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Design and Field Trials of Escape Gaps for a Mixed Crustacean Fishery in the Southern IFCA Region

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ABSTRACT

Escape gaps are a commonly used tool in crustacean trap fisheries management. They are designed to protect individuals below the minimum landing size by facilitating their release from a fishing pot or trap. In the UK escape gap regulations are enforced on a local scale and in England are the responsibility of the Inshore Fisheries and Conservation Authorities (IFCAs). Only half of all IFCAs however, have a byelaw that specifies escape gaps must be fitted to fishing pots. The Southern IFCA is one district where escape gaps are not compulsory. There is however an ongoing interest to establish a suitable escape gap design for this district where a mixed crustacean fishery exists. In 2012, 99.8% of landings from the fishery were made up of the edible crab (*Cancer pagurus*) and European lobster (*Homarus gammarus*), with the velvet swimming crab (*Necora puber*) making up the remaining 0.2%. The outcome of previous aquarium trials was the recommendation of an 87 mm by 45 mm rectangular escape gap for the Southern IFCA district; aimed at releasing *H. gammarus* and *C. pagurus* below the minimum landing size. One aim of the present study was to field trial the recommended design and the other was to establish whether a 'one size fits all' escape gap could be designed for all three species. Field trials of the recommended design revealed pots fitted with escape gaps could reduce the number of undersized *H. gammarus* and *C. pagurus* by 52% and 54%, respectively, whilst slightly enhancing the legal catch of both species. The loss of undersized individuals caused the average size of individuals caught in pots fitted with escape gaps to be significantly larger than control pots for both species, with an increase of 25 mm in the average carapace width of *C. pagurus*. The second phase involved aquarium based trialing of designs that could potentially be suitable for all three species. In order to achieve this, a unique three-dimensional concept was developed which involved the incorporation of deformable material into a standard 87 x 45 mm rectangular escape gap. The concept was based on reducing the available gap opening to 20 mm height to retain legal-sized *N. puber* but still allow undersized *C. pagurus* and *H. gammarus* to escape by pushing their way through the deformable material. One three-dimensional design incorporating brush bristles, achieved a 90% retention of legal-sized *N. puber,* whilst still allowing the escape of undersized *N. puber* and *C. pagurus*. All sizes of *H. gammarus* however, failed to escape. The future development of an escape gap panel for all three species could involve twinning the three-dimensional bristle escape gap for both crab species with an appropriately sized circular escape gap for the European lobster.

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1. INTRODUCTION

1.1. FISHERIES MANAGEMENT TOOLS

Global fisheries are managed using an array of tools that can be categorised into input controls, output controls and technical measures; the majority of which are used to govern crustacean trap fisheries (Bonzon & Cochrane, 1997). Input controls directly regulate fishing effort by imposing limits on the number of fishing vessels and how long each can spend at sea (Bonzon & Cochrane, 1997). For example, in the UK the 2003 Restrictive Shellfish Licensing Scheme prevents new vessels from entering the fishery (Seafish, 2011; AFBI, n.d). Output controls are popular for the management of large-scale fisheries and involve restricting the amount of catch taken out of a fishery, known as the 'Total Allowable Catch' (TAC) (Bonzon & Cochrane, 1997). A TAC is used in the offshore American lobster (*Homarus americanus*) fishery where the limit has remained at 720 tonnes since 1989 (Government of Canada, 2014). Technical measures are an 'umbrella' term for a spectrum of regulations largely concerned with how and where fishermen are allowed to fish (Bonzon & Cochrane, 1997). These include restrictions on fishing gear such as mesh size, closed seasons or areas and minimum landing sizes (Bonzon & Cochrane, 1997).

1.1.1. Minimum Landing Size (MLS)

A minimum landing size (MLS) is one of the most common management controls used in crustacean fisheries (Lovewell & Addison, 1989; Linnane *et al*., 2011). The size limit is designed to allow individuals the opportunity to reproduce at least once before being taken out of the fishery (Ungfors, 2007). Protecting immature or newly mature individuals helps to avoid recruitment-overfishing by sustaining a breeding population (Unfors, 2007; Seafish, 2011). In the UK, minimum landing sizes are set by the European Union (EU), although national legislation and local byelaws have been introduced in some areas to increase the MLS further (AFBI, n.d.). A MLS of 87 mm carapace length is set for the European lobster, *Homarus gammarus*, although in some regions local byelaws, enforced by the Inshore Fisheries and Conservation Authorities (IFCAs) in South Wales, Devon and the Isles of Scilly, have increased the MLS to 90 mm (Defra, n.d., Seafish, 2011).

1.1.2. Mesh Size and Escape Gaps

Controls on mesh size and the use of escape gaps are commonly used in conjunction with the MLS (King 2007; Wilson, 2009). Escape gaps (also known as vents, rings, hatches, mechanisms or openings) are rigid selectivity devices attached to the outside trap wall and whose dimensions are often larger than the size of the trap mesh (Guillory & Hein, 1998). Both measures are designed to improve the selectivity of traps or pots by allowing the release of individuals below the MLS, known as undersized or sublegal, whilst retaining individuals of legal size (e.g. Krouse, 1978; Nulk, 1978; Fogarty & Borden, 1980; Brown, 1982; Polovina *et al*., 1991; Everson *et al*., 1992; Guillory & Hein, 1998). Mesh size has been used to successfully reduce the bycatch of sublegal crustaceans in the American blue crab (*Callinectes sapidus*) fishery where a 3.81 cm hexagonal mesh was found to reduce the catch per unit effort (CPUE) of sublegal blue crabs by 95.4% (Guillory & Prejean, 1997). Conversely, increasing mesh size has also been shown to increase the loss of legal-sized snow crab (*Chionoecetes opilio*) (Winger & Walsh, 2007). Mesh size selection is thought to be less precise as the openings are flexible and therefore do not offer the same precision associated with inflexible escape gap openings (Miller, 1990). The rigidity of escape gaps is complemented by the rigid exoskeleton of crustaceans and their ability to orientate their body into the best position for escape (Miller, 1990).

1.2. ESCAPE GAP BENEFITS

Fishing with traps and pots is considered to be a relatively sustainable method of fishing and has been proven to cause minimal impact to the surrounding environment (Casement & Svane, 1991; Eno *et al*., 2001). Despite this, there are two major concerns associated with trap fisheries worldwide. The first is the discarding of sublegal individuals of the target species and the second is 'ghost fishing' (Lovewell *et al*., 2002). Fitting escape gaps to traps and pots can help to minimise the impacts of both concerns, whilst providing additional benefits to fishermen.

1.2.1. Sublegal Bycatch, Injury and Mortality

The proportion of sublegal individuals discarded from trap fisheries around the world ranges between 10% and 95% (Table 1.0). Such rates are of great concern as the practice of discarding sublegal individuals can increase the risk of injury or mortality in a number of ways. These include rough handling practices by fishermen, displacement from an animal's original habitat and air exposure (Krouse & Thomas, 1975; Brown, 1982; Brown & Caputi, 1985). Around 25% of sublegal lobsters in the Australian western rock lobster (*Panulirus cygnus*) fishery were estimated to be exposed for 10 minutes or more (Brown & Caputi, 1985). Individuals exposed for periods of more than 30 minutes were found to lack the active alert defense posture and such changes in behavior can lead to higher levels (12%) of predation compared to unexposed individuals when returned to sea (Brown & Caputi, 1983; 1986).

Table 1.0. Details of sublegal discards (% of catch discarded) from global crustacean trap fisheries.

Country	Region	Common Name	Scientific Name	% Catch which is discarded/undersized	Source
United Kingdom	Norfolk	Edible crab	*Cancer pagurus*	75-95	Brown (1975)
Ireland	-	Edible crab	*Cancer pagurus*	30 (2001-2008)	ICES (2009)
Australia	-	Blue swimmer crab	*Portunus pelagicus*	>40 (3.9 million individuals per year)	Henry & Lyle, (2003)
Australia	Northern Territory	Giant mud crab	*Scylla serrata*	36-72	Ward *et al*. (2008)
Australia	-	Eastern rock lobster	*Sagamariasus verreauxi*	64	Leland *et al*. (2013)
America	New England	Red crab	*Chaceon quinquedens*	71.7	Tallack (2007)
America	Florida	Spiny lobster	*Panulirus argus*	70-95	Davis (1981) Lyons & Hunt (1991)
Thailand	-	Blue swimming crab	*Portunus pelagicus*	32-42	Boutson *et al*. (2009)
Canada	Newfoundland/ Labrador	Snow crab	*Chionoecetes opilio*	10-40	DFO (2010)

The levels of mortality and injury associated with the handling and discarding of sublegal bycatch vary depending on the area and fishery. In the Australian western rock lobster fishery it was estimated that 14.6% of sublegal individuals die as a result of handling procedures (Brown & Caputi, 1986). An assessment of repeat handling of the Dungeness crab (*Cancer magister*) found mortality to be 100% after being handled 4 times (Zhou & Shirley, 1995). Handling procedures can also result in appendage loss and incidence of injury within a population and has been reported to range between around 10% in the UK edible crab (*Cancer pagurus*) fishery to as high as 57% in the American blue crab fishery (Bennett, 1973; Eldridge *et al*., 1979). Injured crustaceans are more likely to be compromised due to enhanced prey detection from loss of body fluids, lack of defense and escape from predators and impaired ability to feed (Parsons & Eggleston, 2005; Frisch & Hobbs, 2011). Unsurprisingly, a study found that injured Caribbean spiny lobsters (*Panulirus argus*) were three times more likely to die than uninjured individuals (Parsons & Eggleston, 2005). Injured individuals that do manage to survive have been proven to have reduced growth rates. Severe limb loss in the edible crab (6 legs or 2 chelae) reduced the growth increment in carapace width by 25% (Bennett, 1973).

The long term impacts of discard mortality, appendage loss and subsequent reductions in growth can represent a huge cost to the fishery as a result of delayed entry and loss of reproductive input (Davis, 1981; Everson, 1986). Estimates of this cost have been calculated for numerous fisheries and in one of the world's largest rock lobster fisheries for *P. cygnus*, an overall mortality of 18 million sublegal individuals per year is estimated to cost the industry $A13 million (Brown & Caputi, 1986). Losses to the industry can be largely reduced by simply installing appropriately sized escape gaps to prevent the risks associated with discarding practices (Brown & Caputi, 1983). In the blue crab fishery, reductions in the number of undersized individuals caught were expected to reach 75-80% when escape gaps were used (Guillory *et al*., 2004). Similar levels of reduction have been observed in many other fisheries including the UK edible crab and European lobster fishery (Brown, 1979), the Northwestern Hawaiian Islands (NWHI) spiny (*Panulirus marginatus*) and slipper lobster (*Scyllarides squammosus*) fishery (Everson *et al*., 1992) and American lobster fishery (Templemen, 1958). By incorporating escape gaps in the Juan Fernández (*Jasus frontalis*) rock lobster fishery in Chile, it was estimated fishermen would handle 414,000 less sublegal lobsters in a season (Arana *et al*., 2011).

