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Escape Gap Study in Cardigan Bay: consequences of using lobster escape gaps

A Preliminary Report

PRIFYSGOL BANGOR UNIVERSITY

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EXECUTIVE SUMMARY

A study was conducted to evaluate the effectiveness of lobster escape gaps in Cardigan Bay, Wales. Fishers that target lobster and brown crab were concerned about the potential consequences of using escape gaps in their pot gear, as many fishers also land velvet swimmer crabs that they catch in the same pots. This study aimed to determine the ecological and economic benefits and consequences of using escape gaps in lobster/brown crab pots in Cardigan Bay. This study found that using small escape gaps (80mm x 45mm) significantly reduced catches of undersized lobsters and brown crabs and resulted in a higher economic return for the fisher. Further refinements of this work could usefully examine temporal fluctuations in species abundances, as well as investigating different shapes, positions and quantities of escape gaps on pots.

1. INTRODUCTION

1.1 Welsh lobster and crab fishery

In 2013, a total of 3,000 tonnes of lobster and 28,000 tonnes of crab were landed into the UK by UK vessels with a total value of £29.8 million and £38.5 million, respectively. Of this, 200 tonnes of lobster and 800 tonnes of crab were landed into Wales by UK vessels with a value of £1.6 million and £900,000, respectively. In 2013, crabs were the 5th most valuable species in the UK and lobsters were the 7th most valuable (MMO 2014). In Cardigan Bay, Wales, the lobster and crab fishery began to increase after 1945. At this time, the central and northern portions of Cardigan Bay were developed into important lobster fishing areas as the local herring fishery declined. Cardigan Bay has continued to be an important lobster area into present times (Jenkins 2009).

1.2 Theory behind escape gaps

The idea of using escape gaps in traps first appears in the literature from the 1950s when Templeman (1958) notes the use of lath spacing (increased space between the pieces of wood on the bottom of a lobster pot) in lobster pots in Newfoundland as early as 1890. Minimum lath spacing became a requirement by law in Newfoundland in 1893. With the modernisation of lobster pots, lath spacing is no longer used as an escape mechanism. Instead, escape gaps of differing sizes, shapes, and positions are utilised at present. Escape gaps are an opening in the pot of a size that allows undersized target species and non-target species to escape, yet still retain legal sized target species (Miller 1990). There are many advantages to using escape gaps which have been described by Templeman (1958): 1) decreased potential for the selling of undersized lobsters; 2) decreased sorting time; 3) decreased injury or damage to undersized lobsters from handling once caught and from interactions with larger lobster in pots; 4) reduction in the number of undersized lobsters being eaten by other species as they descend to the bottom after discarding; and 5) reduction in the number of undersized lobsters eaten by predators because they have been discarded onto unfamiliar territory without shelter. Other advantages which have been suggested include: 1) freeing up space inside pots for legal sized individuals to enter (Shelmerdine and White 2011); 2) decreased damage to the eggs of berried females from handling and release (Arana *et al*. 2011); 3) increased yields due to an increase in legal sized lobsters being caught (Arana *et al*. 2011; Brown 1982); 4) reduction in ghost fishing if the pot is lost (Arana *et al*. 2011); and 5) decreased air exposure (which can result in behavioural changes) during removal from pots (Groeneveld *et al*. 2005). Throughout the literature, studies investigating the effects of escape gaps on catches have been conducted on *Homarus americanus* (Courchene and Stokesbury 2011; Estrella and Glenn 2006; Krouse 1978; Lanteigne *et al*. 1995), *Homarus gammarus* (Brown 1982; Clark 2007; Murray *et al*. 2009), *Jasus frontalis* (Arana *et al*. 2011), *Portunus pelagicus* (Boutson *et al*. 2009), *Cancer pagurus* (Brown 1982), *Panulirus marginatus* (Everson *et al*. 1992; Polovina *et al*. 1991), *Scyllarides spp.* (Everson *et al*. 1992; Polovina *et al*. 1991), *Panulirus cygnus* (Frusher and Gibson 1998), *Jasus edwardsii* (Frusher and Gibson 1998; Linnane *et al*. 2011), *Scylla olivacea* (Jirapunpipat *et al*. 2008), *Cancer borealis* (Krouse 1978), *Cancer irroratus* (Krouse 1978), *Necora puber* (Shelmerdine and White 2011), *Scylla serrata* (Grubert and Lee 2013), and *Centropristis striata* (Shepherd *et al*. 2002).

In the UK, a number of jurisdictions mandate the use of lobster escape gaps (Table 1); however, there is no mandatory UK-wide or EU legislation. There are no legal obligations in Wales to use escape gaps, but many fishers use them voluntarily. Of 66 Welsh fishers interviewed in a study by Pantin *et al*. (2015), 25% of the lobster fishers interviewed use escape gaps on some of their pots. The number of pots that each fisher used with escape gaps ranged from 12 to 250 pots.

Table 1: Fisheries management areas in the UK and surrounding waters with mandatory escape gap use.

District	Requirement
Cornwall IFCA	One 84x46mm escape gap in pots with soft eyes
Devon and Severn IFCA	One 84x46mm escape gap in pots with soft eyes
Eastern IFCA	One 80x46mm escape gap in all pots
Kent and Essex IFCA	One 84x46mm escape gap in all pots
North Eastern IFCA	One 80x46mm escape gap in all pots
North Western IFCA	One 74x44mm escape gap in all pots
Jersey	One escape gap (unknown size) in all pots
Isle of Man	One 78x44mm escape gap in lower half of all pots

1.3 Sustainable fisheries

The assessment criteria defined by the Marine Stewardship Council (MSC) provide a framework against which the sustainability of a fishery can be defined, and from which data needs and knowledge gaps can be identified. The Principles and Criteria for Sustainable Fishing are composed of three principles that investigate the stock status of the target species, the impact of the fishery on the marine ecosystem, and the performance of fishery management systems. Principle 1 entails that fishing operations do not lead to overfishing or depletion of exploited populations, Principle 2 requires that fisheries maintain the structure, productivity, function and diversity of the ecosystem on which that fishery depends, and Principle 3 requires an effective management system that allows the implementation of the first two principles. Under Principle 3, the operational criteria states that fisheries should use fishing gear and practices to lessen the mortality of non-target species, as well as curtail bycatch and reduce discards of dead animals (MSC 2015b). Gear modifications such as lobster escape gaps are a potential mechanism by which bycatch and discarding can be mitigated and wider ecosystem effects reduced. There are nine lobster fisheries currently certified in the MSC program, with another four fisheries in the process of assessment. Of these nine certified lobster fisheries, four *Homarus americanus* fisheries (Prince Edward Island (SAI Global Assurance Service 2014), Iles-de-la-Madeleine (SAI Global Assurance Service 2013), Eastern Canada offshore (Moody Marine Ltd 2010) and Maine (Intertek Moody Marine Ltd 2013)), one *Homarus gammarus* fishery (Normandy and Jersey (MacAlister Elliot and Partners Ltd 2011)) and one

Panulirus interuptus fishery (Mexico Baja California (MSC 2015a)) have adopted the mandatory use of escape gaps on all pots and traps.

1.4 Aims of the present study

The present study aimed to evaluate the effectiveness of utilising different sizes of escape gaps in pots designed to catch lobster and brown crab. Catches were evaluated to quantify the target species retained and the change in the size distribution of individuals and bycatch retained by gear fitted with and without escape gaps. The effects on escape gap use on sorting time and economic performance were also assessed.

2. METHODS

2.1 Morphometric Measurements

Morphometric data were collected for European lobsters and brown crabs, in order to select appropriate escape gap sizes. Morphometric measurements including carapace length, carapace width, abdomen width, and depth were made in the field onboard fishing vessels in Welsh waters and from tanks located at a wholesale distributor in Wales. The sex, presence of eggs, and whether they were missing any limbs (crippled) were also recorded. The carapace length for lobsters was measured from the eye socket to the end of the carapace. Following Brown (1982), the width was measured as the widest part of the carapace width, the abdomen width was measured as the widest part of the second abdominal segment of the female, and the depth was measured as the highest part of the dorsal surface of the carapace to the lowest protruding part of the ventral surface of the thoracic region. The carapace width for crabs was measured as the widest part of the carapace. Following Brown (1982), the length was measured from the anterior edge of the carapace (in the eye region) to the proximal part of the abdominal flap and the depth was measured from the highest part of the dorsal surface of the carapace to the lowest protruding part of the ventral surface of the thoracic region. As female lobsters mature, their abdominal regions widen and therefore the abdomen width may be the widest part of their body. In these cases, the abdomen width was used in the analysis as the lobster width.

2.2 Morphometric Analysis

To investigate the most appropriate sizes of escape gaps to trial in the field, linear regressions were computed to quantify the relationship between lobster carapace length and width and lobster carapace length and depth. This was done for all lobsters pooled, for males and females separately, and/or excluding cripples. For the regression, the width used was whichever width (carapace width or abdomen width) was greatest. The lobster analysis compared carapace length and width and carapace length and depth, because escape from a pot is considered dependent upon carapace width and depth. When lobsters encounter an opening they pass their chelae through first and then turn on their side to wriggle through the opening (Brown 1982; Estrella and Glenn 2006; Nulk 1978). Similar regressions were created for the crab data by investigating the relationship between carapace width and depth and carapace width and length. This was done using all crabs pooled, for males and females separately, and/or excluding cripples. Crabs move sideways, therefore it was assumed that the length of the escape gap would determine the length of crabs that could escape from the pot (Grubert and Lee 2013).

To ensure that no legal sized lobsters could escape through the opening, the height of the opening was based on whichever sex had the smallest carapace width. The opening height was based on the predicted lobster carapace width instead of depth because the lobster carapace width was consistently smaller. The length of the escape gap was based on the predicted carapace length of a legal sized (130mm carapace width) brown crab. The final height and length of the escape gap was made 1mm smaller than the measurements from the regression to ensure that no legal sized lobsters could escape.

2.3 Field Study

Based on the analysis from the morphometric measurements, the sizes of escape gaps chosen for the trials were 80mm x 45mm and 80mm x 47mm. The 80mm x 45mm escape gap was chosen to exclude lobsters under 87mm carapace length and brown crabs under 130mm carapace width, whilst the 80mm x 47mm escape gap was chosen to exclude lobsters under 90mm carapace length and brown crabs under 130mm carapace width. The 80mm x 45mm escape gap is commercially available; however, the 80mm x 47mm escape gap required customisation to achieve the required dimensions. The current minimum landing size (MLS) for lobsters is 87mm in Cardigan Bay; however, any lobsters caught south of Cemaes Head must be above 90mm carapace length.

