The abundance, movement and site fidelity of the adult whelk, *Buccinum undatum*, in the territorial waters of the Isle of Man

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science (MSc) in Marine Environmental Protection

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This work has not previously been accepted in substance for any degree and is not being currently submitted for any degree.

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Abstract

The maximum and daily movements of the common whelk (*Buccinum undatum*) were investigated in Ramsey Bay, northeast Isle of Man from June to July 2015. A mark-recapture study to estimate abundance was conducted by tagging 5000 *B. undatum* in five different series and releasing them at separate sites in the area of study. *B. undatum* abundance, above and below the minimum landing size, and Catch Per Unit Effort (CPUE) were estimated and were analysed for differences between different pot types and pot soak times. The population abundance for each series was estimated using the Lincoln-Petersen Index, and the density of *B. undatum* was determined based on the area created by the distribution of tagged *B. undatum* from the release points. A total of 772 *B. undatum* were recaptured, a 15.4% recapture rate. Mean CPUE was 3.57 kg pot^{-1} and there was no significant difference in CPUE between lay-down and stand-up pot designs, or between pot soak times of 24, 48 and 72 and over hours. The population density of the study area was estimate to be 2.68 m^{-2}, the mean maximum distance travelled was 155.9 m and the mean daily distance travelled was 15.2 m.

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Acronyms

ANOVA = Analysis of variance

BAP = Biological action plan

CPUE = Catch per unit effort

EU = European Union

FV = Fisheries vessel

FPV = Fisheries protection vessel

GPS = Global positioning system

MLS = Minimum landing size

NM = Nautical mile

TSL = Total shell length

SE = Standard error

1. INTRODUCTION

The common whelk (*Buccinum undatum* L.) is a neogastropod mollusc that is widely distributed on both sides of the north Atlantic (Thomas & Himmelman, 1988; de Vooys & van der Meer, 2010; McIntyre *et al.*, 2015) from Brittany in south to the Arctic in the North (Taylor& Taylor, 1977) (Figure 1). *B. undatum* have been reported living at depths from the low tide mark down to 1200 m, although they are generally found at depths up to 200 m and on a wide range of substrata (de Vooys & van der Meer, 2010; Heude-Berthelin *et al*., 2011). *B. undatum* feed opportunistically and predate shellfish, although predominantly scavenge on dead and moribund organisms (de Vooys & van der Meer, 2010). Like many other marine scavengers, *B. undatum* have well developed chemosensory organs for detecting and locating prey using (Crisp *et al*., 1978). This behavior. The importance of *B. undatum* fisheries in Europe is growing, and the high demand has resulted in the Isle of Man (IOM) fishery is only behind the scallop, crab and lobster fisheries in terms of value (Kaiser *et al*., 2008). There have been few studies on the ecology of B. undatum in IOM waters, with the last comprehensive study in 1990 (Kideys, 1990). It has been suggested that discrete populations of B. undatum exist, and this in addition to them exhibiting 'K' selected traits, such as slow growth, low fecundity and a long life span, makes the species susceptible to recruitment- and growth overfishing (Valentinsson *et al*., 1999) and localized extinction (Morel & Bosey, 2004).

Fig 1. The common whelk, *Buccinum undatum*.

1.1. Distribution and movement

The leading factors that govern the range and distribution of a species can be difficult to identify, with complex interactions between biological and physical factors. Distribution and abundance of populations is controlled by dispersal, competition, predation and physical disturbance (Roughgarden *et al.*, 1988), while the range of a species is controlled by environmental conditions such as temperature, salinity and the type of substratum. The interaction between these factors is likely to cause geographical and temporal variation in the distribution of a population. Populations of *B. undatum* are thought to be localized with a poor understanding of the extent of dispersal and connectivity between them (Shelmerdine *et al.*, 2007). This localization can pose a problem for the management of *B. undatum* fisheries, as strategies for effective management require different approaches for populations with differing ecological traits (Thorpe *et al.*, 2000). Analysis of the genetic connectivity between populations of *B. undatum* found that four distinct groups of populations are found in the northern Atlantic in Canada, Iceland, Sweden and the European continental shelf. There is also significant isolation by distance of populations of *B. undatum* around the coast of the North Sea with a net migration from inshore to offshore (Weetman *et al*., 2006).

B. undatum is found around the entire coast of Britain where muddy sand and gravel is present (Hancock, 1967). The absence of a planktonic larval stage restricts their migration range and they exhibit limited movement as adults (de Vooys & van der Meer, 2010) with a reported average speed of 11.4 cm min^{-1} and total daily movement of 50 m towards a baited trap (Himmelman, 2008).

1.2. Feeding and nutrition

B. undatum, as a sedentary predator, uses chemoreceptors to detect and locate prey and other sources of food (Bailey and Laverack, 1966; Crisp *et al*., 1978; Cato *et al*., 1996) and will feed on live organisms such as sipunculid worms, moulting crustacea, small echinoids and damaged bivalves (Hunt, 1925; Hancock, 1960; Taylor & Taylor, 1977; Martel *et al*., 1986). *B. undatum* do not possess a pedal boring organ with which to open the shell of its prey and instead they will asphyxiate their prey by using their foot or forcing the valves apart with the edge of their shell (Hancock, 1960; Nielson, 1975;

Scolding *et al*., 2007). *B. undatum* is also a scavenger and will opportunistically feed on dead and moribund animals (Hunt, 1925; Hancock, 1960; Taylor & Taylor, 1977). By scavenging, *B. undatum* redirect energy from dead and dying organisms as a result of fishing discards and disturbance and can be an important pathway in the redirection of energy (Evans *et al*., 1996; Hall 1994).

1.3. Growth

Total shell length (TSL) in *B. undatum* can reach up to 120 mm, with a maximum shell width of 60 mm (Ager, 2008). The shell consists of seven or eight whorls with the last whorl, the body whorl, making up 70 % of the TSL. *B. undatum* is a long-lived organism, living at least 10 years (Hancock, 1960) but thought to live longer (Hallers-Tjabbes *et al*., 1996). They are slow growing and exhibit continued indeterminate growth that slows down during the course of its lifetime (Kideys, 1993). Differences in shell morphology, size at sexual maturity, and genetic variation have been observed over large spatial scales (Nicholson & Evans, 1997; Fahy *et al*., 2000; Morel & Bossy, 2004) and significant contrasts in TSL and growth rate have been observed over small spatial scales (Kideys, 1996; Valentinsson *et al*., 1999; Fahy *et al*., 2000) .

1.4. Reproduction and life history

European populations of *B. undatum* usually breed during autumn and winter (de Vooys & van der Meer, 2010). Male *B. undatum* are attracted by pheromones released by females when the sea temperature reaches 9 – 12 °C (Hancock, 1967; Kideys *et al*., 1993). Females will copulate with several males and accumulate sperm until environmental conditions are optimal and they trigger delayed fertilization *(Kideys et al*., 1993). Eggs are laid in capsules attached to hard substrate and several females will often contribute to the same mass of eggs (Cato *et al*., 1996). The larval stage of the lifecycle occurs within the egg capsule and the offspring emerge as juvenile snails, resulting in limited dispersal (Martel *et al*., 1986; Cato *et al*., 1996). During breeding, the rate of feeding in *B. undatum* is reduced and the energetic costs of breeding are supported by energy reserves in the foot muscle breeding (Hayashi, 1983; Martel *et al*., 1986). Female *B. undatum* do not reproduce every year in order to compensate for the energy cost of reproduction (Martel *et al.*, 1986a).

