The design of an escape gap panel for the three species crustacean fishery of the Southern IFCA

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1 Abstract

Escape gaps are a widely used crustacean fishery management strategy. Designed to allow undersized catch to escape whilst retaining the maximum quantity of legal animals, they reduce the sorting time for fishermen and ensure a healthier stock for future years through the reduction of animal damage as a result of in pot aggression and the sorting process. The design of an escape gap must encompass four variables; size, shape, number and position. The Southern IFCA district, on the South coast of the United Kingdom, has a three species fishery which lands *Homarus gammarus, Cancer pagurus* and *Necora puber*. A project conducted in partnership with the University of Southampton has been researching the design of suitable gaps to suit all three species.

In this third phase of the project, two escape gap types (bristled 45 x 87mm rectangle and circle escape gaps) have been trialed in an aquarium to determine their effectiveness. A soft bristled 45 x 87mm rectangle gap proved effective for *C. pagurus* and *N. puber* crabs when positioned 50mm above the base of the pot. It retained all oversized individuals and allowed the escape of 61% of *N. puber* and 62% of *C. pagurus*. As *H. gammarus* are unwilling to push through bristles a 55mm diameter circle was found to be most effective for this species whilst still retaining oversized *N. puber*. Fifty percent of undersized *H. gammarus* could escape through the 55mm circle and it retained a significantly different mean size of animals than those able to escape (76 vs 84 mm).

To create an escape system suitable for the three species fishery the bristled 45 x 87mm rectangle and 55mm circle were combined into a panel and trialed within the commercial fishery of the Southern IFCA district along with a set of 45 x 87mm gaps without bristles. A significant increase in the mean retained size of *C. pagurus* was seen between control (no gaps) and 45 x 87mm pots (123 vs 133mm) but, unfortunately, no significant differences were found between the retained sizes of control and paneled (rectangle and circle) parlour pots for any species. However, a small reduction in the proportion of undersized crabs was seen in the panel pots indicating that some animals had been escaping. These statistically insignificant results were thought to be due to the cold sea temperatures seen during March, which resulted in too few *H. gammarus* collected for statistical analysis and high levels of pot saturation by *C. pagurus*. Further field trials are required throughout the warmer summer and autumn months to determine the true effectiveness of the escape gap panel.

2 Acknowledgments

Firstly, I would like to thank Dr. Antony Jensen for his support, time and help with this dissertation project. I could not have completed this project without Richard Stride and his crewmate Gill, and Pete Dadds who donated their time, and allowed me to undertake practical work on their fishing vessels, thank you very much. I am very grateful to Beth Wills and Rob Robinson, for their advice and help throughout my aquarium trials. In addition, I would like to thank Mark and Kim Smith for their help creating the escape gaps themselves, as well as Naomi Hyland and Vicki Gravestock for sharing their ideas and data so I could continue the project. I could not have made it through the ups and downs of the project without James Wilkie and my family and finally, thank you to all the brown crab, swimming crabs, and lobsters without whom this project would have been impossible.

Table of Contents

3 Introduction

3.1 Fisheries and management

In 2013, the UK landed 624,000 tonnes of shellfish, demersal and pelagic fish which brought £718 million to the economy and supported 12,150 fishermen and their families (Marine Management Organisation 2014). Throughout the world's fisheries, management techniques are enforced to maintain their sustainability, to reduce damage to and ensure there will be recruitment in future years (Huang et al. 2011; Larsen & Eigaard 2014). Management plans aim to reduce the amount of biomass being removed from the sea so enough spawning stock remains to provide future successful catches for fishermen (FAO Fishery Resource Divison and Fishery Policy and Planning Division 1997; Mitchell et al. 2008). They also aim to decrease target and non-target species by-catch and discards, as discards are estimated to make up 40% of global catch (Davies et al. 2009).

Many management strategies are put in place in order to protect marine ecosystems from overfishing and bycatch (Geijer & Read 2013; Huang 2011; Moore et al. 2009). Input control regulations manage the number of vessels and impose fishing time restrictions (Emery et al. 2012). Output controls limit the total allowable catch by enforcing quotas for species specific fisheries such as the yellow and red squat lobsters in the Chilean crustacean fishery (Albornoz & Canales 2006). For example, a maximum of 35,287 tonnes of catch is permitted for the UK *Nephrops norvegicus* fishery (European Commision 2014). All other management techniques are categorised into technical measures which focus on controlling how and where fishing can take place by enforcing gear restrictions, minimum landing sizes (MLSs), closed seasons and no take zones (NTZs) (FAO Fishery Resource Divison and Fishery Policy and Planning Division 1997).

3.2 Technical measures

Gear regulations vary widely depending upon the fishery and location. Bans of certain fishing methods occur when a stock becomes overfished. When trawling was banned for 14 years in the central Mediterranean sea, the *Mullus barbatus* population recovered, with females being larger and spawning-stock increasing significantly (Fiorentino et al. 2008). Whilst, closed seasons prohibit fishing activity for a short time throughout the year for example, due to spawning activity (Atlantic States Marine Fisheries Commission 2013; Halliday 1988). Area 2 in inshore Southern New England has a closed lobster fishery from November 1st to June 15th (Atlantic States Marine Fisheries Commission 2013).

NTZs are implemented when populations have been considered overfished or at risk. They prohibit fishing for a particular species in a designated area (Rowe 2002). Comparative data sets of NTZs and active fishing areas have indicated the NTZs are effective in improving lobster stocks compared to the zones which are continuously fished (Rowe 2002; Kelly et al. 2000). The size and proportion of ovigerous female American lobsters (*Homarus americanus*) increased in just three years at a NTZ in Newfoundland (Rowe 2002).

Demersal fisheries are often regulated by mesh size. In haddock net fisheries bycatch of other commercially valuable species such as cod is high (Campbell et al. 2010). Larger mesh sizes in selected panels of the trawl allowed these fish to leave the net before reaching the smaller mesh, and as the net sizes are selective for the target species' morphology a small increase of catch can be seen (Beutel et al. 2008).

Minimum and maximum landing sizes are designed to limit the number of animals fishermen can take out of the fishery as well as allow each animal to reproduce at least once before it is removed (Ungfors 2008). The MLSs for lobster, brown crab and swimming crab in the UK are 87mm, 140mm and 65mm respectively although some IFCAs have increased these for their region (CEFAS 2011a; CEFAS 2011b; Southern IFCA 2011).

One way fisheries organisations manage the large crustacean fisheries of America and Canada is by limiting the number of pots an individual fisherman can have, and enforcing gear specific labelling regulations (Queensland Government, 2015). This limits the total effort of the fishery in the specified area and reduces the pressure upon the stocks, for example in 2014, a fine of $1,500 was issued to Mr Coffin in Newfoundland for exceeding the maximum number of crab pots (Fisheries & Oceans Canada, 2008).

Bycatch Reduction Devices (BRDs) are an enforced requirement in many parts of the world (Moore et al. 2009; U.S. National Bycatch Report [Karp, Desfosse] 2011). In the Australian tropical prawn fishery the bycatch of turtles, sting rays and sharks was reduced to close to zero by introducing the Super-shooter device, which guides the large bycatch to an escape opening in the net. It was also successful in reducing small fish bycatch by 16% with no change in prawn catch (Robins et al. 1999; Brewer et al. 1998).

3.3 Escape gaps and vents

One gear regulation that has been adopted throughout the world, is the escape vent or gap designed for use in crustacean pot fisheries (Polovina et al. 1991) (Table 1). An escape gap is a small opening located on a fishing pot that is designed to enable small and undersized animals, the bycatch, to escape whilst retaining animals of legal size. Incorporating escape gaps into pot fisheries gives many benefits such as; reduced sorting time and costs for the fishermen, and injury caused by in pot aggression, the sorting process, exposure and displacement of undersized animals is decreased (Stewart 1974). Furthermore, ghost fishing by gear that is lost to sea has less effect upon the residual populations of crustaceans when pots are vented (Cruz & Olatunbosun 2013). The practise of manipulating pot selectivity originated through alteration of the gaps between wooden laths used to make pots, however, a distinct vent worked more efficiently (Fogarty & Borden 1980).

Before integration into a crustacean fishery, the design of escape vents requires detailed research to find the gap size, shape, position and number that is effective for the target species (Boutson et al. 2005 & 2009; Eldridge et al. 1979). The morphometrics of the target species are often used to indicate the best measurements for these variables (Arana et al. 2011). The critical body dimension, the parameter of the animal that determines whether it will be able to escape through a gap, must be determined (Estrella & Glenn 2006). When it is correlated to the minimum landing size (MLS) of the species it can predict the required size of the vent. For example, lobsters turn on their side to exit through a rectangular vent (Nulk & Vernon 1978) so carapace width is used to indicated the height a vent should be.

A successful vent will shift the size frequency distribution of the animals caught within each pot. There should be an equal or higher incidence of animals at or above the minimum landing size and lower incidence of those below the minimum landing size (Arana et al. 2011). Vents of 85mm have increased catch per unit effort (CPUE) of *Jusus frontalis* (Guillory et al. 2004). Ultimately, effective escape vents can increase the financial income of fishermen.

Escape gap shape controls the escape of the target species (Boutson et al. 2009). On the north east coast of America, Krouse (1978) aimed to design a vent that would operate for both the *Homarus americanus* and *Cancer sp.* in a combined fishery. Both a rectangle of 44.5 x 152.4mm and a 58mm diameter circle worked well for both species (Krouse 1978). They were able to select for the dorso-ventrally flattened *Cancer irroratus and C. borealis* crabs and the carapace depth (CD) of *Homarus americanus* lobsters. Whilst in Thailand, Boutson et al. (2005) found that a square shaped vent was best suited to the morphometrics of *Portunus pelagicus,* the small blue swimming crab. Circle gaps are recommended for mixed species vents as they can select for dissimilar morphologies (Everson 1986; Krouse 1978).

The position of an escape vent alters the number of interactions a crustacean will have with the gap (Nulk & Vernon 1978) as they tend to navigate around the bottom of a fishing pot rather than the sides or top (Boutson et al. 2009). Simply placing a vent in the bottom rim side of a fishing pot can increase percentage escape by 85% compared to a top rim positon and result in a more selective catch (Boutson et al. 2005). Findings like this have resulted in regulated escape gap positions for the Louisiana blue crab fishery (Havens et al. 2009).

Furthermore, escape gap regulations often involve stipulating the number of gaps in a pot (Havens et al. 2009) as more than one vent per pot increases the ratio of legal to sublegal animals (Eldridge et al. 1979) and the overall efficiency of escape gap gear (Brown 1978; Stewart 1974; Lovewell & Addison 1989). Brown (1978) showed that having two escape gaps increased efficiency by 15%.

3.4 The Southern IFCA

The Inshore Fisheries Conservation Authorities, formally the Sea Fisheries Committee, are responsible for managing the fisheries of the coast of the UK out to six nautical miles. They are tasked with monitoring and enforcing laws, regulations and byelaws set by the EU, British Government and the individual IFCA regions (Southern IFCA, 2011). There are 10 IFCA's throughout England and Wales with the Southern IFCA covering the Dorset and Hampshire coasts (Figure 1). Many of the districts have enforced bylaws only applicable to those fishing in their designated area and some have enforced increased MLS and mandatory escape gaps for their crustacean fisheries (North Eastern IFCA 2014; Cornwall IFCA 2015)The Southern IFCA now operates a voluntary escape gap scheme and paid for the manufacture of 1000 45x87 mm escape gaps to be distributed throughout the district as well as the mandatory MLSs of 87mm for lobster and 140 mm for brown crab (Gravestock 2014; Southern IFCA 2011a & b). Further regulations include a vessel size limit of 12 m and the prohibited landing of berried female lobsters (Southern IFCA 2011c).

The escape gaps were designed by Hyland (2012)and Gravestock (2014) and have proved effective in reducing the unwanted catch of undersized *Cancer pagurus* and *Homarus gammarus.* However, the crustacean fishery operating in the Southern IFCA district is now a three species fishery as some fishermen are catching *Necora puber* which has an MLS of 65 mm. Due to the smaller morphology of the swimming crab the Southern IFCA has requested an escape gap or series of gaps that will reduce the bycatch of all three species simultaneously.

