2
The breakdown of pot type in the fleet used to conduct the *Buccinum undatum* fisheries catch analysis and mark-recapture study in Oxwich Bay and Swansea Bay, South Wales, from 10th June – 25th July 2014. The fleet comprised 554 pots, of which almost all were lay down pots, and the majority with a 25 litre capacity. Four 36 litre round, stand up scientific pots were attached to the end of four strings in Oxwich Bay, South Wales.

Pot type	Pot capacity (l)	No. pots in fleet	Percentage of fleet	Length (cm)	Width (cm)	Height (cm)	Side holes diameter (cm)
Lay down	30	120	22	40	35	26	2
Lay down	25	420	76	41	29	22	2.5
Lay down	20	10	2	41	25	18	2.5
Scientific (round stand-up)	36	4	1	38	38	35	-
Total		**554**	**100**				

Pots were baited with edible brown crab (*Cancer pagurus*) or *spider crab* (*M. kaempferi*) and catshark spp., depending on supplier availability or what the fisher had caught (Fig. 9). Due to the larger size of the scientific pots, they were given 50 % extra bait, compared to the lay down pots.

a) **b)**

Fig. 9 Bait cut up ready to be used in *Buccinum undatum* pots in Swansea, South Wales **a)** edible brown crab (*Cancer pagurus*) and **b)** catshark spp. *B. undatum* caught using baited pots were used as part of the fisheries catch analysis conducted from 24th June – 25th July 2014, and the mark-recapture study from 10th June – 25th June 2014.

2.2 Fisheries catch analysis

A total of six days of fisheries data were collected from 24th June - 25th July 2014, by two people for a minimum of 8 hours per day. The number of pots surveyed per string ranged from 1 – 9, depending on the number of *B. undatum* caught in each pot and the time taken to analyse them. Pots were emptied into separate buckets along with their bycatch without riddling, to determine the percentage of undersized *B. undatum* (Fig. 10a). Abundance was obtained by counting the number of *B. undatum* per pot, and the TSL of *B. undatum* was measured to the nearest millimetre using a Vernier caliper (Fig. 10b). CPUE (kg) was estimated per pot using the number of bags landed per sting. *B. undatum* below the 45 mm Minimum Landing Size (MLS) were returned to the water, while those above were landed after measuring (Fig. 10c). Pot type (lay down or scientific) and colour (blue, black or white) were recorded for analysis of abundance per pot and TSL. *B. undaum* hauled from particularly silty habitats were rinsed in seawater using a mesh bucket to remove the sediment. The number of bags landed per string hauled was recorded by the fisher to the nearest 0.25 of a bag. The mean bag weight for June – July 2014 was 32.5 kg, and provided by the fisher from landings data.

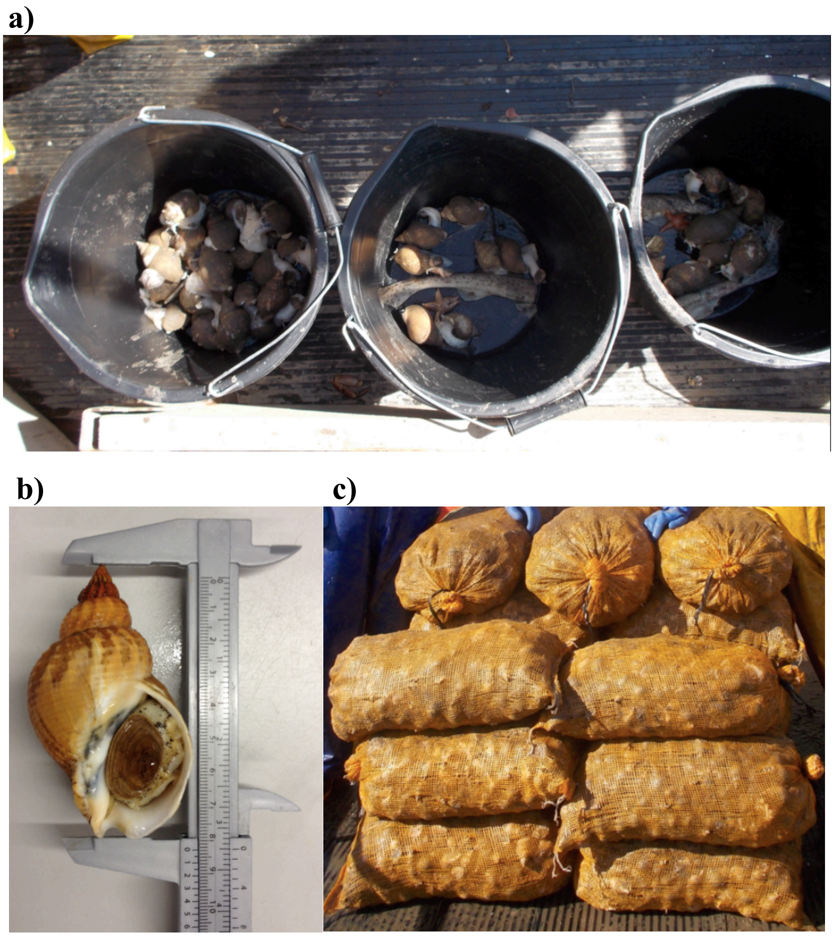

Fig. 10 a) The catch from three *Buccinum undatum* pots before recording abundance, Total Shell Length (TSL), Catch Per Unit Effort (CPUE), and bycatch in Oxwich Bay, South Wales **b)** The TSL of *B. undatum* being measured using a Vernier caliper during the fisheries catch analysis. **c)** Bags of *B. undatum* ready to be landed, with a mean weight of 32.5 kg per bag in Swansea, South Wales. Fisheries catch analysis was conducted from 24th June – 25th July 2014, in Oxwich Bay and Swansea Bay, South Wales.

2.2.1 Environmental variables

Environmental data were collected for each string of pots that the fisheries data were obtained from, at the start of each string of pots being hauled and representative of that string as a whole. Habitat type, GPS position, actual water depth (not accounting for tide) and salinity were recorded per string in Oxwich Bay and Swansea Bay. The substrata types of the survey areas were identified using a drop down camera. A 'Hero3 GoPro' camera in waterproof housing and diving torch were mounted on a metal frame, with 40 m of rope and a buoy line attached (Fig. 11). A '2G, Aladin' dive computer was also attached to the frame but was not used to obtain depth, due to the frequency of deployment causing the computer to lock out.

Fig. 11 The underwater camera and frame configuration used to identify *Buccinum undatum* habitat types at the survey areas in Oxwich Bay and Swansea Bay, South Wales. The camera was deployed for each string of pots hauled to obtain fisheries data, from 24th June – 25th July 2014. Still images were obtained from each video for habitat analysis.

A Tinytag Aquatic 2 submersible temperature logger (diameter 51 mm and 50 mm height) was attached to a *B. undatum* pot using a cable tie, remaining at an approximate depth of 5 m chart datum. The GPS positions of strings were recorded in Decimal Degrees (DD) using an eTrex 10 handheld waterproof GPS unit. The actual water depth in metres was obtained from the fishing vessel's onboard echo sounder. Surface seawater salinity was measured using a hand held optical refractometer. Samples were taken from surface waters, at an approximate depth of 0.2 m, and the refractometer calibrated with deionised water prior to each measurement. Three salinity readings were taken per string and the mean obtained. The underwater temperature at Oxwich Bay was recorded at a single location from 10th June – 25th July 2014.

2.3 Mark-recapture to estimate abundance

2.3.1 Laboratory experiments

All experimental *B. undatum* were caught in the Menai Strait, Anglesey (location shown in Appendix Fig. 7.1), using lay down pots baited with shore crab (*Carcinus maenas* L.) and mackerel (*Scomber scombrus* L.). *B. undatum* were transferred to experimental tanks in the laboratory and acclimated to the tanks for at least two weeks prior to experimentation. Tanks received a continuous flow of seawater from the Menai Strait, with a variable water temperature of 9.1 – 23.1 °C, and were oxygenated using an air stone.

2.3.2 Tag retention study

A total of 58 *B. undatum* were caught from the Menai Strait during September 2013, ranging from 41 – 103 mm TSL, and were kept in a rectangular tank (0.8 m x 0.6 m x 0.37 m) with a water depth of 0.25 m. *B. undatum* were tagged with thick rubber bands of approximately 20 mm x 13 mm, and a 1 mm thickness (Fig. 12a & b). Rubber bands were stretched by hand and positioned across the body whorl of the *B. undatum* shell (Fig. 12c). To validate the mark-recapture study, the tag retention rate was recorded under laboratory conditions from 11th March – 11th August 2014. *B. undatum* were fed on shore crab (*Carcinus maenas*) once a week and monitored twice per week, with dead *B. undatum* removed from the tank as needed.

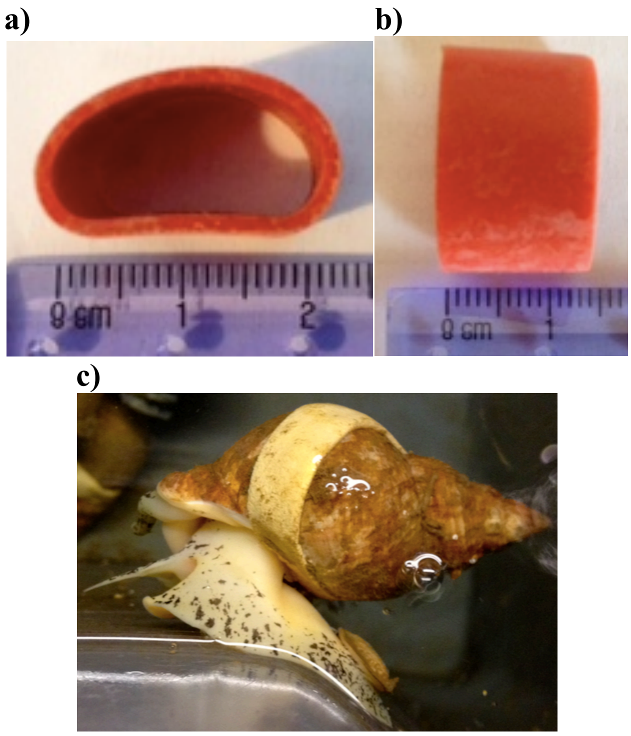

Fig. 12 The thick rubber bands (1 mm thickness) used to tag *Buccinum undatum* for the tag retention study with **a)** a band length of 20 mm and **b)** a band width of 13 mm **c)** a tagged *B. undatum* on the side of a tank as part of the tag retention study. The study ran from 11th April - 11th August 2014 in the School of Ocean Sciences aquarium, to validate the mark-recapture study.

2.3.3 Righting recovery after disturbance

In the laboratory, experiments assessed the effects of tagging, rolling and air exposure on *B. undatum* to simulate handling onboard. The rolling of *B. undatum* reflected pots being inverted and shaken until emptied, while tagging and air exposure more directly replicated the treatment of *B. undatum* in the field, where they were tagged and kept in a bucket (out of the water) for up to one hour before being released. Experiments were carried out in a rectangular tank (1.0 m x 0.5 m x 0.5 m) with a water depth of 0.36 m. A total of 70 experimental *B. undatum* were used for the righting experiment on 2nd June 2014, ranging from 56 – 89 mm TSL (Table 3). Each treatment and the control group had 14 *B. undatum* randomly assigned to them. To mitigate any tank effect, *B. undatum* that had received different treatments were randomly assigned to one of three tanks. Air exposure times of one and three hours were chosen to reflect the upper and lower limits of likely air exposure during fieldwork.

Table 3
The treatments received by *Buccinum undatum* in the laboratory prior to the righting and response to bait experiments. The righting experiment was conducted twice using two batches of *B. undatum*. Response times to bait followed on from the righting experiment, using the same experimental *B. undatum*.

Treatment		**Recovery experiment**	
		Righting	**Righting & response to bait**
		02.06.14	01 - 02.08.14
	Control	14	11
1	Tagged underwater only	14	11
2	Tagged, rolled, no further exposure	14	11
3	Tagged, rolled, exposed to air for 1 hour	14	11
4	Tagged, rolled, exposed to air for 3 hours	14	11
Total		**70**	**55**

The righting experiment was repeated on 1st August 2014 using the same treatments on a new group of 55 *B. undatum* (Table 3). The second righting experiment used *B. undatum* ranging from 66 – 93 mm TSL, which were kept in a single large tank (2.5 m x 0.3 m x 1.2 m), with a water depth of 0.8 m. The control group was taken out of the water and placed in a bucket with air exposure for five seconds before being returned to the water. Treatment two was tagged with thick rubber bands, rolled from side to side in a fish box for one minute, and returned to the water. Treatments three and four were removed from the water, tagged, rolled for one minute and exposed to air for one and three hours respectively, by being kept in a bucket (Fig. 13).

Treatments were conducted so that all *B. undatum* were returned to the water at the same time.

Fig. 13 *Buccinum undatum* tagged with thick rubber bands and placed in a bucket in the laboratory, using righting times as a measure of recovery from disturbance. *B. undatum* received a combination of rolling, tagging and air exposure to simulate the effects of handling and tagging necessary for the mark-recapture study in the field.

2.3.4 Feeding recovery after disturbance

The righting experiment on 1st August 2014 continued until the following day to assess response times to bait, 24 hours after experimental treatments had been completed (Table 3). The 24 hour period reflected the typical soak time of pot strings in commercial *B. undatum* fishing. *B. undatum* were carefully removed from the bottom and sides of the tank, and kept underwater and upright while being relocated to one end of the tank, where they remained upright. Six shore crab (*Carcinus maenas*) were cut in half and used as bait, positioned approximately 60 cm away from *B. undatum*. The response time to bait was recorded as the time taken for *B. undatum* to reach the bait or an adjacent conspecific.

2.3.5 Mark-recapture study

B. undatum were caught from Oxwich Bay and Swansea Bay to be used in the mark-recapture study to estimate abundance (capture sites shown in Appendix Fig. 7.2). *B. undatum* were tagged using thick rubber bands over four consecutive days from 10th – 13th June 2013, and considered as a single tagging event. The tagging effort involved four people tagging consistently for up to 8 hours each day, applying bands by hand or using a lobster banding tool (tagging effort shown in Appendix Table 7.3). To denote the date of tagging and release six band colours were used, three at Oxwich Bay and three at Swansea Bay (Table 4).

Table 4
The band colours used to tag *Buccinum undatum* over the four-day tagging event in Oxwich Bay and Swansea Bay, South Wales, from 10th - 13th June 2014. Beige and green bands were used for the first two days to compensate for initial inefficiencies in tagging rates. Thick rubber bands of the same size were used to tag all *B. undatum*.

Survey area	Tag & release date	Band colour
Oxwich Bay	10 - 11.06.14	Beige
	12.06.14	Red
	13.06.14	Black
Swansea Bay	10 - 11.06.14	Green
	12.06.14	Blue
	13.06.14	Yellow

Each time *B. undatum* were caught from a string of pots, released, or recaptured, the waypoint was recorded using a handheld GPS unit. The rubber bands used to tag *B. undatum* were of the same specifications as those used in the tag retention study. To mitigate initial inefficiencies in tagging rates, the same band colours (beige and green) were used for the first two days (Table 4). To minimise exposure to air, *B. undatum* were kept in buckets of seawater onboard for up to one hour, until they could be tagged. During tagging, *B. undatum* were exposed to air for up to 30 minutes, before being released in batches (Fig. 14). Tagged *B. undatum* were released in batches of 100 or 200, except for three occasions when 400 - 600 tagged *B. undatum* were released in Swansea Bay, due to the travel time from Oxwich Bay. *B. undatum* were usually released in the vicinity of a pot string, although never directly on top of a string. Only adult *B. undatum* were tagged, with a TSL of 45 mm or above, as they had been recruited to the fishery. Tagging *B. undatum* of 45 mm TSL and above avoided the need to use bands of different sizes, which may have reduced the tagging efficiency. *B. undatum* above the minimum landing size of 45 mm TSL were identified by eye, to prevent any physical damage and associated risk of predation that may have been caused by riddling. The six week recapture period began two days after the tagging event had been completed, running from 16th June – 25th July 2014. Each time tagged *B. undatum* were recaptured the fisher recorded the date, GPS position, band colour, number and catch in bags per string. Tagged *B. undatum* had their bands removed for counting and were landed along with the rest of the catch for that day.

Fig. 14 *Buccinum undatum* tagged with beige thick rubber bands before being returned to the water, as part of the mark-recapture study to estimate abundance, on 10th June 2014 in Oxwich Bay, South Wales. *B. undatum* were kept in buckets of water onboard for up to one hour prior to tagging, and exposed to air for no more than 30 minutes during tagging. *B. undatum* were released in batches in the vicinity of a string to ensure that they had a chance of being recaptured.