1.5. Predation

B. undatum is predated by invertebrate species such as crabs, lobsters and starfish (Hancock, 1960; Ramsay & Kaiser, 1998) as well as by dogfish and cod (Hunt, 1925; Hancock, 1960). The presence of the starfish *Asterias rubens*, a common predator of *B. undatum* in the Irish Sea, has been observed to trigger escape responses in *B. undatum* such as rapid flight and foot contortions (Feder, 1963; Mackie *et al.*, 1968). The risk of predation in *B. undatum* is increased as a direct result of disturbance by beam trawling activity, as once they are disturbed it can take them significantly more time to initiate an escape response (Ramsay & Kaiser, 1998).

1.6. *Buccinum undatum* fisheries

B. undatum is fished using baited pots which are designed to be species specific, with a mesh covered opening at the top of a weighted cylindrical structure. Pots are baited with fish or shellfish, often small spotted catshark (*Scyliorhinus canicula*) or waste from the brown crab (*Cancer pagurus*) (Fahy 2001) and set in long strings of pots between 15 and 20 m apart. Soak time of the pots is generally 24 hours, with catches collected daily as the attractiveness of the bait reduces rapidly and once in the pot, *B. undatum* will quickly consume the bait. There is generally low by-catch associated with this method of fishing (Lawler & Vause 2009). Once hauled on to the boat, the catch is passed through a riddle of parallel bars, which retain whelks above the MLS, while undersized whelks for are discarded.

Relevance of Buccinum undatum fisheries

B. undatum is a target fishery in France, Iceland, Ireland and the UK (Hancock, 1967; Shelmerdine *et al.*, 2007). There have been several population declines observed in *B. undatum*, thought to be a direct result of fishing pressure. Areas of the North Sea have seen decline in numbers (ten Hallers-Tjabbes *et al.*, 1996) as well as significant reductions in the mid-20th century in the Dutch Wadden Sea which eventually led to local extinction by 1991 (Cadée *et al*., 1995).

135 tonnes of *B. undatum* were landed to the IOM from its territorial waters in 2011 (Hanley *et al*., 2013). While the IOM whelk fishery is still considered relatively small in comparison to scallop, crab and lobster fisheries on the island, there is an increasing fishing effort towards *B. undatum* which is a non-quota species, both in IOM and elsewhere in the Irish Sea, with little current stock assessment. There appears to be a need for more directed fisheries research and population assessment of the *B. undatum* fishery around the IOM (Kaiser *et al*., 2008; Hanley *et al*., 2013).

Current regulations and management

As a Crown Dependency, the IOM has full management control over its inshore fisheries management. There is currently a minimum landing size (MLS) of 70 mm shell height in IOM waters as well as other fisheries management measures such as a limit of 3600 total pots within 3 NM of the shore and a limit of 600 pots per boat. Compared with the rest of Great Britain, the MLS on the IOM is relatively large, with an MLS of 45 mm in England and 55 mm in Wales (McIntyre *et al*., 2015). Setting an MLS is intended to protect the spawning stock of a species, and as such it must be above the size at sexual maturity for the species. This can present difficulties for species such as *B. undatum* where the size at sexual maturity varies geographically. To date, there has been no comprehensive study to determine the size at sexual maturity of *B. undatum* in IOM waters, but studies in England have shown that there is a great deal of variation between regions (Bell & Walker, 1998; Lawler, 2014).

By-catch

While fishing with baited pots generally produces very little by-catch, there are by-catch species that are associated with whelk fishing. The netted whelk (*Nassarius reticulatus*) and brittle star (*Ophiothrix fragilis*) are commonly caught as by-catch, as well as commercially important species such as spider crab (*Maia squinado*), edible crab (*Cancer pagurus*) and lobster (*Homarus gammarus*) (Robson, 2014). The greatest impact on non-target species however, is on the bait species brown crab and dogfish (Hancock, 1967).

1.7. Mark-recapture in *Buccinum undatum*

Mark-recapture studies can be used to estimate the population size of a species where counting all individuals in the population is not feasible (Lockwood & Schneider, 2000). A sample of the population is tagged and returned to the area of study. A later sample of the population is taken and the tagged individuals amongst it counted. The size of the population can then be estimated, as 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 that were released by the fraction of tagged individuals present in the second sample will provide an estimate of the total abundance of that species with the limits of the area sampled. For the Lincoln-Peterson Index to be valid, assumptions of a constant rate of instantaneous mortality, exploitation and recruitment must be met. The second sample, or recapture event must also be able to be considered instantaneous, with no mortality, recruitment, immigration or emigration between the release and recaptures.

Due to their sedentary nature as adults and low dispersal as juveniles, B. undatum can be considered to have closed populations. This makes them suitable for the Lincoln-Peterson Index for estimating the abundance of a closed population (Lockwood & Schneider, 2000). In comparison to other marine molluscs, particularly bivalves (Jones, 1979; Seber, 1986; Thorpe *et al*., 2001), there has been relatively few marking studies on *B. undatum*.

Examples of mark-recapture in Buccinum undatum

The retention rate of thick rubber bands used to tag *B. undatum* has been tested in laboratory conditions resulting in a retention rate of 100 % (Robson, 2014). Similar retention studies using the same type of 1 mm thick rubber bands were previously seen in mark-recapture studies (Himmelman, 1988; Kideys, 1994). Himmelman (1988) carried out field studies to assess the effect of stress on the recapture rate of *B. undatum*. It was concluded that *B. undatum* that had been removed from the water were less likely to be recaptured than individuals that were tagged in the water by divers. Robson (2014) conducted a laboratory experiment to test the effect of disturbance on the righting and recovery time of *B. undatum* after a being subjected to emersion and simulated riddling. This concluded that there was no difference in the righting time, or in the time taken to reach bait between *B. undatum* that had been subjected to the stressors and those that were not.

It is crucial that the attributes being studied are not affected by the tagging process, as this will lead to errors in conclusions of the study (Himmelman,1988). In a mark-recapture study by Kideys (1990), the recapture rate of tagged *B. undatum* was too low for a successful estimation to be made. It was concluded in this study that the low rate of recapture was a result of poor tagging technique that subjected the organisms to a degree of stress that led to mortality after release.

1.8. Aim

The project aims to estimate the abundance and population density of *Buccinum undatum* in fishing grounds offshore from Ramsey Bay, northeast Isle of Man. There is currently no data on *B. undatum* for this area. The study consists of a mark-recapture study to estimate abundance, as well as total and daily movements of *B. undatum*, in collaboration with a commercial pot fisher. An assessment is also made on the catch per unit effort (CPUE) by conducting fisheries catch analysis.

1.9. Hypotheses

In addition to population abundance and individual movement estimations, the following hypotheses will be tested:

H_1: Population abundance of *B. undatum* in Ramsey Bay will be significantly different when compared with Oxwich and Swansea Bay, South Wales (Robson, 2014).