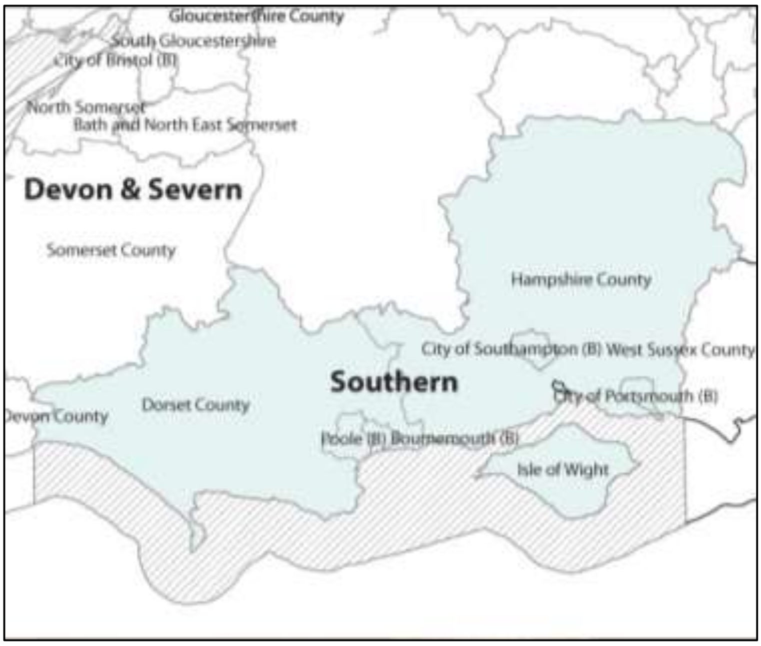


Figure 1. The Southern IFCA district covering a 6 nautical mile inshore zone from the Dorset/ Devon border to the Hampshire/ Sussex border.

3.5 Project aims and objectives

The overall aim of this project was to design an escape gap panel that retains all individuals of *Cancer pagurus* and *Homarus gammarus* above MLS minus five millimeters (MLS^{-5}mm) as well as *Necora puber* above MLS, and releases individuals below MLS^{-5}mm and MLS. By building upon Hyland's (2012) and Gravestock's (2014) work to further develop the 45 x 87mm 3D escape gap and design a novel circular gap for *H. gammarus* from which larger than MLS *N. puber* cannot escape. Finally, the combination of both escape gaps in an escape gap panel was to be tested in the field. To achieve this four aims were set:

Aim 1: Determine the effectiveness of three 3D bristled escape gap designs of the size 45 x 87mm for *C. pagurus* and *N. puber* individuals.
Null hypothesis: The 45 x 87mm bristled escape gaps will not retain all oversized (>MLS^{-5}mm/>MLS) individuals and will not release ≥25% undersized (<MLS^{-5mm}/<MLS) individuals of *C. pagurus* and *N. puber*.
Objective 1: Design three varied strength bristled gaps and determine how the bristles should be attached to the gap.
Objective 2: Trial and quantify the effectiveness of the three 45 x 87mm gaps.

Aim 2: Design and determine the effectiveness of four circular escape gaps for *H. gammarus* and *N. puber* individuals.
Null hypothesis: The circular escape gaps will not retain all oversized (>MLS^{-5}mm/>MLS) individuals and will not release ≥25% undersized (<MLS^{-5mm}/<MLS) individuals of *H. gammarus* and *N. puber*.
Objective 3: Use morphological data to determine four appropriate circle gap diameters.
Objective 4: Trial and quantify the effectiveness of the circular escape gaps.

Aim 3: Compare Hyland's (2012) 57mm circle gap data and Gravestock's (2014) bristled 45 x 87mm gap data to comparable data from this project.

Null hypothesis: There will be no significant difference between the size data of retained individuals from Hyland's 57mm circle and Gravestock's bristled gap when compared to corresponding data from this project.

Objective 5: Statistically analyse comparative retained size data sets.

Aim 4: Determine the effectiveness of an escape gap panel in field trials within the Southern IFCA fishery.

Null hypothesis: There will be no significant difference between the size data of all three species found in pots with the panel, a 45 x 87mm gap pot, or control pots.

Objective 6: Record the carapace length, width, depth and sex of all animals found in all pots and statistically compare the data**.**

Table 1. Examples of escape gap regulations currently managed in crustacean trap fisheries around the world including the minimum landing size. Alphabetized by country. CW – Carapace Width; CL – Carapace Length; TW – Tail Width. * indicate voluntary schemes.

Country	Region	Scientific Name	Minimum Landing Size (MLS)	Escape Gap Regulation	Source
America	Area 2,4, 5 & outer cape cod	*Homarus americanus*	85.7mm CL	Two 50.8 x 146.1 mm or Two 66.7 mm diameter circles	Gravestock 2014
	Southeast Alaska	*Cancer magister*	165 mm CW	Two 4 111.1 mm diameter circles	www.adfg.alaska.gov
	Florida Georgia & Texas Louisiana North Carolina	*Callinectes sapidus*	127mm CW	Three 60.3 mm diameter rings Two 60.3 mm diameter rings Two 58.7 mm diameter rings Two 58.7 mm diameter rings	Gravestock 2014
Australia	West coast	*Panulirus cygnus*	77mm CL	Three 55 x 305mm	de Lestang et al. 2012
	South Australia	*Jasus edwardsii*	150mm CL	Two 57 x 280mm	Linnane et al. 2011
Canada	Bay of Funday (LFA 35-38)	*Cancer borealis* *Cancer irroratus*	121-130 mm CW 102 mm CW	Two 63.5-91mm diameter circles Two 63.5-69mm diameter circles	Robichaud & Frail 2006
Norway	-	*Homarus gammarus*	25cm TL	Two 60 diameter rings	Moland et al. 2013
Sweden	-	*Cancer pagurus*	No MLS	One 75mm diameter ring	Ungfors 2008
United Kingdom	North Eastern IFCA & Kent & Essex IFCA	*Homarus gammarus* *Cancer pagurus*	87mm CL 130mm CW	46 x 80mm 46 x 84mm	North Eastern IFCA 2014 www.kentandessex-ifca.gov.uk
	Cornwall IFCA	*Homarus gammarus* *Cancer pagurus*	90mm CL F: 150mm CW, M: 160mm CW	46 x 84mm	Cornwall 2015
	Southern IFCA *	*Homarus gammarus* *Cancer pagurus*	87mm CL 140mm CW	45 x 87mm	Southern IFCA 2009; Gravestock 2014
	Sussex IFCA * & Jersey	*Homarus gammarus* *Cancer pagurus*	87mm CL 140mm CW	45 x 80mm 44 x 79mm	Sussex IFCA 2010; Sea Fisheries 2015
	Isle of Man	*Homarus gammarus* *Cancer pagurus*	87mm CL 130mm CW	45 x 80mm	Kaiser et al. 2008

4 Methods

4.1 Escape gap and panel design

The rectangle escape gap for *C. pagurus* and *N. puber* species was based on that recommended by Hyland (2012), with a deformable material barrier suggested by Gravestock (2014). All gaps had 45 x 87mm dimensions, where the deformable barrier covered 25mm of the height of the gap, leaving a 20mm opening for *N. puber* recommended by Hyland (2012) (Table 2). Gravestock (2014) had shown that *H. gammarus* would not push through the deformable material so the suggested circular escape gaps were designed and tested (Table 2).

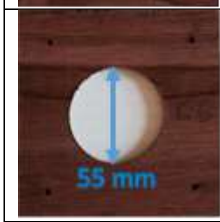
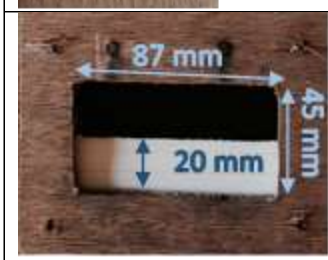
Escape gaps were designed to retain animals 5mm smaller than the MLS for *C. pagurus* and *H. gammarus* but it was not possible for *N. puber* as few sublegal animals were available. This was to make sure fishermen do not rely upon the gaps to eliminate undersized catch and therefore continue to measure their landings. More importantly, the 5mm margin was designed so the chance of legal sized animal escape was very low.

Each rectangle escape gap was hand sawed from 5mm marine plywood (Table 2). Three deformable materials were used for their differing strengths to create the barriers. These were; nylon bristles from a door draft excluder, clear plastic serrated strips, and thick (1mm diameter) plastic spines from a garden broom. The nylon and plastic barriers were screwed into place whilst the broom spines were fixed with double sided masking tape then secured with a second section of wood screwed on top as they were not pre-fixed together.

Using morphological data collected by Hyland (2012), Gravestock (2014) and in the current study of both *N. puber* and *H. gammarus,* four circle gap sizes were determined for testing. The linear regression equation of *N. puber* carapace width (CW) vs carapace length (CL), with a x value of 63 indicated that the circle diameter, 51 mm, would enable animals of CL ≤63 mm to escape. For *H. gammarus*, the equation of CL vs carapace depth (CD) with a x value of 82, indicated a diameter of 48 mm would let ≤82 mm individuals escape. However, Hyland (2012) showed that a 48 mm gap proved too small to allow any *H. gammarus* to escape. It was noted that the CD measurement did not include leg depth, and *N. puber* measurements did not account for width with carapace teeth. Therefore, further measurements were made of animals in the aquarium, and the average extra width and depth was determined to be 2mm for *N. puber* and 7mm for *H. gammarus*. So, two further diameters of 53 mm (51 + 2 mm) and 55mm (48 + 7mm) were selected for testing. Later, as the 55 mm circle had not enabled all *H. gammarus* <82mm CL to escape, a further diameter of 57mm was also tested to see if this could be improved. Each circle gap was made using a corresponding sized hole saw and 5mm marine plywood. Four holes were drilled into all gaps for fixing to the trial pots.

The soft nylon barrier gap and 55mm circle were selected for the panel based on their effectiveness, and the reliability of the data from aquarium trials. The escape gap panel was made from 4mm polypropylene sheet plastic using the same methods as above (Figure 2). Eight attachment holes were drilled in the panel for fitting to the fishing pots.

Table 2. The escape gap designs, names, positions and species tested in aquarium trials. With dimensions displayed on each gap picture.

Gap	*Name*	*Type*	*Position tested*	*Species tested*
	Circle 51	2D	Standard	*Homarus gammarus* *Necora puber*
	Circle 53	2D	Standard	*Homarus gammarus* *Necora puber*
	Circle 55	2D	Standard	*Homarus gammarus* *Necora puber*
	Circle 57	2D	Standard	*Homarus gammarus* *Necora puber*
	A. Soft	3D bristled	Standard Raised	*Homarus gammarus* *Cancer pagurus* *Necora puber* *Cancer pagurus* *Necora puber*
	B. Medium	3D bristled	Standard Raised	*Homarus gammarus* *Cancer pagurus* *Necora puber* *Cancer pagurus* *Necora puber*
	C. Hard	3D bristled	Standard	*Cancer pagurus* *Necora puber*

4.2 Aquarium Trials

Aquarium trials were carried out from 8th September to 1st December 2014. Four plastic aquaculture tanks were used, two stored outside of the size 1.2 x 1.2 x 0.75m and two inside, of the size 0.92 x 0.61 x 0.3m. Species were separated with *C. pagurus* in one large tank, *H. gammarus* in another and *N. puber* in the two small tanks. Tanks were filled via a flow through system with filtered, ozone treated and cooled seawater. The temperature remained constant throughout the trials at 15 – 16.1°C. Each tank was cleaned once per week and *H. gammarus* individuals were banded to protect themselves and the researcher from injury. Rock and tunnel shelters were provided for the animals. Due to limited tank space trialing and stored animals could not be separated and two animal collection trips had to be made. All other attempts were made to repeat the method of Hyland (2012) and Gravestock (2014).

A total of 16 *H. gammarus*, 25 *C. pagurus* and 25 *N. puber* were collected of Christchurch ledge after receiving a letter of permission from the Marine Management Organisation allowing the collection of undersized animals. Livestock were chosen based on their carapace lengths to represent individuals both above and below the MLS minus 5mm (MLS^{-5}mm) or MLS, with a minimum of seven- individuals for each size category.