1.2.2. Bycatch of Non-Target Species

In general, traps produce a much lower bycatch when compared to towed gear types and little attention has been paid to the use of escape gaps as a way of reducing non-target bycatch (Kennelly, 2007; Rotherham *et al*., 2013). Nevertheless, escape gaps have been still been found to achieve significant reductions in the bycatch of non-target species in crustacean trap fisheries. Reductions of up to 80% were achieved in the non-target bycatch species Yellowfin Bream (*Acanthopagrus australis*) which are caught alongside giant mud crabs (*Scylla serrata*) (Rotherham *et al*., 2013). Large declines of more than 50% were also achieved in catches of blue-throat wrasse (*Notolabrus tetricus*) and leatherjackets (*Meuschenta* sp.), which are caught with *Jasus edwardsii* in Northern Zone, Australia (Linnane *et al*., 2011). In Southern Australia, the maori octopus (*Octopus maorum*) is a common bycatch species of the *J. edwardsii* fishery which kills approximately 4% of the annual lobster catch (Brock *et al*., 2003; 2006). It has been demonstrated, by simply fitting escape gap to conventional pots, that the mortality of undersized lobsters killed in this way is reduced by 68%, equivalent to approximately 40,000 lobsters a year (Brock *et al*., 2006).

1.2.3. Sorting Time

The time it takes for a fishermen to clear and sort each pot can be reduced by installing escape gaps to the outer wall of each pot (Templemen, 1958). In the Queensland's commercial fishery for *S. serrata*, fitting two escape gaps (120 mm x 50 mm) to mesh pots was estimated to eliminate the handling of 2,170,000 individuals; equivalent to 1808 hours of labour (Grubert & Lee, 2013). In general, this improves fishing efficiency by saving time and money spent on fuel costs; potentially allowing for more gear to be hauled (Guillory & Prejean, 1997; Shelmerdine

& White, 2011). Additionally, it helps to eliminate the temptation to land and illegally sell sublegal crustaceans (Templemen, 1958).

1.2.4. Size of Legal Catches

Simultaneous increases in legal catch and reductions in the undersized catch have been reported in a number of fisheries where escape gaps have been trialed (e.g. Krouse & Thomas, 1975; Fogarty & Borden, 1980; Brown, 1982; Everson *et al*., 1992; Arana *et al*., 2011; Shelmerdine & White, 2011; Grubert & Lee, 2013). Vast increases in the size of legal catch were reported by Brown (1982) in the UK lobster (350%) and edible crab (125%) fisheries and by Everson (1992) in the NWHI spiny lobster CPUE (0.49 to 1.05 lobsters per haul). Average increases observed by Skillman (1984) in lobster fisheries of the genera *Homarus* and *Panulirus* however, were on average much lower at 5.9%. An enhanced legal catch can be explained by the 'saturation effect' observed in non-vented pots; where the likelihood of a lobster entering a pot decreases as the density of lobsters inside the trap increases (Fogarty & Borden, 1980). When escape gaps are installed, undersized crustaceans are able to escape thus increasing the likelihood that legal-sized crustaceans will enter the trap (Fogarty & Borden, 1980). This phenomenon is most likely a function of behavioral interactions rather than physical space as prestocking traps with a single lobster has shown to reduce subsequent entrance of other crabs and lobsters (Addison, 1995; Guillory & Hein, 1998).

Unfortunately, an increase in legal catch is not a general rule for all crustacean trap fisheries that use escape gaps in their traps (Treble *et al*., 1998). Numerous studies have failed to show any increases at all (e.g. Conan, 1987; Lovewell & Addison, 1989; Treble *et al*., 1998; Murray *et al*., 2009). The lack of increase in legal catch has been attributed to low abundances of wild lobsters, where densities may be insufficient to create the 'saturation effect' and because of inappropriately sized escape gaps (Conan, 1987; Miller, 1990). Furthermore, studies with reported increases have been criticised based on their experimental design, particularly small sample sizes and lack of statistical tests (Miller, 1990; Treble *et al*., 1998).

1.2.5. Ghost Fishing

Ghost fishing largely applies to passive gears such as traps and occurs when lost or abandoned fishing gear continues to fish without any human control (Smolowitz, 1978). The ability of a trap to continue fishing after the bait has gone is thought to occur as a result of an 'autorebaiting' mechanism, whereby the dead bodies of trapped animals attract new animals (von Brandt, 1984). The threat of ghost fishing was first identified in the 1960s and has become increasingly important as the materials used to construct pots have become extremely durable, thus extending the duration that lost pots can fish for (Smolowitz, 1978; Carr & Harris, 1997).

The scale of pots losses ranges from 10 to 20% in the Dungeness crab fisheries (Breen, 1990), 20 to 30% in the American lobster fishery and 10 to 30% in the blue crab fishery (Guillory, 2001; Havens *et al*., 2008; Lee, 2009). The longevity and thus ability to continue fishing varies depending on the fishery but has been estimated at 1 year in parlour pots used off the UK (Bullimore *et al*., 2001), 2 years in the Dungeness crab fishery and up to 15 years after loss in Alaska king crab (*Paralithodes camtschaticus*) traps (High & Worlund, 1979). Despite a low fishing efficiency of ghost traps relative to that of hauled pots (10% in the American lobster fishery (Pecci *et al*., 1978)), high mortality rates have been reported in a number of fisheries. Fifty-five percent of legal sized Dungeness crabs in ten ghost pots died over a period of one year, equivalent to 7% of the weight of reported catches in Fraser River, Canada, where the study was conducted (Breen, 1987).

Studies have proven that fitting traps with escape gaps can reduce mortality of certain animals, namely non-target species and sublegal target species (Pecci *et al*., 1978 Acrement & Guillory, 1993). It was found that mortality was reduced by 3.2 times in vented traps compared to non-vented traps in the blue crab fishery (Acrement & Guillory, 1993). Despite this, escape gaps do not eliminate ghost fishing and represent only part of the solution, as they prevent the escape of most legal-sized animals (Stevens *et al*., 1993; Campbell & Sumpton, 2009).

1.3. ESCAPE GAP DESIGN CONSIDERATIONS

Ideally, an escape gap would permit the escape of all sublegal individuals whilst retaining all animals of legal size (Nulk, 1978; Guillory & Hein, 1998; Treble *et al*., 1998). In reality however, it is not possible to retain individuals at an exact size (Conan, 1987). The design of an escape gap will therefore be a compromise between reducing catches of undersized animals and maintaining catches of legal-size animals (Treble *et al*., 1998) or allowing the minimal egress of legal animals whilst maximizing the escape of undersized individuals (Fogarty & Borden, 1980).

1.3.1. Morphometric Dimensions

Attempts to improve the precision of escape gap selectivity have largely focused on the morphometric dimensions of the target species (Arana *et al*., 2011). The critical body dimension of an animal is the physical dimension that determines whether or not the animal is able to pass through an escape gap and commonly differs from the body dimension on which the MLS is based (Estrella & Glen, 2006). The MLS for lobster is commonly based on carapace length, however when passing through a rectangular escape gap a lobster will first pass its

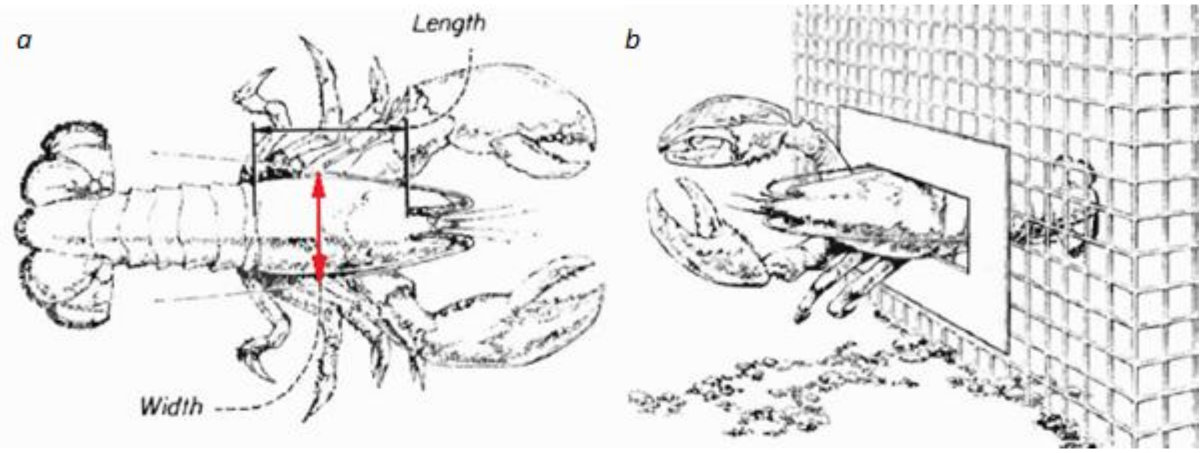


Figure 1.0. (a) Critical body dimension and (b) Exiting strategy of an American lobster (*Homarus americanus*) through an escape gap. Source: Nulk (1978).

chelipeds through (placed on top of one another), followed by twisting its body 90 degrees to pass through sideways; thus carapace width restricts the animals passage (Figure 1.0) (Nulk, 1978; Brown, 1982). Conversely, when a lobster exits through a circular escape gap, body depth becomes the critical dimension (Nulk, 1978). The MLS for a crab is often based on carapace width, however because crabs exit laterally through a rectangular or circular escape gap carapace length restricts its passage (Stewart, 1974; Stasko, 1975). When considering a rectangular escape gap, carapace height is also important (Brown, 1978).