H_2: Maximum and daily movement of individual *B. undatum* in Ramsey Bay will be significantly different when compared with Oxwich and Swansea Bay, South Wales (Robson, 2014).

H3: *B. unadtum* over MLS, under MLS and CPUE will vary with different pot designs and soak time.

2. METHODS

2.1. Logistics

Study area

The study was carried out in an area of 5.75 km^2 just outside the 3 NM limit off Ramsey Bay - a large, moderately exposed sandy bay in the north east of the Isle of Man (Moore, 1979) (Figure 2). The sediment in the study area ranges from fine to very coarse sand and surveys conducted in 2009 suggested that the area is dominated by brittle star (*Ophiothrix fragilis*) beds, *Laminaria* spp., hydroid turf and the anemone *Anthopleura ballii* (Hinz *et al*., 2010). The presence of the UK BAP and OSPAR recognised habitats of horse mussel and maerl beds were also identified in the area. The area is fished for *B. undatum* throughout the year by whelk potting boats.

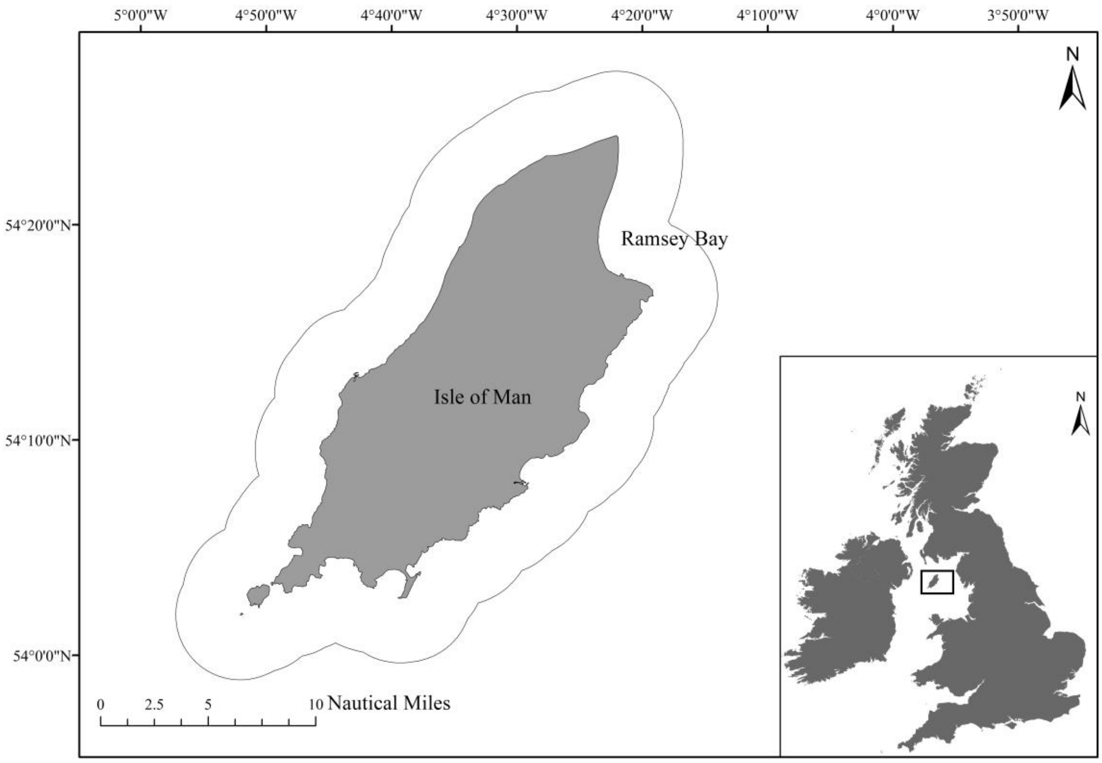

Fig. 2 Survey area off Ramsey bay in the northeast of the Isle of Man where the mark-recapture study on *Buccinum undatum* was conducted from 16th June – 19th July 2015, just outside the 3 NM limit indicated by the black line.

Work vessels

Whelk tagging and initial release was carried out onboard the fisheries protection vessel '*Barrule'* in Ramsey Bay on 16th and 17th June 2015. All work thereafter was conducted onboard the Ramsey based, inshore fishing vessel '*Boy Shayne'* (Figure 3) from 17th June – 19th July 2015. FV *Boy Shayne* is a 7.95m catamaran with twin caterpillar diesel engines, a forward wheelhouse, winch and roller for crab and lobster potting as well as whelk fishing.

Fig. 3 The commercial potting vessel '*Boy Shayne*' used for the recapture period of the mark-recapture study of *Buccinum undatum* to estimate abundance and movement in Ramsey Bay, northeast Isle of Man from 17th June – 19th July.

Fishing gear

During the 33-day recapture period, the fishing gear used was 5 strings for 3 days (17th June – 19th June), 6 strings for 19 days (20th June – 9th July) and 8 strings for 10 days (10th July – 19th July) (Table 1). Each string had 20 pots spaced an average of 20 metres apart. Two types of pot were used with three strings being comprised of plastic 20 litre lay-down pots of dimensions 35 cm x 25 cm x 18 cm, weighed down with steel bars in the base and drainage holes approximately 2cm in diameter. Five strings were comprised of round plastic moulded, stand-up 36 litre pots, 35 cm high and 33 cm in diameter, weighted with a lead base and drainage holes approximately 2 cm in diameter (Fig 4). The function of the drainage holes is to speed up the submersion and sinking of the pots when they are set, and to aid bait detection of *B. undatum*.

Fig. 4 Pots used by the commercial potting vessel '*Boy Shayne*' to capture *Buccinum undatum* throughout the mark-recapture study in Ramsey Bay, northeast Isle of Man from 17th June – 19th July. **a)** A 36 litre round, plastic moulded pot with netting drawn closed at the top. **b)** A 20 litre lay-down pot with netting drawn closed at the top.

Table 1. The number and type of pots used and the number of days each string was fished in the study area throughout the mark-recapture study of *Buccinum undatum* in Ramsey Bay, northeast Isle of Man from 17th June – 19th July. A total of 160 pots were fished, 100 stand-up and 60 lay-

String number	Pot Type	Pot capacity (l)	Number of pots	Days used	Total pots hauled
1	Stand-up	36	20	33	660
2	Stand-up	36	20	33	660
3	Stand-up	36	20	33	660
4	Stand-up	36	20	33	660
5	Stand-up	36	20	33	660
6	Lay-down	20	20	30	600
7	Lay-down	20	20	10	200
8	Lay-down	20	20	10	200

The soak time for the pots was generally 24 hours but varied between 24 and 96 hours due to impractical weather conditions and logistical reasons. All pots were consistently baited with both brown crab (*Cancer pagurus*) and catshark spp. (*Scyliorhinus canicula* or *S. stellaris*) which were caught or bought fresh, depending on availability. The bait in each pot was replaced after each haul and existing bait that had been eaten by captured whelks was removed.

2.2. Mark-recapture study

Tag Design

A total of 5000 *B. undatum* were tagged with five series (A - E) of 1000 individually coded tags (000 - 999). The tag design was based on work by Robson (2014) who used different coloured lobster bands to differentiate between series of tagged *B. undatum*. For this study, the tags were developed to include a unique identification code for greater precision in tracking the movements of *B. undatum* once they were recaptured (Figure 5c).