Field work took place in Cardigan Bay, Wales and four fishers participated in the study. Two fishers fished out of Cardigan, one fisher fished out of Aberystwyth, and one fisher fished out of Aberdovey. Each vessel was given 12 lobster pots; 4 with no escape gaps, 4 with small (80mm x 45mm) escape gaps, and 4 with large (80mm x 47mm) escape gaps. The lobster pots provided were top entry steel parlour pots with a 25cm hard entrance, a width of 46cm, a length of 69cm and a height of 38cm. The escape gaps were made of plastic and attached by cable ties on one side of the lower half of the parlour section of the pot. The 12 pots were fished as one string and arranged in a predetermined order whereby each end pot had a different size escape gap and the pots were mixed throughout the string so that pots with the same size escape gap were not next to each other. The pots were fished together on one string to ensure consistent soak time and to eliminate variations in substrate type. The strings of pots were set with a weight and buoy at each end and fished in the same location for 12 fishing trips. (Figure 1).

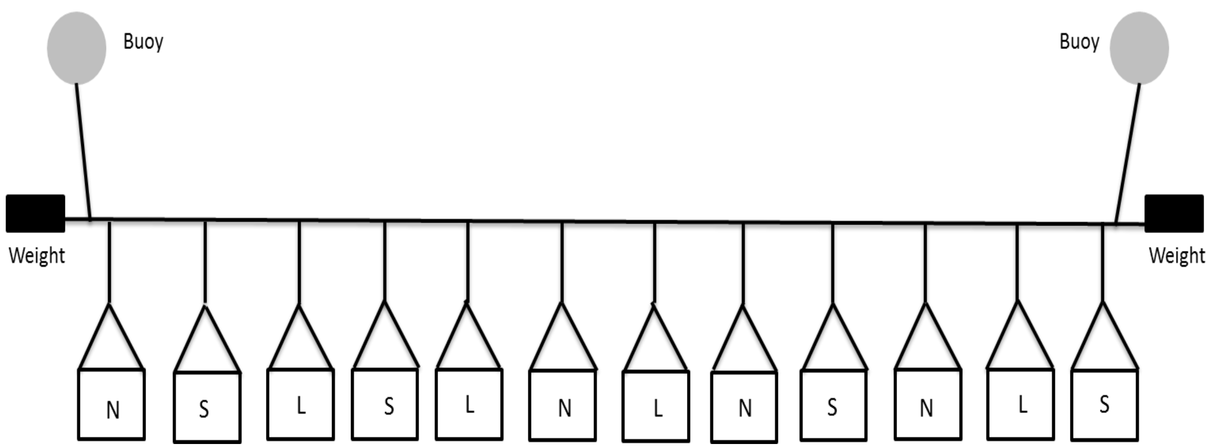

Figure 1: Configuration of twelve pots with either no escape gap or one of two sizes of escape gaps fished for twelve fishing trips by four fishers in Cardigan Bay. N = no escape gaps, S = small escape gaps (80mm x 45mm), L = large escape gaps (80mm x 47mm).

This report presents the results of 12 fishing days from one fisher (i.e. twelve deployments of the string of pots). The other three fishers have not completed their data collection up to this point. The experimental strings were fished 12 times from 7 July 2014 to 27 September 2014 for a total of 144 pots lifted (48 pots of each escape gap size).

The catch of each pot was recorded by an onboard camera system described in Hold *et al*. (2015). In three of the four set-ups the entire area where the fisher sorted his catch, including the pot, was in view of the camera; however, for one vessel involved, this was not possible and each animal was passed under the camera. The fisher sorting the catch placed each animal from each pot under the camera so that later a still photo could be extracted from the video. From this still photo the size and abundance of lobsters was determined along with the abundance of brown crabs and all other species in the pots. Where possible, the level of damage (loss of limbs) of the target species and bycatch was also recorded to give an indication of potential survival and whether aggressive interactions may have occurred in the pots.

2.4 Analysis of Field Experiment

To identify the best distribution of the count data of retained and discarded lobsters and brown crabs, as well as the number of velvet crabs caught, five potential distributions were compared: Poisson, Quasi-Poisson, Negative Binomial Distribution (NBD), Zero-inflated Poisson (ZIP) and Zero-inflated Negative Binomial (ZINB). A model selection approach was applied to these five models.

The five different models of the count data of retained and discarded lobsters and brown crabs were compared using the open source statistical software R (R Development Core Team 2013) with the 'pscl' package for the zero-inflated analysis (Jackson 2010). For the ZIP and ZINB models the Expectation-Maximisation (EM) algorithm was used to obtain the maximum likelihood estimates for the model parameters (Lambert 1992). A total of seven predictors were used in the count data analysis: number of legal lobsters caught, number of undersized lobsters caught, number of legal brown crabs caught, number of undersized brown crabs caught, number of velvet crabs caught, type of escape gap (none, small and large), and month (July, August and September). As all models used the same predictors, this allowed comparisons to be made between the models using the Akaike Information Criterion (AIC) values (Gray 2005) and the likelihood ratio test (LogLik), which can be correctly used only with nested models (Sileshi *et al*. 2009). In addition, the dispersion parameters obtained for the five models was considered.

A Generalized Linear Model (GLM) was performed on the lobster carapace length data from the onboard camera system to assess differences in the size of lobsters caught in the three sizes of escape gaps. Visual inspection of the residual plots was used to verify whether the assumptions of normality, independence, linearity and homoscedasticity were met. In addition, a chi-square test was performed to evaluate whether the number of lobsters over 90mm was associated with the type of escape gap. A P value of less than 0.05 was used to define a significant difference in both cases. This data was analysed in R version i386 3.0.2 (R Development Core Team 2013).

Size-selectivity curves were produced for the two sizes of escape gaps according to the SELECT (Share Each LEngth's Catch Total) model. This model was designed to evaluate the size selectivity of trawls, gillnets and hooks during simultaneous fishing with different size meshes or hooks (Millar 1991). This method has been used in other studies to evaluate size selectivity in trap fisheries as well (Boutson *et al*. 2009; Estrella and Glenn 2006; Groeneveld *et al*. 2005; Harada *et al*. 2007; Shelmerdine and White 2011; Treble *et al*. 1998). The method uses a symmetrical logistic function and an asymmetrical Richard function and the best model is chosen based on the lowest AIC value.

The logistic function is described by the equation:

$$r(l)=\frac{\exp(a+bl)}{1+\exp(a+bl)}$$

The Richard function is described by the equation:

$$r(l)=\left(\frac{\exp(a+bl)}{1+\exp(a+bl)}\right)^{\frac{1}{\delta}}$$

where r(l) is the probability that a lobster of carapace length l, attempting to escape through a gap of a given size, is retained within the pot, and a, b and δ are constants.

These two size-selectivity models were calculated and parameters were estimated using Microsoft Excel with solver following the methodology of Tokai (1997) and Tokai and Mitsuhashi (1998). The subsequent curves were plotted using a maximum likelihood estimation. L_{50} (the length at which 50% of the lobsters are retained) and SR (the selection range between the length at which 75% are retained and the length at which 25% are retained) were calculated from the estimated parameters. All calculations were made using 3mm carapace length size classes covering the entire range of carapace lengths measured.

Multivariate statistics were used to analyse the bycatch data with PRIMER-E software version 6 (Clarke and Gorley 2006). The bycatch species that made up less than 1% of the bycatch were removed (Ballan wrasse, spotted catshark and three-bearded rockling), therefore the analysis was performed on the abundances of velvet crabs, spider crabs and common whelks. For this analysis, bycatch was considered as only non-target species; juvenile target species were addressed in a different analysis. Prior to analysis, the bycatch abundances were square root transformed to down-weight the importance of the highly abundant species. The CLUSTER routine was performed and a resemblance matrix was created. From this matrix the ANOSIM routine was performed using escape gap type as a factor and the R statistic values of the pairwise tests were examined to determine similarity. The ANOSIM routine is similar to a univariate ANOVA and summarises patterns in species abundances and environmental conditions using permutation-based hypothesis testing (Clarke and Warwick 2001). An R statistic close to 1 indicates that the null hypothesis (there is no difference in bycatch composition by escape gap type) can be rejected. A significant relationship was defined when $P < 0.001$.

The damage level of all crustaceans caught was assessed from the video analysis to determine if there was a difference in the abundance of damaged crustaceans between the three types of escape gaps. The incidence of damage may be an indication of the occurrence of aggressive interactions within the pots. The damage level of crustaceans was determined from visual inspection from the onboard video recordings. Due to the positioning of the crustaceans under the camera, damage could only be assessed as missing claws. Each crustacean (lobster, brown crab, velvet crab and spider crab) was coded from 0 to 2, with 0 indicating no missing claws, 1 indicating one claw missing, and 2 indicating both claws missing. Individuals for which the claws could not be observed in the video footage were removed from the analysis. A chi-square test was performed on the lobster and brown crab data to determine whether the amount of damaged individuals is associated with the type of pot in which they were caught.

2.5 Sort Time Analysis

In order to assess whether the use of escape gaps affected pot handling time, the time taken to sort each pot was recorded from the video and was compared among the three kinds of pot. The sort time was recorded as the time from when the pot door was opened until it was closed. This sorting time included the baiting of the pot. This data was analysed in R version i386 3.0.2 (R Development Core Team 2013) using a linear model and the model was tested for normality, independence, linearity and homoscedasticity. As the data did not meet the assumption for normality, the sorting times were square root transformed and the analysis run again.

2.6 Questionnaire

Prior to the trial commencing, a short questionnaire was conducted with the four fishers to determine their opinions about the use of lobster escape gaps. The questionnaire consisted of the following eight questions:

1. Do you think lobster escape gaps will make a difference to your catch?
2. What do you think this difference will be?
3. Do you think lobster escape gaps will be beneficial?
4. Why do you think this?
5. Is there any way that lobster escape gaps could reduce profitability? How?
6. Is there any way that lobster escape gaps could increase profitability? How?
7. Does the influence on profitability depend on season?
8. On a scale of 0 to 10 (with 0 being not at all and 10 being extremely), how useful do you think this experiment is with respect to the sustainability of the fishery?