1.3.2. Shape

Circular escape gaps have been proven to be effective in mixed species fisheries as a circle can simultaneously select for dissimilar body dimensions of individuals that belong to separate species (Krouse, 1978; Everson *et al*., 1992). In the NWHI lobster fishery, a circular escape vent selects for the carapace height of the dorso-ventrally flattened spiny lobster (*P. marginatus*) and carapace width of round-bodied slipper lobster (*S. squammosus*) (Polovina *et al*., 1991; Everson *et al*., 1992). Using four 67 mm diameter circular vents, catches of sublegal spiny lobster and slipper lobster were reduced by 83% and 93% respectively, whilst maintaining legal catches of both species (Everson *et al*., 1992). Similar reductions were achieved using rectangular escape gaps (49 x 285 mm), however legal catches of slipper lobster were reduced by 32% (Everson *et al*., 1992). Similar results were achieved in the Maine mixed fishery for American lobster, rock crab (*Cancer irroratus*) and Jonah crab (*Cancer borealis*) (Krouse, 1978). Rectangular and circular escape gaps have found to be equally effective in maintaining legal-sized American lobster catches (Krouse, 1978). The escape of a lobster through a circular escape gap however has been observed to be more challenging; such difficulty is associated with the narrower diameter which limits the exit of both claws (Krouse, 1978; Estrella & Glenn, 2006). Based on this, Krouse (1978) encouraged fishermen interested in only capturing lobster to use rectangular escape gaps. Additionally, rectangular escape gaps are also well suited to crab only fisheries as this shape is complimentary to the dorso-ventrally flattened crab body form observed in numerous species (Grubert & Lee, 2013). A square-shaped (35 x 45 mm) gap was also recommended by Boutson *et al*., (2009) for use the *Portunus pelagicus* fishery in Thailand, as the extended height allowed for the enhanced egress of non-target bycatch and sublegal individuals.

1.3.3. Size

Generally crustaceans possess a rigid exoskeleton, unless an individual has recently undergone ecdysis, which allows for precise size selectivity and so it is essential that the dimensions of an escape gap are accurate (Boutson *et al*., 2009). It was recommended by Brown (1982) that the dimensions of an escape gap should be 1 mm less than the critical body dimension. Modifications to gap size, as small as 0.5 mm to 1 mm, can significantly affect the retention or escape of sublegal individuals (Conan, 1987; Brown & Caputi, 1986; Lyons & Hunt, 1991). An increase in the height of 2 mm, from 42 mm to 44 mm, increased the escape of undersized American lobster by three times (Fogarty & Borden, 1980). Dramatic changes in retention, as a result of small changes in gap size and the associated critical body dimension, can be explained by greater changes in the corresponding body dimension which the MLS is based on (Guillory *et al*., 2004). In blue crabs, a 1 mm increase in carapace length is equivalent to an increase of 2.92 mm in carapace width (Gulliory *et al*., 2004).

1.3.4. Position

The position of an escape gap within a trap or pot should reflect the random search behavior of the target species which commonly takes places on the floors and walls of the trap (Boutson *et al*., 2009; Havens *et al*., 2009; Arana *et al*., 2011). By placing escape gaps at the base of the trap side panels, the likelihood of encountering and escaping through a vent is increased (Boutson *et al*., 2009). Unsurprisingly, most studies report the highest escape rates (80% of escapes) from escape gaps located close to the floor of the trap and so recommend this as the most suitable position (Krouse, 1978; Boutson *et al*., 2005; Jirapunpipat *et al*., 2007; Boutson *et al*., 2009). Escape gap regulations may specify the position of the escape gap (Havens *et al*., 2009). In the Louisiana blue crab fishery, 5.87 mm diameter escape rings must be placed in the outside vertical panels flush with the trap floor (Havens, 2009).

1.3.5. Number

Fitting more than one escape gap to a trap is frequently recommended and more often than not allows a higher proportion of sublegal individuals to escape (e.g. Stewart, 1974; Krouse, 1978; Brown, 1979; Brown & Caputi, 1986; Lovewell & Addison, 1989). In the American lobster fishery, the number of sublegal lobsters per trap decreased from 1.8 using a single escape gap to 0.98 using a double escape gap (Krouse, 1978). One study found the function of one escape gap became impaired when vented traps were hauled as all individuals attempted to escape at once; creating a bottleneck which stopped a proportion of individuals from escaping before reaching the surface (Rotherham *et al*., 2013). Certain escape gap regulations specify that more than one escape gap must be fitted, for example in 1986, the Australian west coast rock lobster fishery, increased the number of escape gaps required from one to three (de Lestang *et al*., 2012).

1.4. WORLDWIDE USE OF ESCAPE GAPS

Research into the potential benefit and use of escape gaps as a fisheries management tool has taken place in many crustacean trap fisheries around the world. These include the blue swimming crab fishery in Thailand (Boutson *et al*., 2009), the gazami crab (*Portunus trituberculatus*) fishery in the Eastern China Sea (Zhang *et al*., 2010) and the mangrove crab (*Scylla* sp.) fishery in Indonesia (Puspito, 2013). The motivation behind such research can include finding a suitably sized escape gap for a rise in the MLS (Estrella & Glenn, 2006), as a response to declines in catch rates (Schoeman *et al*., 2002; Arana *et al*., 2011; Linnane *et al*., 2011), or to reduce rates of predation (Brock *et al*., 2006). Declines of 45% in the landings of the Chilean Juan Fernández rock lobster over the past 60 years have been blamed on the negative impacts of handling procedures, and so escape gaps were proposed as a way of reducing this mortality (Arana *et al*., 2011). A proportion of escape gap research has resulted in the adoption of escape gaps as part of the fisheries management plan (Table 1.1) (Everson *et al*., 1992), whilst other research has been conducted with limited success (Lyons & Hunt, 1991). In the Floridian spiny lobster fishery, extensive field tests revealed a 90% reduction in sublegal catch could be achieved with a 52.44 mm escape gap (Hunt, 2000). The use of escape gaps however also caused a subsequent drop of 50% in the legal catch which can be explained by the unusual practice of using sublegal lobsters as attractants in traps (Hunt, 2000). Sublegal attractants are not retained in vented traps and so as a result of escape gap research subsequent laws prohibited the Florida Marine Fisheries Commission from authorizing escape gap regulations after 1 April 1998 (Hunt, 2000).

Table 1.1. Escape gap regulations employed in crustacean trap fisheries worldwide including details on the minimum landing size. Sorted by country. CW – Carapace Width; CL – Carapace Length; TW – Tail Width; TL – Total Length.

Country	Region	Common Name	Scientific Name	Minimum Landing Size (MLS)	Escape Gap Regulation	Source
America	Area 1	American lobster	*Homarus americanus*	3 ¼ inches (8.26 cm) CL	1 15/16 x 5 ¾ inches (4.92 x 14.61 cm) or Two 2 7/16 inches (6.19 cm) diameter circles	www.law.cornell.edu NOAA (2014)
America	Area 2, 4, 5 & Outer Cape Cod	American lobster	*Homarus americanus*	3 3/8 inches (8.57 cm) CL	2 x 5 ¾ inches (5.08 x 14.61 cm) or Two 2 5/8 inches (6.67 cm) diameter circles	www.law.cornell.edu NOAA (2014)
America	Area 3 (Offshore)	American lobster	*Homarus americanus*	3 ½ inches (8.89 cm) CL	2 1/16 x 5 ¾ inches (5.24 cm x 14.61 cm) or Two 2 11/16 inches (6.82 cm) diameter circles	www.law.cornell.edu NOAA (2014)
America	Area 6	American lobster	*Homarus americanus*	3 ¼ inches (8.26 cm) CL	2 x 5 ¾ inches (5.08 x 14.61 cm) or Two 2 5/8 inches (6.67 cm) diameter circles	www.law.cornell.edu NOAA, 2014
America	Southeast Alaska	Dungeness crab	*Cancer magister*	6 ½ inches CW	Two 4 3/8 inches diameter circles	www.adfg.alaska.gov
America	California	Dungeness crab	*Cancer magister*	6 ¼ inches CW (15.9 cm)	Two 4 ¼ inches (10.8 cm) diameter circles	Juhasz & Kalvass (2011)
America	Southeast Alaska	Tanner crab	*Chionoecetes bairdi*	5.5 inches CW	Two 4 ¾ inches diameter rings	www.adfg.alaska.gov
America	California	Californian spiny lobster	*Panulirus interruptus*	3.25 inches CL	2 .38 x 11.5 inches	Barsky & Ryan (2003)
America	Florida Georgia Louisiana Maryland North Carolina Virginia Texas	Blue crab	*Callinectes sapidus*	127 mm CW	Three 6.03 cm diameter rings Two 6.03 cm diameter rings Two 5.87 cm diameter rings One 5.87 cm diameter ring Two 5.87 cm diameter rings Two 5.55-5.87 cm diameter rings Four 6.03 cm diameter ringS	Guillory & Hein (1998)
America	Hawaii (Northwestern Hawaiian Islands)	Spiny lobster Common slipper lobster	*Panulirus marginatus* *Scyllarides squammosus*	50 mm TW 56 mm TW	Two escape panels of four 67 mm diameter rings	Polovina (1993)
Australia	West Coast	Western rock lobster	*Panulirus cygnus*	77 mm CL	Three 55 x 305 mm	de Lestang *et al*. (2012)
Australia	Victoria	Spiny rock lobster	*Jasus edwardsii*	105 mm CL	250 x 60 mm	DEH (2004)
Australia	South Australia (Northern Zone)	Spiny rock lobster	*Jasus edwardsii*	105 mm CL	Two 5.7 x 28 cm	Linnane *et al*. (2011)
Australia	Western Australia	Crystal crab	*Chaceon albus*	120 mm CW	56.5 x 301.9 mm	Melville-Smith *et al*. (2007)
Australia	South Australia	Giant crab	*Pseudocarcinus gigas*	150 mm CL	50 mm mesh size or 55 x 150 mm escape gap	Currie & Ward (2009)
Canada	Quebec (Area 22)	American lobster	*Homarus americanus*	83 mm CL	47 x 127 mm or 60 cm diameter circles	www.dfo-mpo.gc.ca
Canada	Quebec (Sub-area 16G)	Rock crab	*Cancer irroratus*	102 mm CW	Four 65 mm circles. Located 51 mm from the base.	www.dfo-mpo.gc.ca