Trial pots were constructed from green garden mesh and plastic coated wire in appropriate

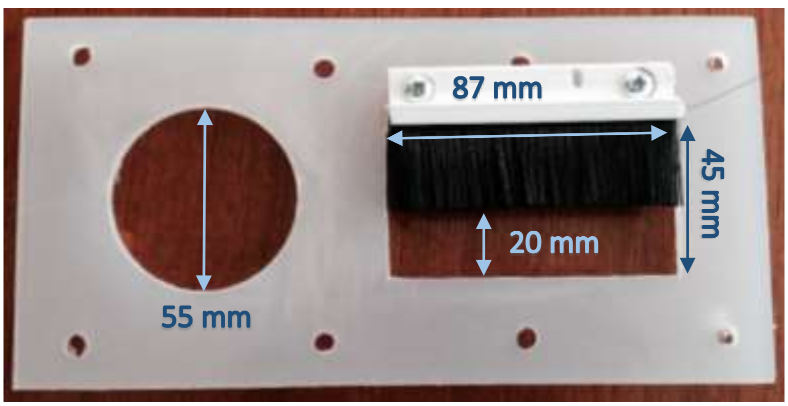


Figure 2. The escape gap panel trialed in the Southern IFCA fishery with a circle gap and the 3D soft bristled rectangle gap. Gap dimensions displayed on the image.

sizes for each of the three species (Figure 3). Each pot had an opening for gap attachment and a lid which could be tied securely after animals had been placed inside.

The animals were starved for a minimum of 48 hours before being selected. Each animal's measurements of CW, CL and CD were made before placing them into a pot with an escape gap fitted. Measurements of *H. gammarus* (Figure 4) CL were made parallel to the medio-dorsal line from the posterior edge of the carapace to the posterior edge of the eye socket. Carapace width was measured at the widest part and carapace depth was measured from the highest part of the dorsal surface to the lowest part of the ventral surface in between leg joints (Brown, 1982).

Carapace length for *C. pagurus* (Figure 4) was measured as the longest length from the two carapace edges and CD was measured at the greatest depth between the dorsal and ventral surface. Carapace width was the distance from the dorsal edge of the carapace between the eyes to the posterior edge of the abdominal flap.

Figure 3. Hand-made mesh pots used for the aquarium trials. Pot size differed for the three different sized species used.

N. puber CD was measured at the greatest depth between the dorsal and ventral surface, whilst CW was measured from the center of the two anterior teeth between the eyes to the center of the abdominal flap. The distance between the two outermost carapace horns was measured as CL.

The type and number of the escape gap and the date and start time of each animal's trial was noted. Individuals were submerged in the pot over night, for a minimum of 24 hours before escape success or failure was recorded. Food (white fish) and shelter (rock hide) was provided outside of the pots as a lure. Animals which did not escape were fed every seven days. Each animal was trialed three times in each gap so the results would be suitable for statistical analysis.

4.3 Statistical Analysis

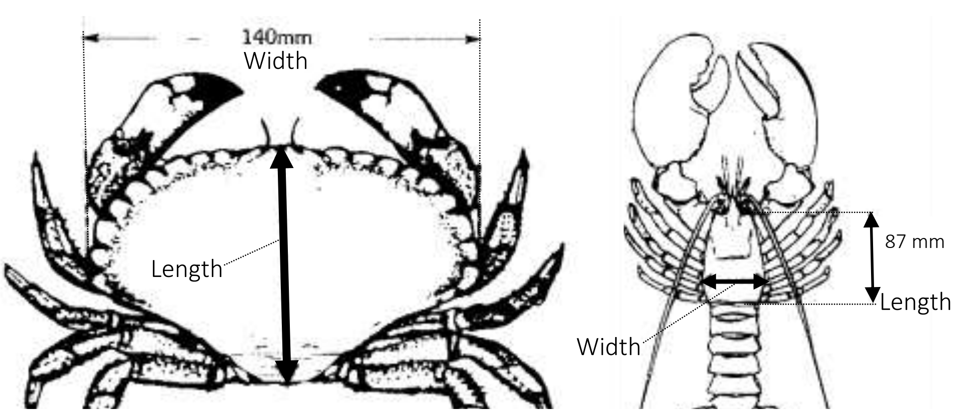


Figure 4. Carapace width and length dimensions for *Cancer pagurus* and *Homarus gammarus* (Edited from Southern IFCA 2011)

All results in this study were recorded onto waterproof paper then inputted into Microsoft Excel spread sheets. Minitab 17 statistical software with significance set at 95% was used for all analysis.

The MLS body dimension of animals retained by the gaps was used for statistical analysis. Each replicate was tested for normality using the Ryan-Joiner test (similar to Shapiro-Wilk test) and if the data was normal a One-Way ANOVA was used to test for significance. Alternately a non-parametric Kruskal-Wallis ANOVA was used for non-normally distributed data. As no significant differences were seen between replicates, data was pooled into samples. The difference between retained and escaped size samples for each gap was tested using a 2 Sample T Test (parametric) or a Mann-Whitney U Test (non-parametric).

A One-Way ANOVA (parametric) or a Kruskal Wallis One-Way ANOVA (non-parametric) was then preformed to determine if the gaps retained significantly different population sizes and different retention percentages. If significant differences were found a Tukey Pairwise comparison was used to identify where those differences lied.

For the 3D bristled gap position data, raised or standard, replicate data was pooled then was tested using either a 2 Sample T Test (parametric) or the Mann-Whitney U Test (non-parametric). This analysis was repeated for the comparison of the current data to that of Hyland's (2012) and Gravestock's (2014) data.

Finally, the overall percentage retention and escape of all data was calculated and plotted onto bar charts for visual comparison and *p*-values and data information was tabulated.

4.4 Field trials

Field trials took place between the 17th and 25th March 2015 near Christchurch Harbour on Christchurch ledge in the Southern IFCA district. A total of 5 fishermen were operating from Christchurch Harbour across depths from 3 to 21m. All parlour pots used had identical construction consisting of a rubber wrapped metal frame, plastic base, stretched mesh size of 4 cm and a plastic cylindrical entrance on the top of each pot.

Twelve escape gap panels (Figure 2) and twelve 45 x 87mm escape gaps were fitted to two strings of trapping pots. Each string had twenty pots of the dimensions 0.75 x 0.5 x 0.5m with two internal compartments; the entrance compartment and holding compartment. Pots were separated by 18m of rope making both strings 380m long with a marker buoy and a flag at either end. The two end pots of each string were not used for data collection as these have been proven to show higher catch per unit efforts (CPUEs) (Bell et al. 2001). Gaps and panels were fitted to the bottom half of the pots, roughly 50mm above the base, in the alternating pattern gap, panel, and control, so that samples would not be biased by location or population size differences (Figure 5.). Strings were shot from east to west, with salted and non-salted bait alternated between pot triplets to eliminate bait bias. Strings were soaked for 24 hours before hauling.

Figure 5 Set up of gear configurations typical of crustacean trap fisheries. Lengths vary depending upon conditions (Edited from Seafish 2009)

Over four trips (Figure 6) a total of 52 *H. gammarus*, 169 *N. puber* and 388 *C. pagurus* were measured from the three pot types. The latitude and longitude of each start and end marker for each string was recorded as well as the date, time, soak time, number of empty pots, bycatch and blocked gaps. Upon hauling, the crew and skipper would split the animals into nine buckets; three for each pot type and one for each species. The CL, CW and CD were measured using plastic 190mm Vernier calipers. The information was recorded using a Dictaphone.

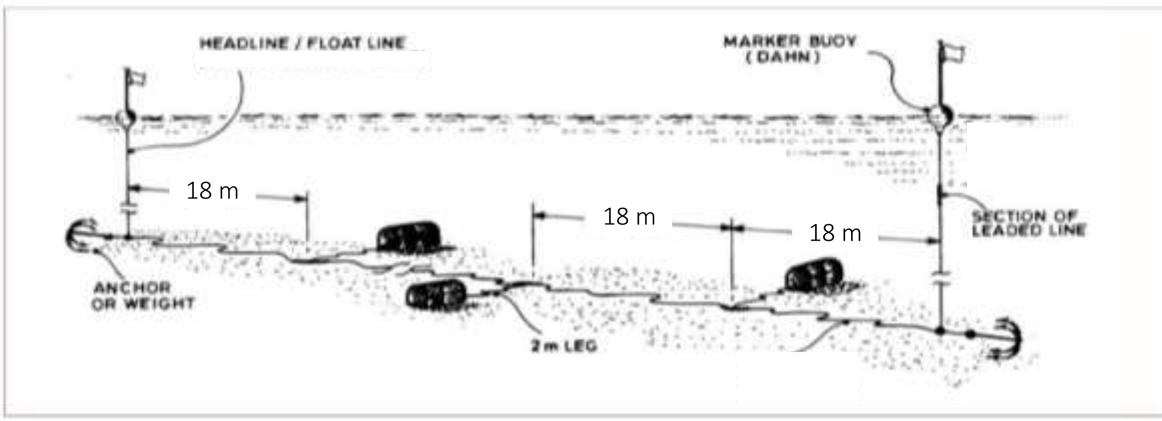


Figure 6. Set up of gear configurations typical of crustacean trap fisheries. Lengths vary depending upon conditions (Edited from Seafish 2009).

4.5 Statistical Analysis

String samples were tested for normality, then differences between pot types were tested and as no differences were found between strings, samples were pooled into pot type and analysed for a difference between the mean retained sizes. Either a One-Way ANOVA (parametric) or a Kruskal-Wallis ANOVA (non-parametric) was used for this testing.

The frequency of 2mm size classes for *C. pagurus* and 1mm for *H. gammarus* and *N. puber* was counted for each pot type and converted into cumulative percentage frequency. Each data type, for each species was split into two groups; >MLS^{-5}mm/>MLS and <MLS^{-5}mm/<MLS, and the difference seen between pot types was analysed using a One-Way ANOVA (parametric) or a Kruskal-Wallis ANOVA (non-parametric).

The frequency of the size classes and cumulative frequency were displayed as bar charts and line graphs for visual comparison. *P*-values and summary data were tabulated.

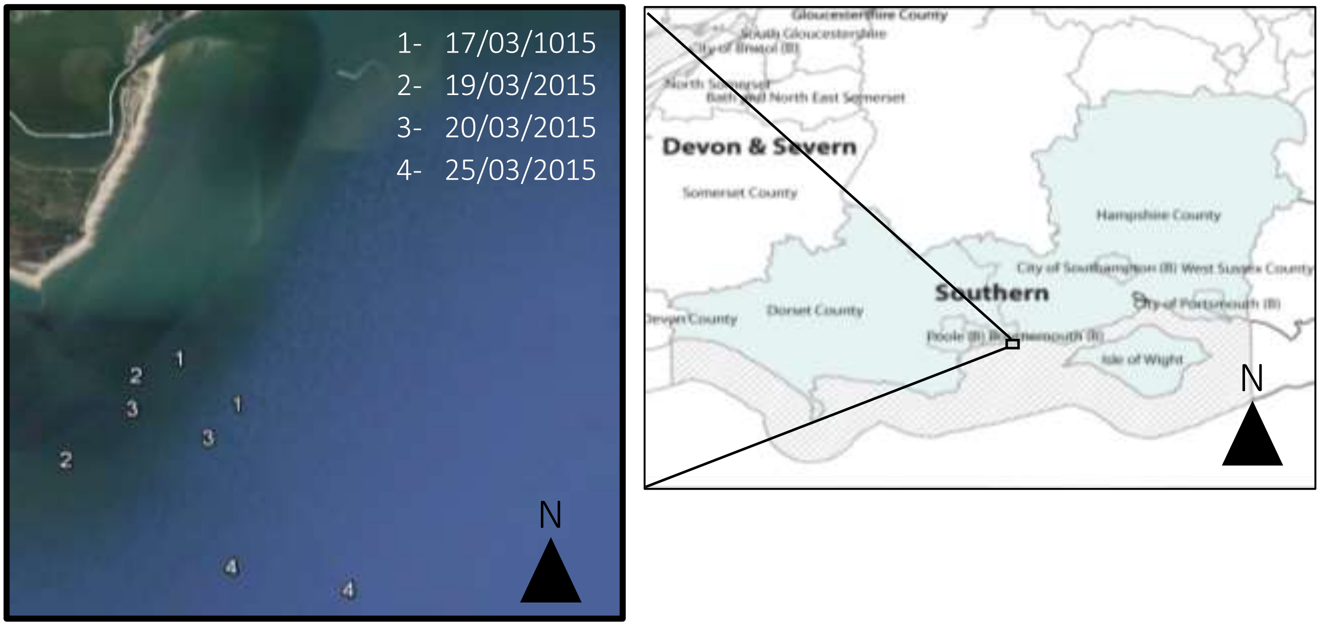


Figure 7. Location of field trial strings (east end) for all four trips marked by trip number (white legend). Christchurch Ledge field area marked on Southern IFCA map by rectangle (Image courtesy of Google Earth).