This questionnaire was repeated after the fishers had used the escape gaps for over one year to determine whether their opinions had changed. Due to the small sample size, formal statistical analysis could not be performed, therefore, the results are described in a narrative form.

3. RESULTS

3.1 Morphometrics

A total of 202 lobsters and 351 brown crabs were measured at sea and at a wholesale distributor facility. Eighty-five female lobsters, 116 male lobsters, 176 female brown crabs, and 173 male brown crabs were measured. The sex of one lobster and two brown crabs were not identified. The measured lobsters ranged from 72mm to 146mm carapace length and the measured brown crabs ranged from 79mm to 220mm carapace width. The lobster carapace length distribution and brown crab carapace width distribution of the measured lobsters and brown crabs are shown in Figure 2. Lobsters and brown crabs that were missing limbs and claws were included in the analysis as it was decided that the absence of limbs was common in the wild and should be considered in the analysis.

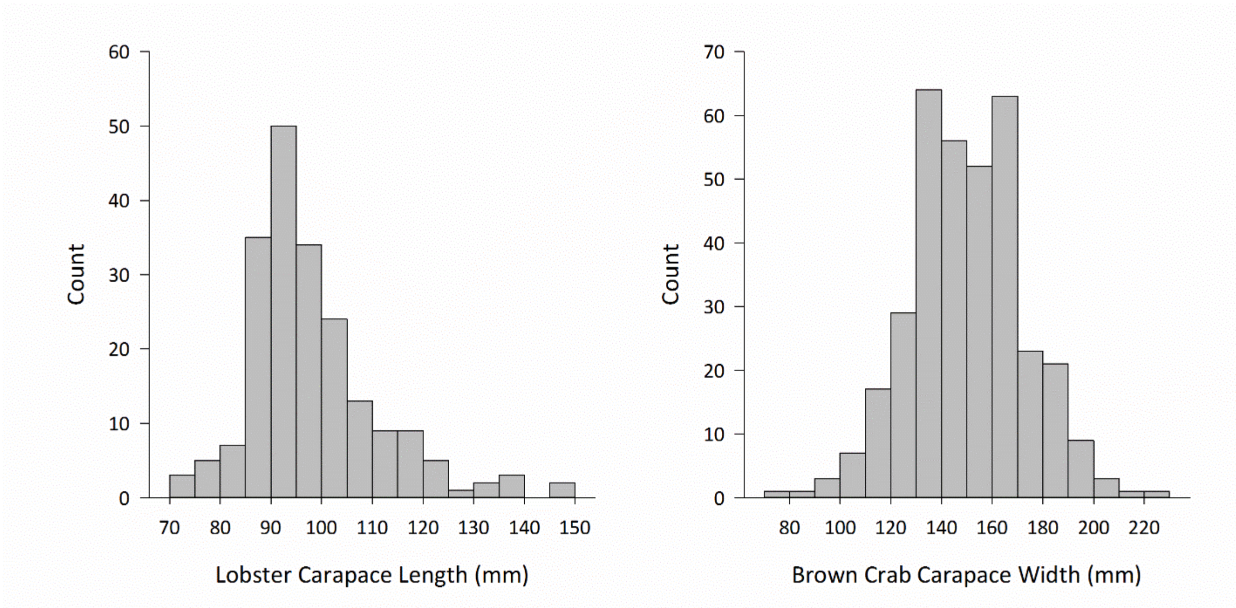

Figure 2: Lobster carapace length and brown crab carapace width frequencies for lobsters and brown crabs measured onboard fishing vessels and at a wholesale distributor facility.

There was a positive relationship between lobster carapace length and total width and carapace length and depth, with increasing total width and depth with increasing carapace length (Figure 3). Females had larger total widths than male lobsters of the same size and similar carapace depth measurements (Figure 4). There was no clear carapace length at which the abdomen width of female lobsters was larger than the carapace width. By carapace length 99mm, no female lobsters had a carapace width larger than abdomen width; however, there were still three female lobsters after this point with equal carapace width and abdomen width. A positive relationship was also seen between crab carapace width and length and carapace width and depth. Both morphometric measures increased with increasing brown crab carapace width (Figure 5).

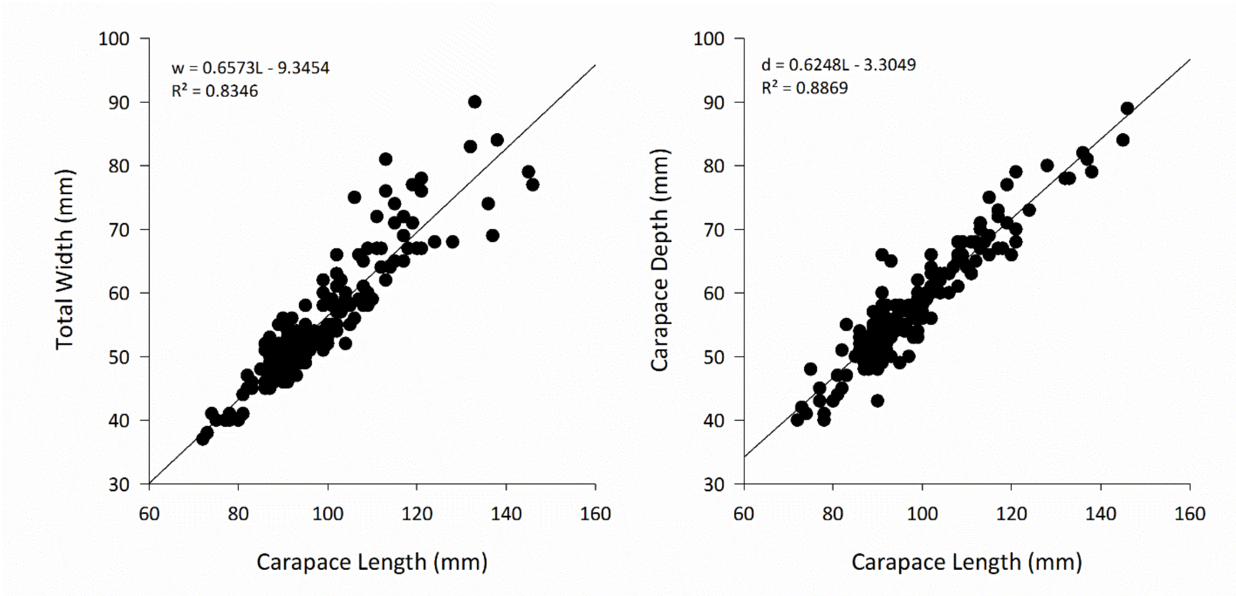

Figure 3: Linear regressions for lobster carapace length against total width (left figure) and carapace length against carapace depth (right figure) for lobsters measured onboard fishing vessels and at a wholesale distributor facility. Regressions follow the equations w = bL + a, where w is total width and L is carapace length and d = bL + a, where d is carapace depth.

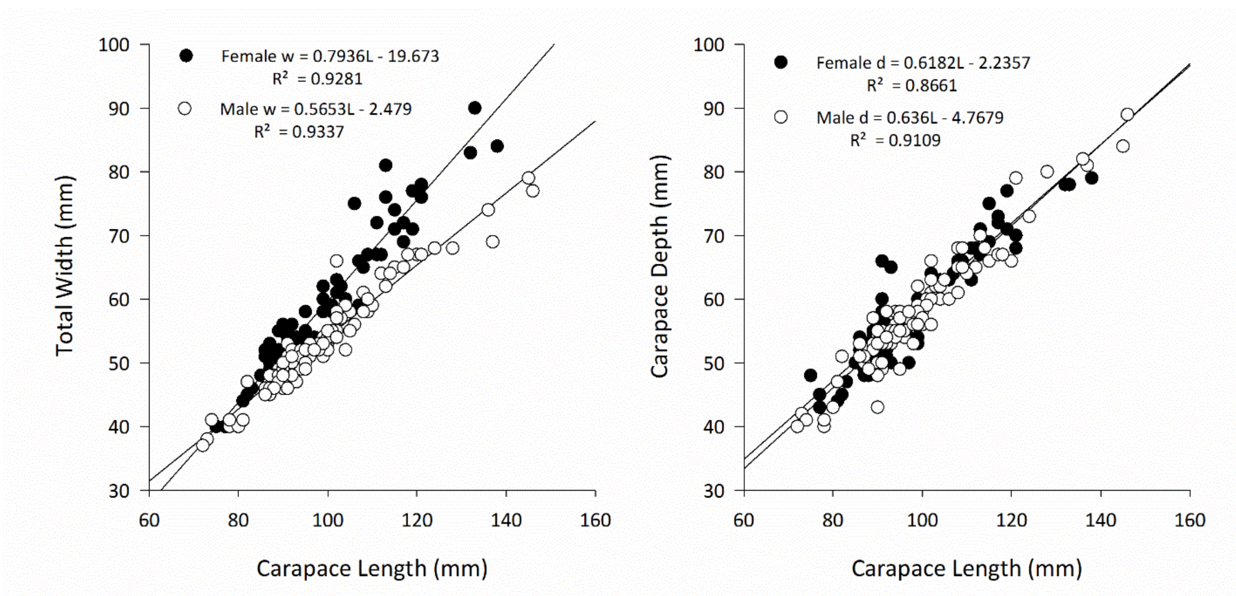

Figure 4: Linear regressions for male and female lobster carapace length against total width (left figure) and carapace length against carapace depth (right figure) for lobsters measured onboard fishing vessels and at a wholesale distributor facility. Regressions follow the equations w = bL + a, where w is total width and L is carapace length and d = bL + a, where d is carapace depth.