Canada	Bay of Fundy (LFA 35-38)	Jonah crab Rock crab	*Cancer borealis* *Cancer irroratus*	121-130 mm CW 102 mm CW	Jonah crab; Two 63.5-91 mm diameter circles Rock crab; Two 63.5-69 mm diameter circles	Robichaud & Frail (2006)
Canada	Nova Scotia	Jonah crab Rock crab	*Cancer borealis* *Cancer irroratus*	130 mm CW 102 mm CW	Jonah crab; Two 79 mm diameter circles Rock crab; Two 69 mm diameter circles	Robichaud & Frail (2006)
New Zealand	-	Spiny rock lobster Packhorse rock lobster	*Jasus edwardsii* *Jasus verreauxi*	Males: 54 mm TW Females: 60 mm TW 216 mm Tail Length	Round/Beehive pots; Three 54 x 200 mm Square/Rectangular pots; no less than 80% of the height or length of the pot face Dimensions of no less than 54 x 200 mm.	www.fish.govt.nz
Norway	-	European lobster	*Homarus gammarus*	25 cm TL	Two 60 mm diameter rings	Moland *et al*. (2013)
Sweden	-	Edible crab	*Cancer pagurus*	No MLS	One 75 mm diameter ring	Ungfors (2008)
United Kingdom	North Eastern IFCA	European lobster Edible crab	*Homarus gammarus* *Cancer pagurus*	87 mm CL 130 mm CW	46 x 80 mm	Hyland (2012)
United Kingdom	Kent & Essex IFCA	European lobster Edible crab	*Homarus gammarus* *Cancer pagurus*	87 mm CL 130 mm CW	46 x 84 mm	Hyland (2012)
United Kingdom	Devon & Severn IFCA	European lobster Edible crab	*Homarus gammarus* *Cancer pagurus*	90 mm CL Female: 140 mm CW Male: 160 mm CW	46 x 84 mm	Devon and Severn IFCA
United Kingdom	Cornwall IFCA	European lobster Edible crab	*Homarus gammarus* *Cancer pagurus*	90 mm CL Female: 150 mm CW Male: 160 mm CW	46 x 84 mm	Cornwall IFCA
United Kingdom	Sussex IFCA*	European lobster Edible crab	*Homarus gammarus* *Cancer pagurus*	87 mm CL 140 mm CW	45 x 80 mm	Hyland (2012)
United kingdom	Jersey	European lobster Edible crab	*Homarus gammarus* *Cancer pagurus*	87 mm CL 140 mm CW	44 x 79 mm	Hyland (2012)
United kingdom	Isle of Man	European lobster Edible crab	*Homarus gammarus* *Cancer pagurus*	87 mm CL 130 mm CW	45 x 80 mm	Isle of Man Government (2014) Hyland (2012)

1.4.1. America and Canada

Since 1893, wider lath spacing has been required by law in the Newfoundland American lobster fishery (Templemen, 1958). Research later took place in the American lobster fishery off the coast of Rhode Island and Maine (Krouse & Thomas, 1975; Krouse, 1978; Fogarty & Borden, 1980). Based on findings from these studies, the Maine Department of Marine Resources recommended all traps should be fitted with a 44.5 x 152.4 mm rectangular escape gap or two 58 mm diameter circular escape gaps (Krouse, 1978; Everson 1986).

In the northwestern Hawaiian Islands, escape gap research began in the late 1970s for the spiny lobster (*P. marginatus*) fishery (Paul, 1982; Everson, 1986). In 1984, further work was initiated by the National Marine Fisheries Service to examine the feasibility of escape vents in plastic lobsters pots, designed to release undersized spiny lobster and slipper lobster (*S. squammosus*) (Everson, 1986; Polovina *et al*., 1991; Everson *et al*., 1992). The outcome of the research, which ended in 1987, was the requirement of two panels of four 67 mm diameter circular vents after 1 January 1988 (Everson *et al*., 1992). Subsequent monitoring of sublegal catch rates revealed declines between 32% and 38% and CPUE of legal lobsters rose from 0.49 to 1.05 from 1987 to 1988 (Everson *et al*., 1992).

1.4.2. Australia and New Zealand

Escape gap research commenced at a similar time in Australia (Bowen, 1963) and New Zealand (Ritchie 1966; Bain, 1967) in the rock lobster fisheries for *P. cygnus* and *J. edwardsii*, respectively (Everson, 1992). In Australia, escape gap trials were first completed off the Albrolhos Islands on the west coast, where reductions of 54% in undersized lobsters were achieved using a 57 mm wide rectangular vent (Bowen, 1963). This research prompted escape gap legislation in both countries and in Australia escape gaps has been in use since 1966, where a 51 x 305 mm escape gap was introduced (Everson *et al*., 1992; de Lestang *et al*., 2012).

1.4.3. Sweden

In the Skagerrak and Kattegat, 75 mm circular escape gaps are used as an alternative to a MLS in the edible crab fishery (Ungfors, 2007). A single escape gap management measure is very unusual and the size of the escape gap is designed to regulate the size of crabs caught at 110 to 120 mm CW, much lower than the recommended 140 mm CW (Ungfors, 2007).

1.4.4. United Kingdom

Research into an appropriate gap for European lobster and edible crab fisheries began in the late 1970s (Brown, 1978; Brown, 1982). The work concluded that an 38 by 74 mm and 42 by 100 mm rectangular escape gaps were suitable for undersized crabs (MLS of 115 mm) and lobsters (MLS of 80 mm) respectively and a 42 x 74 mm escape gap was recommended for a mixed fishery (Brown, 1978; 1979; 1982). Unfortunately recommendations made from early escape gap research did not result in the creation of escape gap legislation, as in America and Australia. Since then, subsequent studies have included local scale research, much of which remains unpublished (e.g. Lovewell *et al*. 2002; Wiggins, 2004; Clark, 2007; North Eastern IFCA, 2010), as well as research into an appropriate escape gap height for the Scottish velvet swimming crab (*Necora puber*) fishery (Shanks, 1997; Shermerdine & White, 2011). Local scale research has largely been conducted by IFCAs, previously known as Sea Fisheries Committees (SFCs), and has supported the creation of local escape gap byelaws (Wiggins, 2004; Clark, 2007; North Eastern IFCA, 2010). Half of all IFCAs in England enforce escape gap byelaws and these include North Eastern, Devon and Severn, Eastern, Kent and Essex and Cornwall, as well as a voluntarily run scheme in the Sussex IFCA district (Clark, 2007; Hyland, 2012) (Figure 1.1). The results of a study based on the Selsey lobster fishery, funded by the organisation Seafish, formed an important role in the implementation of the voluntarily escape gap scheme (Clark, 2007). It allowed the purchase of 6,000 80 x 45 mm escape gaps, recommended as a result of research by Clark (2007), and 48,000 cable ties (Clark, 2007). More recently, research has aimed to find a suitable escape gap design for use in the Southern IFCA district (Hyland, 2012). As part of this research, Hyland (2012) trialed five escape gap designs used in the UK (Table 1.2). The results revealed significant differences in the effectiveness of escape gap designs, with the majority allowing the egress of undersized European lobsters but limiting the egress of undersized edible crab (Hyland, 2012). By elongating the length of the escape gap to 87 mm but maintaining a height of 45 mm, a larger proportion of undersized edible crabs (51.8%) were able to escape alongside 81% of undersized lobsters (Hyland, 2012).

Table 1.2. Escape gap sizes tested by Hyland (2012) including details on the region they were used and the relationship to the minimum landing sizes used by Southern IFCA.

Escape Gap Size	Region	Relationship to Southern IFCA MLS
44mmx79mm	Jersey	Same MLS
45mmx80mm	Sussex IFCA	Same MLS
45mmx80mm	Isle of Man	Smaller MLS
46mm x80mm	North East IFCA	Smaller MLS
46mmx84mm	Kent and Essex IFCA	Smaller MLS

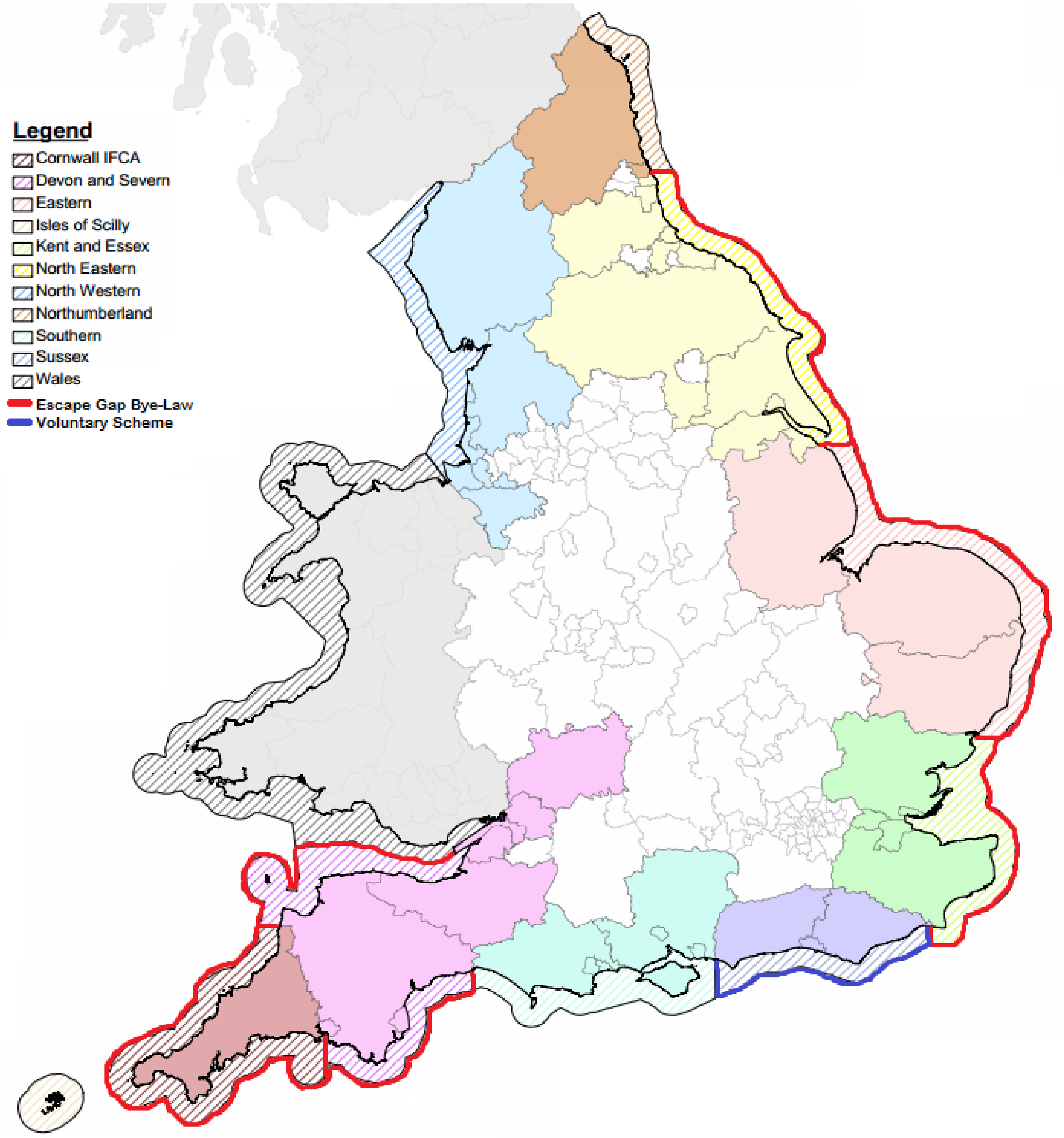


Figure 1.1. Map of all ten Inshore Fisheries and Conservation Authority (IFCA) districts, highlighting those with bye-laws that require the use of escape gaps (red outline) and those that run voluntary schemes (blue outline). Modified from Defra (2011).