3. DATA ANALYSIS

3.1 Fisheries catch analysis

Analysis of the fisheries catch refers to the six days of data collected from 24th June – 25th July 2014, unless otherwise stated. Oxwich Bay and Swansea Bay were compared statistically for *B. undatum* TSL length classes, abundance per pot, overall TSL and CPUE per pot, with all other analyses conducted separately for each bay, for comparative purposes. Fisheries data were summarised using descriptive statistics, with mean values and standard error bars, used to take sample size into account. To identify significant differences in group means, one-way analysis of variance (ANOVA) was used, where the assumptions of normal distribution and homogeneity of variance were met. To test for normal distribution the Shapiro-Wilk test was used, along with the Levene's test for homogeneity of variance. Data not meeting these assumptions were $\log_e$, square root, fourth root or $\log_{10}$ transformed using the least severe transformation as appropriate. A Kruskal-Wallis test was used on untransformed data when the assumptions of parametric testing were not met, with Mann-Whitney *U* tests used for pairwise comparisons when significant differences were identified (Dytham, 2011). When only two groups existed that did not meet parametric assumptions, the Mann-Whitney *U* test was used. The significance level was set at $p = 0.05$ for all analyses, with SPSS v20 used for all tests for differences and correlations.

3.1.1 Habitat type

A total of 45 underwater videos were reviewed, with a duration ranging from 2 – 9 minutes, with 36 from Oxwich Bay and 9 from Swansea Bay. Still images were obtained from each video using VLC media player v2.1.5, with one image representing the habitat from that string as a whole. Habitat classification was based on a modified version of the Udden-Wentworth Grain-Size Classification Scheme (Wentworth, 1922), to accommodate use with still images and the inability to measure grain size. The habitat types were divided into five major categories (Fine Sediment, Coarse Sediment, Rock, Macrophyte-Dominated Sediment and Biogenic Reefs), with various sub-categories (Table 5).

Table 5
The classification of substrata used to identify *Buccinum undatum* habitats during the fisheries catch analysis in Oxwich Bay and Swansea Bay, South Wales, from 10th June – 25th July 2014.

Grain/habitat type		**Size class (mm)**
Fine	Mud	< 0.063
	Fine Sand	0.063 – 0.25
Coarse	Coarse Sand	0.25 – 2
	Gravel	2 - 4
	Pebble	4 – 64
	Cobble	64 – 256
	Shell	-
Rock	Boulder	> 256
	Bedrock	-
Macrophyte	Algae	-
Biogenic reefs	Brittle Star	-
	Maerl	-
	Horse Mussel	-

3.1.2 Catch Per Unit Effort (CPUE)

The mean *B. undatum* CPUE was calculated using the number of bags landed per string, estimated by the fisher. The bags landed per string were multiplied by the bag weight, based on a mean weight of 32.5 kg for June - July 2014. The weight obtained per string was then divided by the number of pots on that string, obtaining the mean CPUE weight in kg per pot. As bag weights were used for the CPUE, this excluded undersized *B. undatum* that were separated during riddling, those below the 45 mm MLS.

The mean daily CPUE was calculated from 3rd June to 25th July 2014, for each day that *B. undatum* was fished during that period. Strings landed on the same day were averaged to be representative of that date. The CPUE was also calculated separately for the six days of fisheries analysis, from 24th June to 25th July 2014. The data obtained was used to compare CPUE between Oxwich Bay and Swansea Bay generally, as well as for pots with different soak times and depth. Mean CPUE (kg/pot) was summarised graphically (± SE).

3.1.3 Length-frequency distribution

A length frequency distribution graph was created using TSL data, including *B. undatum* under the 45 mm MLS. Length frequencies were calculated using the proportion of *B. undatum* in each 5 mm length class (L_T). Chi-square (χ^2) goodness of fit was used to test for significant differences from the expected 1:1 ratio in each length class between bays. χ^2 critical values were obtained using an SPSS v20 generated distribution table. Using 1 degree of freedom length comparisons had a probability of 0.05 when the χ^2 value exceeded 3.84, a probability of 0.01 when the value exceeded 6.63, or a probability of <0.001 when the χ^2 value exceeded 10.83 (Field, 2013). Only length categories with expected values greater than five were used, to meet the assumptions of the chi-square test.

3.1.4 Depth

The actual water depth was recorded for each of the 54 strings of pots hauled using the onboard echo sounder, to be converted to chart datum. The time that each string was hauled was recorded with the GPS position, and used to obtain the tidal height from Swansea 2014 tide tables. Once the correct tidal height had been determined, the rule of twelfths was applied to calculate the height of the tide at a given time.

This tidal height was then subtracted from the actual water depth originally recorded, to obtain chart datum in metres.

Depths were grouped into three metre intervals to allow a suitable number of replicates for each depth band for both Oxwich Bay and Swansea Bay. *B. undatum* abundance per pot, TSL (mm) and CPUE per pot (kg) were compared between depths ranging from 3 - 18 m, using Kruskal-Wallis tests for both Oxwich Bay and Swansea Bay. Mann-Whitney *U* tests were used for pairwise comparisons of median *B. undatum* TSL at Oxwich Bay and Swansea Bay. All mean values were presented graphically (± SE).

3.1.5 Temperature

The minimum, mean and maximum daily seawater temperature at Oxwich Bay was presented graphically, from 10th June - 24th July 2014. The Pearson product-moment correlation was used as a measure of the linear association between the daily temperature (mean and minimum) and *B. undatum* abundance per pot, TSL and CPUE per pot, from 24th June - 24th July 2014. Data were tested for normal distribution using the Shapiro-Wilk test, and transformed as appropriate. The Pearson correlation coefficients were presented in a table, along with mean *B. undatum* abundance per pot, TSL and CPUE per pot (± SE).

3.1.6 Pot type

For Oxwich Bay, lay down and scientific pots were compared for median abundance of *B. undatum* per pot and median TSL (mm), using Mann-Whitney *U* tests, with mean values presented graphically (± SE). Data using scientific pots were not included in any other analysis.

3.1.7 Pot colour

Data for pot colour were recorded for Oxwich Bay and Swansea Bay from four of the six days of fisheries analysis, from 8th - 26th July 2014. Median *B. undatum* abundance per pot and median TSL (mm) were compared for black, blue and white pots, using Kruskal-Wallis tests. Mann-Whitney *U* tests were used for pairwise comparisons of *B. undatum* TSL for Oxwich Bay and Swansea Bay, summarised in a table. All mean values were presented graphically (± SE).

3.1.8 Soak time

The date each string was hauled was recorded by the fisher and used to determine the soak time of each string analysed as part of the fisheries catch analysis, based on the previous date the string was hauled. Soak times of 24, 48 or 72 hours and over were used, with soak times of 72 hours or above grouped as bait would have been consumed between 48 and 72 hours. *B. undatum* abundance per pot, TSL (mm) and CPUE per pot (kg) were compared between soak times of 24 and 48 hours at Oxwich Bay, and 24, 48 and 72+ hours at Swansea Bay. Median *B. undatum* abundance per pot and TSL (mm) were compared for soak times using a Mann-Whitney *U* test at Oxwich Bay, while at Swansea Bay a Kruskal-Wallis test was used, followed by Mann-Whitney *U* tests for pairwise comparisons. For Oxwich Bay, mean *B. undatum* CPUE was compared for soak times using a one-way ANOVA, while at Swansea Bay median CPUE among soak times were compared using a Kruskal-Wallis test. All mean values were presented graphically (± SE).

3.1.9 Percentage undersized

The abundance of undersized *B. undatum*, those below 45 mm TSL, was divided by the total *B. undatum* abundance and multiplied by 100. The percentage of undersized *B. undatum* was obtained to compare Oxwich Bay and Swansea Bay, as well as depth, pot type, pot colour and pot soak time.

3.1.10 Bycatch

The total bycatch and *B. undatum* abundance were used from the six days of fisheries catch analysis, as bycatch numbers were generally low. A list of each bycatch species was compiled, and the proportion relative to *B. undatum* abundance calculated, as this was the targeted species of the fishery.

3.2 Mark-recapture to estimate abundance

The recapture data were obtained from 16th June - 25th July 2014, with recaptures during the tagging event omitted from the data to ensure the recapture period was consistent for all tagged *B. undatum*. A total of 145 *B. undatum* were tagged twice with bands of different colours, but were only counted as a recapture for the first colour they were tagged with, as all other tagged *B. undatum* were only removed from the water once. Anomalous release and recapture points were omitted, when the distance between them greatly exceeded the mean distance travelled for that band colour. Using the GPS positions of pot strings, capture points were mapped for Oxwich Bay and Swansea Bay, while release and recapture points were mapped for each band colour, in ArcGIS v10.1 based on the 1984 World Geodetic System.

3.2.1 Lincoln-Petersen Index

The population size for the survey areas in Oxwich Bay and Swansea Bay were estimated using the following Lincoln-Petersen Index:

$$N = \frac{Kn}{k}$$

Where N = Total estimated population

K = Number of *B. undatum* marked (4 day tagging event)

n = Number of unmarked *B. undatum* captured (6 week recapture period)

k = Number of marked *B. undatum* recaptured (6 week recapture period)

This was based on the assumption that the population in each bay was closed due to the limited movement of *B. undatum*, tags had a 100 % retention rate and were correctly identified by the recorder. The Lincoln-Petersen Index also assumed that tagged *B. undatum* were randomly distributed throughout the population and had the same probability of being recaptured, with the number of births, deaths, emigration and immigration in the populations the same for marked and unmarked *B. undatum*.

The number of unmarked animals was estimated from the fisher's landing records, which is in units of bags. Data for the weight of individual *B. undatum* (including their shell) was obtained for 2013 from the Fisheries and conservation Science Group. Data were collected as part of an independent study in Oxwich Bay and Swansea Bay, using samples from scientific pots with the same fisher. As the weight of *B. undatum* varied seasonally, mean weight (g) was calculated separately for June and July, and applied to the relevant month. The mean weight per bag (32.5 kg), obtained from the fisher's landings data, was converted to grammes and divided by the weight per *B. undatum* (g) for the appropriate month. The number of *B. undatum* per bag was then multiplied by the number of bags caught per day, for each bay. This provided an estimate of the total number of unmarked *B. undatum* caught, required for the Lincoln-Petersen Index.

3.2.1.1 Abundance

To estimate the total fishing area for each bay, the outer perimeter of release and recapture points were joined together using straight lines, creating an area that could be measured in metres using ArcGIS v10.1. The density of *B. undatum* was calculated using the abundance estimates obtained from the Lincoln-Petersen Index, divided by the area to obtain the number of *B. undatum* per m^{-2}, per band colour. The values obtained from the band colours at each bay were averaged, giving a mean *B. undatum* density per bay in m^{-2} (± SE) for both Oxwich Bay and Swansea Bay. Band colours were omitted from density calculations when they were outside of the range seen for that bay.

3.2.2 Minimum and daily distance travelled

To obtain a conservative estimate of movement, the minimum distance travelled by *B. undatum* was calculated in metres using ArcGIS v10.1. For each band colour, the distance between a recapture point and the nearest release point was measured. Where multiple *B. undatum* were recaptured at the same point, the data were recorded separately for each individual (i.e. n = total number of individuals rather than the number of recapture points). A daily distance was estimated for each band colour, by dividing the minimum distance travelled by the number of days since that band colour was released. Mean values were calculated for the minimum and daily distance travelled by *B. undatum* for each band colour, and with an overall mean for each bay (± SE), presented in separate tables for Oxwich Bay and Swansea Bay.

4. RESULTS

4.1 Fisheries catch analysis

4.1.1 Habitat type

A review of 37 habitat stills identified that the sediment in Oxwich Bay was predominantly mud to fine sand, corresponding to a particle size of <0.063 to 2 mm, using a modified Udden-Wentworth Grain-Size Classification Scheme (Fig. 15a). Pots hauled in Oxwich Bay contained a large amount of fine sediment that collected on the vessel, with *B. undatum* needing to be rinsed before measuring Total Shell Length (TSL). The Oxwich Bay sediment appeared to be relatively homogeneous, with brittlestar spp. seen in at least 50 % of stills, and empty razor clam spp. shells commonly seen. The substratum in Swansea Bay appeared to be more variable, with sediment predominantly consisting of coarse sand, gravel and pebbles and broken shell, corresponding to a particle size of 0.25 to 64 mm (Fig. 15b). The common starfish (*Asterias rubens*) was regularly seen in habitat stills, as well as algae spp.

a) **b)**

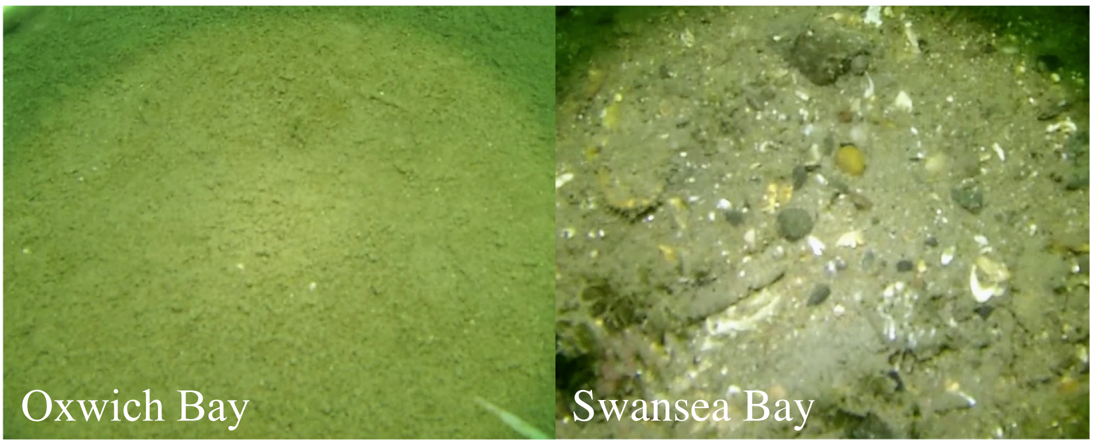

Fig. 15 The *Buccinum undatum* habitat in **a)** Oxwich Bay and **b)** Swansea Bay, South Wales, where the fisheries catch analysis was conducted over six days from 24th June – 25th July 2014.

4.1.2 Daily Catch Per Unit Effort (CPUE): June - July 2014

The mean CPUE varied at Oxwich Bay and Swansea Bay from June to July 2014, but similar peaks and troughs were seen at both bays (Fig. 16). However, greater daily variability in CPUE was seen at Swansea Bay.

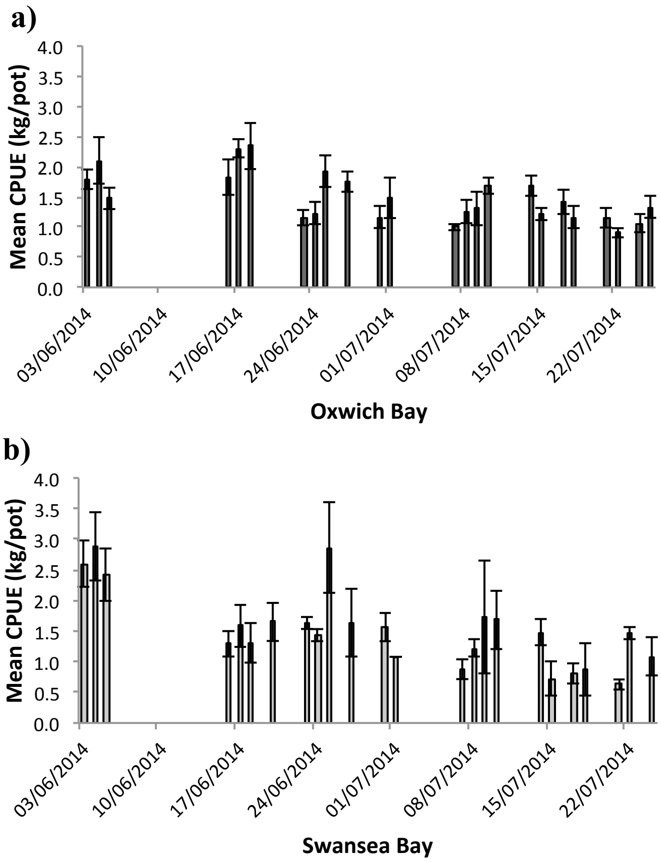

Fig. 16 The mean daily *Buccinum undatum* Catch Per Unit Effort (CPUE) in kg per pot (± SE) landed in **a)** Oxwich Bay and **b)** Swansea Bay, South Wales, from 3rd June to 25th July 2014. Data excludes *Buccinum undatum* caught below the 45 mm Minimum Landing Size (MLS), as these were removed in riddling. (SE = standard error).

4.1.3 Length-frequency distribution

A total of 8,377 *B. undatum* were counted and measured, with 5,595 from Oxwich Bay and 2,782 from Swansea Bay (Table 6). The abundance of *B. undatum* per pot ranged from 1 - 30 in Oxwich Bay, with a TSL of 16 - 106 mm. In Swansea Bay, the abundance of *B. undatum* per pot ranged from 9 - 298, with a TSL of 20 - 86 mm.

Table 6
Summary of *Buccinum undatum* fisheries catch analysis at Oxwich Bay and Swansea Bay, South Wales, conducted over six days from 24th June - 25th July 2014. Data were not obtained at Swansea Bay on 25th July 2014. (No. = number).