4.6 Size selectivity curves

The SELECT (Share Each Length's Catch Total) model was applied to size frequency data of *C. pagurus* found in 45 x 87mm gaped pots. The model allows for the comparison of two or more fishing gear types that are fished at the same time where one has an unknown size selectivity (Treble et al. 1998). Using a Microsoft Excel Spreadsheet with SOLVER add-in and instructions developed by Tokai (1997) the model was fitted to the data using a maximum likelihood estimation procedure for two size selectivity functions which generated selectivity curves. Detailed explanation of the methods and equations can be found in (Tokai 1997).

5 Results

5.1 Bristled gap standard positon

Each of the bristled escape gaps had different strength bristles in order to determine which type was best able to retain oversized individuals but release undersized *C. pagurus* and *N. puber*. Varied levels of effectiveness (Figure 7) were seen with gap C proving too inflexible for all but the smallest edible crabs of ≤97mm CL and zero *N. puber* to escape.

The soft gap A allowed high rates of escape for both species and all gaps retained 100% of oversized *C. pagurus* with 88% of undersized *C. pagurus* individuals able to escape making it the most effective gap for this species. A significant difference was observed in the size of retained individuals between gaps C and A, and C and B with mean sizes of 128, 139.5 and 142mm respectively (Table 4). For *C. pagurus* each gap showed significantly different retained and escaped size samples (Table 3).

Table 3. Results of the statistical analysis between the sizes of retained and escaped individuals for each of the three bristled gap types in standard and raised position. Denoted as P – values. ID represents insufficient data produced for testing, (-) indicates where gap was not trialed.

Design	*H. gammarus*	*C. pagurus*	*N. puber*
A – Soft	ID – 1 escape only	<0.001	0.002
A – Soft RAISED	-	<0.001	0.001
B - Medium	All Retained	<0.001	0.221
B – Medium RAISED	-	<0.001	All Retained
C - Hard	-	<0.001	All Retained
C – Hard RAISED	-	-	-

There was no significant difference between the sizes of retained *N. puber* for the three gaps and whilst 92% of undersized *N. puber* escaped from gap A indicating it was effective, only 38% of oversized individuals were retained (Table 4). However, there was a significant difference between the escaped and retained samples showing means of 63.7 and 67.9mm (Table 3) and the percentage retention of each gap were significantly difference (Table 4). A large proportion (73%) of undersized individuals were retained by gap B, although 33%, of oversized individuals managed to escape. Video footage of an oversized *N. puber* escaping from gap A demonstrated a behavior in which the animal employed the floor of the aquarium to gain the necessary leverage to push through the opening. This required that the gap be re-tested at a height above which the pot base could not be utilised in this manner.

Table 4. Results of the statistical analysis between the size of retained individuals for the three bristled gaps in standard and raised position, and the percentage retention of either of the two size groups (<MLS-5/<MLS, >MLS-5/>MLS) between the three (standard) or two (raised) 3D bristled gaps. Denoted as p – values. ID represents insufficient data produced for testing.

Species	*Percentage retention of* $<MLS^{-5}/<MLS$	*Percentage retention of* $>MLS^{-5}/>MLS$	*Size of retained individuals*	*Gap pair wise significance*
H. gammarus Standard	ID – 1 escape only	All Retained	ID	n/a
H. gammarus RAISED	-	-	-	-
C. pagurus Standard	0.183	All Retained	0.001	A soft vs C hard B medium vs C hard
C. pagurus RAISED	0.003	All Retained	0.379	n/a
N. puber Standard	0.001	0.002	0.105	n/a
N. puber RAISED	0.044	<0.001	0.244	n/a

Only one *H. gammarus* of CL 76mm and CD 43mm escaped through gap A. This supports Gravestock's (2014) findings and reinforces the requirement for a second gap in the escape panel design if the gear is to be suitable for all three species. Therefore, the null hypothesis was rejected for *C. pagurus* only, in all three gaps.

5.2 Bristled gap raised position

Gap C was not tested in the raised position due to its ineffectiveness in the first trials. Raising the gap had a significant effect on the size of escaped *N. puber* and was therefore successful in reducing the unwanted behavior ($t(27)= -2.99$, $p=0.006$). It eliminated the escape of individuals over 63mm CL and 26mm CD for gap A but prevented escape of both size classes for gap B, proving it ineffective. However, gap A raised, enabled 61% of undersized *N. puber* to escape and resulted in a significant difference between escaped and retained mean sizes (62 and 66mm) (Table 3) (Figure 8). Significant differences were seen between the percentage retentions of each of the two gaps.

C. pagurus escape success fell to 62 and 29% when gaps A and B were raised and, unfortunately a significant reduction in the mean retained size between raised and standard gaps was observed ($t(55)= -2.81$, $p=0.007$) ($t(42)= -2.68$, $p=0.010$). For gap A the mean retained size

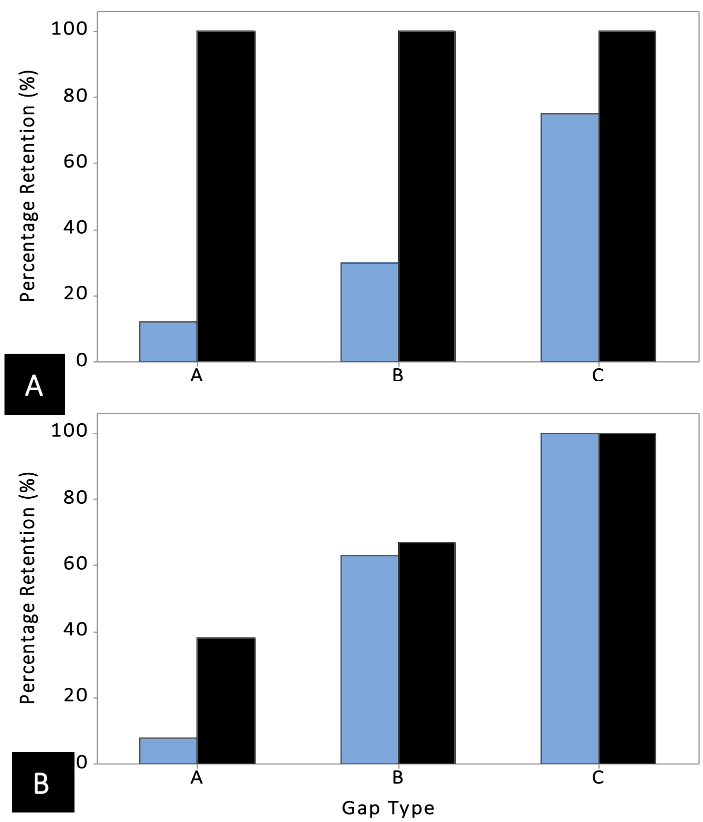


Figure 8. The effectiveness of three different strength bristled escape gaps in aquarium trials. Shown as a percentage retention for A) *Cancer pagurus* and B) *Necora puber* of the two size classes BLUE: <MLS-5mm/<MLS and BLACK: >MLS-5mm/>MLS.

dropped by 6.7mm whilst gap B decreased from 139.5 to 132.7mm. Individuals ≤128mm CL were retained at a higher frequency when the gap was raised.

Nevertheless, closer scrutiny of the data revealed unmatched samples, as large animals of 152 and 158mm had died before the raised trials were conducted so the means of the standard trials were skewed. Comparison when these points were removed from the standard positon data set, with matching samples, resulted in no significant difference between the retained size of *C. pagurus* for the raised and standard gaps (U(39)= -364.5, p=0.325) for either A or B (t(49)=-1.4, p=0.169). Each gap's retained and escaped mean sizes remained significantly different at 11.8 mm difference for gap A, and 13.7mm for B (Table 3).

Raising the gaps proved to be effective and, therefore, the null hypothesis for these trials was rejected for all but *N. puber* in gap B.

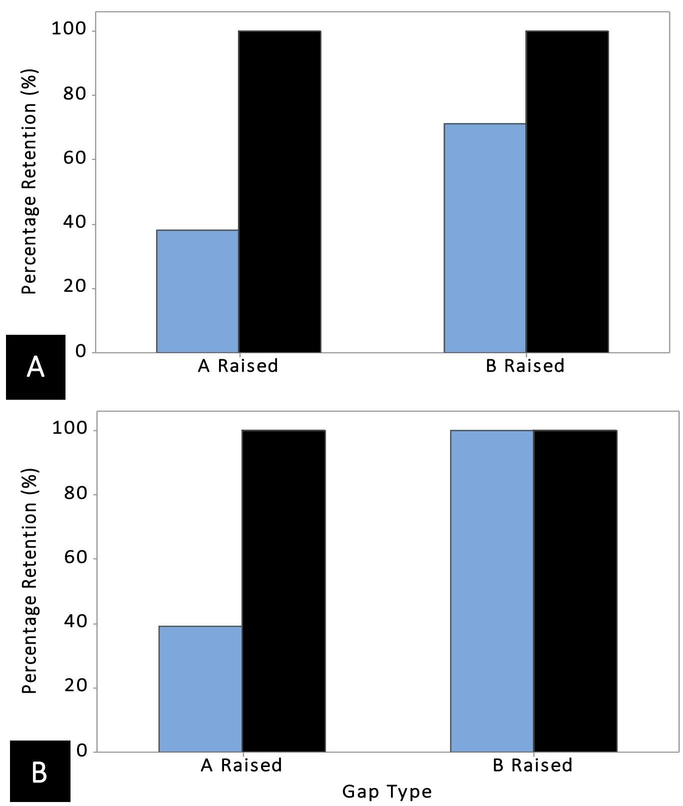


Figure 9. The effectiveness of two different strength bristled escape gaps raised 50 mm above the pot base in aquarium trials. Gap C not tested due to earlier ineffective result. Shown as percentage retention for A) *Cancer pagurus* and B) *Necora puber* of the two size classes BLUE: <MLS-5mm/<MLS and BLACK: >MLS-5mm/>MLS.

5.3 Circular escape gaps

The four different diameter escape gaps showed mixed effectiveness. For *N. puber* each gap retained and facilitated the escape of a significantly different mean size sample, where the 55mm diameter allowed for an escape mean of 59mm compared to a retained mean of 66mm (Table 5). However, there was no significant difference between the mean size retained by all four sized gaps with the 51, 53, 55 and 57mm openings having means of 65, 66, 66 and 66mm, respectively (Table 6).

Conversely, percentage escape calculations indicated a clear difference between the effectiveness of the four gaps (Figure 9) which all retained 100% of oversized individuals but allowed the escape of 0, 32, 50 and 77% of undersized individuals (Table 6). The largest animal that escaped measured 63mm in CL with a 56mm CW. Manual tests confirmed that animals whose CW measurements indicated they should be able to escape, could not, as demonstrated by aquarium trials. This was due to the extra length of the carapace teeth adding 1 - 2mm to the overall CW.

Table 5. Results of the statistical analysis between the sizes of retained and escaped individuals for each of the four circular gap diameters. Denoted as *p* – values. ID represents two few data produced for testing and (-) indicates where a gap was not tested.