1.5. SOUTHERN IFCA

The Southern IFCA is one of ten in England who are responsible for the management of inshore fisheries, out to a distance of six nautical miles from the coast. The Southern IFCA operates from west of the Sussex/Hampshire border and east of the Devon/Dorset border, encompassing the Dorset coast. Within the Southern IFCA district, a mixed crustacean fishery for European lobster, edible crab and velvet swimming crab exists, the latter of which is relatively new (AFBI, n.d). Combined, the fisheries landings for all three species in 2012 was 1,115 tonnes at a value of £2.9 million pounds, with landings dominated by edible crab and value by both edible crab and European lobster (Figure 1.2). The main capture method within the fishery is by baited pots, which accounted for about 98% of catches in 2012. The main management measures that apply to the fishery include MLSs of 87 mm carapace length for European lobster, 140 mm carapace width for edible crab and 65 mm carapace width for velvet swimming crab, a vessel size limit of 12 metres overall length and the protection of berried lobsters (Southern IFCA, 2011).

Figure 1.2. Details of (a) live weight (tonnes) and (b) value (£) of landings for European lobster (red), velvet swimming crab (dashed) and edible crab (black) in the Southern Inshore Fisheries and Conservation Authority district in 2012. Source: Southern IFCA.

1.6. AIMS AND OBJECTIVES

The Southern IFCA has expressed an interest in identifying an escape gap with suitable dimensions that can be recommended to fishermen in the district. The ultimate aim of this study was to therefore design a 'one size fits all' escape gap for use within the Southern IFCA mixed crustacean fishery and to build upon work carried out by Hyland (2012) by field trialing the recommended 87 x 45 mm rectangular design for edible crab and European lobster. To achieve this, the main objectives of the study were:

To determine the effectiveness of two pre-existing two-dimensional designs used by Hyland (2012), in retaining oversized (>MLS^{-5mm}/MLS) individuals of all three species.

To determine the effectiveness of two newly designed two-dimensional escape gaps in retaining oversized (>MLS^{-5mm}/MLS) individuals of all three species.

To design and determine the effectiveness of three dimensional novel escape gaps using deformable material to retain oversized (>MLS^{-5mm}/MLS) individuals of all three species.

To field trial a rectangular escape gap (87 x 45 mm) previously recommended by Hyland (2012), in order to quantify the retention of legally sized (>MLS) *H. gammarus* and *C. pagurus* individuals.

1.6.1. Null Hypotheses

- Each two-dimensional escape gap design will not retain all oversized individuals (>MLS^{-5mm}) whilst also not allowing the escape of any undersized individuals (<MLS^{-5mm}) belonging to each species.
- Each three-dimensional escape gap design will not retain all oversized individuals (>MLS^{-5mm}) whilst also not allowing the escape of any undersized individuals (<MLS^{-5mm}) belonging to each species.
- During field trials, pots fitted with an escape gap will retain the same number of undersized (<MLS) individuals as pots without an escape gap.
- During field trials, individuals retained in pots fitted with an escape gap will not have a significantly larger average size than those retained in pots without an escape gap.

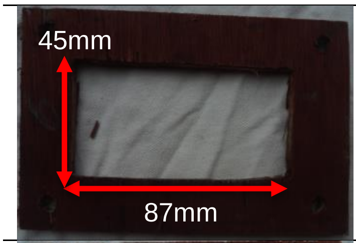
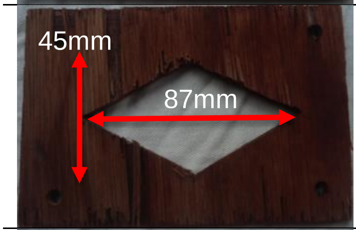
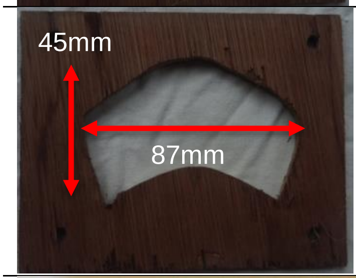
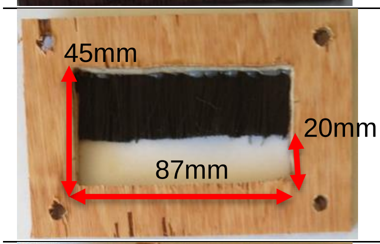
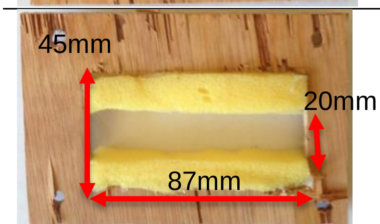
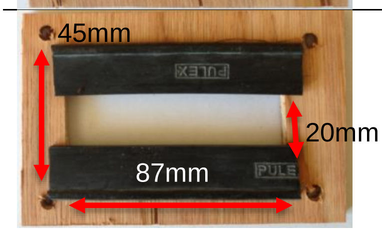
2. MATERIALS AND METHODS

2.1. AQUARIUM TRIALS

2.1.1. Experimental Design and Procedure

All designs were based on retaining *H. gammarus* and *C. pagurus* above the MLS minus 5 mm (MLS^{-5mm}) and *N. puber* above the MLS, as individuals below 60mm were largely unavailable. The MLS^{-5mm} requirement was introduced to prevent the loss of all animals above the MLS and to reassure fishermen that escape gaps were retaining legal-sized individuals, if any design was later adopted by the Southern IFCA. A total of 8 escape designs were trialed, 5 two-dimensional and 3 three-dimensional designs, the latter of which incorporated different types of deformable material. Escape gap dimensions were based on a height of 45 mm and length of 87 mm for *C. pagurus* and *H. gammarus* and height of 20 mm for *N. puber* as recommended by Hyland (2012), except for the keyhole design (Table 2.0). Six of each escape gap design were manufactured from 6 mm marine plywood. The three types of deformable material used; sponge, rubber and bristles, were attached to the upper and lower edges of an 87 x 45 mm escape gap to create a smaller gap opening 20 mm in height (Table 2.0). The 20 mm escape gap height is designed to prevent legal-sized *N. puber* from escaping whilst allowing sublegal *H. gammarus* and *C. pagurus* to escape by pushing their way through the deformable material. Pieces of sponge and bristle were attached using a glue gun. Rubber pieces were initially attached using aquarium sealant but after three days the rubber no longer remained fixed. Instead, plastic 80 x 45 mm escape gaps, provided by the Sussex IFCA, were extended to 87 mm in length and rubber pieces were attached by threading plant twist through the rubber by making a hole in the rubber piece and around the escape gap (Appendix 1).

Table 2.0. Escape gap designs trialed with details of shape, size, material and the species tested.

Shape/Material		Design Type	Species Tested On
	Rectangle	2D	*Homarus gammarus* *Cancer pagurus*
	Rhombus	2D	*Homarus gammarus* *Cancer pagurus* *Necora puber*
	Ellipse	2D	*Homarus gammarus* *Cancer pagurus* *Necora puber*
	Keyhole	2D	*Homarus gammarus* *Necora puber*
	Boomerang	2D	*Homarus gammarus* *Cancer pagurus* *Necora puber*
	Bristles	3D	*Homarus gammarus* *Cancer pagurus* *Necora puber*
	Sponge	3D	*Homarus gammarus* *Cancer pagurus* *Necora puber*
	Rubber	3D	*Homarus gammarus* *Cancer pagurus* *Necora puber*

Aquarium trials were conducted between the 16th of September and 16th October, taking 24 days in total. Attempts were made to replicate the method used by Hyland (2012) to ensure continuity and allow direct comparisons to be made. Trials took place in five separate tanks located at the National Oceanography Centre. Three were plastic aquaculture tanks situated in the research aquarium; two square tanks with dimensions of 1.2 x 1.2 x 0.75 m and one rectangular tank with dimensions of 1.05 x 0.75 x 3.6 m. All three tanks received post-ozone treated seawater. The two square tanks were used for trialing escape designs and the rectangular tank was used to store *H. gammarus* and *C. pagurus* individuals not undergoing escape gap trials. Each square tank was divided into four (to reduce interaction between animals) using garden mesh attached to the side of the tanks with aquarium sealant. The remaining two tanks, measuring 0.6 x 0.7 x 1.1 m, were located on the dockside and filled with seawater pumped directly from the dock. One was used to store *N. puber* and the other to trial escape gaps. This was to reduce the mortality of *N. puber* as previous aquarium trials have highlighted their sensitivity to aquarium conditions (Shelmerdine & White, 2011; Hyland, 2012).

Livestock were collected prior to testing after obtaining dispensation letters from the Marine Management Organisation (MMO) to allow the collection of undersized individuals (Appendix 2). Animals were taken from the Christchurch Ledge in Dorset on two fishing trips with two commercial fishermen. For each species, a total of three animals were collected for each of the five predetermined size classes. Size classes were chosen to span the MLS^{-5mm} for *H. gammarus* and *C. pagurus* and MLS for *N. puber* (Table 2.1). All lobsters were banded to prevent injury to other lobsters and the handler.

Table 2.1. Size classes of each species used in aquarium trials.

Homarus gammarus	*Cancer pagurus*	*Necora puber*
71-75	124-128	59-61
76-80	129-133	62-64
81-85	134-138	65-67
86-90	139-143	68-70
91-95	144-148	71-73

Figure 2.0. Mesh pots of various sizes (a & b) with an escape gap attached to the front using plant twist.