Day	Date	No. *B. undatum* measured		No. pots		No. strings	
		Oxwich	Swansea	Oxwich	Swansea	Oxwich	Swansea
1	24.06.14	619	669	25	10	5	4
2	25.06.14	850	561	18	2	7	2
3	08.07.14	998	311	44	8	7	3
4	09.07.14	1102	577	36	8	7	2
5	24.07.14	856	664	35	9	7	3
6	25.07.14	1170	-	36	-	7	-
Total per bay		**5595**	**2782**	**194**	**37**	**40**	**14**

The majority of *B. undatum* sampled were within a restricted length range, with 71.6 % from Oxwich Bay between 55 - 85 mm TSL and having a unimodal distribution, and 84.9 % of *B. undatum* at Swansea Bay between 40 - 65 mm TSL with a bimodal distribution (Fig. 17).

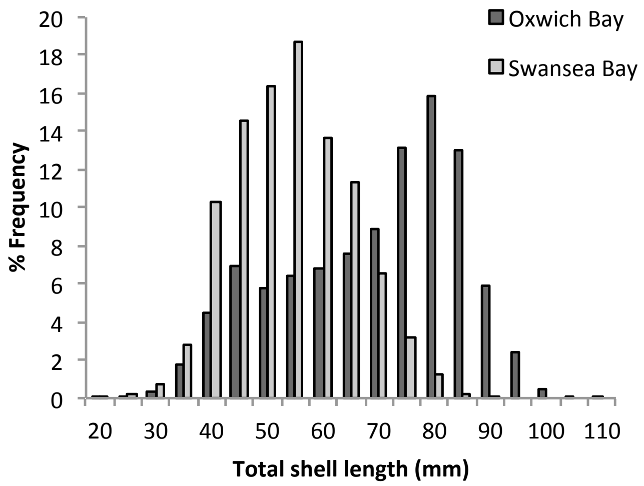

Fig. 17 Percentage length-frequency distribution for *B. undatum* Total Shell Length (TSL) at Oxwich Bay (n = 5595) and Swansea Bay (n = 2782), South Wales. Fisheries data were obtained from 24th June - 25th July 2014.

The *B. undatum* abundance ratio was significantly different in the 50 to 85 mm length classes between Oxwich Bay and Swansea Bay (p = <0.001), with the exception of the 60 mm class (Table 7). The total *B. undatum* abundance ratio was also significantly different between Oxwich Bay and Swansea Bay (χ^2 = 680.90, n = 7864, p = <0.001).

Table 7
The Chi-square goodness of fit test for *Buccinum undatum* length-frequency ratios between Oxwich Bay (n = 5089) and Swansea Bay (n = 2775), South Wales. Length classes of 5 mm were used, based on Total Shell Length (TSL). Fisheries data were obtained from 24th June – 25th July 2014. Significant differences at the p = 0.05 level are shown in bold. (L_T = length class).

L_T (mm)	30	35	40	45	50	55	60	65	70	75	80	85	Total
Oxwich Bay	22	96	251	388	325	357	378	421	499	737	886	729	5089
Swansea Bay	19	79	287	404	457	520	379	315	184	89	36	6	2775
χ^2	0.22	1.65	2.41	0.32	22.28	30.30	0.00	15.27	145.28	508.36	783.62	711.20	680.90
p	0.64	0.20	0.12	0.57	**<0.001**	**<0.001**	0.97	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**

4.1.4 General comparison between Oxwich Bay and Swansea Bay

The median *B. undatum* abundance per pot was significantly different between Oxwich Bay and Swansea Bay (Mann-Whitney U = 1647.00, n = 229, df = 1, p = <0.001) (Fig. 18a). However, a smaller sample size at Swansea Bay resulted in greater variability in the data, 192 pots were surveyed from Oxwich Bay and only 37 from Swansea Bay. *B. undatum* caught using lay down pots at Oxwich Bay and Swansea Bay had a significantly different median TSL, (Mann-Whitney U = 3369170.50, n = 7792, df = 1, p = <0.001) (Fig. 18b). The mean CPUE in kg of *B. undatum* caught per pot was not significantly different between Oxwich Bay and Swansea Bay (ANOVA, $F_{1,51}$ = 0.18, p = 0.67) (Fig. 18c).

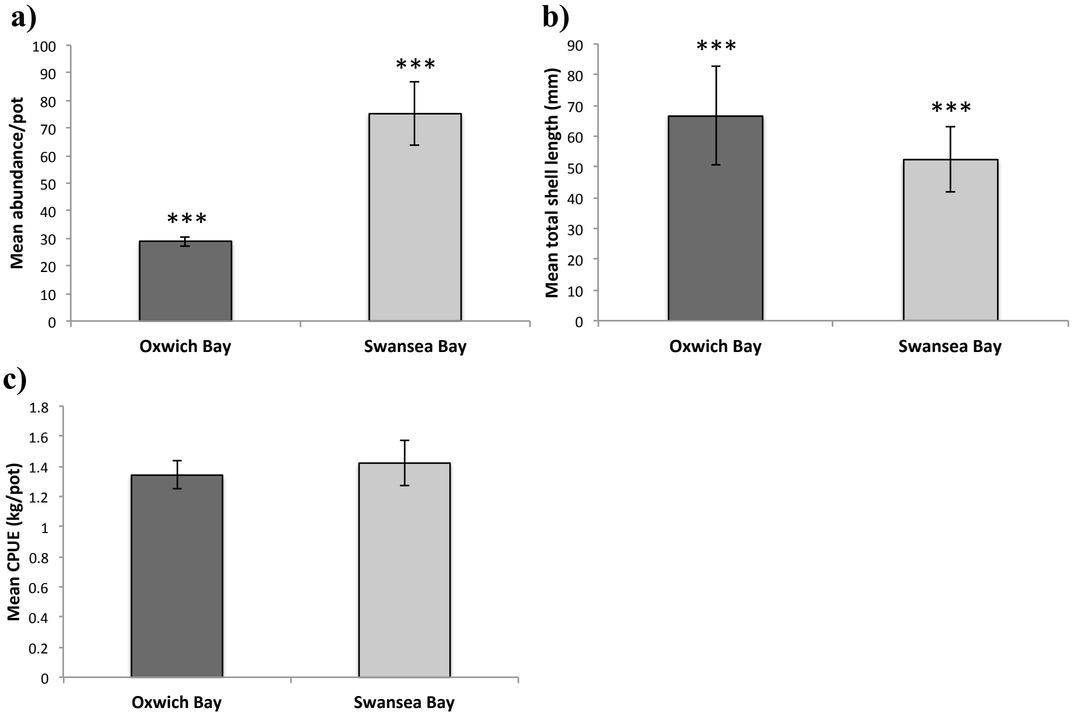

Fig. 18 The comparison of *Buccinum undatum* between Oxwich Bay and Swansea Bay, South Wales. **a)** The mean *B. undatum* abundance (± SE) **b)** CPUE for the estimated weight of *B. undatum* (kg) per pot (± SE) and **c)** Total Shell Length (mm) of *B. undatum* (± SE). Data were obtained from six days of fisheries catch analysis from 24th June - 25th July 2014. Significance level represented by p = * <0.05, ** <0.01, *** <0.001, absence of * indicates non-significant findings. (SE = standard error).

4.1.5 Depth

Median *B. undatum* abundance per pot was non-significant between depths at both Oxwich Bay and Swansea Bay (Kruskal-Wallis $H = 8.22$, $n = 169$, df = 4, $p = 0.08$, $H = 6.31$, $n = 37$, df = 3, $p = 0.10$), although the sample size at Swansea Bay was only a quarter of that at Oxwich Bay (Fig. 19a).

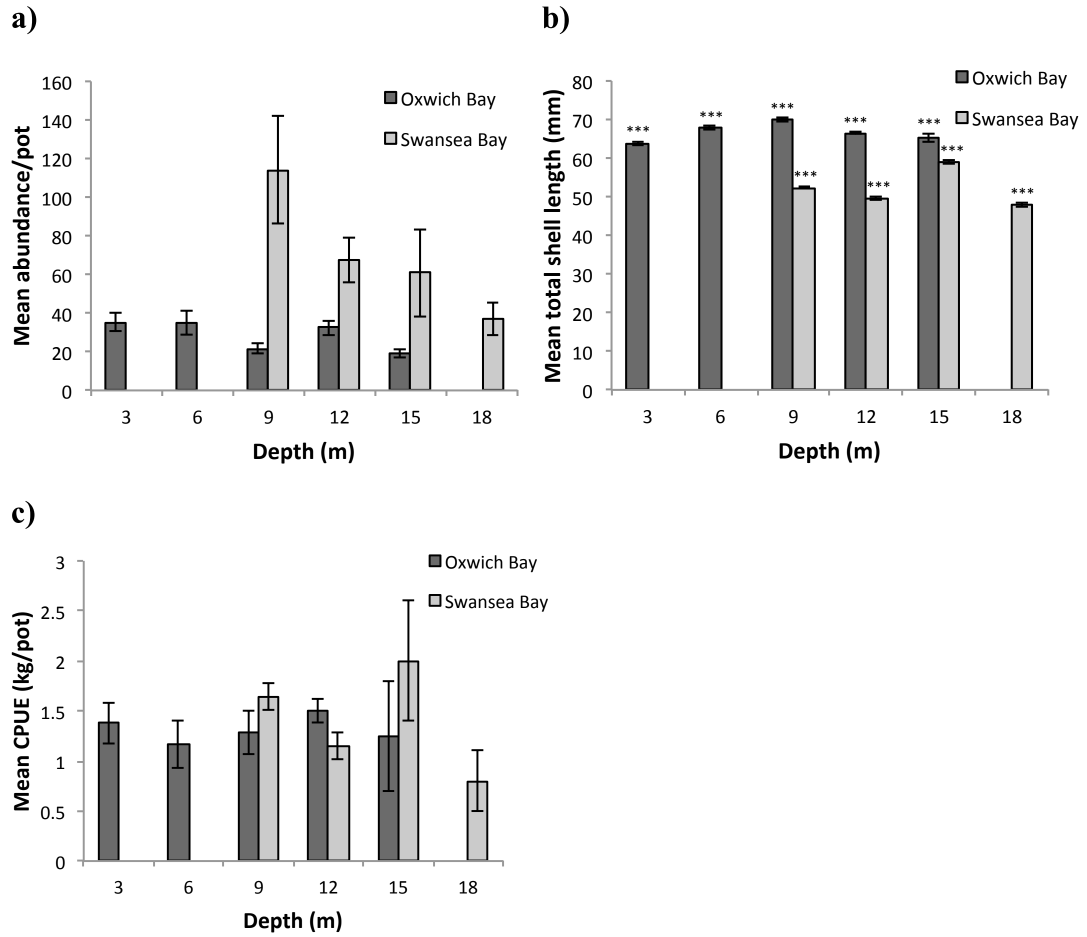

Fig. 19 Comparison between chart datum depth (m) for *Buccinum undatum* in Oxwich Bay and Swansea Bay, South Wales with mean values (± SE) for **a)** *B. undatum* abundance per pot **b)** Total Shell Length (TSL) (mm) (± SE) **c)** Catch Per Unit Effort (CPUE) (kg/pot). Data were obtained from six days of fisheries catch analysis from 24th June – 25th July 2014. Significance level represented by *p* = * <0.05, ** <0.01, *** <0.001, absence of * indicates non-significant findings. (SE = standard error).

At Oxwich Bay, the smallest mean *B. undatum* TSL was 64 mm in the 3 m depth range, and the largest was 70 mm in the 9 m range (Table 8).

Table 8
The *Buccinum undatum* Total Shell Length (TSL) (mm) across three metre depth ranges in Oxwich Bay and Swansea Bay, South Wales. Mean (± SE), minimum and maximum TSL data were obtained from six days of fisheries catch analysis from 24th June - 25th July 2014. (M = metres; SE = standard error).

Depth (m)	Total Shell Length (mm)							
	Mean (± SE)	Minimum	Maximum	*n*	Mean (± SE)	Minimum	Maximum	*n*
	Oxwich Bay				Swansea Bay			
3	64 (0.39)	23	100	1494	-	-	-	-
6	68 (0.49)	16	102	733	-	-	-	-
9	70 (0.48)	30	99	1038	52 (0.27)	20	80	1366
12	67 (0.46)	19	99	1496	50 (0.35)	26	85	673
15	65 (1.20)	19	105	249	59 (0.51)	31	86	486
18	-	-	-	-	48 (0.54)	26	75	257

The median *B. undatum* TSL at Oxwich Bay was significantly different between depths ranging from 3 - 15 m (chart datum) (Kruskal-Wallis H = 103.41, n = 5010, df = 4, p = <0.001) (Fig. 19b). Pairwise comparisons of median TSL between depths showed no clear pattern at Oxwich Bay (Table 9).

Table 9
The Mann-Whitney *U* pairwise comparisons of median *Buccinum undatum* Total Shell Length (TSL) across depth in Oxwich bay and Swansea Bay, South Wales. Significant differences at the p = 0.05 level are indicated in bold. (M = metres).

Pairwise comparison		
Depth (m)	Median total shell length (mm)	
	Oxwich Bay	Swansea Bay
3, 6	**<0.001**	-
3, 9	**<0.001**	-
3, 12	**<0.001**	-
3, 15	0.09	-
6, 9	**<0.001**	-
6, 12	0.74	-
6, 15	0.34	-
9, 12	**<0.001**	**<0.001**
9, 15	**<0.001**	**<0.001**
9, 18	-	**<0.001**
12, 15	0.43	**<0.001**
12, 18	-	0.03
15, 18	-	**<0.001**

At Swansea Bay, the mean *B. undatum* TSL had a larger range than at Oxwich Bay, with the smallest TSL 48 mm in the 18 m depth range, and the largest at 59 mm in the 15 m depth range (Table 8). The median *B. undatum* TSL at Swansea Bay was significantly different between depths ranging from 9 - 18 m (chart datum) (Kruskal-Wallis H = 271.82, n = 2782, df = 3, p = <0.001) (Fig. 19b), with significant differences between all depths except 12 and 18 m (Table 9). At both Oxwich Bay and Swansea Bay, median CPUE (kg) was non-significant for depth (Kruskal-Wallis $H = 2.00$, $n = 40$, df = 4, $p = 0.74$, $H = 8.07$, $n = 13$, df = 3, $p = 0.06$) (Fig. 19c).

4.1.6 Temperature

Seawater temperature was accurately recorded using a logger attached to a *B. undatum* pot in Oxwich Bay. However, the maximum daily temperature was distorted by the air temperature each time pot strings were hauled (Monday to Friday). The two most prominent peaks in maximum temperature relate to the air temperature when pot strings were hauled (Fig. 20). The potential of using maximum temperature peaks as an indicator of pot strings being hauled was assessed, by comparing peaks with known fishing dates and times. However, the difference in the sea and air temperature was not great enough to be reliable source of fishing effort. The mean values obtained are likely to be reliable as the temperature was logged at five minute intervals, compensating for any erroneous readings (Fig. 20).

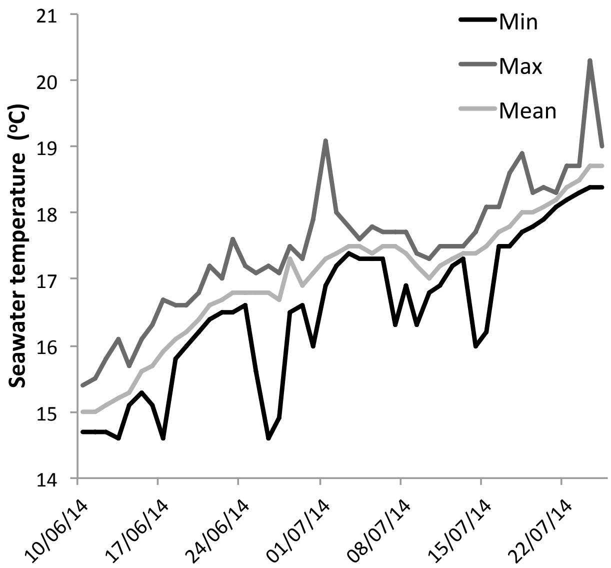

Fig. 20 The minimum, mean and maximum seawater temperature (°C) at Oxwich Bay, South Wales from 10th June - 24 July 2014. (Min = Minimum; Max = Maximum).

The *B. undatum* abundance per pot showed no correlation to the mean or minimum temperature at Oxwich Bay or Swansea Bay (Table 10). At Oxwich Bay there was no correlation between *B. undatum* TSL and the mean temperature, but there was a positive correlation with the minimum temperature. However, at Swansea Bay, both the minimum and mean temperature were negatively correlated to TSL (Table 10). CPUE was negatively correlated to the mean and minimum temperature at both Oxwich Bay and Swansea Bay (Table 10).