Design	*H. gammarus*	*C. pagurus*	*N. puber*
51mm	ID – 1 escape only	-	All Retained
52mm	<0.001	-	<0.001
55mm	<0.001	-	<0.001
57mm	<0.001	-	<0.001

A clear and significant difference was seen between the mean retained size of *H. gammarus* for the 51 and 57mm gaps, at 82 and 86mm, respectively (Table 6). Both the 53 and 55mm gaps retained a mean size of 84mm CL. The three larger gaps showed significant differences between each of their retained and escaped mean size with the 55mm gap showing sizes of 76 and 84mm (Table 5). The 57mm gap had the largest difference; however, this was interpreted with caution as the sample sizes were smaller and no animals were tested at the lower limit of the >MLS^{-5}mm category (83 and 84mm).

The reduced retentions of *H. gammarus* were a result of the escape of animals with a CL of 82mm and this saw retentions of 100, 95.8, 87.5 and 80% for each of the four gaps in ascending order. Percentage escape of undersized animals increased with gap size from 6% for the 51mm, to 93% for the 57mm gap. The 57mm gap retained 80% of oversized individuals which, because of the lack of data, was deemed unreliable.

Table 6. Results of the statistical analysis for the size of retained samples between the four circular gap diameters. Denoted as *p* – values (-) indicates where a gap was not tested.

Species	*Percentage retention of <MLS^{-5}/ <MLS*	*Percentage retention of >MLS^{-5}/ <MLS*	*Size of retained individuals*	*Gap Pairwise significance*
H. gammarus	<0.001	0.299	0.003	51mm vs 57mm
C. pagurus	-	-	-	-
N. puber	0.046	All Retained	0.669	n/a

Therefore, the 55mm gap was deemed most effective and selected for field trials as this gap released 50% of undersized *N. puber* and *H. gammarus.* It retained 100% of oversized *N. puber* and only enabled one oversized *H. gammarus* individual with a CL of 82mm to escape. It was to be combined with the soft (gap A) bristled 45 x 87mm gap as this retained 100% of oversized and released 61% of undersized crabs suggesting an improvement should be seen in the field for all three species. The null hypothesis for the circular gaps was rejected for *H. gammarus* 57mm and for all but the 51mm gap for *N. puber*.

5.4 Comparisons to Hyland and Gravestock

Comparison of data from Hyland's (2012) aquarium trials for the 57mm gap showed a significantly different mean size of retained individuals (U(27)=132.0, *p*=0.002) (Table 7). A smaller mean of 84mm was observed in the previous study compared to 87mm seen in this research. There was no significant difference between the median size of either trials total sample (U(79)=1948.5, p=0.165). Only 25% of oversized individuals were retained by Hyland's 57mm circle gap compared to 80 % in the current trials. Hyland's 57mm circle failed to retain all but one *N. puber* compared to the current study which retained 100% of oversized individuals. Therefore, the null hypothesis of no significant difference between the two size groups of retained individuals was rejected.

Table 7. Comparative data for the circle gap diameter 57mm trialed with *H. gammarus* in the two aquarium trials by Hyland (2012) and the present study (2015).

Trial	Mean size retained (mm)	Mean size escaped (mm)	Size range (mm)	Percentage <MLS^{-5} retained	Percentage >MLS^{-5} retained
Hyland	84	78	55-87	25	25
Present study	87	78	71-92	7	80

The data for the original design bristled 3D gap (Gravestock, 2014) was compared to this second study (Table 8). No significant difference was seen between the two retained size samples for either *C. pagurus* or *N. puber* (t(12)=-1.63, *p*=0.130, t(19)=0.52, *p*=0.606). Both studies proved the gap to be 100% effective at retaining oversized *C. pagurus* but the current gap allowed for the escape of 50.5% more undersized individuals. This is most likely due to changes in construction of the gap utilising more easily deformable bristles, thereby increasing the gap height to its maximum 45mm. Small increases of 10% and 11% for retained and escaped individuals of *N. puber* were seen in the current study compared to Gravestock's. The comparison

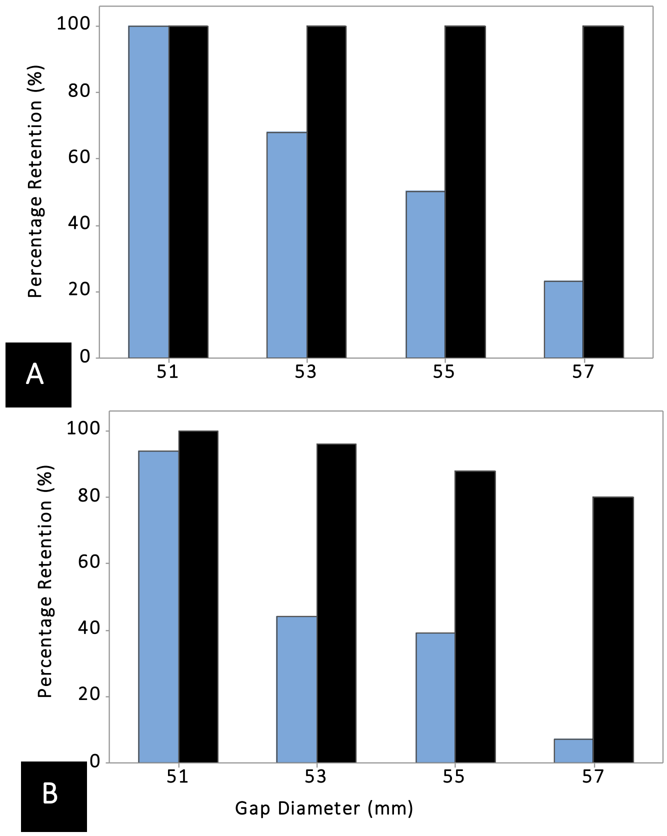


Figure 9. The effectiveness of four different diameter circle escape gaps in aquarium trials. Shown as percentage retention for A) *N. puber* and B) *H. gammarus* of the two size classes BLUE: <MLS^{-5}mm/MLS and BLACK: >MLS^{-5}mm/MLS

therefore for Gravestock's bristled gap allows the null hypothesis to be accepted for both species although improvements were made for *C. pagurus* escape rates in the current study.

Table 8 Comparative data for the 3D soft bristled gap trialed with *N. puber* and *C. pagurus* in the two aquarium trials by Gravestock (2014) and the present study (2015).

Trial (Species)	Mean size retained (mm)	Mean size escaped (mm)	Size range (mm)	Percentage <MLS^{-5} retained	Percentage >MLS^{-5} retained
Gravestock *(N. puber)*	66.5	64.4	59-72	62.5	90
Present study *(N. puber)*	65.7	60.75	57-70	22	100

Gravestock *(C. pagurus)*	137.1	130.7	124-148	50	100
Present study *(C. pagurus)*	142.8	107.4	118-158	39	100

5.5 Panel field trials

No significant difference was seen in the size of *H. gammarus* and *N. puber* retained by the three pot types control, panel and gap; and therefore, the null hypothesis was accepted for these species (Table 9).

However, for *C. pagurus* field trials confirmed Gravestock's (2014) finding that the mean size of retained animals found in pots with a single 45 x 87mm gap increases significantly to 133mm compared to controls (123mm) and paneled pots (130mm) (Table 9). There was a significantly higher frequency of <MLS^{-5}mm animals in control pots compared to gap and paneled pots ($F(2,81)=17.41$, $MSE=5.788$, $p=<0.001$) (Figure 10). The percentage of >MLS^{-5}mm animals increased by 24% for gapped pots and 11% for paneled pots compared to controls. Therefore, the null hypothesis could be rejected for *C. pagurus* between gap and control pots.

Conversely, there was no significant difference between the size, or frequency, of *N. puber* caught in all three pot types (Table 9, Figure 11). However, the paneled pot produced the highest percentage of MLS animals at 63% of the catch, and also increased CPUE by 0.4, to 1.11, compared to the control and gapped pots.

Table 9. Results of the statistical analysis between the percentage retention of </>MLS-5/ MLS mm groups and the size of retained individuals between the three pot types; control, panel and gap. Denoted as p – values. ID represents two few data produced for testing.

Species	*Percentage retention of <MLS^{-5}/ <MLS*	*Percentage retention of >MLS^{-5}/ <MLS*	*Size of retained individuals*	*Gap Pairwise significance*
H. gammarus	ID	ID	0.689	n/a
C. pagurus	0.235	0.623	0.003	Gap vs Control
N. puber	0.428	0.428	0.065	n/a

Disappointingly, CPUE for MLS *H. gammarus* was very low at this time of the year showing a maximum at 0.2 for the control pots, and just 0.4 for animals >MLS^{-5}mm. Unfortunately, too few animals were collected for statistical analysis.

Therefore, field trials were unfortunately unsuccessful at showing the effectiveness of the escape gap panel which is discussed in detail in the discussion.

It was noted that most pots contained high numbers of *C. pagurus*. On three occasions pots were hauled with a crab or lobster trapped in the gap opening therefore blocking the exit point for all other animals, and this resulted in high numbers of both over and undersized individuals.

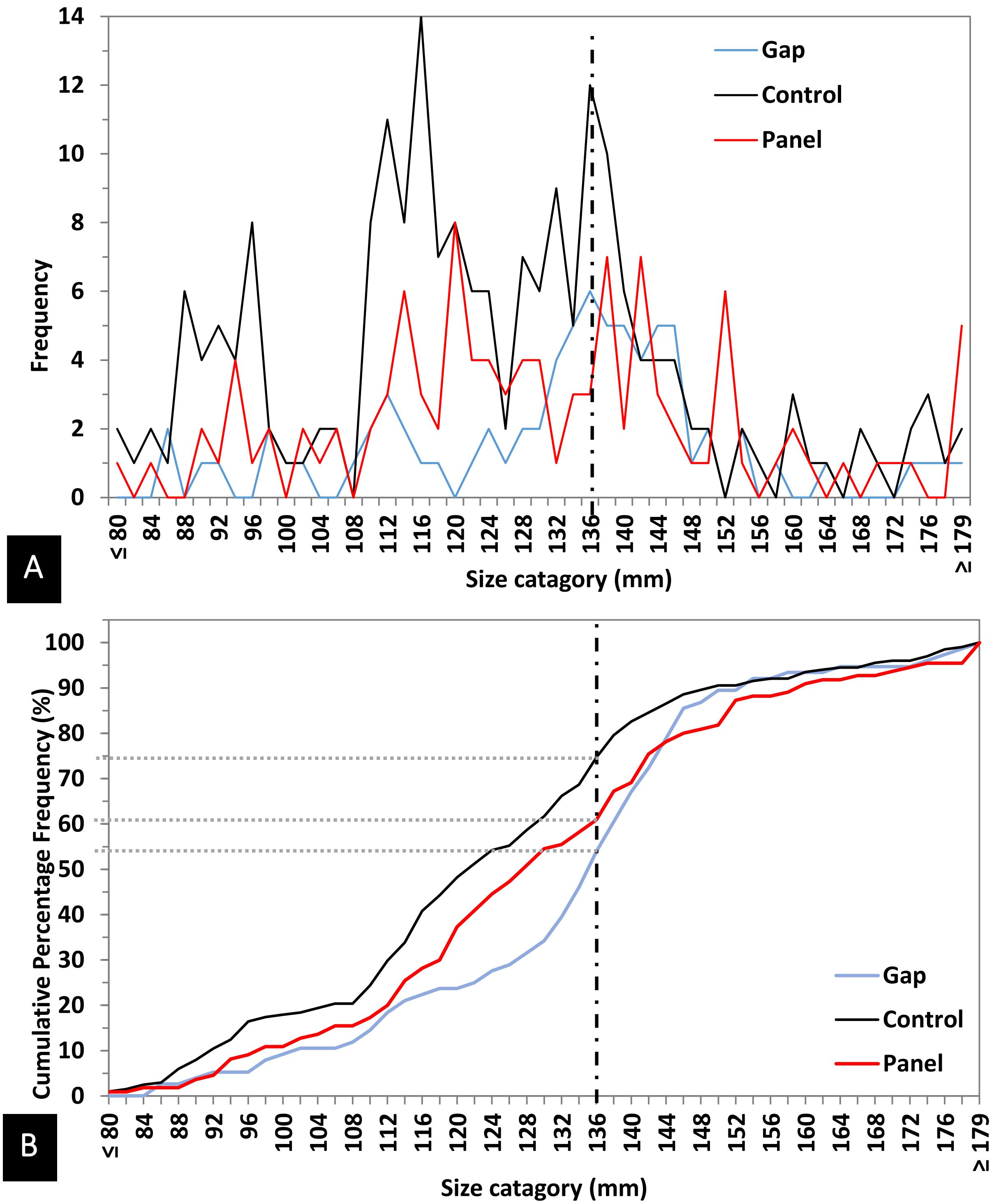


Figure 10. The frequency (A) and cumulative percentage frequency (B) of *C. pagurus* found in control pots, pots with a 45 x 87mm escape gap and pots with the escape gap panel. Black line indicates MLS^{-5}mm. Size categories in 2mm groups excluding the two end groups which are ≤ 80mm and ≥ 179mm.