The unique identifying codes were punched into a section of hard plastic embossing tape using an embossing label maker (Figure 5a). A small hole was then punched in the tag and it was attached to a thick rubber lobster claw band of 20 mm x 10 mm with a thickness of 1 mm. using a plastic snap lock tag fastener (Figure 5b). Two types of tag fasteners were used as the suitability and durability of this component was not certain. The two types differed in the design of the snap lock, and while one type seemed to fail more often during the tagging process, there was no evidence to suggest that it was any less suitable once applied to the whelk.

Fig. 5 The tag design used in the mark-recapture study of *Buccinum undatum* in Ramsey Bay, northeast Isle of Man from 17^{th} June – 19^{th} July. **a)** Embossed plastic label with a unique code, **b)** thick rubber lobster claw band of width 10 mm, diameter 20 mm and thickness 1 mm and **c)** the complete tag with plastic snap lock tag fastener.

B. undatum tagging

B. undatum were caught from the study area on 16^{th} and 17^{th} June 2015 by the FV *Boy Shayne* where they were riddled, placed into whelk sacks and transferred at sea to the FPV *Barrule* (Figure 6a). The whelk sacks were emptied into large plastic drums of seawater with a continual flow of fresh seawater from the ships pump to ensure the whelks had sufficient oxygen and were kept at a suitable temperature (Figure 6b). *B. undatum* were tagged by hand or with the aid of lobster banders by stretching the lobster claw band over the shell of the whelk so that it rested across the body whorl of the *B. undatum* shell, ensuring that the aperture was not covered and the whelk's movements would not be hindered (Figure 7 a & b).

In addition to the 5000 *B. undatum* tagged for the purposes of this study with the above tag design, a tagging method was trialed with 72 *B. undatum.* The shell of the individual was roughly dried with a paper towel and a small area was cleaned to remove the periostracum – the thin organic coating on the outer surface of the shell. Epoxy resin was then applied to the underside of the tag and it was placed on to the cleaned area of the shell. A rubber lobster claw banded was then placed on the body whorl of the whelk to aid the identification of a recaptured individual (Figure 8).

Each series was released at separate release points in the area of study on 16th and 17th June 2015 (Table 2). To reduce disturbance and for greater precision in the release points, the tagged *B. undatum* were released by placing them into a basket and lowering them to the sea floor where they were tipped out (Figure 9). The position of the release points were recorded from the onboard GPS.

Table 2 Dates the *Buccinum undatum* series were tagged and released on during the release phase of the mark-recapture study of *B. undatum* in Ramsey Bay, northeast Isle of Man from 17th June – 19th July. Series D was tagged and released over two days due to time constraints, but released in the same position.

Series	Release Date
A	16.06.2015
B	16.06.2015
C	16.06.2015
D (000 - 300)	16.06.2015
D (301 - 999)	17.06.2015
E	17.06.2015
Glue	17.06.2015

Only *B. undatum* that had been riddled and were therefore over the MLS of 70 mm were tagged as these had been recruited to the fishery. Prior to release, a subsample of 100 individuals was selected at random from each series, the TSL was measured using calipers and the shell damage was assessed and given a score of 1 – 3. The damage score was assigned based on the proportion of the total shell that was damaged (Figure 10 a, b & c) and was generally caused by the riddling process onboard FV *Boy Shayne*.

During tagging, *B. undatum* were exposed to air for up to one hour before they could be transferred from FV *Boy Shayne* to FPV *Barrule*. Once tagged they were placed in barrels of seawater and released in batches of 300. The position of each batch release was recorded on the onboard GPS as the vessel drifted slightly from the original release point.

Recapture period

The 31 day recapture period began 24 hours after the initial *B. undatum* had been released. For each string hauled within the study area, the date, GPS position, total number of bags, number of discarded *B. undatum* below MLS and the identification number, size and damage of each recaptured whelk were recorded. The whelks from five full whelk sacks were counted and the mean number of *B. undatum* was used to estimate the total number of whelks caught in each string by multiplying the mean number of whelks per sack by the total number of sacks filled from each string.

2.3. Data Analysis

Catch per unit effort (CPUE)

Mean CPUE per pot (kg) was calculated from the number of sacks landed per string. All full sacks were weighed once landed and the mean sack weight was multiplied by the number of sacks landed from each string, and then divided by the number of pots on that string. CPUE therefore only took into account *B. undatum* that were landed and had therefore over the MLS and had been recruited to the fishery.

Pot type

The abundance of *B. undatum* over the 70 mm MLS and under the MLS that were caught from the two different pot types were compared statistically, along with CPUE per pot (kg). This fisheries catch data was collected from every haul during the mark-recapture study. These data were presented graphically with mean values and standard error bars to allow comparisons to be made between different sample sizes, and they were summarized with descriptive statistics. Significant differences between the group means were determined by using one-way analysis of variance (ANOVA). Prior to the use of all analysis of variance, data were tested for the assumptions of normal distribution and homogeneity of variance. The Shapiro-Wilk test was used to test for normal distribution, while the Levene's test was used to test for homogeneity of variance. With data sets meeting these criteria for parametric testing, the use of non-parametric tests was not required. All statistical tests were carried out in SPSS v2.0 and the level of significance was set at $P = 0.05$.

Soak time

The soak time for each string was calculated by recording the date each string was hauled and reset. Soak time groups of 24, 48 and 72 and over were used, as consumption by captured *B. undatum* will render the bait ineffective at attracting more individuals after 72 hours. The abundance of *B. undatum* over the MLS, the abundance of undersized discards and the CPUE per pot (kg) were compared between all three soak time groups. Mean values were presented graphically.

2.4. Mark-recapture

The position of the release points for tagged *B. undatum*, recapture points and the position of the pot strings were recorded using a GPS onboard the FV *Boy Shayne*. They were plotted on a map in ArcGIS v 10.1 using the 1984 World Geodetic System. One anomalous recapture was omitted from series E as the distance between it and the release point far exceeded the mean distance travelled by individuals from all series.

Lincoln-Petersen Index

The Lincoln-Petersen Index was used to estimate the abundance of *B. undatum* in the study area. The Lincoln-Petersen Index is calculated from the equation:

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

Where: N = Total estimated population

K = Number of *B. undatum* tagged and released

n = Number of untagged *B. undatum* captured during the recapture period

k = Number of tagged *B. undatum* recaptured during the recapture period.

When using the Lincoln-Petersen Index to estimate abundance, it is based on the assumption that the population being estimated is closed. This was assumed for this study due to limited movement of *B. undatum*. The tag retention rate must also be 100 % for an accurate estimation and it is also based on the assumption that the tagged individuals are randomly distributed throughout the population, have the same probability of being captured as untagged individuals, and that the mortality, recruitment immigration and emigration are the same for tagged and untagged individuals. The number of untagged *B. undatum* caught in the study area was estimated by multiplying the sacks landed by the mean number of *B. undatum* per sack, which was calculated by counting all individuals from ten full sacks. Only *B. undatum* caught within the area formed by the outer perimeter of release and recapture points for each series were used to estimate abundance.