Table 10
Pearson correlation coefficient for *Buccinum undatum* abundance (per pot), Total Shell Length (TSL) and Catch Per Unit Effort (CPUE) (kg/pot) at Oxwich Bay and Swansea Bay, South Wales. Abundance and TSL data were obtained from the fisheries catch analysis from 24th June – 25th July 2014, over six days, while CPUE was obtained from each fishing day from 10th June – 25th July 2014. Significant correlations at the $p = 0.05$ significance level are indicated in bold. (SE = standard error).

Bay	Correlation	Temperature (°C)	r^2	*p*	Transformation	Mean (± SE)	*n*
Oxwich	Abundance (per pot)	Mean	0.025	0.73	Log10	29 (1.81)	189
		Minimum	-0.044	0.55	Log10	29 (1.81)	189
	TSL (mm)	Mean	0.025	0.07	Log10	67 (0.23)	5010
		Minimum	0.04	**0.005**	Log10	67 (0.23)	5010
	CPUE (kg per pot)	Mean	-0.439	**<0.001**	-	1.44 (0.05)	141
		Minimum	-0.402	**<0.001**	-	1.44 (0.05)	141
Swansea	Abundance (per pot)	Mean	-0.072	0.67	Log10	75 (11.53)	37
		Minimum	-0.15	0.38	Log10	75 (11.53)	37
	TSL (mm)	Mean	-0.243	**<0.001**	Log10	52 (0.21)	2565
		Minimum	-0.199	**<0.001**	Log10	52 (0.21)	2565
	CPUE (kg per pot)	Mean	-0.317	**<0.01**	-	1.37 (0.08)	63
		Minimum	-0.284	**<0.05**	-	1.37 (0.08)	63

4.1.7 Salinity

Measurements obtained for salinity using a refractometer were not accurate enough for inclusion in analysis; results ranged from 31 - 38 ‰ at Oxwich Bay and Swansea Bay.

4.1.8 Pot type

From the 311 pots located at Oxwich Bay, four were scientific pots, large round stand-up, while the remaining 307 were rectangular lay down pots of various sizes. A total of 23 scientific pots were hauled from 24th June - 25th July 2014, with *B. undatum* abundance per pot ranging from 3 - 72, and TSL ranging from 28 – 106 mm. Differences in median abundance between lay down and scientific pots were non-significant (Mann-Whitney $U = 2085.50$, $n = 229$, df = 1, $p = 0.35$) (Fig. 21a). Median *B. undatum* TSL was significantly different between lay down and scientific pots at Oxwich Bay (Mann-Whitney $U = 1341640.00$, $n = 8377$, df = 1, $p = <0.001$) (Fig. 21b). However, sample sizes were imbalanced with 7792 *B. undatum* measured from lay down pots compared to 585 from scientific pots.

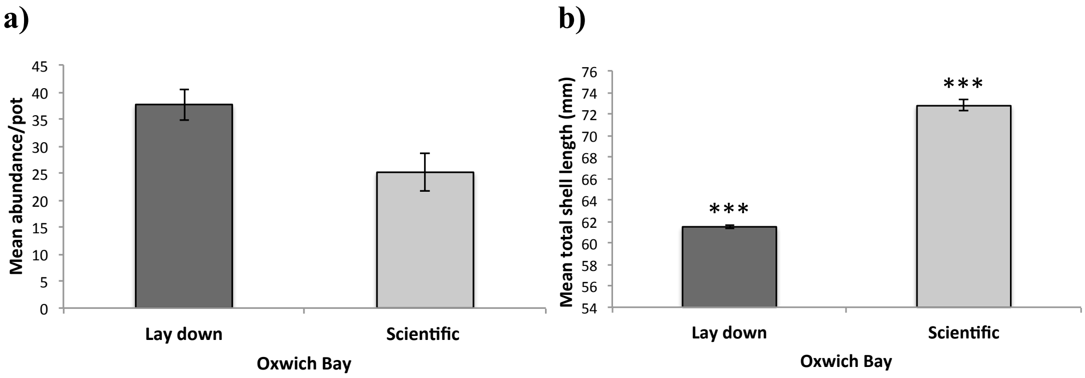

Fig. 21 Comparison of lay down and stand up scientific pot types used to catch *Buccinum undatum* at Oxwich Bay, South Wales **a)** mean *B. undatum* abundance per pot (± SE) and **b)** mean Total Shell Length (TSL) (mm) (± SE). Data were obtained from six days of fisheries catch analysis from 24th June – 25th July 2014. Significance level represented by p = * <0.05, ** <0.01, *** <0.001, absence of * indicates non-significant findings. (SE = standard error).

4.1.9 Pot colour

The median abundance of *B. undatum* per pot was non-significant between black, blue and white pot colours at Oxwich Bay and Swansea Bay (Kruskal-Wallis H = 4.67, n = 131, df = 2, p = 0.10; H = 3.21, n = 22, df = 2, p = 0.20) (Fig. 22a). The sample size at Swansea Bay was considerably smaller than that at Oxwich Bay, with only three black, and four white pots analysed, and abundance showing greater variability.

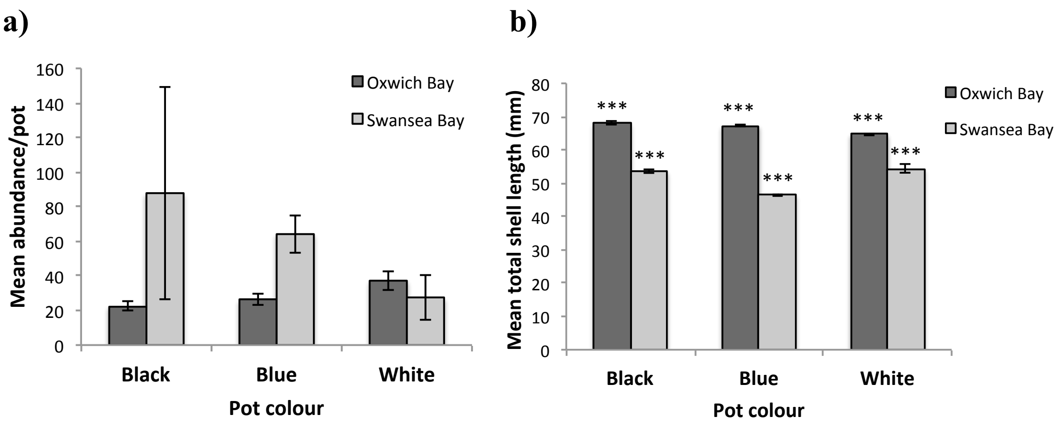

Fig. 22 Analysis of lay down and stand up scientific pot types used to fish *Buccinum undatum* at Oxwich Bay and Swansea Bay, South Wales **a)** mean *B. undatum* abundance per pot (n = 131 Oxwich Bay and n = 22 Swansea Bay) **b)** mean *B. undatum* Total Shell Length (TSL) (mm) (± SE). Data were obtained from four days of fisheries catch analysis from 8th – 25th July 2014. Significance level represented by p = * <0.05, ** <0.01, *** <0.001, absence of * indicates non-significant findings. (SE = standard error).

Median *B. undatum* TSL was significantly different between pot colours at Oxwich Bay (Kruskal-Wallis H = 24.65, n = 3689, df = 2, p = <0.001), with *B. undatum* TSL significantly larger for black and blue pots when compared to white pots (Table 11). Median *B. undatum* TSL was also significantly different at Swansea Bay (Kruskal-Wallis H = 110.36, n = 960, df = 2, p = <0.001), with *B. undatum* TSL significantly larger for black and white pots when compared to blue pots, contrasting to that of Oxwich Bay (Table 11).

Table 11
The Mann-Whitney U test pairwise comparison of median *Buccinum undatum* Total Shell Length (TSL) between black, blue and white pots, in Oxwich Bay and Swansea Bay, South Wales. Significant differences at the p = 0.05 level are indicated in bold.

Pairwise comparison		
Pot colour	Median total shell length (mm)	
	Oxwich Bay	Swansea Bay
Black, Blue	0.26	**<0.001**
Black, White	**<0.001**	0.65
Blue, White	**<0.001**	**<0.001**

4.1.10 Soak time

Median *B. undatum* abundance per pot was non-significant between soak times of 24 and 48 hours at Oxwich Bay (Mann-Whitney U = 2204.50, n = 169, df = 1, p = 0.59) (Fig. 23a). At Swansea Bay, median *B. undatum* abundance per pot was significantly different between soak times of 24, 48 and 72+ hours (Kruskal-Wallis H = 12.32, n = 32, df = 2, p = 0.002) (Fig. 23a). Pairwise comparisons at Swansea Bay indicated that median *B. undatum* abundance with soak times of 24 and 48 hours were significantly lower than abundance after 72+ hours (Mann-Whitney U = 12.00, n = 23, df = 1, p = 0.0002; U = 24.00, n = 24, df = 1, p = 0.008).

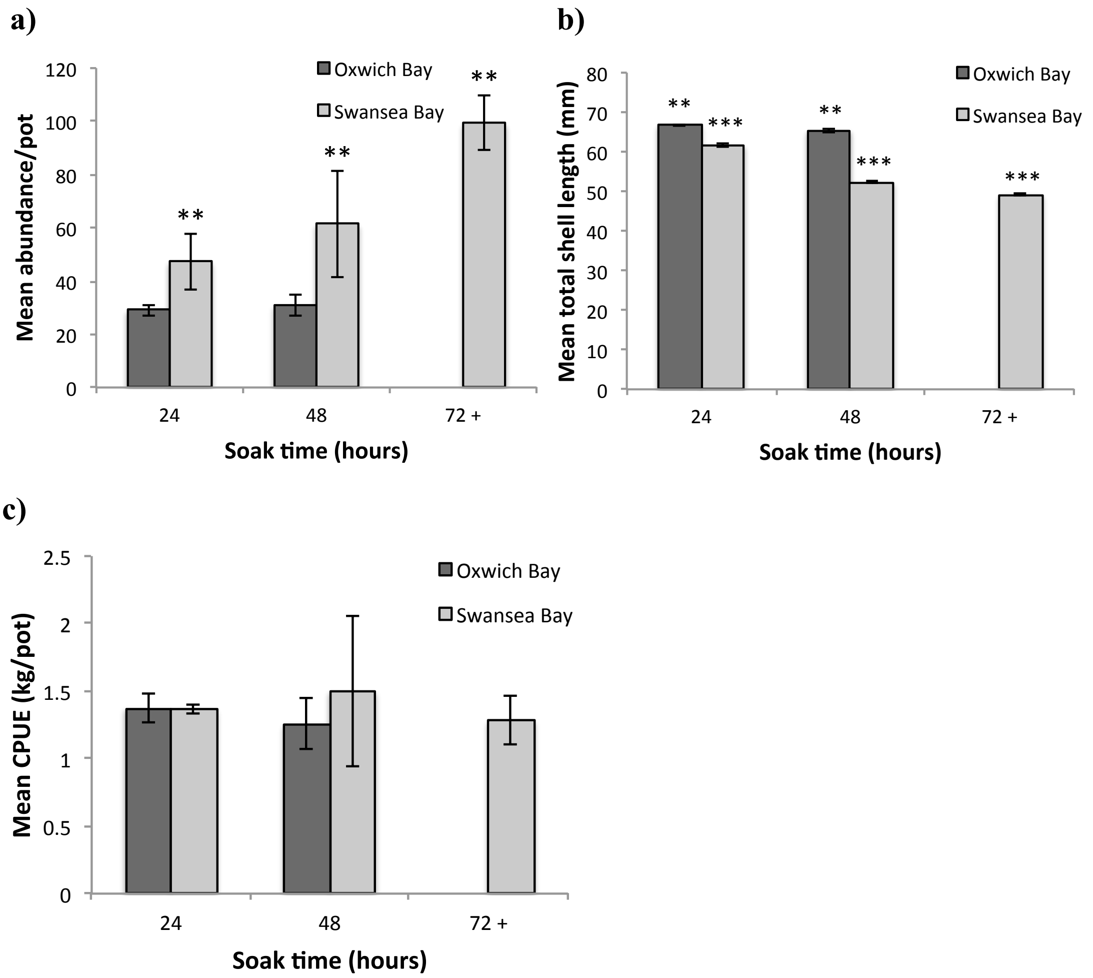

Fig. 23 The mean *Buccinum undatum* **a)** abundance per pot **b)** Total Shell Length (TSL) (mm) and **c)** Catch Per Unit Effort (CPUE) per pot (kg) at Oxwich Bay and Swansea Bay, South Wales, from 24th June - 25th July 2014. All strings at Oxwich Bay were hauled on every fishing trip, while the strings located in Swansea Bay were rotated, with between two and four strings hauled each day, resulting in longer soak times. Significance level represented by $p =$ * <0.05, ** <0.01, *** <0.001, absence of * indicates non-significant findings. (SE = standard error).

At Oxwich Bay, TSL was significantly different between pots with a soak time of 24 and 48 hours (Mann-Whitney $U = 2027439.5$, $n = 5010$, df = 1, $p = 0.02$) (Fig. 23b). Although there was a large sample size, the difference in TSL was marginal, with a mean TSL of 67 mm TSL after 24 hours and 65 mm TSL after 48 hours. The same pattern was seen in Swansea Bay, with *B. undatum* TSL significantly different between soak times of 24, 48 and 72+ hours (Kruskal-Wallis $H = 374.35$, $n = 2221$, df = 2, $p = <0.001$) (Fig. 23b). Mann-Whitney U test pairwise comparisons indicated that *B. undatum* TSL was significantly different between all soak times at Swansea Bay ($p = <0.001$).

At Oxwich Bay, untransformed *B. undatum* mean CPUE was non-significant between soak times of 24 and 48 hours (ANOVA, $F_{1,38} = 0.27$, $p = 0.61$) (Fig. 23c). Differences in median CPUE at Swansea Bay were non-significant between soak times of 24, 48 and 72 hours (Kruskal-Wallis $H = 0.15$, $n = 12$, df = 2, $p = 0.93$) (Fig. 23c). Although soak times at Swansea Bay covered a wider time range, up to 72+ hours, there were only three replicates for the soak times of 24 and 48 hours.

4.1.11 Percentage undersized

The overall percentage of undersized *B. undatum* caught below the 45 mm Minimum Landing Size (MLS) was considerably lower at Oxwich Bay than at Swansea Bay, 13.1 % and 25.8 % respectively (Table 12). At Oxwich Bay, the percentage of undersized *B. undatum* caught generally increased with depth, over a three to 15 m range, however no clear pattern can be seen in the 9 - 18 m depth range at Swansea Bay, which may be due to the smaller sample size (Table 12). When comparing pot type at Oxwich Bay, only 2.7 % of *B. undatum* caught using scientific pots were undersized, compared to 13.1 % using lay down pots (Table 12). At both Oxwich Bay and Swansea Bay, black pots appeared to have the lowest percentage of undersized *B. undatum.* At Oxwich Bay white pots caught the highest percentage of undersized *B. undatum*, at 17.2 %, while at Swansea Bay this was blue pots, with 32.3 % undersized (Table 12). At both Oxwich Bay and Swansea Bay, longer soak times attracted a greater percentage of undersized *B. undatum* (Table 12). At Oxwich Bay the percentage undersized was 12.3 % after 24 hours and 16 % after 48 hours. At Swansea Bay only 2.4 % of *B.undatum* were undersized with a soak time of 24 hours, which increased to 25.3 % after 48 hours and 31.2 % at 72+ hours.

Table 12
The percentage of undersized *Buccinum undatum* below the 45 mm Total Shell Length (TSL) at Oxwich Bay and Swansea Bay, South Wales, obtained over six days of fisheries catch analysis from 24th June - 25th July 2014. (M = metres).

		Oxwich Bay	*n*	Swansea Bay	*n*
Percentage of *B. undatum* undersized					
Bay	-	13.1	5010	25.8	2782
Depth (m)	3	11.2	1494	-	-
	6	5.0	733	-	-
	9	11.7	1038	24.1	1366
	12	18.6	1496	35.0	494
	15	20.9	249	15.0	448
	18	-	-	36.2	257
Pot type	Scientific	2.7	585	-	-
	Lay down	13.1	5010	-	-
Pot color	Black	10.3	1016	22.8	263
	Blue	11.3	1332	32.3	963
	White	17.2	1341	28.4	109
Soak time (hours)	24	12.3	3929	2.4	379
	48	16.0	1081	25.3	704
	72+	-	-	31.2	1699

4.1.12 Bycatch

A total of 806 animals from 13 species were caught as bycatch at Oxwich Bay, with netted dog whelk (*Nassarius reticulatus* L.), common starfish (*Asterias rubens*) and velvet swimming crab (*Necora puber* L.) being the most abundant (Table 13). The spider crab (*M. kaempferi*), edible crab (*C. pagurus*) and lobster (*Homarus gammarus* L.) caught as bycatch were all undersized.

Table 13
The total and percentage bycatch relative to *Buccinum undatum* abundance at Oxwich Bay, South Wales. Based on six days of fisheries catch analysis from 24th June - 25th July 2014.