Each escape gap was numbered one to six and attached using garden string or wire to mesh pots fabricated from garden mesh and string (Figure 2.0). A total of 18 pots were made to allow for six animals from each species, one from each size class and the sixth from a size class between the MLS and MLS^{-5mm}, to be trialed at the same time (Table 2.1). Dimensions of each pot varied but largely reflected the size of each species (Figure 2.0). A T-shaped slit was created in all pots to allow the animal to be placed inside and twine was used to close the slit to ensure any escape would be out of the escape gap only. Before being placed inside the mesh pot, details of the escape gap number and the animals sex, carapace depth, width and length were taken to the nearest millimeter using 30 cm vernier calipers. For *H. gammarus,* body depth (BD) was taken from the highest part of the dorsal surface to the lowest part of the ventral surface, excluding walking legs. Carapace width (CW) was taken at the widest section of the carapace and carapace length (CL) was measured from the rear of the eye socket to the posterior edge of the carapace, parallel to the midline (Brown, 1982). For *C. pagurus* and *N. puber*, BD was measured as the greatest vertical distance between the ventral and dorsal surfaces and CL from the anterior edge of the carapace between the eyes to the proximal region of the abdominal flap. For *C. pagurus*, CW was measured at the widest region of the carapace and for *N. puber* was measured between the two outermost carapace thorns. Animals were placed inside the mesh pot and left for a soak period of 24 hours in the experiment tanks, after which the animals that had escape were noted onto waterproof paper. Food (sprat and juvenile herring) and shelter were offered outside each escape gap to encourage animals to exit through the escape gap, similar to methods used by Nulk (1978). This procedure was repeated three times to obtain three replicates for each size class for each design to ensure the data collected were feasible for statistical analysis.

2.1.2. Data Analysis

For data generated during both aquarium and field trials, Microsoft Excel was used for data management, SigmaPlot 12.5 for data representation and SigmaStat for statistical analyses. Statistical significance was set at 95% for all analyses.

Size data of retained or escaped individuals from each replicate was tested for normality using Shapiro-Wilk test and then compared across replicates using a *t*-test (parametric) or Mann-Whitney U test (non-parametric). Replicate data for each design was pooled as no significant differences were found. Percentage retention and escape were calculated for individuals above and below the MLS^{-5mm} for *H. gammarus* and *C. pagurus* and MLS for *N. puber*. For each species, differences in the effectiveness of all 3D and 2D designs were determined using either a One-Way ANOVA (parametric data) or Kruskal-Wallis One-Way ANOVA (non-parametric) by testing for differences in the size of escaped individuals for *N. puber* and retained individuals for *H. gammarus* and *C. pagurus* and percentage retention above and below the MLS (*N. puber*) or MLS^{-5mm} (*H. gammarus* and *C. pagurus*). A Student Newman-Keuls (SNK) pairwise comparison was used to identify where significant differences existed.

Comparisons from the present study were made with the data obtained by Hyland (2012) for the manual manipulation of *N. puber* through the keyhole design (referred by Hyland (2012) as 'half hybrid') and the natural escape of *H. gammarus* and *C. pagurus* through the 87 x 45 mm rectangular design. The size range and average size of individuals from each species that were retained, escaped and overall, were tested for normality using a Shapiro-Wilk test and compared statistically using a *t*-test or Mann-Whitney U test.

All statistical analyses on size data was performed on the body dimension that the MLS is based on i.e. carapace length for *H. gammarus* and carapace width for *C. pagurus* and *N. puber*.

2.2. FIELD TRIALS

2.2.1. Experimental Design and Procedure

Field trials took place on Christchurch Ledge (within Christchurch Bay) on the Dorset Coast within the Southern IFCA District (Figure 2.2a & b). The residual current in this area runs from west to east and this creates an accumulation of weed to the east, making Christchurch Bay unsuitable for trawlers. In 2013, a total of four pot fishermen operated from Mudeford, fishing along the Christchurch ledge in depths ranging from 3 to 20 metres. The 87 x 45 mm rectangular escape gap recommended by Hyland (2012) was fitted to 12 commercial parlour

Figure 2.1. Commercial parlour pot with escape gap attached to the parlour door. Escape gap is constructed from 6mm plastic and attached using cable ties.

pots measuring approximately 750 x 500 x 500 mm. Each parlour pot consisted of two chambers, the entrance parlour and holding parlour. All pots had identical construction consisting of a metal frame, plastic base, stretched mesh size of 8 cm and a plastic cylindrical entrance mounted on the top of each pot. Escape gaps were fabricated from 6 mm plastic and attached to the bottom half of the parlour door, approximately 10-15 cm from the base, using cable ties (Figure 2.1). Four strings, 2 short (10 pots) and 2 long (20 pots) were fitted with three escape gaps each. Pots with escape gaps were alternated in the centre of the string with control pots (i.e. those with no escape gap) (Figure 2.2c). This configuration was designed to reduce any spatial differences in size composition and to allow comparison to other studies using the same method (Brown, 1978; Brown, 1982; Skillman *et al*., 1984; Lovewell & Addison, 1989; Lovewell *et al*., 2002; Arana *et al*., 2011). In short strings, escape gaps were located in pots 3, 5 and 7 and in long strings in pots 7, 9 and 11. No pots with escape gaps were situated at the end of any of the four strings as this position has been proven to achieve higher catch rates (Bell *et al*., 2001). In all strings, pots were separated by 20 metres of rope, making short strings 220 metres long from end weight to end weight and long strings 440 metres between end weights. The flag on the marker buoy of each string was marked with rings of red tape to denote each string number (1 to 4). Strings were shot on the ledge from east to west and all pots were baited with fresh fish including scad, wrasse and gurnard.

Over a total of seven trips, from the 22nd September to the 9th November 2013, the size of the catch in pots with and without escape gaps was recorded. During each trip, the skipper and crew would sort the catch of the control and escape gap pots into six buckets; one per pot type for each species. Details of each animal, including sex, carapace depth, width and length were taken to the nearest millimeter using 30 cm vernier calipers and recorded onto waterproof paper. Additional details on bycatch, string position (east end buoy), soak time and the number of empty pots were noted.

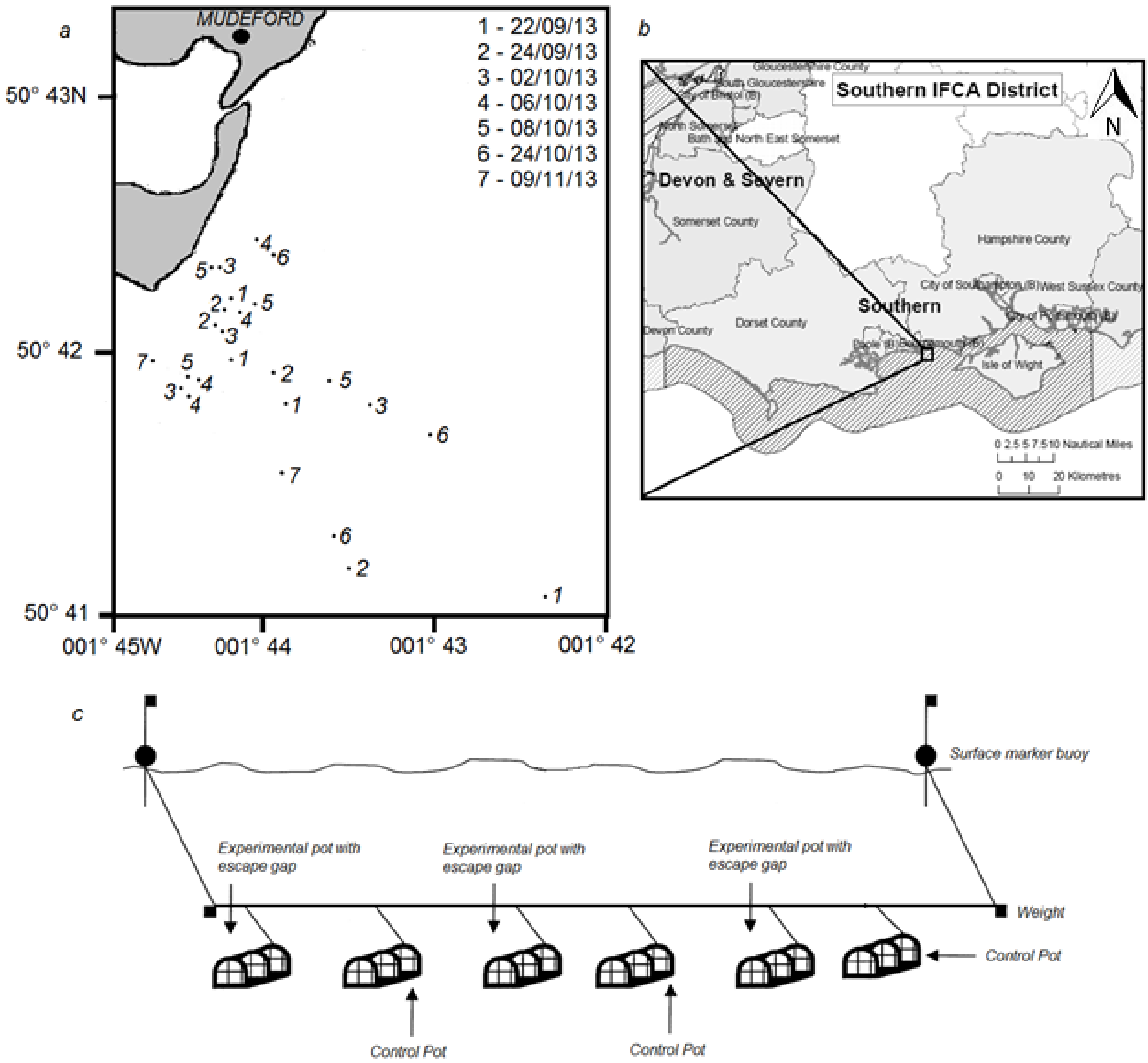


Figure 2.2. (a) Location of all strings (east end) from all seven trips. Numbers correspond to the trip number with the date given in the legend. (b) Map of the Southern Inshore Fishery and Conservation Authority district with the field trial area highlighted by a black box. (c). Configuration of experimental and control pots used within each string with escape gaps; pots were 20 metres apart.

2.2.2. Data Analysis

The relative performance of pots with and without escape gaps were compared on the basis of (a) size of individuals caught, (b) size frequency distribution, (c) proportion of individuals <MLS and >MLS and (d) CPUE (number of individuals per trap haul) for each species. For each trip, the size of the individuals caught in each pot type was tested for normality using a Shapiro-Wilk test and then compared across all trips using a One-Way ANOVA or Kruskal-Wallis One-Way ANOVA. Data was pooled across all trips for each pot type as no significant differences were observed between trips except for *C. pagurus* in escape gap pots. The size data were then compared between escape gap pots and control pots using a *t*-test or Mann-Whitney U test and average size (± standard deviation) was calculated. The frequency of individuals in 1 mm size classes for each pot type was calculated, tested for significant differences between pot types using a *t*-test or Mann-Whitney U test and presented in a bar graph. Frequency was converted to percentage and presented as a cumulative frequency graph. The proportion (frequency and percentage) of the catch above and below the MLS was calculated for each trip and compared between pot types using a *t*-test or Mann-Whitney U test. CPUE of individuals above and below the MLS was calculated for both pot types for each string per trip. A *t*-test or Mann-Whitney U test was used to test for significant differences between pot types and the average CPUE (± standard deviation) was calculated.