Population density

To estimate the population density, the area that included all *B. undatum* used to estimate the abundance was calculated. This was done by creating a polygon with straight lines joining the perimeter of the release and recapture points for each series.

The area of these polygons was measured in m^2 in ArcGIS v10.1. Population density of *B. undatum* was calculated by dividing the abundance estimate from the Lincoln-Petersen Index by the area to give the number of *B. undatum* m^{-2}, per series. Mean population density was calculated in m^{-2} (± SE).

Daily distance travelled

Distance between each recapture point and the corresponding release point was measured in metres using ArcGIS v10.1.

3. RESULTS

The mean daily CPUE from all pots fished from 17th June to 19th July was 3.57 (± 0.59) kg pot^{-1} (Figure 11).

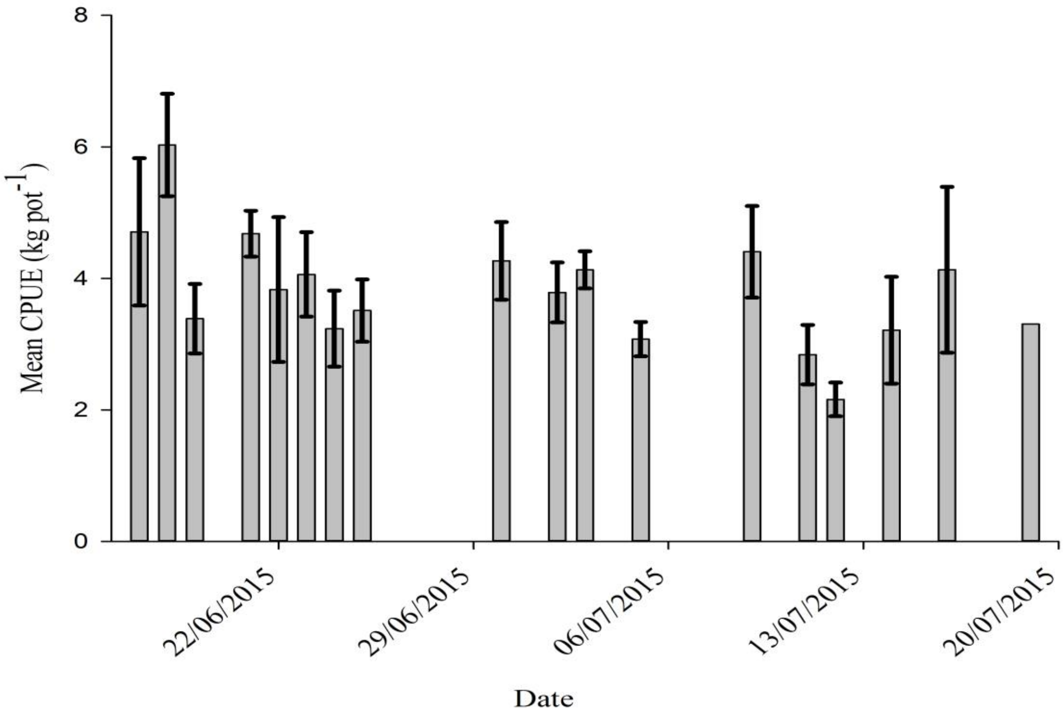

Fig. 11 The mean daily catch per unit effort (CPUE) of *Buccinum undatum* in kg per pot (± SE) landed by FV Boy Shayne during the mark-recapture study of *B. undatum* in Ramsey Bay, northeast Isle of Man from 17th June – 19th July. Scores were based on the proportion of the total shell damaged.

3.1. Pot type

A total of 100 stand-up pots and 60 lay-down pots were used during the study between 17th June and 19th July 2015. A total of 3300 stand-up pots and 1000 lay-down pots were hauled with the total abundance of *B. undatum* over the 70 mm MLS per 20 pot string ranging from 274 – 2060 (mean 975 ± 46) for stand-up pots and 206 – 1236 (mean 777 ± 72) for lay-down pots. Mean abundance of *B. undatum* per 20 pot string (one-way ANOVA; $F_{1,102}$ = 3.93, P = 0.05) was significantly higher in stand-up pots than in lay-down pots (Figure 12 a).

Total number of discarded *B. undatum* under the 70 mm MLS per 20 pot string ranged from 2 – 861 (mean 43.2 ± 10.7) for stand-up pots and 18 – 589 (mean 88.1 ± 29.1) for lay-down pots. The difference in mean number of discarded *B. undatum* between stand-up and lay-down pots was non-significant (one-way ANOVA; $F_{1,102} = 2.97$, $P = 0.088$) (Figure 12 b).

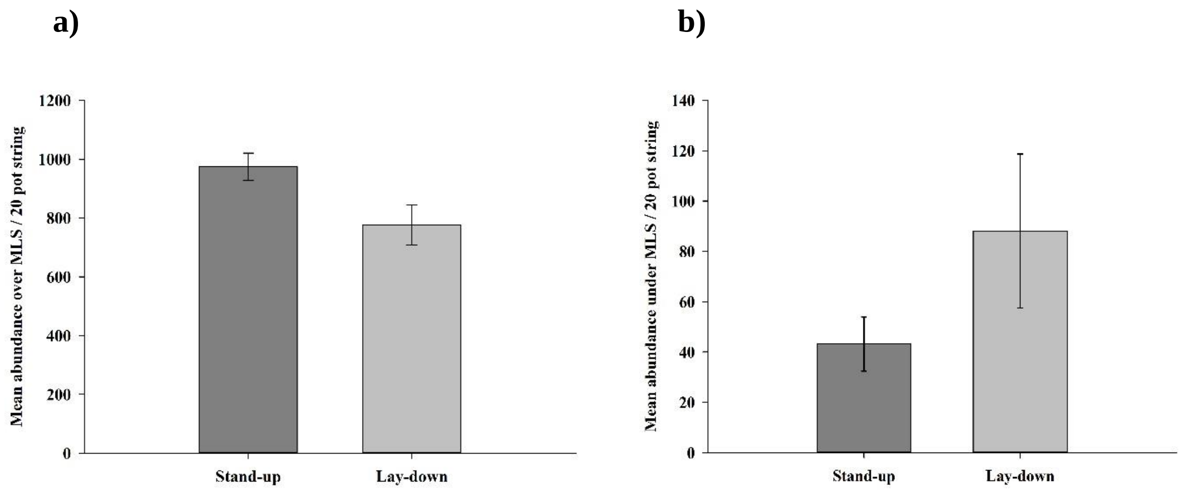

Fig. 12 The mean abundance of *Buccinum undatum* with total shell length over the minimum landing size of 70 mm **(a)** and under the MLS of 70 mm **(b)** for stand-up and lay-down pot types landed by FV *Boy Shayne* during the mark-recapture study of *B. undatum* in Ramsey Bay, northeast Isle of Man from 17th June – 19th July.