***B. undatum* and bycatch abundance at Oxwich Bay**			
Common name	Species name	Total	Percentage
Common whelk	*Buccinum undatum*	5596	87.4
Netted dog whelk	*Nassarius reticulatus*	379	5.9
Common starfish	*Asterias rubens*	233	3.6
Velvet swimming crab	*Necora puber*	90	1.4
Shrimp spp.		33	0.5
Hermit crab	*Pagurus bernhardus*	32	0.5
Serpent star	*Ophiura ophiura*	17	0.3
Spider crab	*Macrocheira kaempferi*	11	0.2
Edible crab	*Cancer pagurus*	4	0.1
Oyster drill	*Ocenebra erinacea*	2	0.0
Butter fish	*Pholis gunnellus*	2	0.0
Lobster	*Homarus gammarus*	1	0.0
Arctic cowrie	*Trivia arctica*	1	0.0
Polychaete spp.		1	0.0

Fewer species were caught as bycatch in Swansea Bay, with 172 animals from 7 species (Table 14). Netted dog whelk (*Nassarius reticulatus)* was also the most abundant bycatch species, along with the predatory marine gastropod known commonly as an oyster drill (*Ocenebra erinacea* L.) and the common starfish (*Asterias rubens*) (Table 14). The relative abundance of bycatch to *B. undatum* was higher at Oxwich Bay than Swansea Bay, 12.6 % compared to 5.8 %. The considerably lower fishing effort at Swansea Bay is likely to be responsible for the lower bycatch abundance, as total values were used. All four of the spider crab caught as bycatch were undersized.

Table 14
The total and percentage bycatch relative to *Buccinum undatum* abundance at Swansea Bay, South Wales. Based on six days of fisheries catch analysis from 24th June - 25th July 2014.

***B. undatum* and bycatch abundance at Swansea Bay**			
Common name	Species name	Total	Percentage
Common whelk	*Buccinum undatum*	2783	94.2
Netted dog whelk	*Nassarius reticulatus*	65	2.2
Oyster drill	*Ocenebra erinacea*	43	1.5
Common starfish	*Asterias rubens*	26	0.9
Velvet swimming crab	*Necora puber*	15	0.5
Hermit crab	*Pagurus bernhardus*	15	0.5
Spider crab	*Macrocheira kaempferi*	4	0.1
Painted top shell	*Calliostoma zizyphinum*	4	0.1

4.2 Mark-recapture to estimate abundance

4.2.1 Tag retention study

B. undatum tagged with thick rubber bands had a 100 % retention rate over a four month period in aquaria. A total of 58 *B. undatum* were tagged at the start of the experiment, with 14 dying, but none losing their tags. The integrity of the bands began to deteriorate after three to four months, although not to the extent that tags were lost. For all *B. undatum*, bands began to perish where the foot extends from the aperture (Fig. 24). This was likely to be caused by movement and may occur sooner when *B. undatum* are in their natural environment and potentially more active.

a) **b)**

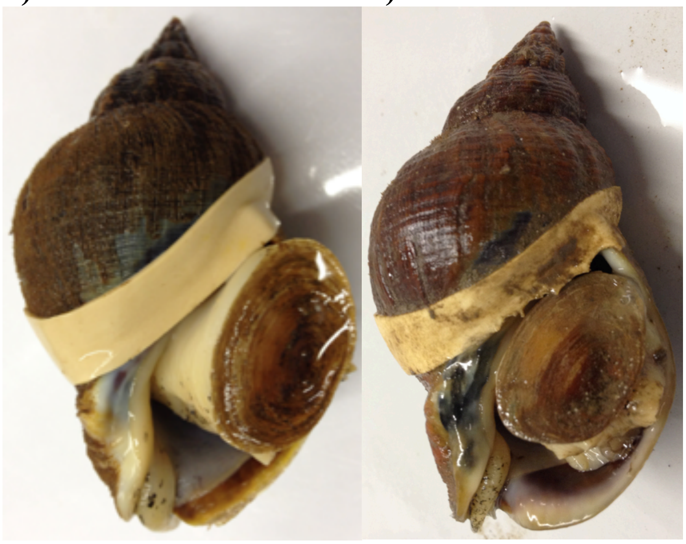

Fig. 24 The thick rubber bands used to tag the *Buccinum undatum* for the tag retention study in the laboratory **a)** on the day of tagging and **b)** with deterioration after four months. The study ran from 11th April - 11th August 2014 in the Bangor University School of Ocean Sciences aquarium, to validate the mark-recapture study.

4.2.2 Righting recovery after disturbance

Differences in righting times between experiments conducted on different dates were non-significant (Mann-Whitney U = 1526.00, n = 118, df = 1, p = 0.37). For the righting experiment conducted on 2nd June 2014, there was no significant tank effect (Kruskal-Wallis H = 1.62, n = 22, df = 2, p = 0.45). Hence data from the two experiments were pooled across treatments. The control group had a median righting time of 22 minutes (Table 15). Righting times varied from 1 - 207 minutes, although 73 % had righted themselves within 180 minutes. The effect of treatments compared to the control group were non-significant (Kruskal-Wallis H = 8.73, n = 118, df = 4, p = 0.07). *B. undatum* that had been tagged, rolled and exposed to air for one or three hours had among the longest righting times, but these were not significantly different to the control group (Table 15). Rolled *B. undatum* often had chips to the outer lip of their last whorl, damage seen after riddling during fieldwork. This type of light damage was observed in beam trawl fisheries by Cadée et al (1995) and Mensink et al (2000), along with more severe damage.

Table 15
The median righting times (minutes) of the *Buccinum undatum* after receiving four treatments involving rolling, tagging and exposure to air. Treatments simulated the disturbance caused to *B. undatum* from being caught, handled onboard, kept out of water and tagged as part of the mark-recapture study. Experiments took place in the Bangor University School of Ocean Sciences aquarium on 2nd June and 1st August 2014, with data pooled.

Treatment		Median righting time (mins)	*n*
	Control	22	25
1	Tagged underwater only	51	22
2	Tagged, riddled, no further exposure	33	23
3	Tagged, riddled, exposed to air for 1 hour	54	25
4	Tagged, riddled, exposed to air for 3 hours	86	23

4.2.3 Feeding recovery after disturbance

The effect of different treatments on response times to bait was non-significant (Kruskal-Wallis $H = 4.61$, $n = 14$, df = 3, $p = 0.20$) (Table 16). *B. undatum* response times to bait was conducted with a total of 55 *B. undatum* ($n = 11$), however only 14 *B. undatum* reached the bait provided. The control group had a median response time of 24 minutes in aquaria ($n = 3$). Response times to bait ranged from 10 - 92 minutes, with 86 % of *B. undatum* that responded reaching the bait within 34 minutes. None of the *B. undatum* that had been rolled, tagged and exposed to air for three hours had reached the bait in a 3.5 hour observation period, as these were the *B. undatum* that had among the longest righting times 24 hours earlier.

Table 16
The median response times to bait (minutes) of the *Buccinum undatum,* 24 hours after receiving four treatments involving rolling, tagging and exposure to air. Treatments simulated the disturbance caused to *B. undatum* from being caught, handled onboard, kept out of water and tagged as part of the mark-recapture study. Experiments took place in the Bangor University School of Ocean Sciences aquarium on 2nd August 2014.

Treatment		Median response times to feeding (mins)	*n*
	Control	24	3
1	Tagged underwater only	11	4
2	Tagged, riddled, no further exposure	11	4
3	Tagged, riddled, exposed to air for 1 hour	18	3
4	Tagged, riddled, exposed to air for 3 hours	-	-

4.2.4 Mark-recapture study

A total of 11,528 *B. undatum* were tagged from 402 pots across both survey areas, requiring 100 hours of tagging in total (tagging effort can be seen in Appendix Fig. 7.1). On 12th June 2014 *B. undatum* tagged with blue bands were returned to the water in Oxwich Bay, and observed using the fisher's underwater camera. Approximately eight *B. undatum* were observed righting themselves within five to ten minutes, which was all of those in view. Tagged *B. undatum* were recaptured from 16th June - 25th July 2014 (Table 17), with each string of pots fished up to a maximum of five times per week. Recapture rates differed between bays, likely to be due to the difference in fishing effort; 6,311 pots fished from 141 strings at Oxwich Bay and 2,533 pots from 63 strings at Swansea Bay. *B. undatum* tagged with yellow bands at Swansea Bay had a poor recapture rate, with 600 tagged *B. undatum* released at once in the same location. Efforts were made to alert other *B. undatum* fishers in the area of the experiment, although no other recaptures of tagged *B. undatum* were reported.

Table 17
The number of tagged and released *Buccinum undatum* at Oxwich Bay and Swansea Bay, South Wales, from 10th - 13th June 2014, used in the mark-recapture study to estimate abundance. (No. = number).

Bay	Tag & release date	Band colour	No. tagged & released	Recaptures	
				Number	Percentage
Oxwich	10 - 11.06.14	Beige	1797	280	15.6
	12.06.14	Red	1597	282	17.7
	13.06.14	Black	1799	256	14.2
Total	-	-	5193	950	18.3
Swansea	10 - 11.06.14	Green	2375	338	14.2
	12.06.14	Blue	1799	339	18.8
	13.06.14	Yellow	2161	81	3.7
Total	-	-	6335	758	12.0
Total across both sites			11528	1576	13.7

4.2.4.1 Fishing effort

As part of the Lincoln-Petersen Index to estimate abundance, it was necessary to identify the number of untagged *B. undatum* caught, from a known bag weight of 32.5 kg. Data obtained from 2013 appeared to show different patterns for Oxwich Bay and Swansea Bay, with *B. undatum* increasing in weight from 49 to 74 g at Oxwich Bay (June n = 63, July n = 73) and decreasing from 32 to 24 g at Swansea Bay, although there was a smaller sample size at Swansea Bay for July (June n = 91, July n = 36) (Fig. 25).

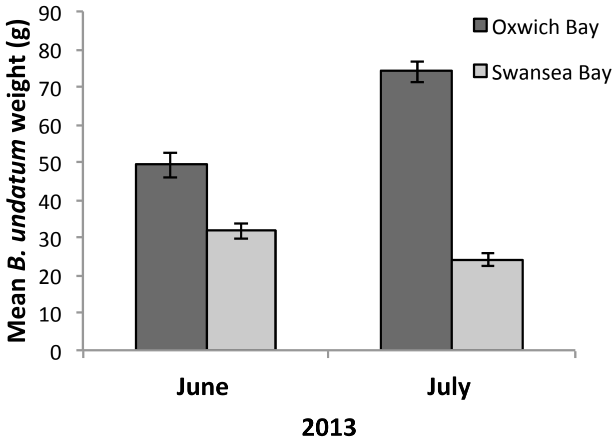

Fig. 25 The mean *Buccinum undatum* weight (g) (including shell), for whelks equal to or above the 45 mm Minimum Landing Size (MLS), caught using baited scientific pots at Oxwich Bay and Swansea Bay in June and July 2013. Weights for each month were used to determine the catch effort, where unmarked whelks were caught, needed as part of the Lincoln-Petersen Index to estimate abundance. As the number of bags landed per string was known, the 32.5 kg mean bag weight was converted to grammes and divided by the whelk weight for the relevant month and bay.

4.2.4.2 Release and recapture points

In Oxwich Bay, *B. undatum* tagged with beige bands had the most release points, resulting in them having the most recapture points and being the most widely dispersed band colour in the bay (Fig. 26a). *B. undatum* tagged and released with red bands remained concentrated in a relatively small area of 165 m^2, based on the area created by their recapture points. The distribution of red bands did not overlap with the beige and black band colours, indicating that the red banded *B. undatum* may not have been randomly distributed throughout the population (Fig. 26b). *B. undatum* tagged with black bands were well mixed with those tagged with beige bands, suggesting that both the beige and black banded *B. undatum* were well mixed in the population (Fig. 26c).

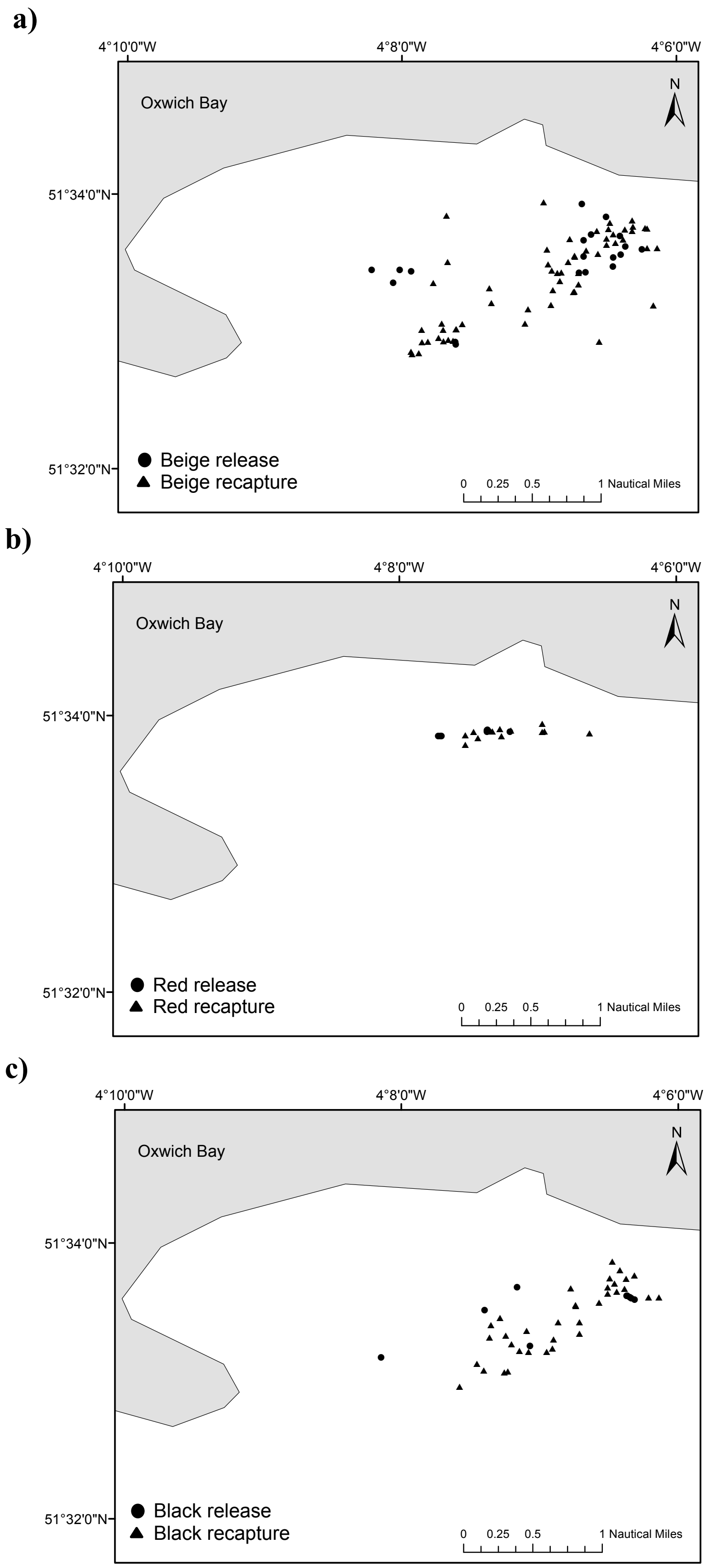

Fig. 26 The *Buccinum undatum* release and recapture points in Oxwich Bay, South Wales, for **a)** beige **b)** red and **c)** black band colours, from 10th - 13th June 2014. *B. undatum* were tagged with thick rubber bands as part of the mark-recapture study to estimate abundance.

B. undatum tagged with green, blue and yellow band colours at Swansea Bay were all well mixed, which suggests that they were randomly distributed throughout the population (Fig. 27). However, the blue banded *B. undatum* were recaptured in a line, with the recapture points creating an area of only 83 m^2 (Fig. 27b).