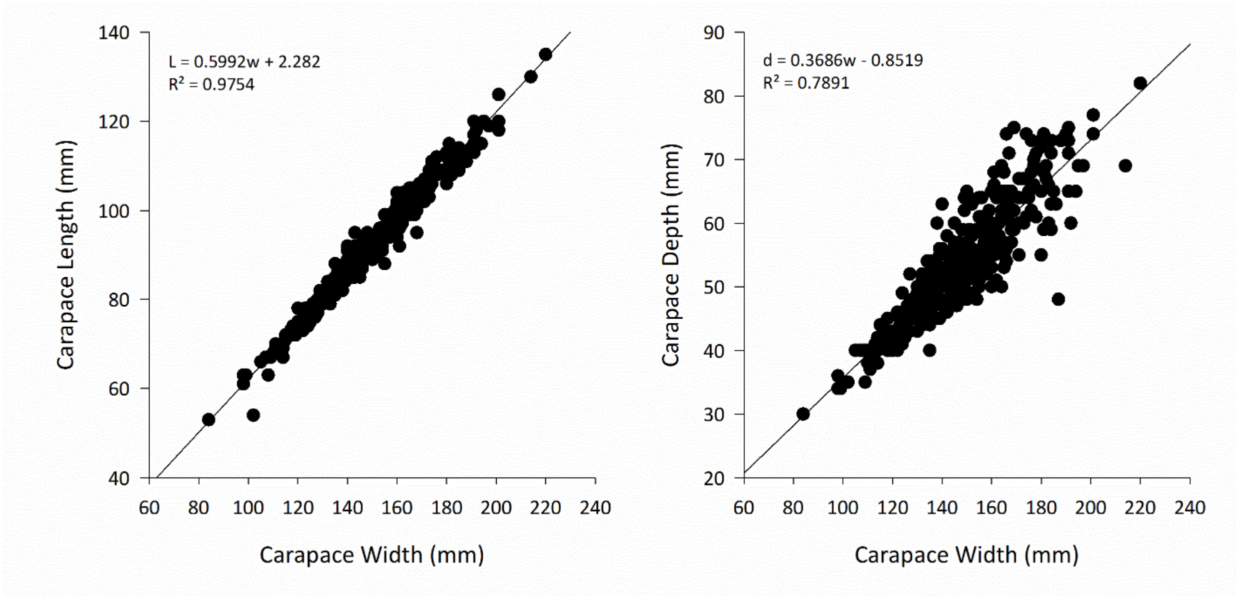

Figure 5: Linear regressions for brown crab carapace width against carapace length (left figure) and carapace width against carapace depth (right figure) for brown crabs measured onboard fishing vessels and at a wholesale distributor facility. Regressions follow the equations L = bw + a, where w is carapace width and L is carapace length and d = bw + a, where d is carapace depth.

The sizes of escape gaps chosen to trial were based on the predicted carapace width of an 87mm carapace length lobster (small escape gap), an 90mm carapace length lobster (large escape gap), and the predicted carapace length of a 130mm carapace width brown crab (Table 2). The chosen sizes (80mm x 45mm and 80mm x 47mm) were 1mm less than the predicted measurements.

Table 2: Predicted carapace length (L), carapace width (w) and depth (d) of lobsters (87mm and 90mm carapace length) and brown crabs (130mm carapace width) using regressions equations w or d = a + bL for lobsters and l or d= a + bw for brown crabs

	Carapace Length (mm)	**Carapace Width (mm)**	**Carapace Depth (mm)**
All Lobsters	87	47	51
Male Lobsters	87	46	50
Female Lobsters	87	49	51
All Lobsters	90	49	52
Male Lobsters	90	48	52
Female Lobsters	90	51	53
Brown Crabs	80	130	47

3.2 Field Study

A total of 144 pots were lifted during the study, which caught 243 individuals of eight species. Twenty-five pots contained no animals when hauled (18 with Large escape gaps and 7 with Small escape gaps).

3.2.1 Retained and Discarded Lobsters and Brown Crabs

In total, 52 lobsters were retained, 77 lobsters were discarded, 24 brown crabs were retained, and 48 brown crabs were discarded. Table 3 and Figure 6 show that the pots with no escape gaps had the highest total and mean abundance of undersized lobsters and undersized brown crabs and the lowest total and mean abundance of legal sized brown crabs.

Table 3: Total abundance of retained and discarded lobsters and brown crabs in 144 pots with three sizes of escape gaps (None = no escape gap, Small = 80mm x 45mm escape gap, Large = 80mm x 47mm escape gap) in Cardigan Bay. Discarded lobsters are < 87mm carapace length and discarded brown crabs are < 130mm carapace width.

Escape Gap	Lobsters Retained	Lobsters Discarded	Crabs Retained	Crabs Discarded
None	19	70	3	23
Small	22	5	10	13
Large	11	2	11	12

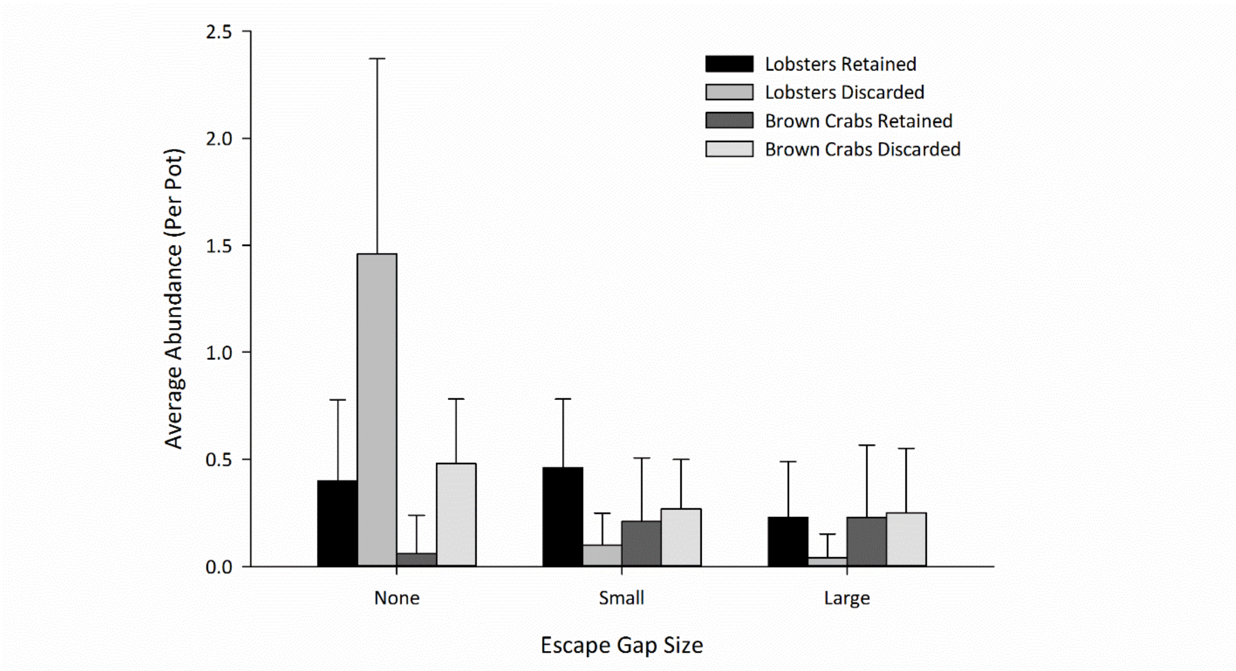

Figure 6: Mean abundance ± standard error per pot of retained and discarded lobsters and brown crabs in 144 pots of three different size escape gaps (None = no escape gap, Small = 80mm x 45mm escape gap, Large = 80mm x 47mm escape gap) in Cardigan Bay. Discarded lobsters are < 87mm carapace length and discarded brown crabs are < 130mm carapace width.

Model selection found the model with Poisson distribution to be the best for investigating the count data for retained lobsters, discarded lobsters, retained brown crabs and discarded brown crabs. The following models were used in each investigation:

Discarded lobsters: m1 = glm (LD ~ LEG + Month + CD)

Retained lobsters: m2 = glm (LR ~ LEG + LD)

Discarded brown crabs: m3 = glm (CD ~ LEG + LD)

Reatined brown crabs: m4 = glm (CR ~ LEG + Month)

where LD is discarded lobsters, LEG is lobsters escape gap type (none, small or large), CD is discarded brown crabs, LR is retained lobsters, and CR is retained brown crabs. All models included all previously stated predictors, as well as the number of velvet crabs caught (V) and the month sampled (July, August or September) initially; however, they were then simplified by removing non-significant predictors.

With respect to discarded lobsters (undersized lobsters), there were significantly more undersized lobsters caught in pots with no escape gaps than pots with small escape gaps ($P < 0.001$) and in pots with no escape gaps than pots with large escape gaps ($P < 0.001$). There was no significant difference in the number of undersized lobsters caught in pots with small escape gaps compared to pots with large escape gaps ($P = 0.26$).

With respect to retained lobsters (legal sized lobsters), there were significantly more legal lobsters caught in pots with no escape gaps than pots with large escape gaps ($P = 0.03$), and in pots with small escape gaps than pots with large escape gaps ($P = 0.05$). There was no significant difference between the number of legal lobsters caught from pots with no escape gaps and pots with small escape gaps ($P = 0.53$).

With respect to discarded (undersized) brown crabs, there were significantly more undersized brown crabs caught in pots with no escape gaps than pots with small escape gaps ($P < 0.001$), and in pots with no escape gaps than pots with large escape gaps ($P < 0.001$). There was no significant difference in the number of undersized brown crabs caught in pots with small escape gaps and pots with large escape gaps ($P = 0.76$).

With respect to retained brown crabs (legal sized brown crabs), there were significantly more legal sized brown crabs caught in pots with large escape gaps than pots with no escape gaps ($P = 0.04$). There was no significant difference between the number of legal sized brown crabs caught in pots with no escape gaps and pots with small escape gaps ($P = 0.07$), or in pots with small escape gaps and pots with large escape gaps ($P = 0.83$).

The influence of the month within which the lobsters and brown crabs were caught was also investigated. The month was only a significant factor with respect to discarded (undersized) lobsters and retained (legal sized) brown crabs. There were significantly more lobsters discarded in July than in September ($P = 0.005$) and there were significantly fewer legal sized brown crabs caught in July than in August ($P = 0.028$) or September ($P = 0.001$).

3.2.2 Lobster Sizes from Video Analysis

Video analysis allowed for estimation of the size of 98% (127) of the lobsters caught in the 144 pots hauled. Table 4 shows the average size and size range of lobsters caught in the three sizes of escape gaps, and Figure 7 shows the size distribution of the caught lobsters.

Table 4: The average carapace length (mm) and carapace length range (mm) of lobsters caught in 144 pots of three different size escape gaps in Cardigan Bay.