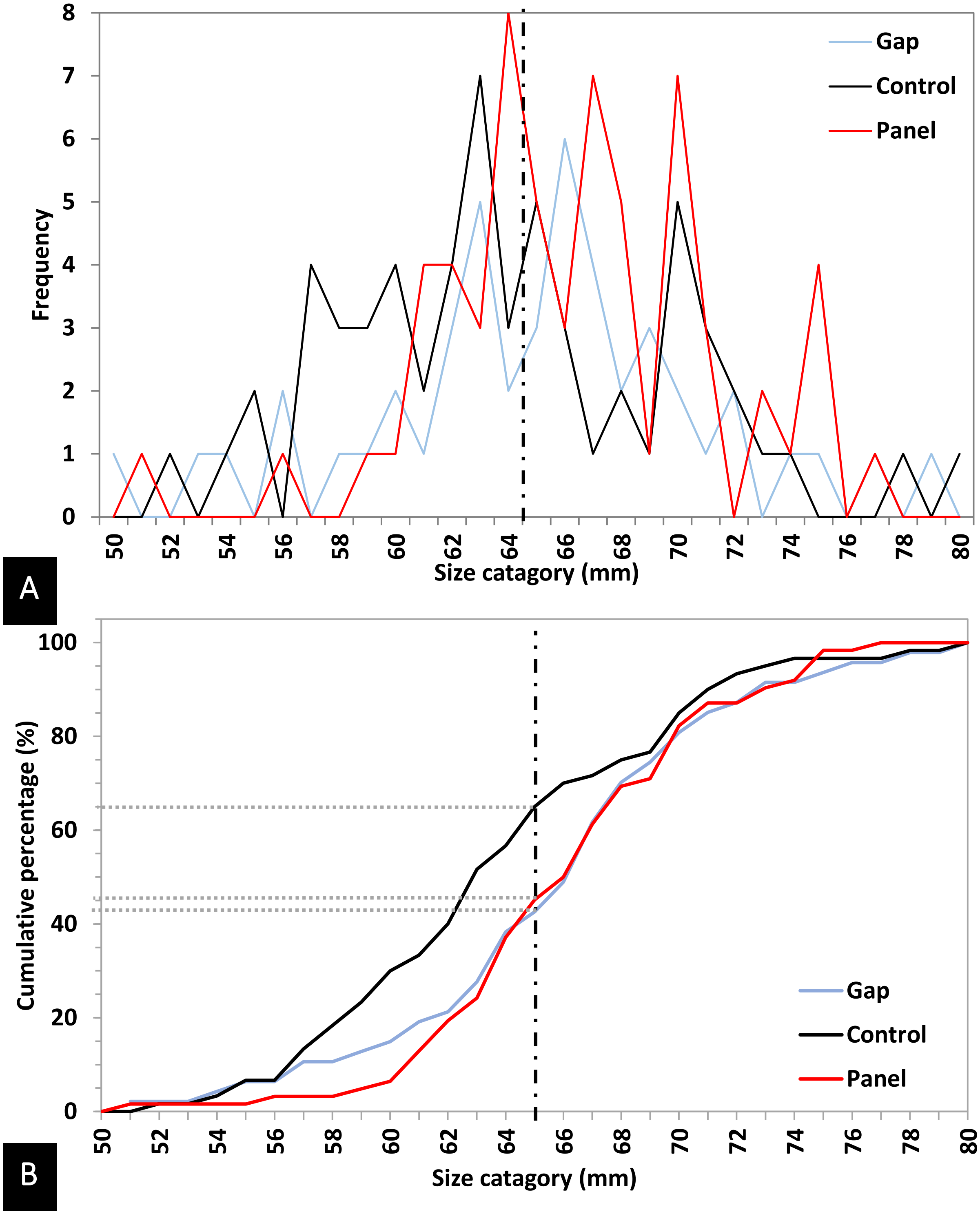


Figure 10. The frequency (A) and cumulative percentage frequency (B) of *N. puber* found in control pots, pots with a 45 x 87mm escape gap (Gap) and pots with the escape gap panel (Panel). Black dashed line indicates MLS. Size categories in 1mm groups.

5.6 SELECT Size Selectivity Curves

As the *C. pagurus* 45 x 87mm data set proved significantly different in the field trials the SELECT model could be fitted to this data set only. Both the Richards and Logistic model fitted equally well based on their similar AIC values (Table 10) and showed a steady increase of selectivity with carapace length (Figure 12). As there was no sharp incline it was concluded that the gap was only mildly selective for larger animals. The model predicts that for animals of 135mm and below selectivity will be less than 0.3. Therefore, the majority of undersized crabs will be able to escape.

Comparison of the model fitted to Gravestock's *C. pagurus* 45 x 87mm data set highlights a slightly better fit of the model to her data. The current data set gave a much higher L_{50} of 178.79mm indicating in that the panel was operating with less effectiveness than the 45 x 87mm rectangle gap for *C. pagurus*. However, both data sets did not reach 100% selectivity (Figure 12).

Table 10 Comparative parameter values for the SELECT model fitted to *C. pagurus* field trial retention data for a 45x87 mm escape gap. Parameters; constants a, b and δ, L50 (the size (mm) of an animal at 50% retention), selection range (SR) and Akaike's Information Criterion (AIC) for Logistic and Richards curves. SR is L25- L75. AIC describes the goodness of fit of the model to the data, lower values indicate a closer fit.

	Parameter						
Pot Type	Curve	*A*	*B*	δ	*L*50	SR	AIC
Current Study	Logistic	-3.52	0.02	-	178.79	111.54	74.73
	Richards	0.00	0.01	0.138	180.85	129.73	76.25
Gravestock (2014)	Logistic	-6.34	0.04	-	156.89	54.35	67.15
	Richards	-3.64	0.03	0.75	156.75	60.77	68.60

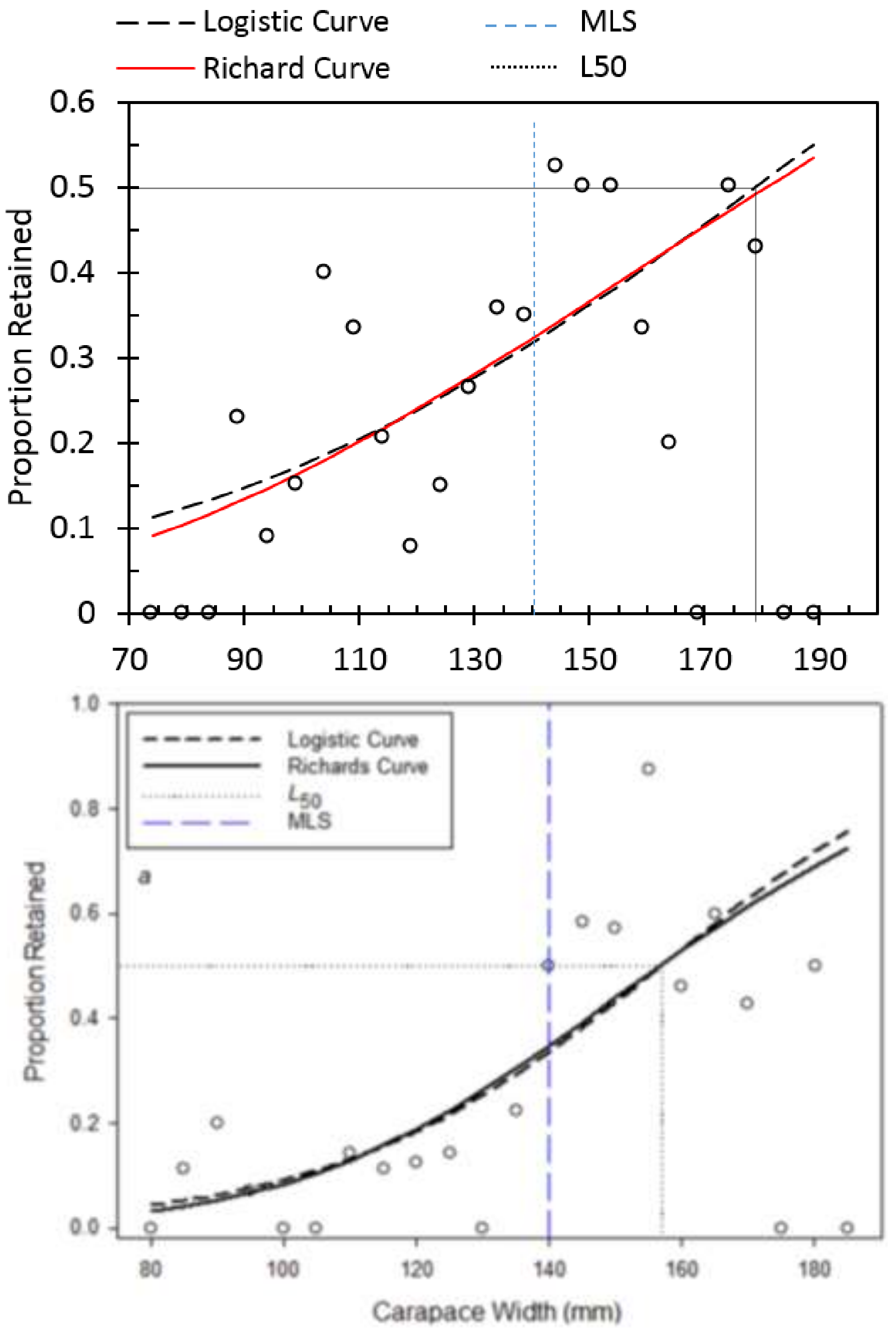


Figure 11. Size selectivity curves, Logistic (dashed lines) and Richard's model (RED solid lines) fitted to the proportion of retained *Cancer pagurus* in escape gap field trials of an 87 x 45mm escape gap design. A) Current study and B) Gravestock (2014) study. Frequency data was clustered in 5mm size classes. The blue dashed line represents the minimum landing size and the dotted line represents the size at which 50% retention occurs (*L*50).

6 Discussion

6.1 Aquarium trials

Escape gaps are used around the world as an effective tool for improving the selectivity of trap fisheries (Shanks et al. 1997; Everson et al. 1992; Linnane et al. 2011). This is the first study investigating a three species fishery with the aim of creating an escape gap device that works simultaneously for; *H. gammarus, C. pagurus* and *N. puber*. The results of aquarium trials demonstrate that it is possible to produce an effective escape gap suited to two species with differing morphologies. Undersized *C. pagurus* will push through a 45 x 87mm soft bristled gap, whilst oversized *N. puber* can be successfully retained by the same gap when it is positioned 50mm above the base of the fishing pot.

Meanwhile, for *H. gammarus*, a 55mm diameter circle gap will allow most undersized individuals to escape, whilst still retaining oversized individuals of both *H. gammarus* and *N. puber*. Few studies have demonstrated escape gaps suited to more than one species (Brown 1982; Krouse 1978) and most focus solely on lobster species due to their higher monetary value (Murray et al. 2009; Polovina et al. 1991; Nulk & Vernon 1978). Escape gaps that permit the escape of two species can be of huge benefit to fishermen who pot for both crab and lobster simultaneously. Effective gaps for both target species have the potential to significantly reduce pot sorting time compared to single species gaps and improve the survival of future stocks leading to a more productive and sustainable fishery.