3.2. Soak time

There was no significant difference in the mean abundance of *B. undatum* over the 70 mm MLS (one-way ANOVA; $F_{2,82}$ = 1.61, P = 0.206), or in the abundance of *B. undatum* under the 70 mm MLS (one-way ANOVA; $F_{2,84}$ = 1.71, P = 0.187) between strings of soak times of 24, 48 and 72+ hours for stand-up pots. There was similar non-significance between all three soak times for lay-down pots in the mean abundance of *B. undatum* over the 70 mm MLS (one-way ANOVA; $F_{2,20}$ = 3.19, P = 0.066) and in the mean abundance of *B. undatum* under the 70 mm MLS (one-way ANOVA; $F_{2,20}$ = 0.103, P = 0.903) (Figure 13 a & b). Differences in the mean CPUE between soak times of 24, 48 and 72+ hours were non-significant for stand-up pots (one-way ANOVA; $F_{2,82}$ = 3.12, P = 0.207) and lay-down pots (one-way ANOVA; $F_{2,20}$ = 3.12, P = 0.066) (Figure 13 c).

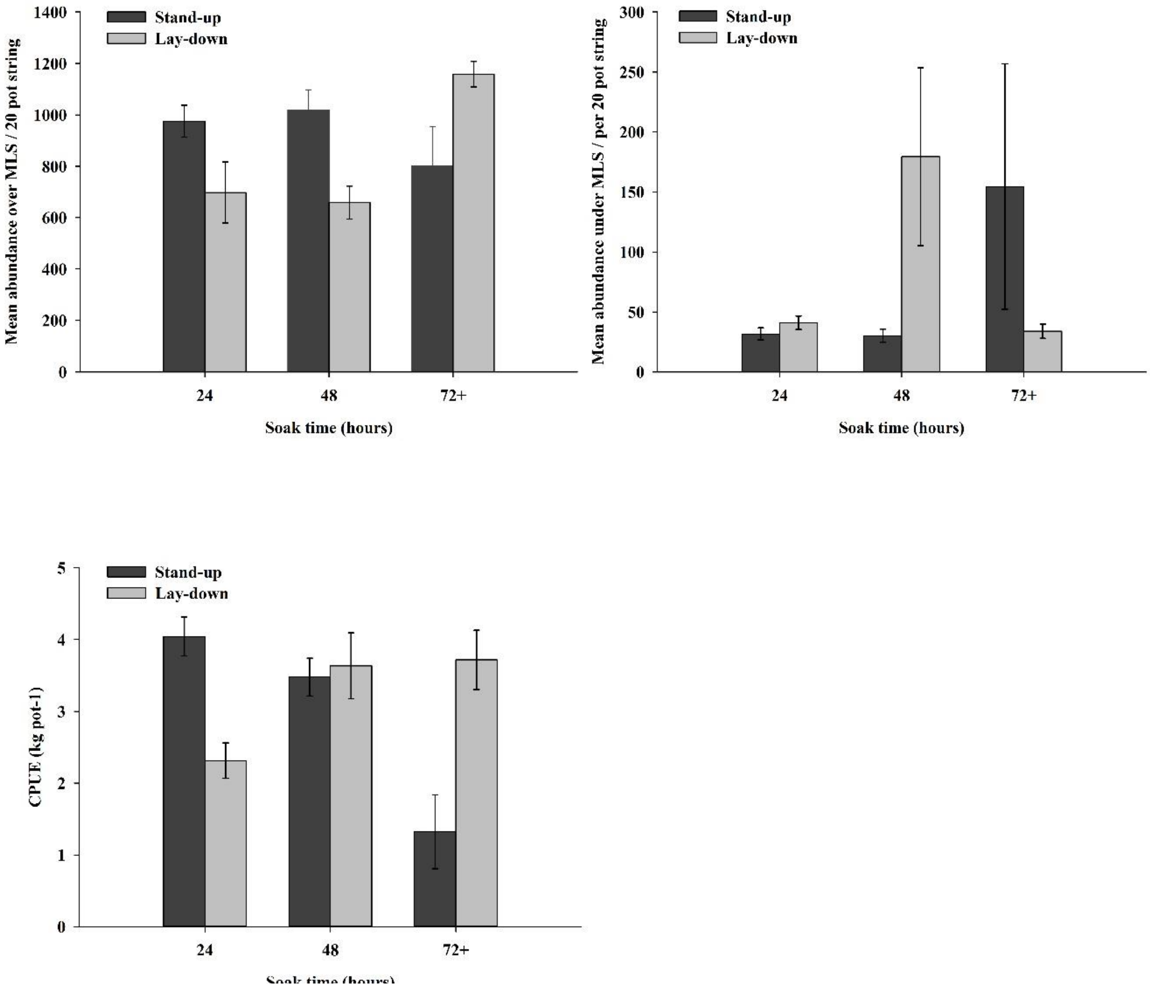

Fig. 13 Mean abundance of *Buccinum undatum* with total shell length over the minimum landing size of 70 mm **(a)** under the MLS of 70 mm **(b)** and catch per unit effort (CPUE) **(c)** for stand-up and lay-down pot types landed by FV *Boy Shayne* during the mark-recapture study of *B. undatum* in Ramsey Bay, northeast Isle of Man from 17th June – 19th July.

3.3. Mark-recapture study

Release and recapture points

A total of 5000 *B. undatum* were tagged and released on 16th and 17th June 2015. 772 (15.44 %) were recaptured during the mark-recapture study. Series D had the most recaptures with 338 (33.8 % of the total released). Series D also had the most recapture points with 11, and was the most widespread over the study area. Series C and E had the least recaptures with 76 and 45 respectively (7.6 % and 4.5 % of the total released). Series C and E also had the fewest recapture points with three each (Figure 14). Tagged *B. undatum* from any series did not overlap their distribution with any from another series (Figure 15)