Escape Gap Size	Mean ± standard error	Range
None	79 ± 1	63 – 97
Small	91 ± 2	72 – 119
Large	90 ± 2	69 – 98

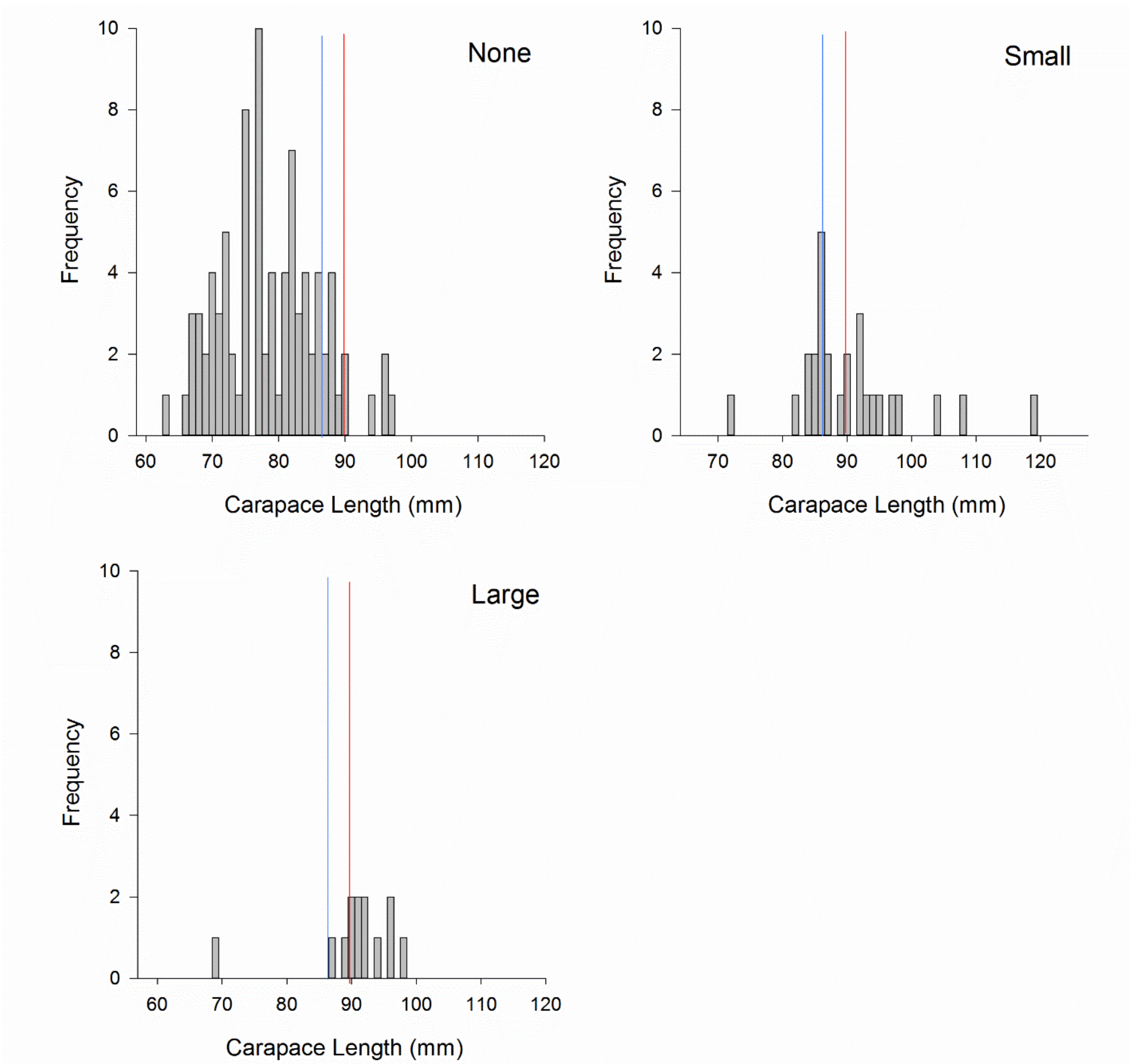

Figure 7: Size frequencies of lobsters caught in 144 pots with three different escape gaps in Cardigan Bay. 87mm carapace length is indicated by the blue line and 90mm carapace length is indicated by the red line.

A generalized linear model (GLM) performed on the lobster carapace length data from the videos revealed a significant difference in the size of lobsters caught between the pots with no escape gap and the pots with small escape gaps ($P < 0.0001$), and the pots with no escape gaps and the pots with large escape gaps ($P < 0.0001$). There was no significant difference in the size of lobsters caught in pots with small escape gaps and pots with large escape gaps ($P = 0.90$). It is evident from Figure 8 that the pots with no escape gaps caught significantly smaller lobsters than the pots with escape gaps.

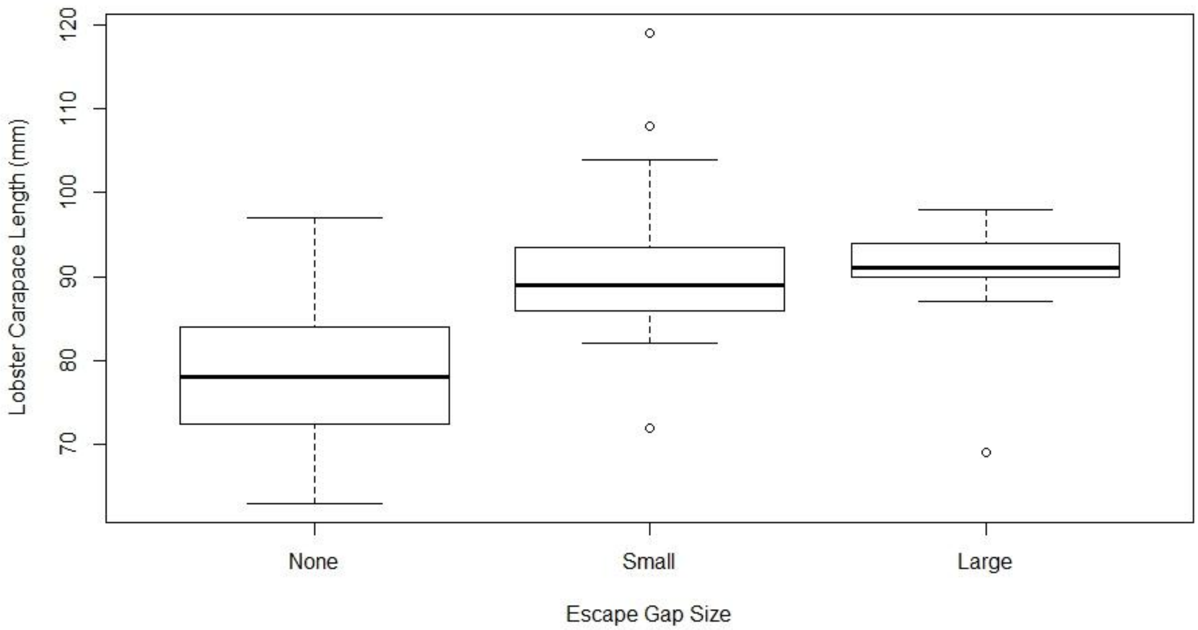

Figure 8: Boxplot of the carapace length of lobsters caught in 144 pots of three different size escape gaps in Cardigan Bay. The box encloses the interquartile range (IQR, where the middle half of the data lies), the "whiskers" show the range of the data and the circles represent suspected ourliers that are data points 1.5 x IQR. The median (or middle) value is represented by the bold line within the box.

From Figure 7, it appears that pots with escape gaps catch more lobsters over 90mm; however, a chi-square test performed to determine if there was an association between the numbers of lobsters over 90mm carapace length caught and the type of escape gap in the pot found no association between lobsters over 90mm carapace length and escape gap type (x^2 = 2.55, d.f. = 2, P = 0.28). Nonetheless, the pots with large escape gaps did seem to select for lobsters greater than 87mm, with only one lobster smaller than 87mm caught.

Size-selectivity curves were calculated for the two sizes of escape gaps (Figure 9). A comparison of the AIC values for the logistic function and the Richard function found the logistic function to have the best fit for both size of escape gaps (Table 5). The pots with small escape gaps were found to have higher retention values for 87mm carapace length and 90mm carapace length lobsters than the pots with large escape gaps.

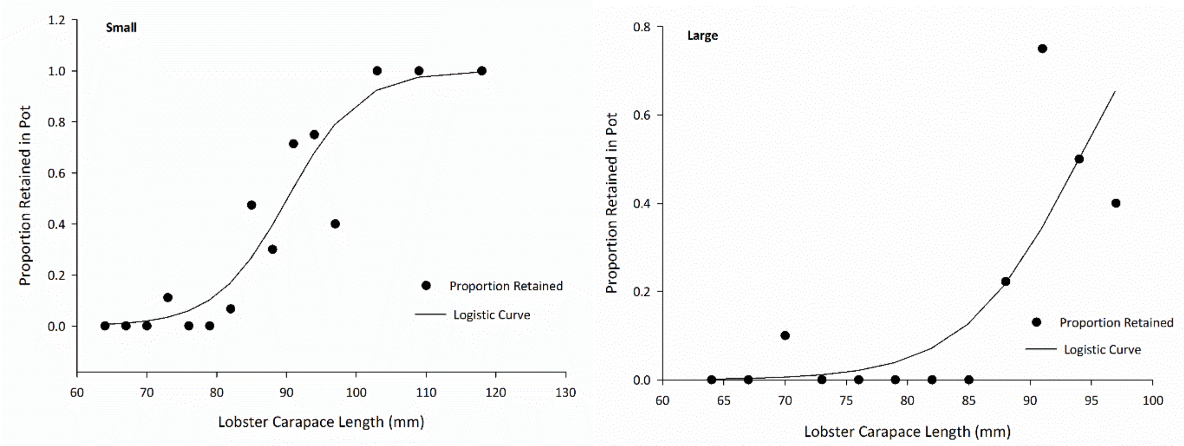

Figure 9: Size-selectivity curves for European lobsters using two different sizes of escape gaps (Small – 80 x 45mm; Large – 80 x 47mm) for 144 pots fished in Cardigan Bay.

Table 5: Parameter estimates (a, b and δ) calculated by the logistic and Richard functions and the associated L_{50} (length at 50% retention), SR (selection range), r_{87} (retention at 87mm CL), r_{90} (retention at 90mm CL) and AIC (Akaike Information Criterion) values for lobsters caught in pots with two sizes of escape gaps (small and large). Calculations are based on 144 pot hauls in Cardigan Bay.