Behavioural observations during this study confirmed that both UK crab and lobster species escaped more often over night when the animals were more active whilst searching for food and suitable habitat (Brown 1982; Smith et al. 1999). Further to this, escape behaviour appears to be learned, as some individuals did not escape in their first trial, but those that had escaped previously showed several escapes within 20 minutes of being put back into the pots. This is because escape success depended upon the precise orientation of the carapace to the escape gap and with larger crabs and lobsters required the claw/s to be positioned through the opening first (Winger & Walsh 2007). If this behaviour is carried through into the field the effectiveness of the gaps may increase overtime as the undersized animals learn where and how to escape from parlour pots. However, this may result in larger quantities of bait being required per trip, as smaller animals may learn that pots are a source of food. They may learn to enter, eat and then leave, thereby removing a certain amount of bait before larger animals get there, increasing fishermen's costs and potentially reducing their yield.

In my aquarium trials no animals achieved carapace depth or width reductions in order to escape from a gap smaller than their critical body dimension, however this behaviour has been seen by Nulk (1978). This suggests that *C. pagurus* species are not capable of reducing their carapace depth by even 1 mm in order to escape whilst a circular escape gap would require body depth reduction in *H. gammarus* which is not possible. Therefore, the chance of oversized animal escape is reduced providing stakeholders with the confidence that their catch will not be negatively affected through oversized animal escape.

Gap shape has been evaluated repeatedly in pot selectivity research (Estrella & Glenn 2006; Krouse 1978; Boutson et al. 2005). Circles versus rectangles have been shown to show both little difference and significant difference when retaining under and oversized crustacean species (Everson et al. 1992; Polovina et al. 1991). My research demonstrates that a circle gap is an effective shape for releasing undersized and retaining oversized *H. gammarus*. Furthermore, the gap has been proved to work for the *N. Puber* crab species so far only tested with rectangle gaps (Shanks et al. 1997; Shelmerdine & White 2011; Hyland 2012). Further comparison to Hyland's (2012) results of *H. gammarus* escape through the 45 x 87mm rectangle show there is no significant difference between the rectangle's or circle's retention and escape sizes ((F=2.42, , p=<0.130), (U(55)= 1217.5, *p*=0.170)).

During my research the gap positon was manipulated in order to reduce legal escape of *N. puber.* A gap that was placed above the base of the pot achieved this aim by increasing the difficulty for *N. puber* to push through the 3D bristles. Escape gap position studies, by Nulk & Vernon (1978) and Boutson et al. (2005), concluded that gaps placed at a lower height on the pot will achieve higher success rates than those placed elsewhere. This would therefore suggest that the increase in positon height of 50mm should have reduced sublegal escape of both *N. puber* and *C. pagurus*. Whilst a small reduction did occur, the gaps position allowed for the escape of over 50% of undersized individuals thereby positively increasing the size selectivity of any pots it may be placed into. As the retention of legal animals is considered of higher importance when designing escape gaps, the exact positioning of the bristled gap is extremely important and the reduction in escape is a sensible sacrifice.

Overall, there have been few studies into the effect of escape gap management techniques on pot selectivity for the UK shellfish fishery. Published studies tend to be outdated and based upon much smaller minimum landing sizes than those used now (Brown 1978 & 1982; Lovewell & Addison 1989). More recent studies have not been published in scientific journals and are generally publications from management bodies (Murray et al. 2009; Clark 2007). Therefore, this project makes an up to date contribution to a relatively unknown field of fisheries management in the UK and will enable future byelaws to be implemented based on sound evidence.

Escape gap design is most frequently based on critical body dimension (Polovina et al. 1991; Brown 1982). The relationship to this dimension and the MLS dimension of each species is required in order to accurately predict the escape or retention of any one individual by an escape gap of a known size (Treble et al. 1998). Here, measurements and escape success of *C. pagurus* through a rectangle indicated that both body depth and width are equally important critical body dimensions, whilst for *H. gammarus* the critical body dimension for a circle is body depth with legs. For *N. puber,* however, body width is critical in predicting the escape behaviour through a circular gap.

6.2 Field trials

The field trials were carried out with a panel 'the panel' of one circle gap 55mm wide and one rectangle 45 x 87mm gap with bristles, installed into twelve parlour pots as well as twelve rectangle gaps 45 x 87mm, installed into twelve further pots.

The field trials indicated that an improvement in the number or proportion of undersized animals could be made if the panel was to be instated into the Southern IFCA fishery. The escape of undersized crustaceans would reduce the sorting time for fishermen, and decrease the mortality and damage incurred to the sublegal animals during and after the sorting process (Tallack 2007; Shanks et al. 1997). Generally, parlour pots that have been fitted with escape gaps may also display increased efficiency for catching legal sized animals. Escape reduces pot saturation and creates more space for additional legal sized individuals to enter (Boutson et al. 2009; Tallack 2007). Individuals who escape should have higher chances of survival as disruption to feeding, homing and predation behaviour is reduced. Thus, effects on growth and limb loss should be low resulting in increased recruitment in the following years (Shelmerdine & White 2011). Recruit increases could be around 5%, based on the discard mortality seen in the red crab fishery caused by the handling and exposure during sorting (Tallack 2007).

Unfortunately no significant change in the mean retained sizes of *N. puber* or *C. pagurus* was found in these field trials and an insufficient number of lobsters were caught to identify any changes. A key factor that may have affected the results of the field trials was the time of year. During March, sea surface temperature is low at around 8°C off the coast of South England, Boscombe (Channel Coastal observatory, 2015). These low temperatures have been correlated to reduced movement of *H. gammarus* individuals on the south coast of England (Smith et al. 1998; Smith et al. 1999; Smith et al. 2001). The very low catch per unit efforts of *H. gammarus* seen during the trials is therefore likely due to inactivity during winter months.

Furthermore, the pots used for this study were soaked for a maximum of 24 hours. Studies investigating the effect of emersion time on crustacean catches have shown that longer immersion times result in higher numbers of MLS *C. pagurus* suggesting time increases the chance of juvenile escape (Gravestock 2014; Bennett & Lovewell 1977; Krouse 1978). For example Pengilly & Tracy (1998) showed that the sublegal to legal ratio of red king crabs decreased with longer soak times of 72h. Whilst this is not the case for *H. gammarus* (Bennett & Lovewell 1977) the high productivity of *C. pagurus* caught at this time of year (Bennett, 1974) may have reduced the entry of *H. gammarus* species through agonistic interactions between single and multiple species or simply through trap saturation (Bell et al. 2001).

The comparative effectiveness of the panel compared to the single 45 x 87mm gap show that the gap was more effective over a 24h time period. Observations during aquarium trials showed that escape through the bristled gap took many attempts and a relatively long duration compared to gaps with no bristled structure. This must be considered when deploying the panel as fishermen leave pots in the water for differing time lengths and therefore not only should their gap choice suit the species they are potting for but also the length of time individuals will have to escape. In addition to this, field trials showed that individual animals can get wedged in the gap opening and therefore block the exit point. In each case this resulted in a very high retention of brown crabs of all size classes. To prevent this from occurring in the commercial setting it is suggested that every pot holds a minimum of two escape gaps or panels as this has been shown to improve the gears efficiency (Lovewell and Addison 1989; Everson et al 1992).

Based on the results of this study I recommend that the escape gap panel be incorporated into the three species fishery of the Southern IFCA on a trial basis as was done with the 45 x 87mm gap (Gravestock 2014). Region wide use of the panel would increase the selectivity and therefore sustainability of the fishery for future years. Furthermore, stake holders would benefit from reduced sorting times and fuel costs and could therefore increase their overall catches and potential income. In particular the panel should be recommended to those who wish to pot for *N. puber* crabs as well as the two more common species *C. pagurus* and *H. gammarus*.

The recommendations of this study to fit the described sized escape gap panel into the SIFCA fishery applies at the current time for the current MLSs of 87mm, 140mm and 65mm. If MLS sizes were altered it would be recommended that further studies should look to increase the size of escape gaps in order to continue their effectiveness at reducing sublegal catch and sorting time. It has been suggested that new escape gaps should be 1mm smaller than the size of the critical body dimension for a legal sized animal (Brown 1982; Murray 2009). However, as this study highlighted where a circular gap is adopted, an extra 7mm should be added to the diameter to account for the width of lobsters legs on top of carapace depth. Furthermore, regional populations of UK shellfish species display different population sizes (Addison and Lovewell 1991) therefore, thought should be given before these gaps are considered for use in alternative areas.

7 Conclusions

This project achieved the aim of designing an effective escape gap panel for the three species crustacean fishery of the Southern IFCA. Aquarium trials determined the effectiveness of seven escape gap designs indicating that a 45 x 87mm rectangle bristled escape gap worked well for *C. pagurus* and *N. puber,* when the gap is positioned 50mm above the base of the pot. Whilst a 55mm circular gap effectively allowed for the escape of undersized *H. gammarus* and *N. puber* simultaneously. Most importantly, both escape gaps retained 100 percent of oversized animals, giving fishermen the confidence that their catches will not be negatively affected by installing the gaps into their pots.

Unfortunately, field trials of the bristled rectangle and circle combined into an escape gap panel, did not affect the overall mean size of retained animals. This is believed to be due to the cool water temperature seen during field trials, which leads to reduced activity of *H. gammarus* and pot saturation by *C. pagurus*. However based on aquarium trials little confidence can be found in these results and, a small reduction in the proportion of undersized crabs was observed in paneled parlour pots suggesting the panel may work well in the field throughout the warmer months of April - September. Ultimately, the use of the escape gap panel as a fishery management tool throughout the Southern IFCA district should lead to a more sustainable and profitable fishery by reducing sorting time for fishermen and the damage incurred to undersized stocks.

7.1 Further work

Based on the positive yet insignificant results obtained from the field trials of this study I suggest that further trials be carried out over the course of a full potting season. This should allow for a reliable sample size to be produced for *H. gammarus* in order for full statistical analysis and fair mean values to be produced. A study which runs throughout the spring, summer and autumn months would more fairly represent the whole fishing season for the Southern IFCA district and would hopefully reduce the dominant crab bias within the pots.
As the aquarium trials of this study failed to determine if the 57mm escape gap was reliably effective a set of field trials which compared the two circular gap sizes 55 and 57mm would be beneficial to allow for the possibility that the 55mm gaps effectiveness can be improved upon.

8 References

Albornoz, V.M. & Canales, C.M., 2006. Total allowable catch for managing squat lobster fishery using stochastic nonlinear programming. *Computers and Operations Research*, **33(8)**, pp.2113–2124.

Anon, 2015. *SEA FISHERIES (MISCELLANEOUS PROVISIONS) (JERSEY) REGULATIONS 1998*,

Arana, P.M., Orellana, J.C. & De Caso, Á., 2011. Escape vents and trap selectivity in the fishery for the Juan Fernández rock lobster (*Jasus frontalis*), Chile. *Fisheries Research*, 110, pp.1–9.

Atlantic States Marine Fisheries Commission, 2013. *ADDENDUM XVII TO AMENDMENT 3 TO THE INTERSTATE FISHERY MANAGEMENT PLAN FOR*,

Bell, M.C., Addison, J.T. & Bannister, C.A. 2001. Estimating trapping areas from trap-catch data for lobsters and crabs. Mar. Freshwater Res., **52**, 1233-1242.

Bennett, D. B. (1974) The effects of pot immersion time on catches of crabs, *Cancer pagurus* L. and lobsters, *Homarus gammarus* (L.). *Journal du Conseil* **35.3**: 332-336.

Bennett, D.B. & Lovewell, S.R.J., 1977. The effects of pot immersion time on catches of lobsters *Homarus gammarus* (L) in the Welsh coast fishery. *Fisheries research technical report*, **36**, pp.1–4.

Beutel, D. et al., 2008. Bycatch reduction in the Northeast USA directed haddock bottom trawl fishery. *Fisheries Research*, **94,** pp.190–198.

Boutson, A. et al., 2009. Use of escape vents to improve size and species selectivity of collapsible pot for blue swimming crab *Portunus pelagicus* in Thailand. *Fisheries Science*, **75(1)**, pp.25–33.

Boutson, A., Mahasawasde, C. & Mahasawasde, S., 2005. *The Suitable Escape Gap of Selective Collapsible Crab Trap and Appropriated Bait for Blue Swimming Crab Trap Fishery*. Kasetsart University.