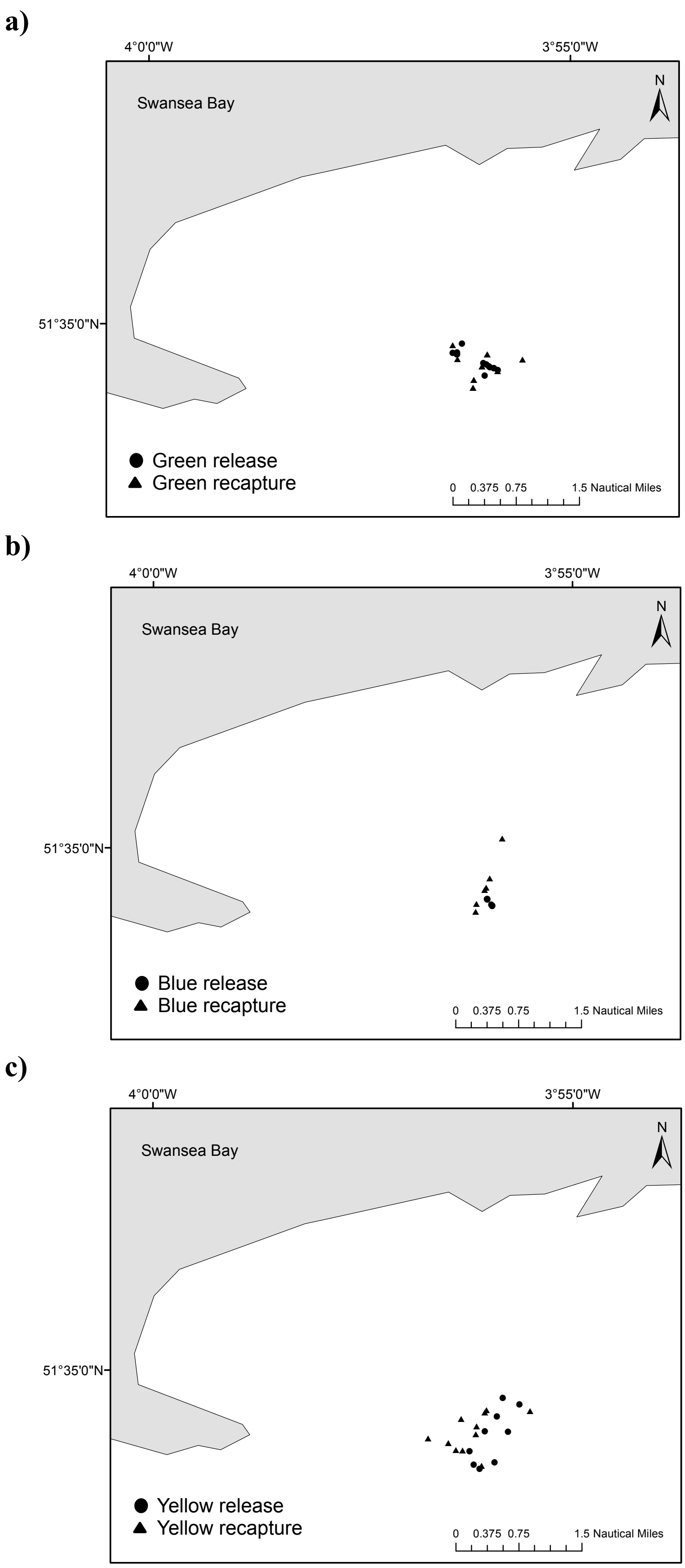

Fig. 27 The *Buccinum undatum* release and recapture points in Oxwich Bay, South Wales, for **a)** beige **b)** red and **c)** black band colours, from 10th - 13th June 2014. *B. undatum* were tagged with thick rubber bands as part of the mark-recapture study to estimate abundance.

4.2.4.3 Abundance

Based on the *B. undatum* abundance estimates at Oxwich Bay, the density was calculated to be 134 (± 8) m^{-2} (Table 18). The red banded *B. undatum* were included in the mean density for Oxwich Bay despite potentially not being randomly distributed in the population, as the abundance estimate was similar to the other band colours in the same bay.

Table 18
The mean minimum and daily distance travelled by *Buccinum undatum* and Lincoln-Petersen estimate of abundance in Oxwich Bay, South Wales, based on the mark-recapture study from 10th June - 25th July 2014. (SE = standard error).

Oxwich Bay	**Beige**	**Red**	**Black**	**Mean (± SE)**
B. undatum density (m^{-2})	135	119	148	134 (8)
Total mean *B. undatum* minimum distance travelled (m) (± SE)	184 (11)	190 (10)	220 (8)	198 (11)
Mean daily distance travelled (m) (± SE)	11 (1)	11 (1)	11 (1)	11 (1)
Number of *B. undatum* recaptured (*n*)	277	282	257	-

From the *B. undatum* abundance estimates at Swansea Bay, the density was calculated to be 249 (± 35) m^{-2} (Table 19). The abundance and density estimates for *B. undatum* tagged with yellow bands were omitted from data due to the poor recapture rate, which caused the abundance to be overestimated using the Lincoln-Petersen Index. The density at Swansea Bay was almost double that of Oxwich Bay, although there was more variability in the data.

Table 19
The mean minimum and daily distance travelled by *Buccinum undatum* and Lincoln-Petersen estimate of abundance in Swansea Bay, South Wales, based on the mark-recapture study from 10th June – 25th July 2014. (SE = standard error).

Swansea Bay	**Green**	**Blue**	**Yellow**	**Mean (± SE)**
B. undatum density (m^{-2})	284	214	-	249 (35)
Total mean *B. undatum* minimum distance travelled (m) (± SE)	145 (7)	320 (7)	154 (8)	206 (56)
Mean daily distance travelled (m) (± SE)	10 (1)	15 (0)	6 (1)	10 (3)
Number of *B. undatum* recaptured (*n*)	338	340	81	-

4.2.4.4 Minimum and daily distance travelled

The mean total *B. undatum* movement at Swansea Bay was 206 (± 56) m, but was variable between the three band colours at Swansea Bay, while the daily distance travelled was 10 m day^{-1}, and was also more variable across band colours than those at Oxwich Bay (Table 18). The mean minimum distance travelled by *B. undatum* at Oxwich Bay was 198 (± 11) m and was relatively consistent for all three band colours, while the daily distance travelled was 11 m day^{-1}, and was the same for all band colours (Table 19).

5. DISCUSSION

The project aimed to determine the population parameters of *Buccinum undatum* in Oxwich Bay and Swansea Bay, South Wales, as the distribution, abundance and movement of *B. undatum* in Wales is currently unknown.

5.1 Fisheries catch analysis

5.1.1 General comparison between Oxwich Bay and Swansea Bay

Substrata were different between Oxwich Bay and Swansea Bay, with fine and coarse sediment respectively. Martel et al (1986) studied *B. undatum* feeding activity using mark-recapture, in the Northern Gulf of St. Lawrence, Eastern Canada. When sites had similar current characteristics, but different substrates (fine compared to coarse) substratum did not appear to affect the movement of *B. undatum* towards a food source. This suggests that variability in CPUE between bays may not be a result of habitat type. Median *B. undatum* abundance per pot was significantly different between Oxwich Bay and Swansea Bay, with mean abundance at Oxwich Bay less than half that of Swansea Bay, 29 (± 1.8) and 75 (± 11.5) respectively. *B. undatum* abundance appears to be greater off the Llyn Peninsula, North Wales, when compared to South Wales, where a mean abundance of 105 was reported (Turtle, 2014 M. Sc. thesis). The pattern of abundance observed between Owxich Bay, Swansea Bay and the Llyn Peninsula, is likely to be reliable as analysis used the same fishing method, was conducted over the same period and large sample sizes were obtained from all three locations.

At Oxwich Bay, *B. undatum* TSL had a larger range than Swansea Bay, 16 - 106 mm and 20 - 86 mm respectively. The ratio of *B. undatum* TSL between Oxwich Bay and Swansea Bay was significantly different in almost all length classes from 50 - 85 mm TSL. At Oxwich Bay the length frequency was unimodal and skewed towards the larger size classes, while Swansea Bay was bimodal and skewed towards the smaller classes. A small-scale difference in *B. undatum* TSL was also observed in Shetland, UK, where West Shetland had a larger TSL range than East Shetland, 39 - 122 mm and 50 - 110 mm TSL respectively (Shelmerdine et al, 2007). Large-scale differences were observed when Shetland was compared to a *B. undatum* fishery that experienced a higher level of fishing pressure in Deal, South England, which had a 31 - 86 mm TSL range (Shelmerdine et al, 2007). The restricted TSL range for the *B.*

undatum fishery in Deal is similar to that of Swansea Bay, suggesting that Swansea Bay may experience greater fishing pressure than Oxwich Bay. In the Llyn Peninsula, North Wales, TSL had a much larger range from 10 - 119 mm, with the 40 - 45 mm TSL length class being the most represented (Turtle, 2014 M. Sc. thesis), again indicating that the population has been less exploited than Oxwich Bay and Swansea Bay, with better recruitment to the fishery.

French (2011 M. Sc. thesis) compared *B. undatum* TSL for Carmarthen Bay, South Wales, collected by the South Wales Sea Fishery Committee in February 1996 and July 1997 (n = 1,896), with that obtained for March and April 2011 (n = 9,371). The two studies in South Wales had a similar size range, despite being five years apart, with continued fishing pressure over that time (French, 2011 M. Sc. thesis). However, samples were taken from different times of the year and the 2011 sample size was much larger. *B. undatum* TSL range at Oxwich Bay was marginally smaller than those obtained in Carmarthen Bay for 1996 - 7 and 2011, but Swansea Bay had a considerably smaller range compared to Carmarthen Bay. The restricted TSL range observed in Swansea Bay may be due to differences in habitat type or morphology, but may also be as a result of fishing pressure, with larger animals being removed from the population.

Up until 2008, France was the second largest producer of *B. undatum*, after the UK, with approximately 90 % of the fishery coming from West Cotentin, Normandy, (Heude-Berthelin et al, 2011). The fishery began to decline in 2000, but despite the number of fishing days and licences being restricted the fishery was closed in 2009. Based on data obtained from the *B. undatum* fishery in West Cotentin during 2005 - 9, *B. undatum* had a TSL range of 7 - 88 mm, representing a fishery with a with a high level of fishing intensity (Heude-Berthelin et al, 2011).

Although *B. undatum* in Swansea Bay have a smaller TSL than Oxwich Bay, and Carmarthen Bay, it is not possible to establish whether they are reaching sexual maturity any earlier. Immature male and female *B. undatum* were identified as having a mean TSL of approximately 55 mm in South Wales (French, 2011 M. Sc. thesis). As the *B. undatum* MLS is currently set at 45 mm TSL, this may pose a threat to the sustainability of the fishery in South Wales. However, the absence of larger *B. undatum* in Swansea Bay, is a similar pattern to that seen in areas with a high fishing intensity, such as in Deal, South England (Shelmerdine et al, 2007) and Normandy, France (Heude-Berthelin et al, 2011).

5.1.2 Catch Per Unit Effort (CPUE)

CPUE reported using weight is conventionally used in fisheries science as a proxy for the relative abundance of a species. *B. undatum* CPUE per pot (kg) was estimated in the present study, with the number of bags landed per string judged by the fisher to the nearest 0.25 of a bag. No clear pattern was seen in daily CPUE at Oxwich Bay and Swansea Bay, obtained for every fishing day in June and July 2014. From the six days of fisheries catch analysis, CPUE compared between Oxwich Bay and Swansea Bay, depth and pot soak times were all non-significant. However, significant differences were found in *B. undatum* abundance and TSL between bays and soak times, and for TSL across depth. This suggests that CPUE estimates may not have been sensitive enough to detect potential differences in CPUE, with more than six days of data required to detect trends. Ideally, CPUE would be weighed, as opposed to estimated, and obtained over the entire fishing season, or a full annual cycle, to account for seasonal variability. French (2011 M. Sc. thesis) found that *B. undatum* CPUE per pot in Carmarthen Bay, South Wales, was lowest in March and highest in July, 1.8 kg per compared to 3.2 kg. However, samples were collected over a large depth range of 10 - 40 m, and the two commercial fishing vessels used to collect data had different levels of fishing expertise.

The mean *B. undatum* CPUE per pot at Oxwich Bay and Swansea Bay was 1.3 (± 0.09) and 1.4 (± 0.15) kg respectively, considerably lower than the CPUE reported in other parts of the UK. Over the same period in the Llyn Peninsula, North Wales, a CPUE of 3.2 kg was recorded (Turtle, 2014 M. Sc. thesis), which was similar to that in Jersey, Channel Islands, at 3.3 kg per pot (Morel & Bossy, 2004). As the *B. undatum* fishery in Jersey had been unexploited until 1996 (Morel & Bossy, 2014), this suggests that the CPUE in the Llyn Peninsula may reflect that of an unexploited population. In Carmarthen, South Wales, a CPUE of 2.5 kg per pot was reported, based on data obtained from March to August 2011 (French, 2011 M. Sc. thesis). Although the CPUE for Oxwich Bay and Swansea Bay was estimated, and therefore less reliable, it is closest to that of Carmarthen Bay, indicating that the *B. undatum* fishery in South Wales is generally more heavily exploited than the Llyn Peninsula.

5.1.3 Morphology

Variation in the size, age, and estimated growth rates of *B. undatum* can occur on both small and large geographic scales (Shelmerdine et al, 2007). Anecdotal evidence from the commercial fisher in Swansea, South Wales suggested that the *B. undatum* populations in Oxwich Bay and Swansea Bay had contrasting morphologies. Oxwich Bay was thought to comprise large, thin-shelled *B. undatum,* while the Swansea Bay population was thought to consist of smaller, thick-shelled individuals (Dr Jodie Haig, personal communication, April 2014). Shell thickness can be an indicator of predation pressure, with *B. undatum* having thinner shells in areas where predators are relatively scarce (Thomas & Himmelman, 1998). Although *B. undatum* TSL at Oxwich Bay was larger than at Swansea Bay**,** with some variation seen in shell thickness, there was no clear pattern in the distribution of *B. undatum* morphology between the two bays. Additionally, the main *B. undatum* predator, the common starfish (*A. rubens*), had a greater relative abundance in Oxwich Bay, which would have resulted in *B. undatum* having thicker shells.

Due to their limited movement, *B. undatum* may be confined to the food availability of a relatively small area, or there may be differences in their ability to access food. During field observations, it was noted that *B. undatum* body mass (flesh) appeared to fit shells to different extents, irrespective of the size of the shell. The fisher had observed that pot strings not hauled for approximately one to three weeks, contained *B. undatum* that were 'thinner' in their shells. This was also seen in the tag retention study, where *B. undatum* kept in laboratory conditions for four months seemed to lose weight during that time, with shells appearing more spacious for a given body mass. During the tag retention study, larger *B. undatum* seemed to have better access to food, reaching the food source faster and dominating the space, compared to smaller *B. undatum.*

5.1.4 Depth

B. undatum abundance across depth was significantly different for both Oxwich Bay and Swansea Bay, but there was no clear trend for Oxwich Bay. At Swansea Bay *B. undatum* abundance decreased with increasing depth, but was highly variable. A small depth range was covered in both bays, as there was a maximum depth of 15 m at Oxwich Bay and 18 m in Swansea Bay, with studies over more substantial depths likely to show clearer abundance trends. TSL across depth was also significantly different, with TSL increasing slight at 9 m for Oxwich Bay and 15 m in Swansea Bay.

5.1.5 Temperature

B. undatum are thought to respond to changes in water temperature at the start of the breeding season (Hancock, 1967; Kideys et al, 1993). However, no clear correlations were observed, with the significant correlations detected conflicting between Oxwich Bay and Swansea Bay.

5.1.6 Pot type, colour and soak time

Lay down and scientific pots at Oxwich Bay showed no difference in *B. undatum* abundance, but median TSL between pot type was significantly different. The mean TSL for *B. undatum* captured using lay down pots was 12 mm less than scientific pots, 61 (± 0.18) mm and 73 (± 0.51) mm respectively. The larger size of stand up scientific pots means that *B. undatum* had a longer vertical distance to travel before entering the pot, which would be difficult in currents. As no difference in abundance was seen for pot type, smaller *B. undatum* are likely to have been disproportionately affected.

Anecdotal evidence from fishers suggested that white pots had a higher CPUE than other pot colours. Although no difference in *B. undatum* abundance was seen at Oxwich Bay or Swansea Bay, TSL was significantly different between pot colours at both bays. TSL was larger for black pots at Oxwich Bay and Swansea Bay, but no other trends were observed, with Swansea Bay having a small sample size. As this trend in *B. undatum* TSL was not observed between blue and white pots, the difference may not be related to pot colour, as differences are likely to have existed between dark (blue and black) and light pot colours generally. The results obtained for pot colour may have been confounded with an environmental variable that was not considered as part of the study.

Himmelman (1988) reported peak *B. undatum* recapture times of ~ 24 hours in a 10 m water depth, 48 hours for those released in 18 m and 72 hours in 30 m (n = 30, 30, 40 respectively), in the Northern Gulf of St Lawrence, Eastern Canada. Although no difference in *B. undatum* abundance was seen at Oxwich Bay, abundance increased with longer soak times at Swansea Bay. As *B. undatum* at Swansea Bay had a smaller TSL than those at Oxwich Bay the travel time to pots may be longer or the oceanographic regime in the bay may cause the detection and location of pots to take longer. The increase in TSL between soak times of 48 and 72 + hours at Swansea Bay may be attributable to variables not accounted for in the present study, as bait had been entirely consumed when pot strings were hauled after 48 hours.