	Small (80mm x 45mm)		**Large (80mm x 47mm)**	
	Logistic	**Richard**	**Logistic**	**Richard**
a	-17.61	-10.68	-20.08	-20.26
b	0.20	0.14	0.21	0.21
δ		0.29		1.01
L_{50} (mm)	90.26	90.06	94.05	94.05
SR	11.26	12.86	10.29	10.25
r_{87}	0.35	0.37	0.18	0.18
r_{90}	0.49	0.50	0.30	0.29
AIC	35.54	36.51	31.14	33.14

3.2.3 Bycatch

Six species of bycatch were recorded in the 144 pots lifted; spider crab (*Maja squinado*), velvet swimming crab (*Necora puber*), common whelk (*Buccinum undatum*), lesser spotted catshark (*Scyliorhinus canicula*), three-bearded rockling (*Gaidropsarus vulgaris*), and ballan wrasse (*Labrus bergylta*). Spider crabs were recorded in 9 pots, velvet swimming crabs were recorded in 15 pots, whelks were recorded in three pots, one lesser spotted catshark was recorded in one pot, rockling were recorded in two pots and one wrasse was recorded in one pot. Eighty-one percent of the pots contained no bycatch. The mean abundances of these bycatch species caught in the three types of pots is presented in Figure 10. Pots with no escape gaps caught six species of bycatch, whilst pots with small or large escape gaps caught only three species of bycatch.

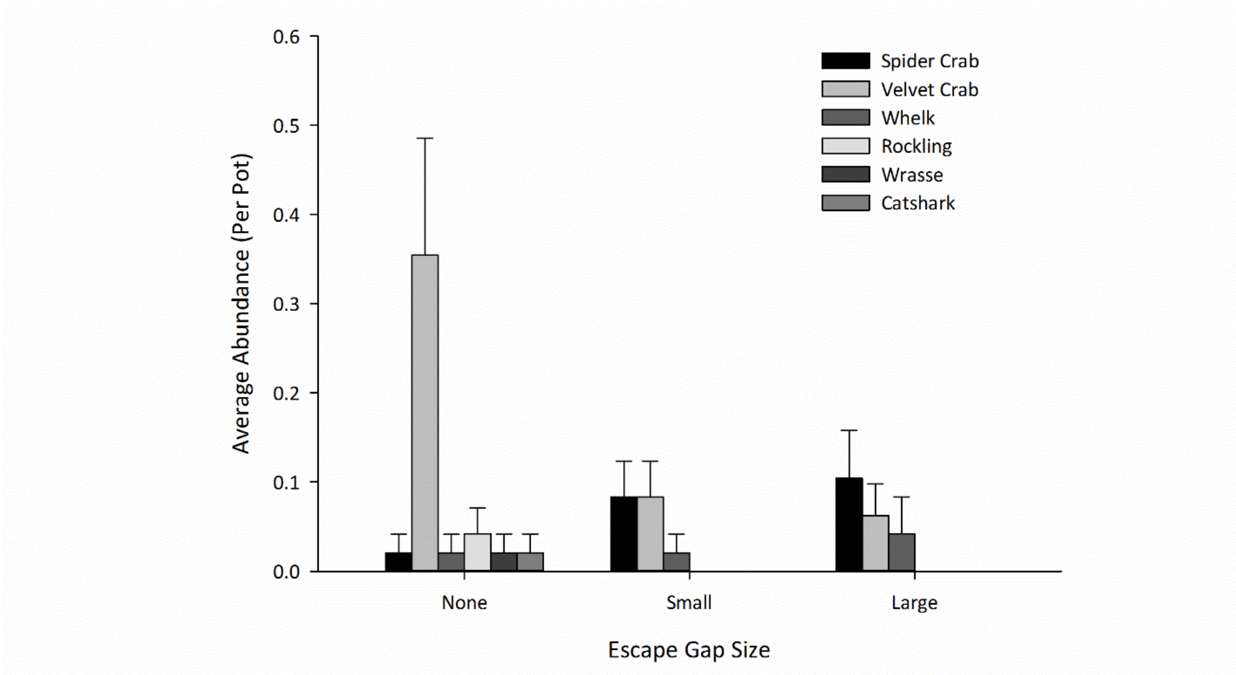

Figure 10: Average abundance ± standard error of bycatch species caught in 144 pots of three different size escape gaps (None = no escape gap, Small = 80mm x 45mm escape gap, Large = 80mm x 47mm escape gap) in 144 pots hauled in Cardigan Bay.

If velvet crabs are not considered as a bycatch species (since some fishers land them), then all three types of pot have very similar total numbers of bycatch individuals caught (None – 6 individuals, Small – 5 individuals, Large – 7 individuals). This indicates that escape gaps do not influence the total abundance of bycatch (excluding velvet crabs) caught in lobster pots.

Multivariate statistics were performed on the bycatch data to determine whether there were significant differences in the bycatch composition in the pots with three types of escape gaps. ANOSIM routines were performed using both escape gap type and month of capture as factors on the square root transformed abundance data for velvet crabs, spider crabs and common whelks. The analysis found no significant differences in the bycatch composition for the three types of escape gaps (None and Small: $R = 0.006$, $P = 0.20$; None and Large: $R = 0.013$, $P = 0.098$; and Small and Large: $R = -0.012$, $P = 0.96$) or for two of the months of capture (July and August: R = 0.025, P = 0.097; July and September: R = 0.009, P = 0.15). There was a significant difference in the bycatch composition between August and September: R = 0.045, P < 0.001). This difference appears to be because whelks and spider crabs were caught in August but not September and velvet crabs were caught in September, but not August.

Due to the nature of the data collection (on-board video recordings), it may be possible that there were smaller non-target species that were not noticed by fishers and subsequently not removed from the pots and captured by the video camera.

3.2.4 Velvet Crabs

Model selection found the zero-inflated Poisson (ZIP) distribution to be the best model for investigating the density of velvet crabs (number of velvet crabs per pot). The following model was used in this investigation:

m5 = zeroinfl (V ~ LEG)   where V is the number of velvet crabs caught and LEG is the type of escape gap

The ZIP model identified a probability *p* when the only possible observation was zero velvet crabs in the pot, and a probability 1-*p* for the density distribution of the Poisson type. The probability of not encountering any velvet crabs in a pot was 0.84. Therefore, the probability that the number of velvet crabs caught followed a Poisson distribution was 0.16. Probability *p* refers to the logistic regression component of the model: the probability of finding zero velvets crabs in a pot did not depend on any specific covariates used in the model. On the other hand, the Poisson regression component (with a probability of 0.16) modeled the abundance of velvet crabs in a pot, which was found to be dependent on the type of escape gap used. The model thus suggests that there is a small probability (0.16) that the average value of velvet crabs caught is greater than zero, and this is more likely in pots with no escape gaps.

3.2.5 Damage

Fourteen lobsters (11% of total lobsters), thirteen brown crabs (18% of total brown crabs), seven velvet crabs (32% of total velvet crabs), and one spider crab (14% of total spider crabs) were reported as damaged. Of these damaged individuals, only three lobsters and three velvet crabs were missing both their claws; all other damaged individuals were missing one claw. There were no dead individuals found in any of the pots.

A chi-square test on the lobster and brown crab data found no association between the amount of damage (no damage, one claw missing, both claws missing) and the type of escape gap in the pot for lobsters (x^2 = 4.18, d.f. = 4, P = 0.38) or for brown crabs (x^2 = 5.33, d.f. = 4, P = 0.26). This analysis could not be performed on the velvet crab data or spider crab data due to the small number of velvet crabs caught in pots with small and large escape gaps and the small number of total spider crabs caught.

A chi-square test on the data pertaining to the presence of other lobsters and brown crabs in the pot found no association between the lobster damage and the presence of other lobsters in the pot (x^2 = 2.82, d.f. = 2, P = 0.24) or the presence of brown crabs in the pot (x^2 = 3.48, d.f. = 2, P = 0.18). Similarly, there was no association found between the brown crab damage and the presence of other brown crabs in the pot (x^2 = 0.87, d.f. = 2, P = 0.65) or the presence of lobsters in the pot (x^2 = 2.40, d.f = 2, P = 0.30).

A comparison of the percentage of damaged undersized lobsters and damaged legal sized lobsters found similar levels of damage occurrence for these two size categories; 92% of undersized lobsters were undamaged, 7% were missing one claw and 1% were missing both claws, whereas 88% of legal sized lobsters were undamaged, 10% were missing one claw and 2% were missing both claws.

3.3 Time Savings and Economic Impact

3.3.1 Sorting Time

Analysis of the time it took the fisher to sort each pot showed significant differences between all combinations of pots with escape gaps (None and Small t = -3.31, P = 0.001; None and Large t = -6.27, P < 0.0001; Small and Large t = -2.96, P = 0.004). As the size of escape gap in the pot increases, the amount of time required to sort and bait the pot decreases (Table 6, Figure 11).

Table 6: Mean sorting time per pot, standard error and range for 144 pots with three types of escape gaps in Cardigan Bay. All values are in seconds.

Lobster Escape Gap	Mean Sorting Time ± SE	Range
None	33 ± 2	15 – 77
Small	25 ± 1.5	6 – 51
Large	19 ± 1.6	2 – 67

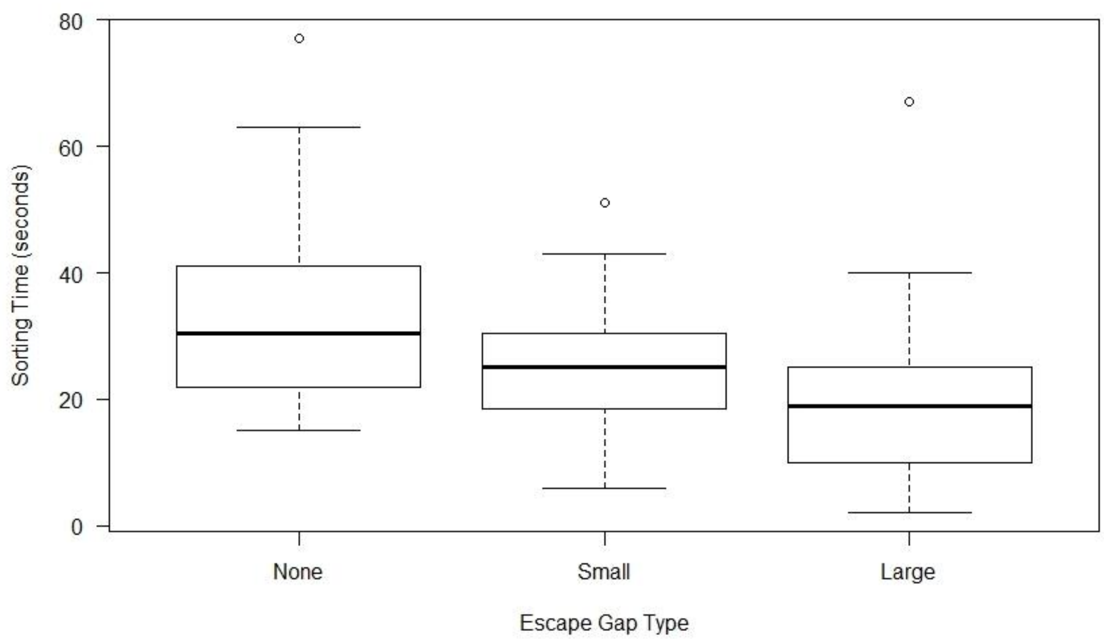

Figure 11: Boxplot of the sorting time (in seconds) for 144 pots with three different size escape gaps in Cardigan Bay. The box encloses the interquartile range (IQR, where the middle half of the data lies), the "whiskers" show the range of the data and the circles represent suspected ourliers that are data points 1.5 x IQR. The median (or middle) value is represented by the bold line within the box.