Morphometric data taken from all individuals belonging to each species was plotted in a series of scatter graphs. For each gender, the critical body dimension (y-axis) was plotted against the body dimension on which the MLS is based (x-axis) and both genders were plotted on the same graph. (Table 2.2). A line of best fit and linear regression were performed on each sex to generate an equation ($y= mx + c$) linking the two body dimensions. Differences between each sex were tested by finding the ratio between the two body dimensions (divide one by the other) and then compared using a *t*-test or Mann-Whitney U test.

Table 2.2. Critical body dimensions for European lobster, edible crab and velvet swimming crab when exiting through an escape gap.

Species	MLS Dimension	Critical Body Dimension(s)
Homarus gammarus	Carapace Length	Carapace Width
Cancer pagurus	Carapace Width	Carapace Length; Body Depth
Necora puber	Carapace Width	Body Depth

Ancillary temperature data recorded by the Boscombe Wave Buoy was obtained for September to November 2013 from the Channel Coastal Observatory website (www.channelcoast.org). Temperature was recorded at 30 minute intervals so the average temperature was calculated for each day and presented in a line graph.

2.2.3. Size-selectivity Curves

The SELECT (Share Each Length's Catch Total) modeling method was applied to the size frequency data recorded from escape gap pots and controls pots and used to calculate size-selectivity curves. The SELECT method allows the comparison of two or more fishing gear types that are fished at the same time (Treble *et al*., 1998). One gear type has an unknown size-selectivity (i.e. escape gap pots) and the other is assumed to retain all size classes (i.e. control pots) (Treble *et al*., 1998). The model has been utilisd for analysing data generated from crustacean trap fisheries, including escape gap trial studies (e.g. Treble *et al*., 1998; Shelmerdine & White, 2011). Size frequency data was organised into 1 mm size classes for *H. gammarus* and 5 mm size classes for *C. pagurus*. Using a Microsoft Excel spreadsheet with SOLVER add-in and instructions developed by Tokai (1997), the SELECT model was fitted to the data using a maximum likelihood estimation procedure for two size-selectivity functions and this generated selectivity curve parameters. The two size-selectivity functions included a symmetrical logistic function and an asymmetrical Richards function, given by the following two equations:

$$\text{Logistic Function: } r(l) = \frac{e^{(a+b\cdot l)}}{1+e^{(a+b.l)}} \qquad \text{Richards Function: } r(l) = \left(\frac{e^{(a+b\cdot l)}}{1+e^{(a+b\cdot l)}}\right)^{\frac{1}{\delta}}$$

Where *r(l)* is the probability of retaining an animal of length *l* in the gear of unknown size selectivity (with *l* in the present study referring to the carapace width of *C. pagurus* and carapace length of *H. gammarus*) and *a* (<0), *b* (>0) and δ are constants (Treble *et al*., 1998; Shelmerdine & White, 2011). δ is a constant defining the level and direction of asymmetry of a size-selectivity curve (see Treble *et al*., 1998). Other parameters also generated during the analysis included the selection range (SR) (L_{25}-L_{75}) and the Akaike's Information Criterion (AIC), which describes the goodness of fit of the model to the data, where lower values indicate a better fit (Wileman *et al*., 1996; Shelmerdine *et al*., 2011). Both the logistic and Richards size-selectivity function was used because the logistic model has been shown to provide unrealistic curves (Treble *et al*., 1998).

3. RESULTS

3.1. AQUARIUM TRIALS

3.1.1. Two-Dimensional Escape Gap Designs

Each escape gap design retained oversized individuals (>MLS^{-5mm}) and released undersized individuals (<MLS^{-5mm}) from each species with varying degrees of success. The ellipse and 87 x 45 mm rectangle were the most successful at releasing undersized *H. gammarus* and *C. pagurus* individuals, whilst retaining oversized individuals from both species (Figure 3.0a & 3.0b). The ellipse retained the highest number of oversized individuals (91.7% and 100% of *H. gammarus* and *C. pagurus* respectively) whilst the rectangle achieved the greatest release of undersized individuals (83.3% and 87.5% of *H. gammarus* and *C. pagurus* respectively). Despite a lower retention of oversized lobsters (58.3%) and edible crabs (80%) achieved by the rectangle, no individuals above the MLS were able to escape. The largest lobster and edible crab to escape from the rectangle measured 86 mm CL by 44 mm CW and 136 mm CW and 45 mm BD respectively. The size of retained lobsters and edible crabs were significantly greater than those able to escape from the oval and 87 x 45 mm rectangle designs (Table 3.0). The boomerang design was effective in retaining 100% of oversized lobsters and releasing 83.3% of undersized lobsters, however proved to less effective for *C. pagurus*; releasing individuals up to 140 mm CW. The rhombus and keyhole designs released no *H. gammarus* or *C. pagurus*. This allows the null hypothesis, that 'each two-dimensional escape gap design will not retain all oversized individuals (>MLS^{-5mm}) whilst also not allowing the escape of any undersized individuals (<MLS^{-5mm}) belonging to each species' to be rejected for two of the five two-dimensional designs. These include the boomerang for *H. gammarus* and ellipse for *C. pagurus*.

Table 3.0. *p*-Values from statistical analysis on the size difference between retained individuals and those able to escape from each 2D escape gap design. A (-) represents where the escape gap wasn't tested. 'All-retained' was where the escape gap retained all size classes.

	***p*-Value**		
Design	*H. gammarus*	*C. pagurus*	*N. puber*
87x45mm	0.012	0.000	-
Ellipse	0.001	0.002	0.802
Boomerang	0.000	0.647	0.894
Keyhole	All retained	-	0.408
Rhombus	All retained	All retained	0.485

The effectiveness of 2D designs were found to significantly differ when based on the percentage retention of undersized *H. gammarus* and *C. pagurus* and size of retained *H. gammarus* (Table 3.1). Unfortunately, a Student-Newman-Keuls (SNK) pairwise comparison could not identify where the significant differences existed and concluded there was no significant difference between any two rank sums (Appendix 3).

Table 3.1. *p*-Values from statistical analysis on differences in the effectiveness of 2D designs based on the percentage retention <MLS/ MLS^{-5mm} and >MLS/ MLS^{-5mm} and the size of escaped/ retained individuals. MLS was used for *N. puber* and MLS^{-5mm} for *C. pagurus*. MLS – minimum landing size.

	***p*-Value**		
Species	Percentage Retention <MLS/MLS^{-5mm}	Percentage Retention >MLS/MLS^{-5mm}	Size of Retained/Escaped Individuals
H. gammarus	0.015	0.392	0.044
C. pagurus	0.023	0.627	0.246
N. puber	0.511	0.262	0.919

No two-dimensional designs appeared to be effective at retaining legal-sized *N. puber*. The highest retention was achieved by the keyhole design, although there was no discrimination between individuals above or below the MLS with an equal retention of 44.4% (Figure 3.0c). Unsurprisingly, the effectiveness of the 2D escape designs were not found to significantly differ for *N. puber* (Table 3.1).

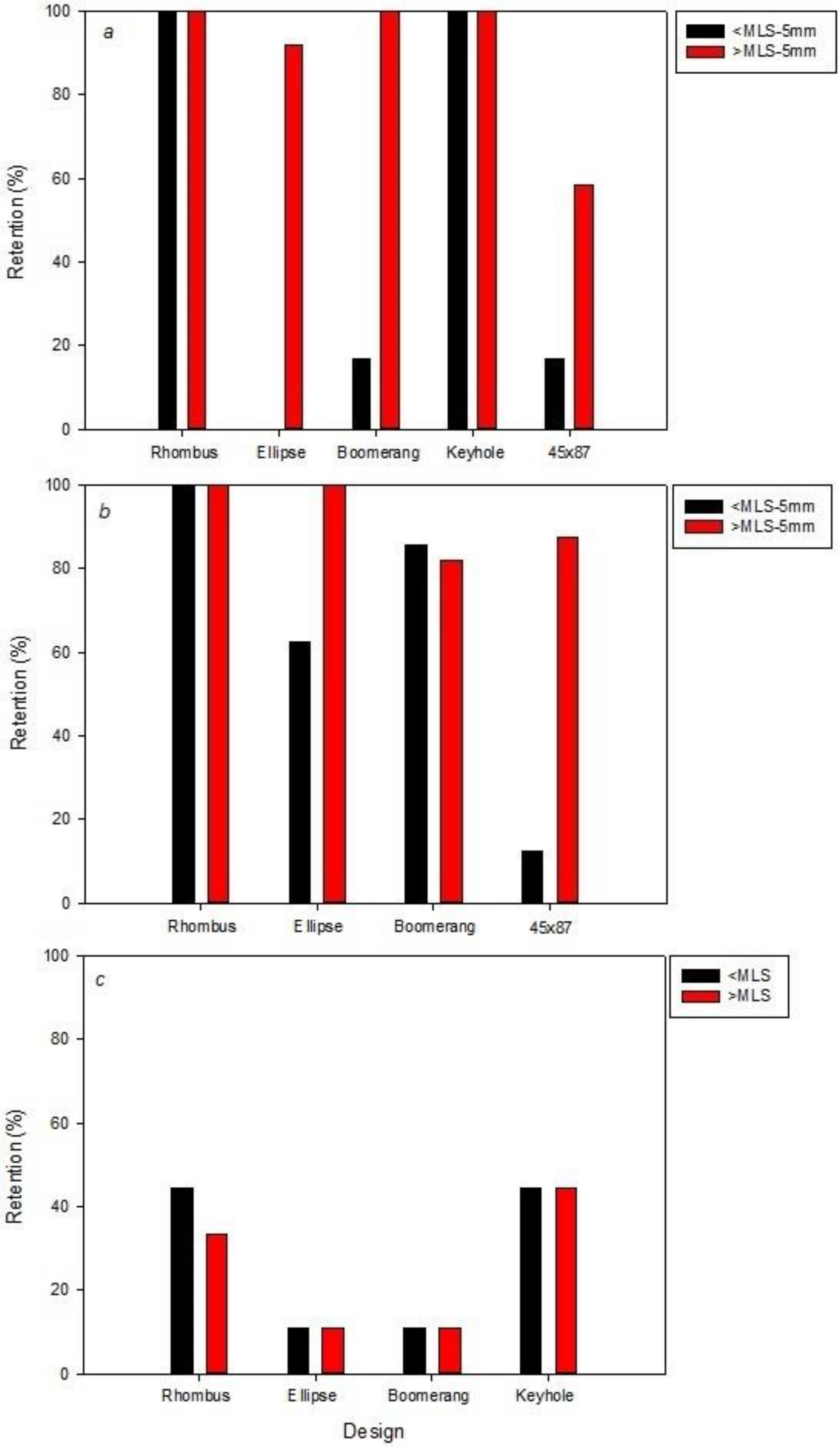


Figure 3.0. Percentage retention (%) of individuals above (red) and below (black) the minimum landing size (MLS) or MLS^{-5mm} for a) *Homarus gammarus*, b) *Cancer pagurus* and c) *Necora puber* for all two dimensional escape gaps.