5.1.7 Percentage undersized

The percentage of undersized *B. undatum,* those caught below the 45 mm Minimum Landing Size (MLS), was assessed between Oxwich Bay and Swansea Bay, pot type, pot colour and soak time. The overall percentage of undersized *B. undatum* was considerably lower at Oxwich Bay than at Swansea Bay, 13.1 % (n = 5010) and 25.8 % respectively (n = 2782). However, the soak times at Swansea Bay were considerably longer than those at Oxwich Bay, as pot string were fished less frequently. Therefore, soak times of 24 hours are more relevant for comparison, with 12.3 % undersized at Oxwich Bay, and 2.4 % at Swansea Bay. The difference in undersized *B. undatum* after soak times of 24 hours better fits the length-frequency distribution observed between the bays, and suggests that the fishing pressure in Swansea Bay is more than at Oxwich Bay. Swansea Bay is an attractive location for fishers as it is economical in terms of fuel and time, due to the proximity of Swansea harbour. In Carmarthen Bay, South Wales, the percentage of undersized *B. undatum* caught was considerably lower with 3.6 % undersized, possibly due to using the more typical soak time of 24 hours, although soak times were not reported (French, 2011 M. Sc. thesis). The percentage of undersized *B. undatum* in the Llyn Peninsula, North Wales, was 32.6 % (n = 9,041), with soak times of 24 hours predominantly used (Turtle, 2014 M. Sc. thesis). However, as the *B. undatum* fishery in North Wales is likely to be less exploited than the one in South Wales, and the population has a larger size distribution, the difference is likely to be indicative of better recruitment, and therefore the sustainability of the fishery.

Although the percentage of undersized *B. undatum* caught generally increased with depth at Oxwich Bay, the range was limited at three to 15 m, with no pattern observed at Swansea Bay. Comparison of pot type at Oxwich Bay highlighted that only 2.7 % of *B. undatum* caught using scientific pots were undersized, compared to 13.1 % using lay down pots. Scientific 'Fishtec' pots could be used to reduce the effort in sorting catch, as riddling would be faster, but are much more expensive than lay down pots. When looking at pot colour, black pots appeared to have the lowest percentage of undersized *B. undatum,* although the difference between black and blue pots was marginal at Oxwich Bay, where the largest sample size was obtained.

5.1.8 Bycatch

The most abundant bycatch species in Oxwich Bay and Swansea Bay was the netted dog whelk (*N. reticulatus*), and was also the case in the Llyn Peninsula, North Wales, where it represented 60 % of the total bycatch caught (Turtle, 2014 M. Sc. thesis). The relative abundance of bycatch to *B. undatum* was 12.6 % at Oxwich Bay, but considerably less at Swansea Bay at 5.8 %. If bycatch were measured in weight, Oxwich Bay would have a lower relative percentage of bycatch than Swansea Bay. In the Llyn Peninsula, bycatch abundance relative to *B. undatum* was 2.9 %, considerably less than in South Wales (Turtle, 2014 M. Sc. thesis).

Assessing the impact of the *B. undatum* fishery on other species biomass would have been a better gauge than abundance. The majority of the bycatch species caught represented a small biomass, including the commercially fished species, spider crab (*M. kaempferi*), edible crab (*C. pagurus*) and lobster (*Homarus gammarus* L.), which were all undersized. Compared to the pot fishing of lobster, which attracts a wide range of larger sized invertebrates and vertebrates, the *B. undatum* fishery is a relatively 'clean' form of fishing in terms of the volume of bycatch. Hancock (1967) identified the availability of cheap bait as one of the main problems with the *B. undatum* fishery, which continues to be relevant based on the quantity of bait required by the fishery. The sustainability of using catshark spp., spider crab (*M. kaempferi*) and edible crab (*C. pagurus*) as bait has not been assessed.

5.2 Mark-recapture to estimate abundance

Mark-recapture methods for *B. undatum* have been used previously to measure field of attraction to baited pots and movement (Himmelman, 1988; McQuinn et al, 1988; Sainte-Marie, 1991). The feasibility of using mark-recapture to estimate *B. undatum* abundance was assessed off the Sussex coast, UK, using rubber bands as tags (Lawler & Vause, 2009). The recapture rate was very poor due to the study being conducted outside of the main *B. undatum* fishing season, and therefore abundance estimates could not be obtained.

The current mark-recapture study was conducted during the *B. undatum* fishing season, from June to July, when *B. undatum* are known to feed and have the best potential of being captured using baited pots. European populations of *B. undatum* are thought to breed during autumn and winter, with a single major egg-laying period (Valentinsson, 2002; de Vooys & van der Meer, 2010). South of the

Isle of Man, Irish Sea, egg-laying has been reported to occur from late December to January (Kideys et al, 1993), and from November to January in South Wales (French, 2011 M. Sc. thesis), with juveniles emerging from egg capsules three to eight months later (Fretter & Graham 1962; Martel et al, 1986).

The primary aim of the project was to estimate the *B. undatum* abundance in two bays in South Wales. As a mark-recapture study to estimate *B. undatum* abundance had not been successfully conducted previously, the main concern was to tag enough *B. undatum* to optimise the potential for recaptures, and to meet all the assumptions of the Lincoln-Petersen Index.

5.2.1 Tagging methods

The present study identified that thick rubber bands could be successfully retained by *B. undatum* over a four month period in laboratory conditions, with a 100 % retention rate observed. This was based on previous laboratory experiments, where *B. undatum* tagged with glue and thick rubber had a 100 % retention rate after two months (unpublished data, Haig, 2013). Despite the reliability of using glue, this methodology is impractical for fieldwork as it necessitates that the *B. undatum* shell be dried before and after applying glue (Dr Jodie Haig, personal communication, April 2014). A preliminary tagging experiment using numbers glued to *B. undatum* shells caused them to be notably stressed (Himmelman, 1988).

The tagging of *B.undatum* using rubber bands can be successful in field experiments, provided that the study is short term (Himmelman, 1988; Kideys, 1994). The ability of thick rubber bands to be retained by *B. undatum* in the marine environment may be considerably less than under laboratory conditions, due to the dynamic substrata and possible increased movement. Rubber bands used in the Sussex mark-recapture trial began to perish 12 weeks after tagged *B. undatum* were released, although the specification of the bands is unknown (Lawler & Vause, 2009). *B. undatum* tagged using thick rubber bands in Oxwich Bay and Swansea Bay are likely to have retained their bands for the entire six week recapture period, as no bands were lost after four months in the laboratory.

Studies involving the tagging of fish are known to have an effect on the animal, by increasing energetic demands (Parker et al, 1963). Kideys (1994) investigated the effect of tagging *B. undatum* in the laboratory over a one year period, drilling shells near the edge of the largest whorl and attaching a plastic tag with wire.

Despite a difference in growth rates, Kideys (1994) concluded that there was no evidence of tags hindering locomotion or feeding, and no sex-specific difference. Although Kideys (1994) used a different tagging method, applying a rubber band is likely to be less obtrusive than drilling a hole in the shell. Due to the short recapture period of six weeks, any potential effect of tagging on growth would not have been relevant.

5.2.2 Recovery from handling disturbance

The ability of *B. undatum* to be recaptured after handling disturbance was simulated using tagging, rolling and air exposure in the laboratory. The recovery response of *B. undatum* to righting and feeding was non-significant when compared to the control group. Therefore, tagged *B. undatum* are unlikely to have been adversely affected by handling, with the capture probability the same as for undisturbed *B. undatum*. When *B. undatum* are captured using baited pots and tagged under laboratory conditions, they commonly experience a period of stress-induced inactivity after field release (Hancock & Urquhart, 1959; Himmelman, 1988; McQuinn et al, 1988). A period of inactivity was observed in the handling disturbance experiments, with some *B. undatum* not responding at all. In field experiments, *B. undatum* respond more readily to baited pots when care has been taken not to make them stressed (Himmelman, 1988). Field studies conducted by Saint-Marie (1991) observed more than 97 % of *B. undatum* moving away from release points at speeds equalling those of undisturbed *B. undatum.* During handling disturbance experiments the water temperature ranged from 9.1 - 23.1 °C, which may have affected the time taken for *B. undatum* to recover by righting themselves and to respond to a food source. However, righting experiments conducted by Ramsay and Kaiser (1998) indicated that water temperature ranging from 10 - 15 °C had no effect on *B. undatum* righting times (n = 32), although this range was substantially smaller.

Ramsay and Kaiser (1998) assessed the ability of *B. undatum* to escape predation after fishing damage (rolling and being dropped), by righting and displaying an escape response (foot contortions) in the presence of the common starfish (*A. rubens*). Although righting times varied from 28 seconds to over 180 minutes, 83 % had a righting time of less than ten minutes. In the present study, righting times varied from 1 - 207 minutes, although 73 % had righted themselves within 180 minutes. For *B. undatum* that had been dropped, the righting time and proportion of

B. undatum that initiated an escape response were not significantly different to the control group. *B. undatum* that had been rolled took significantly longer to right themselves and initiated significantly fewer escape responses than the control group, despite the absence of any visible damage. However, fishing disturbance is likely to involve greater impact than handling, which was reflected in the rolling methodology used. The rolling experiment used a cylindrical container filled with a mixture of sand, gravel and seawater, rolled 20 times down a slope (Ramsay and Kaiser, 1998). This was potentially more traumatic than the righting experiment to assess the effect of handling, where *B. undatum* were rolled in a fish box for one minute, tagged, and exposed to air. The considerably shorter righting times seen by Ramsay and Kaiser (1998), compared to the present study, may have been due to the presence of a predator. Underwater video during the mark-recapture study saw all eight of the *B. undatum* in view righting themselves within five to ten minutes, suggesting that *B. undatum* will initiate a righting response faster when susceptible to predation. The ability of *B. undatum* to recover from handling disturbance can be applied to undersized *B. undatum* in the fishery that have been caught, and are then rolled across a riddle before being returned to the water. Based on field observations by divers, Kaiser and Spencer (1995) found that *B. undatum* had high survival rates after fishing disturbance, which is likely to be the same for handling disturbance.

The ability of *B. undatum* to recover from handling disturbance in response to a food source could have been assessed 48 hours after disturbance, as opposed to the 24 hour period used. The longer recovery time would have more closely resembled the mark-recapture study in the field, where fishing resumed 48 hours after the last tagging day, and would have allowed for a longer period of inactivity. Additionally, the bait used to assess the recovery response of *B. undatum* to a food source could have been made more attractive by combining the shore crab (*C. maenas*) used with a catshark spp., as a combination of crab and catshark are consistently used in the *B. undatum* fishery in Wales, based on personal observations.

5.2.3 Lincoln-Petersen Index

The assumptions of the Lincoln-Petersen index are that the population is closed, 100 % of tags are retained, and the species is correctly identified by the recorder. Tagged *B. undatum* also need to be randomly distributed throughout the population and have the same probability of being recaptured, with the number of births, deaths, emigration and immigration the same for marked and unmarked *B. undatum.*

B. undatum were correctly identified during the mark-recapture study in Oxwich Bay and Swansea Bay. The red whelk (*Neptunea antiqua* L.) closely resembles *B. undatum*, but has a reddish appearance to the shell and a taller spire (Pearce, & Thorsen, 1967). Although the red whelk (*N. antiqua)* was present in the survey area, it was not observed as part of the mark-recapture study or fisheries catch analysis.

In calculating the number of unmarked animals captured, the individual *B. undatum* weights obtained for 2013 by Fisheries and Conservation Science Group were accurately weighed in the laboratory. However, from June to July 2013 mean individual weights at Oxwich Bay increased by 25 g, while at Swansea Bay they decreased by 8 g. As *B. undatum* are thought to breed during autumn and winter in Europe (Valentinsson, 2002; de Vooys & van der Meer, 2010), they are likely to gain weight during the summer when there is greater food availability. Therefore the pattern of weight gain at Oxwich Bay is likely to be more reliable than the decrease seen at Swansea Bay, where a considerably smaller sample size was obtained for July (Oxwich Bay: June n = 63, July n = 73; Swansea Bay June n = 91, July n = 36).

5.2.3.1 Recapture rate

Excluding the recapture rate for *B. undatum* tagged with yellow bands, the five remaining band colours from Oxwich Bay and Swansea Bay had consistent recapture rates, ranging from 14.2 - 18.8 %. The first two band colours used to tag *B. undatum*, beige in Swansea Bay and green in Oxwich Bay, were recaptured during the tagging week, up to a maximum of 48 hours after being released. Although the recaptured *B. undatum* were tagged and released for a second time, they were ultimately omitted from the recapture data to ensure all *B. undatum* had an equal chance of being recaptured. However, they do support the results of the simulated handling disturbance experiments, where *B. undatum* were able to right themselves and respond to a food source within 24 hours.

Tagged *B. undatum* released across a small area, and with few release points, were resultantly recaptured from a localised area, such as the red band colour in Oxwich Bay and blue in Swansea Bay. Recapture points were widely dispersed when tagged *B. undatum* were released at considerably more points and over a larger area, as was seen for the beige band colour in Oxwich Bay. *B. undatum* tagged with red bands in Oxwich Bay did not mix with the beige and black band colours, but may have mixed with the untagged population. Red banded *B. undatum* were released to the North East of Oxwich Bay, across a very small area relative to the beige and black release points. As the red release points were further inshore, their limited movement and the prevailing oceanographic regime may have caused them to remain in a confined area. The fishing area was estimated using the release and recapture points from the mark-recapture study. The fishing area could have reflected the actual area of effort were GPS positions recorded for the fishing days when no tagged *B. undatum* were recaptured, for each string hauled. This would have improved the accuracy of the abundance and density estimates.

B. undatum were noted to have variable morphology based on differences in TSL and shell thickness, potentially affecting their survival rate when released in a habitat different to the one they were adapted to. This would have been most relevant on the three occasions that 400 - 600 *B. undatum* were caught in Oxwich Bay and released at a single location in Swansea Bay, as the bays had different habitats and *B. undatum* at Oxwich Bay were larger. For *B. undatum* tagged with yellow bands, the 600 released at a single location in Swansea Bay represented over one quarter of their releases, possibly affecting the recapture rate. The 3.7 % recapture rate for *B. undatum* tagged with yellow bands was substantially lower than for all other band colours, which may also have been due the release point not being fished during the recapture period. However, the remaining two release points were for *B. undatum* tagged with green bands, which had a recapture rate of 14.2 %, in line with those for all other band colours.

During the six week recapture period one other commercial *B. undatum* vessel was operational in both Oxwich Bay and Swansea Bay, but on an intermittent basis. Tagged *B. undatum* recaptured by the other commercial vessel may have reduced the number of tagged *B. undatum* available for recapture, as they would have been landed. However, this would not have affected the abundance estimates as the Lincoln-Petersen Index is based on the ratio of tagged and untagged animals.

The beige band colour used to tag *B. undatum* is the most appropriate colour to mitigate the risk of increased predation, as it is camouflaged against the shell. For the same reason, beige bands can easily be missed in fisher's catch, exacerbated by the volume of *B. undatum* they work with and the pace at which catch is sorted. This was a particular problem at Oxwich Bay due to the fine sediment in the bay, which frequently obscured beige bands until *B. undatum* were rinsed in seawater. However, the recapture rate for *B. undatum* tagged with beige bands was similar to the other band colours in the same bay.

Recapture data were not recorded after 25th July 2014 due to very poor catch rates of *B. undatum*, inevitably affecting the recapture rate of tagged *B. undatum*, which caused the fisher to relocate pot strings outside of the survey area. The poor catch rates are thought to be due to *B. undatum* mating, when feeding stops, as it is noted by the fisher to occur annually at approximately the same time of year. Although catch rates typically increase again after a few weeks of decline, the retention rate of rubber bands would be less certain over a longer period, but would have provided more accurate estimates of the minimum and daily distance travelled.

5.2.3.2 Abundance

B. undatum density was estimated to be 134 (± 8) m^{-2} at Oxwich Bay and 249 (± 35) m^{-2} at Swansea Bay, with the density at Swansea Bay almost twice that of Oxwich Bay. A similar pattern was seen in the mean *B. undatum* abundance per pot, 29 (± 1.8) at Oxwich Bay and 75 (± 11.5) at Swansea Bay (n = 5,595 and 2,782 respectively), with the abundance at Swansea Bay 2.6 times greater than that at Oxwich Bay. Although *B. undatum* abundance at Swansea Bay appears to be approximately double the abundance at Oxwich Bay, *B. undatum* size at Swansea Bay is considerably smaller. In 2013 individual *B. undatum* weights were larger at Oxwich Bay than Swansea Bay (Oxwich Bay: June = 49 g, July = 74 g; Swansea Bay: June = 32 g, July = 24 g), based on data collected by the Fisheries and Conservation Science Group. Therefore, CPUE (kg) is higher at Oxwich Bay than Swansea Bay, despite the greater abundance at Swansea Bay. For the mean individual weight *B. undatum* were caught using scientific pots, but the pots used in the recapture period were predominantly lay down. This may have skewed the size more towards larger *B. undatum*, as this was the trend seen when pot type was compared.