If fishers switched to pots with large escape gaps they would save on average 14 seconds per pot, therefore, if they haul 300 pots per day then they would gain one hour and 10 minutes per day. If they switched to pots with small escape gaps they would save on average eight seconds per pot, therefore, if they haul 300 pots per day then they would gain 40 minutes per day. This time savings could equate to a reduction in fuel costs (if the boat engine is running while sorting) or would allow fishers to set and haul more pots per day potentially increasing yield.

3.3.2 Economic Impact

There is no significant difference in the abundance of legal lobsters caught in pots with no escape gaps and pots with small escape gaps and a greater probability of catching velvet crabs in pots with no escape gap (Table 7). On average, there were over four times more velvet crabs in pots with no escape gaps.

Table 7: The average number of legal-sized lobsters and brown crabs and all velvet crabs per pot caught, and associated standard error (SE), in 144 pots with three types of escape gaps in Cardigan Bay.

Lobster Escape Gap	Average number of legal lobsters per pot ± SE	Average number of velvet crabs per pot ± SE	Average number of legal brown crab per pot ± SE
None	0.40 ± 0.38	0.35 ± 0.54	0.06 ± 0.18
Small	0.46 ± 0.32	0.08 ± 0.19	0.21 ± 0.30
Large	0.23 ± 0.26	0.06 ± 0.13	0.23 ± 0.34

Using a logistic regression of weight and carapace length data from 710 lobsters from Welsh waters (Bangor University, unpublished data), the weights of the lobsters caught in this study were calculated and the price per lobster was calculated from the price per kg obtained from the fisher for each month. From these calculations, the fisher will receive over £1 more per lobster caught in a pot with small escape gaps than a pot with no escape gaps due to the larger lobsters caught in these pots. Therefore, there is a potential gain of in excess of £300 per fishing trip if a fisher uses 300 pots with small escape gaps as opposed to 300 pots with no escape gaps. The difference between the average price per lobster caught with pots with no escape gaps and pots with large escape gaps is £0.22 which could amount to an increase in £66 per fishing trip if a fisher uses 300 pots with large escape gaps as opposed to 300 pots with no escape gaps.

The carapace widths of velvet crabs were not obtained during this study, therefore all velvet crabs caught were assumed to be of minimum landing size (65mm). Using the linear regressions created by Fahy (2008) for velvet crabs caught in Ireland and prices obtained from the fisher for this study, the weight for a velvet crab of minimum landing size (65mm) would be 0.07kg and the average price per velvet crab would be £0.14. If there is an average of 0.35 velvet crabs per pot with no escape gap and a fisher uses 300 pots, then they would make £14.70 ± 22.68 per fishing trip from velvet crabs in these pots, as opposed to £3.36 ± 7.98 per fishing trip with pots with small escape gaps and £2.52 ± 5.46 per fishing trip with pots with large escape gaps.

It was not possible to obtain the carapace widths of the brown crabs caught in this study from the video footage; therefore, to be conservative, all brown crabs retained during this study will be assumed to be 130mm carapace width (minimum landing size for North and Mid Wales). Using a polynomial regression of weight and carapace width data from 647 brown crabs from Welsh waters (Bangor University, unpublished data) and prices obtained from the fisher for this study, the weight for a brown crab of minimum landing size would be 0.41kg and the average price per brown crab would be £0.45. If a fisher uses 300 pots, then they would make £8.10 ± 24.30 per fishing trip from brown crabs in pots with no escape gaps, £28.35 ± 40.50 per fishing trip with pots with small escape gaps, and £31.05 ± 45.90 per fishing trip with pots with large escape gaps.

The theoretical average catch income per fishing trip for a fisher using 300 pots during the summer season would be:

No escape gap – £412.24

Small escape gap - £624.96

Large escape gap - £409.32

Economically speaking, it appears more advantageous to catch larger lobsters that fetch a better price in pots with small escape gaps and lose most of the velvet crabs (a possibility of at most £37.38 for 300 pots not using escape gaps), than to use pots with no escape gaps to optimise velvet crab catch which does not have as much value.

If escape gaps were to be implemented, there would be an initial economic impact on fishers. The cost of escape gaps per pot is approximately £0.40; however, for a fisher with 300 lobster pots, the escape gaps would cost £111.00 (£0.37 per escape gap), and the cable ties would cost £7.80 (£0.65 for 100 cable ties (160mm x 2.5mm), at least four required per escape gap), for a total investment of £118.80. The indirect costs of installing escape gaps would most likely be higher than the actual gaps, as the fishers would need to bring all their pots to shore, install the escape gaps, and return the pots to the sea. As many lobster and crab fishers in Wales use boats under 10m in length, bringing 300 pots to shore and returning them will take many trips and therefore require a lot of fuel. Whilst cutting a hole and cable tying an escape gap to a pot may take only one minute, with 300 pots this could take five hours to complete and a lost day of fishing revenue. The size of the small escape gaps (80mm x 45mm) is commercially available, therefore there would be no extra cost incurred from requiring a new mold to be created.

3.4 Questionnaire

Three of the four fishers involved in the study were available to provide answers to the questionnaire before and after using escape gaps for one year.

1. Do you think lobster escape gaps will make a difference to your catch?

   Two out of three fishers indicated they believed lobster escape gaps would impact their catch prior to commencement of the experiment and all three fishers believed escape gaps changed their catch after using the escape gap pots for one year. These impacts are explained in Question 2.

2. What do you think this difference will be?

   Of the two fishers who believed there would be a difference in their catch, one indicated it would be a negative change in which he would lose velvet crabs and prawns and the other indicated a positive change whereby there would be less undersized lobsters to sort. After using the escape gaps for one year, two of the three fishers observed a positive effect of escape gaps on decreasing the abundance of undersized lobsters and decreasing their sorting time. One fisher believed the use of escape gaps negatively affected his catch by allowing some legal sized lobsters to escape.

3. Do you think lobster escape gaps will be beneficial?

   Prior to the experiment, two of the three fishers believed that using escape gaps would be beneficial; however, after the experiment all three fishers believed them to be beneficial. These reasons are explained in Question 4.

4. Why do you think this?

   The two fishers who believed escape gaps would be beneficial prior to the experiment felt they would decrease lobster fighting within the pots and therefore reduce damage to the lobsters, as well as decrease sorting time. The fisher who thought escape gaps would not be beneficial felt he would lose landable bycatch. After the experiment, the opinion of two of the fishers remained the same and they believed escape gaps to be beneficial by decreasing sort time, whilst one fisher changed his mind and felt that they would be beneficial for reducing lobster fighting, reducing ghostfishing, and reducing unwanted bycatch.

5. Is there any way that lobster escape gaps could reduce profitability? How?

Prior to the experiment, two of the three fishers believed that using escape gaps could reduce the profitability of their fishing operations by reducing the abundance of bycatch species that they land, such as velvet crabs and prawns. Their opinions did not change after using pots with escape gaps for one year.

6. Is there any way that lobster escape gaps could increase profitability? How?

Prior to the experiment, two of the three fishers did not believe that using escape gaps could increase the profitability of their fishing operations and their opinions did not change after using escape gaps. One fisher was not sure if escape gaps could increase profitability, but thought after the experiment that perhaps the undersized lobsters could be deterring larger lobsters from entering the pots with no escape gaps.

7. Does the influence on profitability depend on season?

Prior to the experiment, one fisher did not think the season influenced whether escape gap use affected profitability, whilst the other two fishers did not provide answers. After the experiment, two of the fishers believed season did not affect the profitability of escape gap use and one fisher remained unsure.

8. On a scale of 0 to 10 (with 0 being not at all and 10 being extremely), how useful do you think this experiment is with respect to the sustainability of the fishery?

Prior to the experiment, two fishers felt the study was somewhat useful (5 and 6) and one fisher thought the study would be very useful (9). After using the pots with escape gaps for one year, the two fishers changed their opinions and felt the study to be very useful (8 and 9) for investigating possible solutions for a sustainable fishery, whereas the other fisher changed his mind and felt it was a somewhat useful study (5).

These results highlight that seeing first-hand how a management measure works can affect the opinions of fishers and their support of the measure.

4. DISCUSSION

4.1 Conservation Benefits

The results of this study highlight the conservation benefits and the economic consequences of using lobster escape gaps in Cardigan Bay. It was very clear from the study that undersized lobsters and undersized brown crabs are using the gaps to escape from the pots. This result has been well documented in the literature for a variety of species of crabs: *Cancer pagurus* (Brown 1982), *Cancer setosus* (Anguilar and Pizarro 2006), *Portunus pelagicus* (Boutson *et al*. 2009), *Scylla serrata* (Grubert and Lee 2013), and *Scylla olivacea* (Jirapunpipat *et al*. 2008); and several lobster species: *Homarus gammarus* (Brown 1982; Clark 2007; Murray *et al*. 2009), *Homarus americanus* (Courchene and Stokesbury 2011; Krouse 1978), *Jasus edwardsii* (Linnane *et al*. 2011; Treble *et al*. 1998), *Jasus frontalis* (Arana *et al*. 2011), *Panulirus marginatus* (Everson *et al*. 1992; Polovina *et al*. 1991), *Scyllarides* spp. (Everson *et al*. 1992), and *Scyllarides squammosus* (Polovina *et al*. 1991).