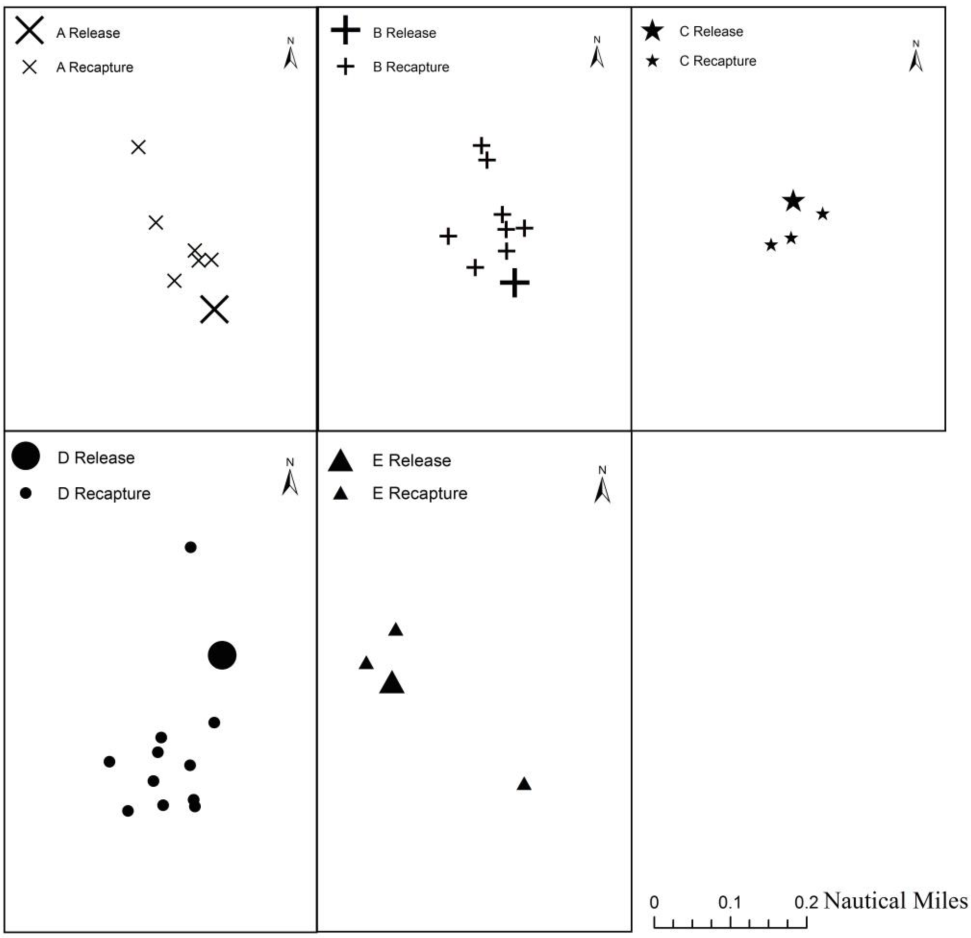

Fig. 14 *Buccinum undatum* release and recapture points in Ramsey Bay, northeast Isle of Man for series A – E of the mark-recapture study to estimate abundance and movement.

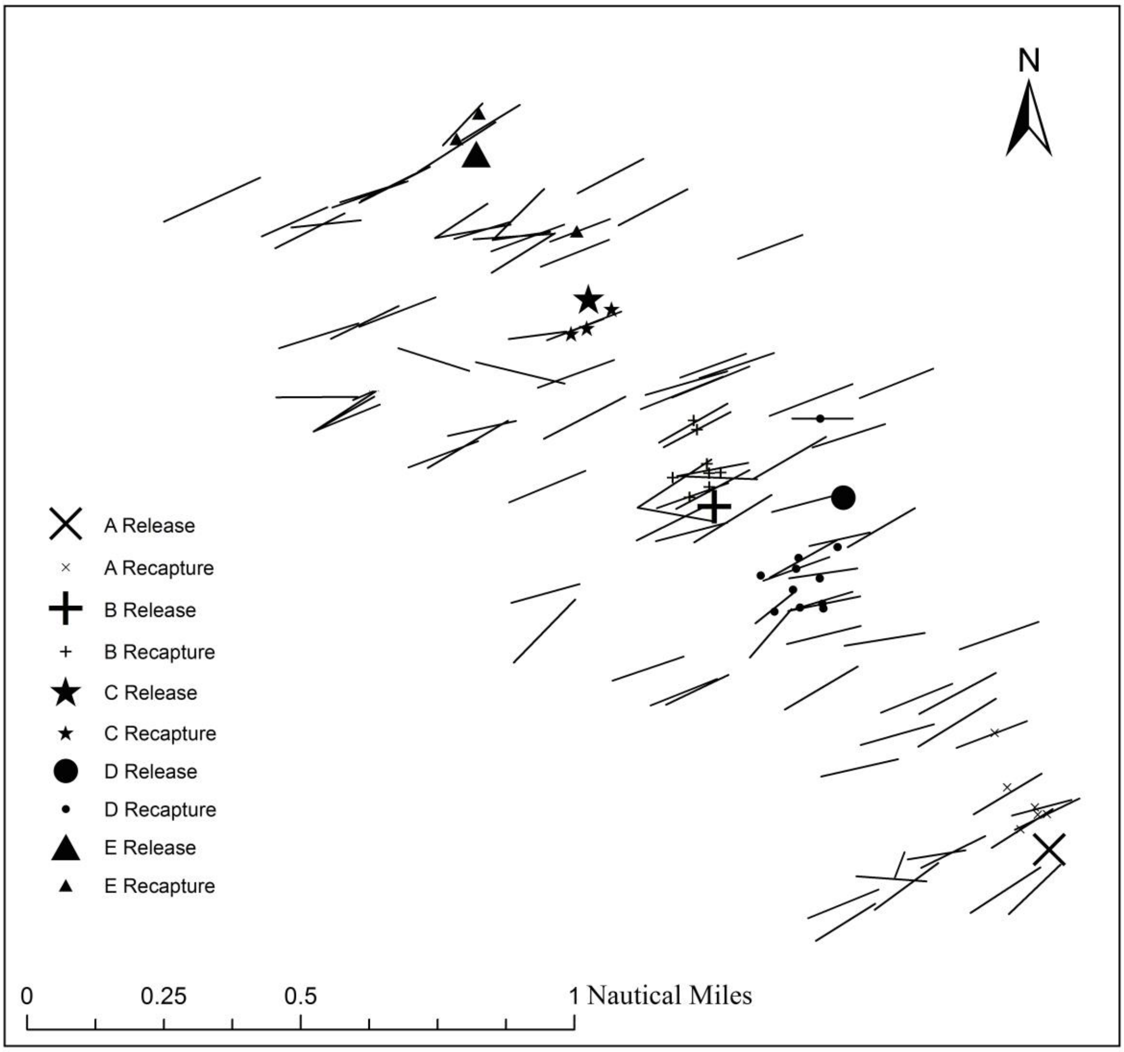

Fig. 15 Full extent of the study area in Ramsey Bay, northeast Isle of Man, with release and recapture points for tagged *Buccinum undatum* from series A – E of the mark-recapture study to estimate abundance and movement. Lines indicate the position of all pot strings fished during the study.

Population density and abundance

To estimate the abundance of *B. undatum* in the study area, it was necessary to calculate the total number of untagged population that was caught during the recapture period. The contents of ten full whelk sacks were counted. The mean number of individual *B. undatum* in each sack was 412 (± 4.2), showing little variation (Table 3).

Table 3 Number of *Buccinum undatum* in each full sack counted after landing. The mean value was used to calculate the number of MLS *B. undatum* caught from each string during the mark-recapture study, Ramsey Bay, northeast Isle of Man.

***B. undatum* sack**	**No. individuals**
1	428
2	420
3	396
4	401
5	431
6	419
7	416
8	414
9	390
10	409
Mean	**412.4**

From the abundance estimates calculated from each series, the mean population density was 2.68 (± 1.10) m^{-2} (Table 4).

Table 4 The Lincoln-Petersen estimate of abundance and population density of *Buccinum undatum* for each series in the mark-recapture study in Ramsey Bay, northeast Isle of Man from 17th June – 19th July.

	A	**B**	**C**	**D**	**E**	**Mean (± SE)**
No. untagged *B. undatum* caught (n)	4326	8137	3296	8343	5356	
No. of *B. undatum* recaptured (n)	183	130	76	338	45	
Total area of distribution (m^2)	23927	26378	6613	104308	29712	
B. undatum abundance (n)	23639	62542	43368	24683	96800	
B. undatum density (n m^{-2})	0.99	2.37	6.56	0.24	3.26	2.68 (1.10)

Distance travelled

The mean total movement of *B. undatum* during the study was 155.9 (± 15.2) m and showed little variation between the series, with the exception of series D which showed the greatest mean individual movement of 326.7 (± 14.3) m. The mean daily distance travelled was 15.2 (± 7.0) m and was fairly consistent with little variation within each series and relatively small variation between series with the exception of series D which had the greatest mean daily distance travelled and the greatest variation with 43.2 (± 0.4) m (Table 5)

Table 5 The mean total and daily distance travelled by Buccinum undatum in the mark-recapture study in Ramsey Bay, northeast Isle of Man from 17th June – 19th July.