Brewer, D. et al., 1998. An assessment of Bycatch Reduction Devices in a tropical Australian prawn trawl fishery. *Fisheries Research*, **36**, pp.195–215.

Brown, C.G., 1978. Trials with Escape Gaps in Lobster and Crab Traps. , p.6.

Campbell, R. et al., 2010. The reduction of cod discards by inserting 300 mm diamond mesh netting in the forward sections of a trawl gear. *Fisheries Research*, **102,** pp.221–226.

CEFAS, 2011a. Cefas Stock Status 2011 : Edible crab (*Cancer pagurus*) in the Central North Sea. , pp.1–2.

CEFAS, 2011b. Cefas Stock Status 2011 : European lobster (*Homarus gammarus*) in Southeast & South Coast. , pp.1–2.

Clark, R., 2007. Lobster escape hatches in Selsey. *Sea Fish Industry Authority*, pp.3–6.

Cornwall, I., 2015. *New Cornwall IFCA Byelaws*,

Cruz, Y.M. & Olatunbosun, O., 2013. *Comparative study on the efficiency of new antiphlogistics*.

Davies, R.W.D. et al., 2009. Defining and estimating global marine fisheries bycatch. *Marine Policy*, **33,** pp.661–672.

Eldridge, P.J., Burrell, V.G. & Steele, G., 1979. Development of a Self-Culling Blue Crab Pot. *Marine Fisheries Review*, (December), pp.21–27.

Emery, T.J. et al., 2012. Are input controls required in individual transferable quota fisheries to address ecosystem based fisheries management objectives? *Marine Policy*, **36(1)**, pp.122–131.

Estrella, B.T. & Glenn, R.P., 2006. Lobster trap escape vent selectivity. *Massachusetts Division of Marine Fisheries Technical Report*, **27**(August), p.15.

European Commision, 2014. *Fishing TACs & Quota's 2014*,

Everson, A.R., 1986. *Summary of Worldwide Research on Lobster Escape Vents*,

Everson, A.R., Skillman, R.A. & Polovina, J., 1992. Evaluation of Rectangular and Circular Escape Vents in the Northwestern Hawaiian Islands Lobster Fishery. *North American Journal of Fisheries Management*, **12,** pp.161–171.

FAO Fishery Resource Divison and Fishery Policy and Planning Division, 1997. *Fisheries Management*,

Fiorentino, F. et al., 2008. Changes in spawning-stock structure and recruitment pattern of red mullet, *Mullus barbatus*, after a trawl ban in the Gulf of Castellammare (central Mediterranean Sea). *ICES Journal of Marine Science*, **65(7)**, pp.1175–1183.

Fogarty, M. & Borden, D., 1980. EFFECTS OF TRAP VENTING ON GEAR SELECTIVITY IN THE INSHORE RHODE ISLAND AMERICAN LOBSTER , *Homarus americanus*, Fishery. *Fishery Bulletin*, **77(4)**, pp.925–933.

Geijer, C.K. a. & Read, A.J., 2013. Mitigation of marine mammal bycatch in U.S. fisheries since 1994. *Biological Conservation*, **159,** pp.54–60.

Gravestock, V., 2014. *Design and Field Trials of Escape Gaps for a Mixed Crustacean Fishery in the Southern IFCA Region*. University of Southampton.

Guillory, V. et al., 2004. An Evaluation of 5.87-cm and 6.03-cm Escape Rings for Blue Crab *Callinectes sapidus* Traps. *North American Journal of Fisheries Management*, **24(4),** pp.1431–1434.

Halliday, R.G., 1988. Use of Seasonal Spawning Area Closures in the Management of Haddock Fisheries in the Northwest Atlantic. *NAFO Scientific Council Studies*, **12**, pp.27–36.

Havens, K.J. et al., 2009. Location, Location, Location: The Importance of Cull Ring Placement in Blue Crab Traps. *Transactions of the American Fisheries Society*, **138(4)**, pp.720–724.

Huang, F., Andow, D. a. & Buschman, L.L., 2011. Success of the high-dose/refuge resistance management strategy after 15 years of Bt crop use in North America. *Entomologia Experimentalis et Applicata*, **140(1),** pp.1–16.

Huang, H.-W., 2011. Bycatch of high sea longline fisheries and measures taken by Taiwan: Actions and challenges. *Marine Policy*, **35,** pp.712–720.

Hyland, N.J., 2012. *Research and Design of Escape Gaps for a* Mixed Crustacean Fishery. University of Southampton.

Kaiser, M.J. et al., 2008. Isle of Man sustainable fisheries strategy. *Fisheries and Conservation Report No.1 Bangor University*, p.11.

Kelly, S. et al., 2000. Spiny lobster, *Jasus edwardsii*, recovery in New Zealand marine reserves. *Biological Conservation*, **92(3)**, pp.359–369.

Krouse, J.S., 1978. Effectiveness of ecapse vent shape in traps for catching legal-sized lobster, Homarus americanus, and harvestable-sized crabs, *Cancer borealis* and *Cancer irroratus*. *Fishery Bulletin*, **76(2),** pp.425–432.

Larsen, F. & Eigaard, O.R., 2014. Acoustic alarms reduce bycatch of harbour porpoises in Danish North Sea gillnet fisheries. *Fisheries Research*, **153**, pp.108–112.

De Lestang, S. et al., 2012. Stock assessment for the west coast rock lobster fishery. *Fisheries Research Report No. 217*, (**217**), p.200.

Linnane, A. et al., 2011. Assessing the effectiveness of size limits and escape gaps as management tools in a commercial rock lobster (*Jasus edwardsii*) fishery. *Fisheries Research*, **111(1-2)**, pp.1–7.

Lovewell, S.R. & Addison, J.T., 1989. *Escape Gap Experiments in a Lobster and Crab Fishery off the East Coast of England*,

Marine Management Organisation, 2014. UK Sea Fisheries Statistics 201 3. *National Statistics*, pp.1–159.

Mitchell, R.W.D. et al., 2008. Comparing management of recreational Pagrus fisheries in Shark Bay (Australia) and Sagami Bay (Japan): Conventional catch controls versus stock enhancement. *Marine Policy*, **32(1),** pp.27–37.

Moland, E. et al., 2013. Lobster and cod benefit from small-scale northern marine protected areas: inference from an empirical before-after control-impact study. *Proceedings of the Royal Biological Society*, 280(1754).

Moore, J.E. et al., 2009. A review of marine mammal, sea turtle and seabird bycatch in USA fisheries and the role of policy in shaping management. *Marine Policy*, **33**, pp.435–451.

Murray, L.G., Hinz, H. & Kaiser, M.J., 2009. LOBSTER ESCAPE GAP TRIALS. *Fisheries & Conservation report*, **(9),** pp.1–11.

North Eastern, I., 2014. *North Eastern Inshore Fisheries and Conservation Authority BYELAWS BOOKLET*,

Nulk, V.E. & Vernon, E., 1978. The Effects of Different Escape Vents on the Selectivity of Lobster Traps. *Marine Fisheries Review*, May-June, pp.50–58.

Pengilly, D. & Tracy, D., 1998. Experimental Effects of Soak Time on Catch of Legal-Sized and Nonlegal Red King Crabs by Commercial King Crab Pots. *Alaska Fishery Research Bulletin*, **5(2)**.

Polovina, J., Everson, A.R. & Kazama, T.K., 1991. Evaluation of circular and rectangular escape vents ina multispecies lobster fishery in hawaii. *Gulf and Caribbean Fisheries Institute*, **40,** pp.471–481.

Robins, J.B., Campbell, M.J. & Mcgilvray, J.G., 1999. Reducing Prawn-trawl Bycatch in Australia : An Overview and an Example from Queensland. *Marine Fisheries Review*, **61(3),** pp.46–55.

Rowe, S., 2002. Population parameters of American lobster inside and outside no-take reserves in Bonavista Bay, Newfoundland. *Fisheries Research*, **56(2)**, pp.167–175.

Seafish, 2009. Responsible Sourcing Guide : Crabs & Lobsters. *Responsible Sourcing Guides*, (August), pp.1–8.

Shanks, A.M., Robertson, J.H.B. & Bova, D.J., 1997. Trials of creels fitted with an escape gap in a fishery for velvet swimming crabs (*Necora puber*). *Scottish Fisheries Working Paper*, **1(97)**, p.10.

Shelmerdine, R.L. & White, E., 2011. Escape gaps for velvet crabs (*Necora puber*); stock and economic benefits for the catching sector. *Scottish Industry Science Partnership Report*, 01(11).

Smith, I.P. et al., 2001. Movement of wild European lobsters *Homarus gammarus* in natural habitat. *Marine Ecology Progress Series*, **222**, pp.177–186.

Smith, I.P., Collins, K.J. & Jensen, a. C., 1998. Movement and activity patterns of the European lobster, *Homaras gammarus,* revealed by electromagnetic telemetry. *Marine Biology*, **132(4)**, pp.611–623.

Smith, I.P., Collins, K.J. & Jensen, a. C., 1999. Seasonal changes in the level and diel pattern of activity in the European lobster *Homarus gammarus*. *Marine Ecology Progress Series*, **186**, pp.255–264.

Southern IFCA, 2009. Marine and coastal access act 2009 - Prohibition of gathering (sea fisheries resources) in seagrass beds byelaw. , 2009(5).

Stewart, N.E., 1974. Discussion on the use of escape ports in crab traps. *State/Federal Dungeness Crab Management Program*, April.

Sussex, I., 2010. S ussex Inshore Fisheries and Conservation Authority MARINE AND COASTAL ACCESS ACT 2009 Shellfish Permit Byelaw The Authority for the Sussex Inshore Fisheries and Conservation District in exercise of its.

Tallack, S.M.L., 2007. Escape ring selectivity, bycatch, and discard survivability in the New England fishery for deep-water red crab, Chaceon quinquedens. *ICES Journal of Marine Science*, **64(8),** pp.1579–1586.

Tokai, T. 1997. Maximum likelihood parameter estimates of a mesh selectivity logistic model through SOLVER on MS-Excel. Bull. Jpn. Soc. Fish. Oceanogr., **61, 3**, 288-298

Treble, R.J., Millar, R.B. & Walker, T.I., 1998. Size-selectivity of lobster pots with escape-gaps: Application of the SELECT method to the southern rock lobster (*Jasus edwardsii)* fishery in Victoria, Australia. *Fisheries Research*, **34(3),** pp.289–305.

U.S. National Bycatch Report [W. A. Karp, L. L. Desfosse, S.G.B. &] E., 2011. US National Bycatch Report. *NOAA Tech*, pp.1–508.

Ungfors, A., 2008. Fisheries biology of the edible crab (*Cancer pagurus*) in the Kattegat and the Skagerrak - implications for sustainable managemen*t*.

Winger, P.D. & Walsh, P.J., 2007. The feasibility of escape mechanisms in conical snow crab traps. *ICES Journal of Marine Science*, **64(8)**, pp.1587–1591.

8.1 Websites

Channel Coastal Observatory (2015) Regional coastal monitory programs – Boscombe. Available at:http://www.channelcoast.org/data_management/real_time_data/charts/?chart=66&tab=waves&disp_option=1 [Accessed: 30th April 2015]

Fisheries and Oceans Canada (2008) Convictions - Newfoundland and Labrador Region. Available at: http://www.dfo-mpo.gc.ca/media/charges-inculpations/nl-tnl-eng.htm [Accessed: 7th April 2015]

Queensland Government (2015) Crabbing and fishing gear. Available at: https://www.daf.qld.gov.au/fisheries/recreational/rules-regulations/crabs-and-lobsters [Accessed: 3rd April 2015]

www.adfg.alaska.gov.uk http://www.adfg.alaska.gov/index.cfm?adfg=PersonalUsebyAreasoutheasttannerCrab.regs – Tanner Crab (Alaska) Escape Gap Regulations

www.kentandessex-ifca.gov. (2015) http://www.kentandessex-ifca.gov.uk/im-interested-in/fishing-commercially/potting-2/lobsters-crabs/ - Lobsters and crabs

8.2 Appendices

A full data set can be found on the attached CD.