In the Northern Gulf of St. Lawrence, Eastern Canada, *B. undatum* densities of up to 3.01 m^{-2} have previously been recorded, although this was 1.74 m^{-2} once corrected for stress (McQuinn et al, 1988), and 0.24 m^2 (Himmelman, 1988). As the mark-recapture study involved accompanying a fisher, the survey areas were known to have high *B. undatum* abundance, which may cause the abundance to be higher than if s survey area had been selected as part of an independent study, such as the studies conducted in Eastern Canada. However, a study accompanying a fisher in the Llyn Peninsula, North Wales also had a considerably lower abundance than in South Wales, 3.6 m^{-2} based on a mark-recapture study with a 3.3 % recapture rate from 4,007 *B. undatum* tagged (Turtle, 2014 M. Sc. thesis). The abundance and CPUE of *B. undatum* per pot was considerably higher for the Llyn peninsula, compared to Oxwich Bay and Swansea Bay. Therefore, the area measurements for North Wales and South Wales are unlikely to be accurate, due to the fishing area being estimated.

5.2.4 Minimum and daily distance travelled

B. undatum are thought to travel distances of up to 50 m day^{-1}, at average speeds ranging from 8.3 cm min^{-1} to 11.4 cm min^{-1}, based on underwater observations using SCUBA (Himmelman, 1988). Sainte-Marie (1991) recorded *B. undatum* moving a maximum distance of 22.5 m in 228 minutes, and speeds of up to 13.2 cm min^{-1} during underwater observations. The mean minimum distance travelled was analogous for Oxwich Bay and Swansea Bay, 198 (± 11) m and 206 (± 56) m respectively. The mean daily distance travelled was also very similar between bays, 11 (± 1) m day^{-1} at Oxwich Bay and 10 (± 3) day^{-1} at Swansea Bay. The greater variability in movement estimates at Swansea Bay may be due to the considerably lower fishing effort. In the Llyn Peninsula, North Wales, the mean minimum distance travelled by *B. undatum* was 222 (± 36) m (Turtle, 2014 M. Sc. thesis). The *B. undatum* mean minimum distance travelled at Oxwich Bay, Swansea Bay and the Llyn Peninsula were in a similar range of 198 - 222 m, and are therefore made more reliable by comparison. In the Llyn Peninsula, three *B. undatum* were recaptured 24 hours after being released with a minimum distance travelled of 111 m (Turtle, 2014 M. Sc. thesis), although this exceeds the daily distance recorded by Himmelmann (1988), this was not based on underwater observations.

The minimum and daily distance travelled by *B. undatum* are useful as conservative estimates, but may considerably underestimate the distance travelled due to *B. undatum* movement being multidirectional. Minimum distances travelled were omitted from data when they were vastly different to the mean for that band colour. Six beige and 126 black tagged *B. undatum* were recaptured approximately 3,400 m from their nearest release point. As *B. undatum* have been documented to travel a maximum 50 m day^{-1}, these distances may relate to inaccuracies in the GPS positions recorded. However, more detailed movement measurements would help to identify the normal range of *B. undatum* movement. A higher resolution of movement could have been obtained by tagging *B. undatum* with unique numbers to identify individuals. Numbered tags would need to be obtained from a manufacturer, were a large volume of *B. undatum* to be tagged, with numbers potentially printed on thick rubber bands.

5.2.5 Limitations

During the fisheries catch analysis, the fishing effort at Swansea Bay was considerably less than that at Oxwich Bay, resulting in smaller sample sizes and greater variability in the data.

The pot strings used to fish *B. undatum* ranged in length from 600 – 1,560 m, with GPS positions recorded as each pot string started being hauled. As the data obtained represented that string as a whole, the GPS positions recorded for the environmental data and recaptures were only approximate locations due to the considerable length of pot strings.

The actual fishing area during the six week recapture area should have been obtained by taking GPS positions each time a pot string was hauled, irrespective of whether tagged *B. undatum* were recaptured. This would have made the density calculations more accurate, by avoiding the need to estimate the fishing area based on only the release and recapture points at each bay.

The mark-recapture study to estimate abundance had some inherent limitations in the experimental design, as it involved accompanying a fisher during routine commercial fishing activity. Were the mark-recapture study conducted as an independent fisheries study, the survey area could have been clearly defined, to improve the accuracy of the abundance estimates. This would have necessitated accurate fishing effort data, which could have been obtained from weighing the *B. undatum* catch per string, with sub-samples used to record individual *B. undatum* weights for extrapolation to the rest of the catch. The survey areas were known by the fisher to have a high density of *B. undatum*, causing the abundance estimates to appear disproportionately large.

The mark-recapture study to estimate abundance did not account for the effective range of baited pots, or the effect of the oceanographic regime in Oxwich Bay and Swansea Bay, known to affect the ability of *B. undatum* to detect respond to baited pots. Martel et al (1986) studied *B. undatum* feeding activity using mark-recapture, in the Northern Gulf of St. Lawrence, Eastern Canada. *B. undatum* feeding decreased prior to breeding, and did not resume until two to three months after reproduction. Martel et al (1986) suggested that the effective fishing area of baited pots is dependent on a site- and season-specific basis, and is likely to be the result of physical and biotic factors. Conditions such as current strength and directionality, as well as reproductive state and feeding rates may bias CPUE when a constant effective fishing area is assumed (Martel et al, 1986).

To standardise the probability of *B. undatum* being recaptured, baited pots could have been distributed using a grid system. The thick rubber bands used to tag *B. undatum* are purchased by weight, but the bags of beige bands were thicker than all of the other band colours used, therefore containing fewer bands. This made the application of beige bands very strenuous, requiring them to be stretched by hand before being applied to *B. undatum*. The tag retention study in the laboratory only used beige bands, and therefore the retention rate of the other band colours used, which were slightly thinner, may be less than the four months recorded in the laboratory experiment.

To improve the accuracy of movement estimates, distances measured in ArcGIS v10.1 should have used a projected coordinate system to better fit the UK, such as OSG 1936 or UTM 30.

5.2.6 Conclusion

The distribution, abundance, population densities, movement and size of *B. undatum* at sexual maturity are not well understood. This is true of Wales, the UK and the North Atlantic. Although ad hoc abundance estimates can be found predominantly in 'grey literature', the range of geographic locations, times of year and methodologies used make it difficult to draw conclusions about the status of *B. undatum* populations in a given area. However, comparison of *B. undatum* abundance, TSL, CPUE and density between North and South Wales suggests that fishing pressure in South Wales may be greater than for North Wales.

B.undatum abundance at Oxwich Bay was half that of Swansea Bay based on the mean *B.undatum* abundance per pot. *B. undatum* TSL at Oxwich Bay had a larger range than Swansea Bay, with an absence of larger sized *B. undatum* at Swansea Bay. However, both Oxwich Bay and Swansea Bay had a smaller *B. undatum* TSL range when compared to the Llyn Peninsula, which is likely to experience less fishing pressure than South Wales. The overall percentage of undersized *B. undatum* was considerably higher at Oxwich Bay than Swansea Bay, with 12.3 % discarded at Oxwich Bay and 2.4 % discarded at Swansea Bay, based on 24 hour soak times.

CPUE estimates for Oxwich Bay and Swansea Bay were only half that of Carmarthen Bay, South Wales (French, 2011 M. Sc. thesis), with CPUE in Carmarthen Bay 20 % less than Jersey, Channel Islands (Morel & Bossy, 2004) and off the Llyn Peninsula, North Wales (Turtle, 2014 M. Sc. thesis). The lower CPUE recorded in South Wales may be an indication of the *B. undatum* fishery having experienced a greater level of fishing pressure. However, as *B. undatum* populations are localised (Shelmerdine et al, 2007; Palsson, 2014) density can be used more accurately for comparison between different locations, as a higher CPUE may relate to a larger area of habitat and therefore population.

The tag retention study identified that 100 % of thick rubber bands could be retained by *B. undatum,* over a four month period in laboratory conditions. Tagged *B. undatum* are unlikely to have been adversely affected by handling disturbance, with the capture probability the same as for undisturbed *B. undatum*. The ability of *B. undatum* to recover from handling disturbance can be applied to undersized *B. undatum* in the fishery that have been caught, and are then rolled across a riddle before being returned to the water, which a likely to have a high survival rate.

The use of mark-recapture to estimate *B. undatum* abundance, applying the Lincoln-Petersen Index, has been successfully demonstrated in this study. A total of 11, 528 *B. undatum* were tagged and released in Oxwich Bay and Swansea Bay, with similar recapture rates for five out of the six band colours, ranging from 12 - 18.3 %. *B. undatum* density at Oxwich Bay was just over half that of Swansea Bay, consistent with the mean abundance per pot between the bays.

The estimates of minimum and daily distance travelled support the idea that *B. undatum* have limited movement, and live in localised populations, with little mixing between them (Shelmerdine et al, 2007; Palsson, 2014). The mean minimum and daily distance travelled was analogous between Oxwich Bay and Swansea Bay, with minimum distances of 200 m in total and 10.5 m day^{-1} for both bays.

The dispersal potential for *B. undatum* is limited by their low fecundity, benthic reproduction and limited movement, with little or no migration, resulting in closed populations (Shelmerdine et al, 2007). Variation in *B. undatum* population size, age, and estimated growth rates have been identified to exist on both a small, between East and West Shetland, and large geographic scale, between Shetland and South England (Shelmerdine et al, 2007). Small-scale variation in *B. undatum* populations has also been reported in the Isle of Man (Kideys, 1996), the Gulf of St. Lawrence (Gendron, 1992) and Nova Scotia, Canada (Kenchington & Glass, 1998). Palsson et al (2014) analysed samples from Iceland and found that large differentiation could occur over small geographical distances, with genetic separation even occurring within the same bay.

B. undatum size at sexual maturity has been consistently shown to exceed the 45 mm TSL minimum landing size, for both males and females (French, 2011 M.Sc. thesis; Lawler, 2013). *B. undatum* size at maturity was analysed from ten important English fisheries, using visual observation of gonad maturity (Lawler, 2013). Considerable regional variation was identified in size at sexual maturity. However, the 45 mm MLS would only have protected spawning stocks in one out of the ten locations analysed, which was in the Solent, UK.

The trend towards increased fishing pressure for *B. undatum* can clearly be seen from the landings data for Wales, and is driven by demand from the South Korea market. The informed management of the *B. undatum* fishery in Wales could be achieved by standardising methodology for analysis of the fishery over time, to facilitate routine monitoring. The potential use of mark-recapture methods to estimate *B. undatum* abundance and movement have been demonstrated in the present study, and can act as a basis for future work.

In Shetland, the *B. undatum* MLS was increased to 75 mm TSL within the 6-mile limit around, due to pressure from local fishers (Shelmerdine et al, 2007). Increases in *B. undatum* MLS have also been suggested for fisheries in the Southern Irish Sea (Fahy et al., 1995, 2000), and Jersey, Channel Islands, (Morel & Bossy, 2004). Management measures have also been imposed for Buccinum species outside of the UK, for Isaotaki Buccinum (*Buccinum isaotakii* Kira, 1959) fishery in Japan

(Ilano et al, 2003).

In conclusion, mark-recapture can be used successfully to estimate *B. undatum* abundance and movement. The populations of *B. undatum* in Oxwich Bay and Swansea Bay may be showing some signs of fishing pressure affecting the size range and abundance, relative to less exploited fisheries in the UK, which is particularly the case for Swansea Bay. However, the fishery would need to be monitored over a longer time frame, along with the collection of size at maturity data. Further management restrictions for the *B. undatum* fishery should be made at a regional level, to account for the species' biological variability.

5.2.7 Future work

To assess the sustainability of the *B. undatum* fishery, further research is required to provide information on the population and size at sexual maturity. This is needed from a more extensive range of locations, with studies conducted over a longer time period than the present study, and standardised data collection. The potential need for further management measures for *B. undatum* fisheries in the UK has been identified at a range of locations (Morel & Bossy, 2004; Shelmerdine et al, 2007; Lawler, 2013).

The sustainability of the *B. undatum* fishery in Wales could be protected by an increase in the minimum landing size at the EU level. However, this would not allow for the regional differences in size at sexual maturity that *B. undatum* has been observed to have (Shelmerdine et al, 2007; Lawler, 2013). Increases in the minimum landing size at a regional level would account for small-scale changes in size at sexual maturity (Shelmerdine et al, 2007; Palsson, 2014), but necessitates further research to make informed management decisions. The *B. undatum* fishery has a restricted number of merchants, compared to those for some other shellfish, which could facilitate an economical approach to data collection (Lawler, 2013), in conjunction with research and routine monitoring in the field.

For fieldwork involving *B. undatum* the timing and duration of experiments needs to be carefully considered, as behavioural responses vary considerably depending on the stage of the breeding cycle. Therefore, future work should represent *B. undatum* population parameters over a more considerable time period, with routine monitoring of the fishery, to account for the variability in *B. undatum* response.

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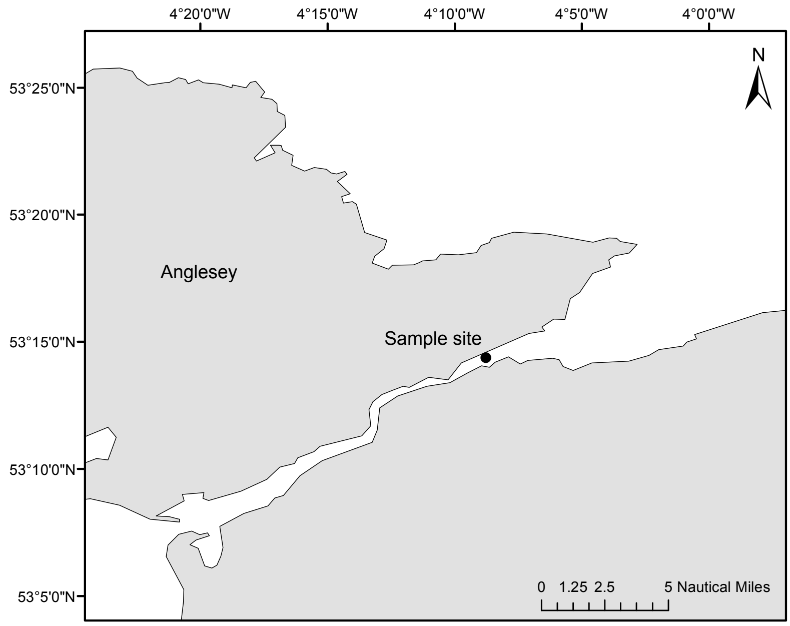
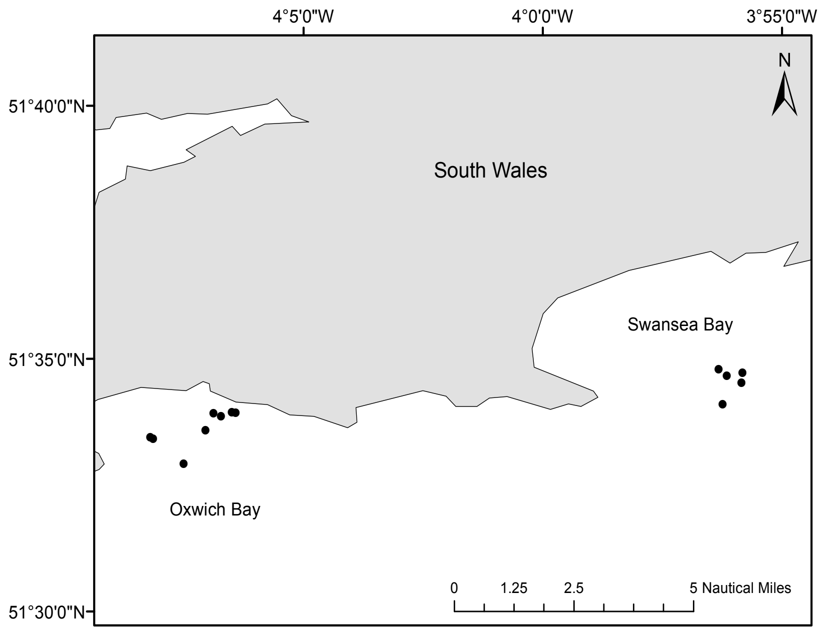
APPENDICES



Appendix Fig. 7.1 The sample site in the Menai Strait, Anglesey, where experimental *Buccinum undatum* were caught using baited lay down pots. *B. undatum* were used for the tag retention study and disturbance experiments in the laboratory, assessing recovery by righting and in response to a food source after tagging, rolling and air exposure.



Appendix Fig. 7.2 The capture locations of *Buccinum undatum* used as part of the mark-recapture study to estimate abundance in Oxwich Bay and Swansea Bay, South Wales, caught and released from 10th – 13th June 2014. *B. undatum* were caught using baited pots, and tagged with thick rubber bands before being released.

Appendix Table 7.3

The tagging effort in hours for *Buccinum undatum* at Oxwich Bay and Swansea Bay, South Wales, excluding travel time to and from the survey areas. Whelks were tagged continuously by four people, applying bands by hand or using a lobster banding tool. Tagging took place for up to eight hours per day, with a total tagging effort of 100 hours from 10th - 13th June 2014.

			Tagging time			
Day	**Date**	**Number of people tagging**	**Start**	**End**	**Hours**	**Total**
1	10.06.14	4	10:20	16:12	6	24
2	11.06.14	4	10:11	15:09	5	20
3	12.06.14	4	10:13	16:05	6	24
4	13.06.14	4	09:05	17:21	8	32
Total						**100**