	A	**B**	**C**	**D**	**E**	**Mean (± SE)**
Mean distance travelled (m) (± SE)	95.9 (6.0)	99.9 (4.3)	133.8 (6.0)	326.7 (14.3)	123.2 (9.9)	**155.9 (43.3)**
Mean daily distance travelled (day^{-1}) (± SE)	10.5 (0.8)	8.1 (0.5)	7.3 (0.7)	43.2 (0.4)	6.7 (0.1)	**15.2 (7.0)**

4. DISCUSSION

4.1. Catch per unit effort

There was no apparent pattern to the mean daily CPUE over the study period. Differences in mean daily CPUE between different pot types and soak times were all non-significant. However, significant differences were found in *B. undatum* abundance between the two different pot types. As CPUE can often be used as a proxy for the relative abundance of a species, this suggests that more data from a longer period of time may have resulted in a more sensitive estimate of CPUE and potential differences between pot types may have been seen. Data from a full year would account for any seasonal changes in CPUE. CPUE has been seen to vary significantly with the time of year, French (2011 M. Sc. thesis) in Carmarthen, South Wales found that maximum CPUE in *B. undatum* was achieved in July, with the lowest recorded in March. The mean CPUE per pot at Ramsey Bay was 3.57 kg pot-1. This is higher than many reported CPUE in *B. undatum* elsewhere in Britain. Robson (2014) reported a CPUE over the same period of 1.3 and 1.4 kg pot^{-1} in Oxwich and Swansea Bay, South Wales respectively. In north Wales, CPUE of 3.2 kg pot^{-1} was recorded (Turtle, 2014) and Morel & Bossy recorded CPUE of 3.3 kg pot^{-1} in Jersey, which are similar to the present study. The relatively high CPUE of the present study suggests that *B. undatum* are not heavily exploited in Ramsey Bay.

4.2. Pot type and soak time

There was greater abundance of *B. undatum* over the MLS in stand-up pots compared to lay-down pots. The stand-up pots are larger in size and have a greater capacity than lay-down pots. This may account for the greater numbers of *B. undatum*, however both pot types were rarely at full capacity when hauled, suggesting that capacity was not the driving reason behind the difference in abundance.

There was no difference in the abundance of *B. undatum* over or under the MLS between strings with different soak times. While it was expected that there would be no difference in abundance between pots with a 48 and 72+ hour soak time, as the bait was entirely consumed after 48 hours, previous studies have reported differences in abundance between 24 and 48 hour soak times. Himmelman reported that optimal soak time for maximum abundance of *B. undatum* was dependent on depth, with 24 hour and 48 hour soak times achieving peak abundances at 10 m and 18 m respectively.

4.3. Mark-recapture to estimate abundance

The most comprehensive mark-recapture study to estimate abundance in *B. undatum* was conducted by Lawler and Vause (2009). Previous tagging studies on *B. undatum* had been limited to measuring movement and the area of influence of a baited pot (Himmelman, 1988; McQuinn *et al.*, 1988; Sainte-Marie, 1991). Lawler and Vause used a similar tagging method to the present study by attaching thick rubber bands around the body whorl of the shell. Although the study was unsuccessful in reliably estimating abundance, due to poor recapture rates, it demonstrated the feasibility of this tagging method.

Tag retention was an important consideration for the mark-recapture study as it is necessary to be able to assume 100 % retention for the purposes of an accurate Lincoln-Petersen Index estimate of abundance. Robson (2014) carried out a tag retention study in laboratory conditions using the same specification of rubber band as the present study. A 100 % tag retention rate was reported from tagged *B. undatum* after four months in an aquarium. Lawler and Vause (2009) reported that the bands they used to tag B. undatum began to break down and were lost after 12 weeks in the marine environment. From these experiments and the high rate of recapture in the present study, it is likely that 100 % tag retention was achieved.

4.4. Lincoln-Petersen Index

The assumptions of the Lincoln-Petersen Index were most likely met, with the *B. undatum* population being closed and a tag retention rate of 100 %. The recaptured animals were easily noticeable and it is unlikely that of a tagged whelk was missed by the recorder.

4.5. Recapture rate

The recapture rates from all five series were inconsistent, with recapture rates ranging from 4.5 % - 33.8 %. This variation is most likely due to the different levels of fishing effort in the immediate vicinity of the release points. This was unavoidable due to the necessity for the fisherman to set his pots where there was the best chance of good catches. The variability in recapture rate did not matter in terms of estimating the abundance, as both recaptured and non-tagged captures are elements of the Lincoln-Petersen Index and low recapture rates corresponded with low total catches in the dispersal area. This also suggests that the tagged *B. undatum* were evenly dispersed within the population. The mean recapture rate of 15.44 % was similar to the recapture rate 13.7 % achieved by Robson (2014).

Abundance

B. undatum density was estimated to be 2.68 m^{-2} , contrasting with Robson's (2014) estimate for South Wales of 134 m^{-2}. A mark-recapture study in North Wales however, estimated a *B. undatum* density of 3.6 m $^{-2}$ (Turtle, 2014), which is more in line with the findings of the present study.

4.6. Minimum and daily distance travelled

B. undatum have been recorded through comprehensive studies travelling distances of up to 50 m day^{-1}, based on precise measuring techniques by underwater surveying using SCUBA (Himmelman, 1988). The mean maximum distance travelled by *B. undatum* in Ramsey Bay was 155.9 m. This is comparable with the mean distance travelled in South Wales of 153.5 m (Robson, 2014). Although the maximum distance travelled was used, the estimates may still be underestimating the true distance covered, as *B. undatum*'s movements will not necessarily ne unidirectional. The unique ID tags were not used to their full potential and greater precision in estimating movements could have been achieved by recording the precise location each tag number was released and recaptured.

4.7. Limitations

The fishing effort was not consistent around each release point. Although this does not affect the precision of the abundance estimate, it reduces the sample size for total and daily distance travelled.

The recapture points were approximate location, taken as the mid point of the pot string where the tagged whelk was caught. For greater precision, the pot number in which the recaptured whelk was caught along the string could be recorded and the precise location calculated as the distance from the previously recorded start of the string. This was attempted in this study but was not possible due to the necessarily face passed work of the fisherman. As the study relied on the cooperation of commercial fishermen and working alongside them during their routine fishing activity, they fishing effort could not be standardized. If the study was conducted as part of an independent fisheries survey, more precise abundance estimates could be made.

The mark-recapture study to estimate abundance did not take into account the effect of tidal currents on the attractiveness of the baited pots to *B. undatum*. As they rely on chemoreceptors to detect chemical cues in the water, speed and direction of currents will influence the effectiveness of the baited pots. High-resolution current data was not available for the study area.

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