From a conservation perspective, lobster escape gaps are highly beneficial in that undersized lobsters and undersized brown crabs will not be displaced from their territories or stressed from handling or air/light exposure. A study by Brown and Caputi (1983) looking at the effects of displacement and air exposure on rock lobsters (*Panulirus cygnus*) in Australia through laboratory, diver observation and tagging experiments found that lobster mortality increased with increasing air exposure, lobsters that had been exposed to the atmosphere did not immediately find shelter once released and had a higher incidence of predator attack, and that lobsters that had been displaced from their original territory had lower recapture rates indicating possible predator interactions. A complimentary study by these authors (Brown and Caputi 1985) found that lobster growth rate was affected by air exposure and that displacement affected the growth size increment by possibly interrupting normal feeding behaviour. The importance of shelter to juvenile lobsters is well-studied, with most studies indicating that small, juvenile lobsters spend more time in shelters and as they grow this dependence decreases (Cobb 1971; Lawson and Lavalli 1995). A laboratory experiment with European lobsters found that smaller lobsters are more dependent on the presence and rapid availability of shelters than larger lobsters and that this behaviour appears to change around a carapace length of 75mm (Mehrtens *et al*. 2010). In the present study, only one lobster under 75mm was caught in each of the pots with escape gaps; however, 25 lobsters under this size were caught in pots with no escape gap and placed back in the water. As potting for lobster takes place during daylight hours, this is especially disruptive to the patterns of small lobsters as they tend to spend the daylight hours in shelter and venture outside shelters in the night (Mehrtens *et al*. 2010), which is when they are most likely caught in pots. Reducing displacement of small lobsters from their shelters can easily be achieved through the use of escape gaps.

Escape gaps could also be a useful conservation measure in reducing ghostfishing of lost traps, especially if the escape gaps are attached using biodegradable twine or ferrous metal hog rings. When the pot is not lost, the undersized animals can escape, and when the twine or hog rings degrade, the hole through which to escape is larger and of flexible mesh that all individuals can escape though (Smolowitz 1978). A study by Swarbrick and Arkley (2002) which evaluated three types of anti-ghostfishing mechanisms found biodegradable twine to be ineffective due to being cut by crustaceans and panels attached by hog rings to last around six months and be the recommended device. A study by Pantin *et al*. (2015) which interviewed 66 Welsh fishers regarding their fishing activity revealed a high level of lost pots per year (an average of 25 lost pots per lobster fisher per year). A study by Bullimore *et al*. (2001) of a set of 12 ghost fishing parlour pots found an average of 6.06 brown crabs and 0.44 lobsters were killed per pot during one year of ghost fishing. Combining these numbers with those of the Welsh fisher questionnaire (Pantin *et al*. 2015) would give an estimate of 151.5 brown crabs and 11 lobsters killed each year by each fishers' lost pots. Installing escape gaps could minimise the impact these lost pots have on the ecosystem.

It has been suggested that escape gap use may reduce the mortality or injury of lobsters and crabs due to fighting in pots (Templeman 1958) or from capture and handling (Brouwer *et al*. 2006). The consequences of injury in decapod crustaceans can include reduced growth rates, reduced reproductive success (decreased mate attraction, hindered copulation and reduced fecundity), increased possibility of predation and cannibalism, and decreased ability to forage (Barber and Cobb 2007; Juanes and Smith 1995). A review on the effects of limb damage or loss in decapod crustaceans (Juanes and Smith 1995), stated that loss of chelipeds (claws) can have a drastic effect on foraging efficiency and damaged chelipeds can cause a shift to alternative preys. In addition, a study of shore crabs (*Carcinus meanas*) found a much lower proportion of crabs missing chelae in mating pairs than crabs with intact chelae indicating missing chelae are a handicap for mating shore crabs (Abello *et al*. 1994). There was no evidence from this study indicating greater fighting (and consequently injury) in pots with no escape gaps as there was no difference in the amount of damaged lobsters and crabs between the three types of pots with escape gaps. The level of damage observed during this study (15%) was higher than some of the rates of damaged lobsters recorded in a variety of American lobster fisheries. These studies have found rates of 7% along the north shore of Prince Edward Island (Pickering and Quijon 2010), 8-14% in the Maine lobster fishery (Kelly 1991; Krouse 1976), 8-15% in western Long Island Sound (Briggs and Mushacke 1979), and 18-21% along the US eastern seaboard (Estrella and Glenn 2001). The level of damage to lobsters and crabs due to handling was not directly assessed in this study. From the videos it did not appear as though any individuals were damaged during removal from the pots; however, the removal of the organisms was not always clear from the video. The possibility for damage in this way would be reduced for undersized lobsters and brown crabs if they have the opportunity to escape the pots. Nevertheless, the presence and absence of claws was the only indication of damage used in this study as the other appendages were not easily observable from the videos and therefore it is possible that individuals had missing legs, appendage tips, antennae, or had open wounds to the exoskeleton.

Other studies have also highlighted the effects escape gap use can have on bycatch abundance; however there was no evidence of different abundances of bycatch species (excluding velvet crabs) amongst the three types of pots with escape gaps in this study. The bycatch species richness was surprisingly low in this study (six species in total), as the number of bycatch species observed in lobster pots by 53 Welsh lobster fishers interviewed for a questionnaire (Pantin *et al*. 2015) was 42 species. The complete species list from the questionnaire can be found in Appendix 1. The bycatch level was quite low (0.1 bycatch species per pot) during this study, therefore it does not appear to be a great issue for which escape gaps are the solution. These results could be different if bycatch species abundances differ spatially or temporally. The bycatch species found in pots with escape gaps differed from those without with respect to species richness. There were six species caught in pots with no escape gaps and three species caught in pots with escape gaps. None of the fish species (wrasse, rockling or catshark) were caught in pots with escape gaps. It is not possible to make any conclusions regarding this pattern as very small numbers of wrasse, rockling and catsharks were caught.

The results of the selectivity curves indicate a greater proportion of legal sized lobsters retained in pots with small escape gaps in comparison to pots with large escape gaps. These retention rates may be affected by the fact that lobsters can escape from pots through the entrance. A study in which American lobsters were recorded in traps found that of the lobsters that escaped the traps (94%), 72% escaped through the entrance and only 28% escaped through the escape gap (Jury *et al*. 2001). Based on that study, 68% of the lobsters that entered the traps, escaped through the entrance.

4.2 Economic Consequences

At first glance, it may appear as though lobster escape gaps are not economically beneficial to fishers, as there is no significant difference in the number of legal lobsters retained by pots with no escape gaps and pots with small escape gaps, and there is a higher probability of catching an average number of velvet crabs greater than zero in pots with no escape gaps. However, when the size, and consequently weight, of the lobsters is considered, the results suggest that pots with small escape gaps catch larger lobsters which weigh more and are therefore worth more money, as price is based on £/kg. The income earned from larger lobsters caught in pots with small escape gaps outweighs any economic loss of velvet crabs. It has been stated by fishers, however, that the abundance of velvet crabs is higher in the winter months, therefore the financial loss of velvet crabs may be higher in winter than calculated for this study as this experiment was conducted during the summer months. This could be more pronounced for fishers during these months as the catches of lobsters are usually much lower. A telemetry study on European lobsters in England found movement and activity to be greatest in summer and lowest in the winter months (Smith *et al*. 1999). Nevertheless, not all fishers land velvet crabs, therefore in these cases the only economic impact of using escape gaps is the initial cost of installation. Of 53 Welsh lobster fishers interviewed for a fishers' knowledge questionnaire (Pantin *et al*. 2015), only 30% landed velvet crabs. Additionally, the results suggest that using pots with escape gaps decreases the time required to sort and bait pots. Consequently, an economic benefit could be attained from this as using 300 pots with small escape gaps would save 40 minutes of fuel for the engine and winch generator or allow for setting additional pots.

4.3 Future Work

To obtain a complete understanding of the ecological and economic impacts of using escape gaps, this study would ideally continue to collect data through all seasons of lobster potting activity. This would ensure that the temporal fluctuations in species abundances could be incorporated into the analysis, especially in the economic impact analysis. This would be particularly important for velvet crab abundances in winter and spider crab abundances in spring. However, many pot fishers do not rely on velvet crab catches in the winter months as there are other species such as prawns and king scallops that they target during these months.

Additional aspects of escape gap assessment that have been investigated in other studies are the shape (circular versus rectangular), position, and number of escape gaps per pot. This would be an obvious next step as answering these questions could further optimise legal sized catch and reduce undersized catch. It is possible that the position of the escape gap could influence whether velvet crabs escape or not. Video observations of lobster, brown crab and velvet crab behaviour in pots would be especially useful for determining the correct position within the pot for the most effective escape and retention. Additionally, due to the retention results, it may be beneficial to trial slightly smaller escape gaps to determine whether legal sized lobsters are escaping through the gaps. Video footage would also help explain these results.

5. CONCLUSIONS

In conclusion, the best escape gap size is that which provides the best balance between low catches of undersized lobsters, whilst maintaining the catch of legal sized lobsters. This study would recommend installing at least one small (80 x 45mm) escape gap on all lobster pots in Cardigan Bay. This will be beneficial for the conservation of this lobster fishery whilst not negatively affecting the fishers economically.

Whilst there is plenty of literature on the subject of escape gaps and most come to similar conclusions, it appears as though allowing fishers to use escape gaps is the best way to convince them of the benefits. From the small questionnaire conducted with the fishers, it is apparent that hands-on experience fishing with pots with escape gaps influenced their opinions on escape gaps (in most cases in a more positive light).

6. ACKNOWLEDGEMENTS

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8. APPENDIX

Appendix 1 – Bycatch species mentioned by 53 Welsh lobster fishers interviewed for a Fishers' Knowledge Questionnaire (Pantin *et al*. 2015).

Fish	**Crustacean**	**Other**
Bass	Crawfish	Brittlestar
Blenny	Green crab	Cuttlefish
Bream	Hermit crab	Octopus
Bull huss	Mantis shrimp	Sea urchin
Butterfish	Prawn	Squid
Cod	Spider crab	Starfish
Coley	Sponge crab	Whelk
Conger eel	Squat lobster	

Dab	Velvet swimming crab	
Dogfish		
Goby		
Gurnard		
Lumpfish		
Pipefish		
Pollack		
Pouting		
Red Mullet		
Rockling		
Scorpion fish		
Sole		
Sun fish		
Topknot		
Trigger fish		
Wrasse		