3.1.2. Comparison to Hyland (2012)

Manual manipulation of *N. puber* through the keyhole design (referred to as half hybrid by Hyland (2012)) was used by both studies and found a similar range of individuals could be passed through the escape gap (Table 3.2). Hyland (2012) found only individuals with a CW of 72 and 73 mm were unable to pass through, combined with the results from the current study this implies individuals with CW greater than 72 mm are be retained by this design.

During aquarium trials of the 87 x 45 mm rectangle, both studies found a similar proportion of undersized lobsters were able to escape (Table 3.2). The egress of undersized edible crab on the other hand was 33.9% higher in the present study compared to Hyland (2012) (Table 3.2). Conversely, the retention of oversized lobsters and edible crabs in the present study was 36.1% and 20% lower than that achieved by Hyland (2012), respectively (Table 3.2). This can be explained by a larger retention of individuals with a CL or CW that is greater than the MLS^{-5mm} but less than the MLS in experiments conducted by Hyland (2012). The maximum size of lobster and edible crab able to fit through the rectangle were 86 mm CL and 136 mm CW in the present study and 85 mm CL and 133 mm CW in Hyland (2012) respectively. This gives a 3 mm difference in maximum CW of edible crabs. Overall the size of edible crabs able to escape proved to be significantly greater in the present study ($t(22)=2.430$, $p=0.024$). The size range of animals used in each study were also relatively dissimilar (Table 3.2) and the mean sizes of lobster and edible crab were 4.5 mm and 3 mm greater in the present study, both of which are statistically significant (European lobster; $U=363.0$, $T=1032.0$, $p=0.008$; edible crab; $t(67)=2161$, $p=0.034$).

Table 3.2. Comparison between the current study and Hyland (2012) with respect to the size range and average size of retained and escape individuals and the % escape and % retention of individuals below and above the MLS respectively for two escape gap designs; keyhole and 87x45mm rectangle.

Study	**Species**	**Design**	**Retained Individuals**		**Escaped Individuals**		**<MLS/ MLS^{-5mm}**	**>MLS/ MLS^{-5mm}**
			Size Range (mm)	Average Size (±SD) (mm)	Size Range (mm)	Average Size (±SD) (mm)	% Escape	% Retention
Present Study	*N. puber*	Keyhole	-	-	60-72	66.3 (±4.3)	100	0
Hyland (2012)	*N. puber*	Keyhole	72-73	72.5 (±0.5)	61-72	6.03 (±3.5)	100	25
Present Study	*H. gammarus*	87x45	71-93	87.5 (±7.9)	74-86	80.8 (±4.5)	83.3	58.3
Hyland (2012)	*H. gammarus*	87x45	68-87	82.9 (±3.8)	68-85	74.1 (±4.9)	84.4	94.4
Present Study	*C. pagurus*	87x45	133-148	140.8 (±4.7)	124-136	131.2 (±4.2)	87.5	80
Hyland (2012)	*C. pagurus*	87x45	125-140	135.1 (±3.2)	125-133	128 (±2.4)	53.6	100

3.1.3. Three-Dimension Escape Gap Designs

The 3D escape gap designs yielded interesting differences in the percentage retention of each species. All three designs retained 100% of *H. gammarus*, regardless of size (Figure 3.1a). Behavioral observations revealed that no lobsters tried to exit by forcing their way through the deformable material. Unlike *H. gammarus*, *C. pagurus* and *N. puber* were able to exit through all 3D escape gap designs (Figure 3.1b & 3.1c). The most effective escape gap design for both *C. pagurus* and *N. puber* was the 3D design incorporating brush bristles. This design achieved the highest retention of legal-sized *N. puber* (90%) whilst allowing 50% of undersized individuals to escape. The same design achieved 100% retention of oversized *C. pagurus* whilst releasing 37.5% of undersized *C. pagurus*. The remaining 3D designs achieved conflicting results with those incorporating sponge retaining a high proportion of *C. pagurus* (85.7% of undersized and 100% of oversized) and releasing a greater proportion of *N. puber* (55.6% of undersized and 33.3% of legal-sized). Those incorporating rubber blades on the other hand released a large proportion of *C. pagurus* (42.9% of undersized and 18.2% of oversized) and retained a high proportion of *N. puber* (100% of undersized and 87.5% of legal-sized). Despite disparity in the effectiveness of each 3D design, no significant differences were found (Table 3.3).

Results generated from trialing all three-dimensional design trials allowed the null hypothesis, that ‘each three-dimensional escape gap design will not retain all oversized individuals (>MLS^{-5mm}) whilst also not allowing the escape of any undersized individuals (<MLS^{-5mm}) belonging to each species’ to be rejected for only one design; the 3D design incorporating bristles for *C. pagurus*. This design also provided promising results for *N. puber*.

Table 3.3. *p*-Values from statistical analysis on differences in the effectiveness of 3D designs based on the percentage retention <MLS/ MLS^{-5mm} and >MLS/ MLS^{-5mm} and the size of retained individuals. MLS used was for *N. puber* and MLS^{-5mm} for *C. pagurus*. MLS – minimum landing size.

	***p*-Value**		
Species	Percentage Retention <MLS/MLS^{-5mm}	Percentage Retention >MLS/MLS^{-5mm}	Size of Retained Individuals
H. gammarus	-	-	0.935
C. pagurus	0.562	0.361	0.886
N. puber	0.057	0.702	0.807

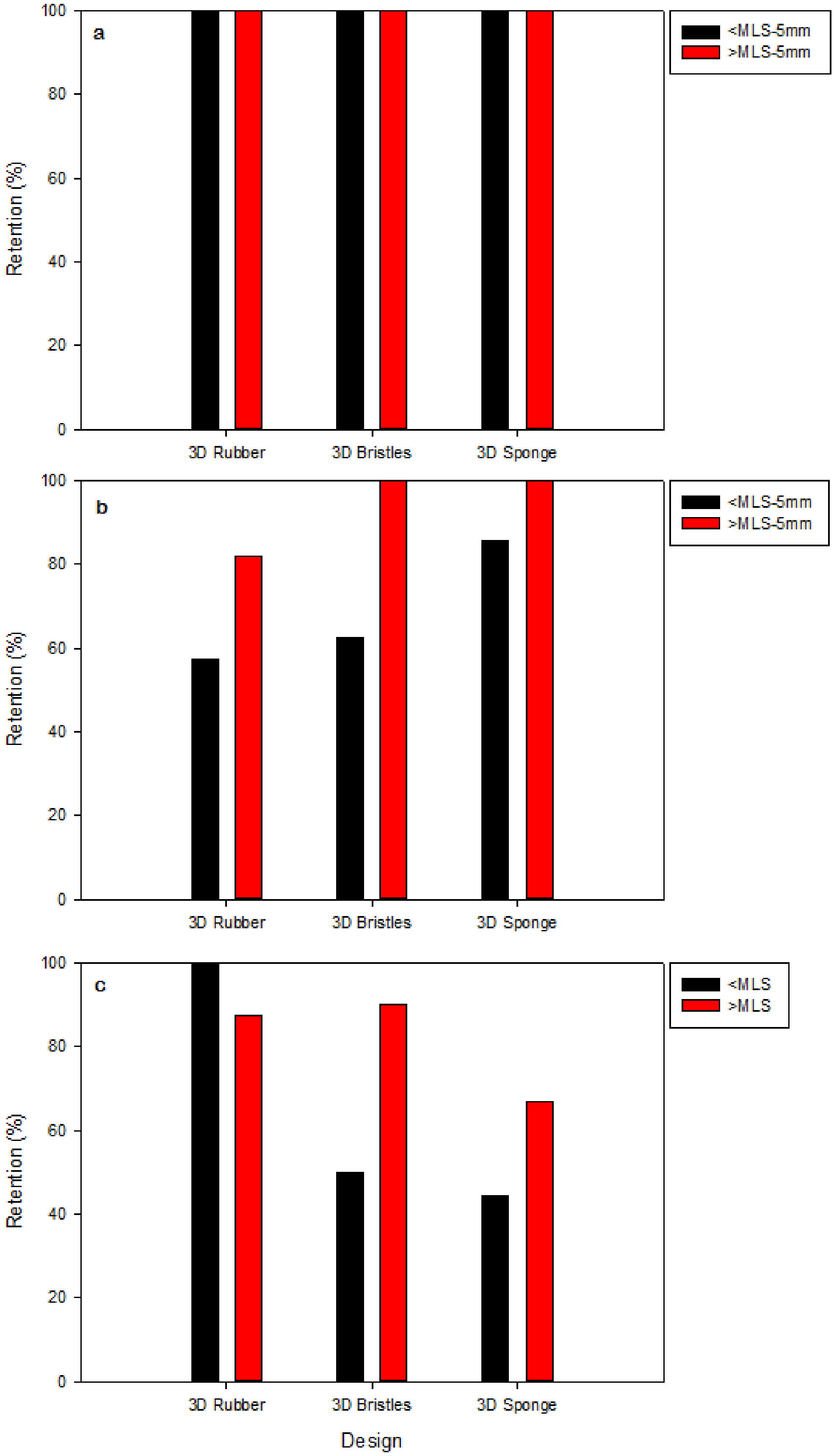


Figure 3.1. Percentage retention (%) of individuals above (red) and below (black) the minimum landing size (MLS) or MLS^{-5mm} for a) *Homarus gammarus*, b) *Cancer pagurus* and c) *Necora puber* for all three dimensional escape gaps.

3.2. FIELD TRIALS

3.2.1. Ancillary Data

Over the 7 experimental fishing trips (22/09/2013-09/11/2013) average Sea Surface Temperature (SST) ranged from 17.1°C on 24/09/2011 to 13.4°C on the 9/11/2013 (Figure 3.2). During the first five trips, SST remained fairly constant, between 16.8°C to 17.1°C. Thereafter it dipped to 15.0°C on 17/10/2013 and then rose slightly to 15.6°C on the 25/10/2013, where after it continued to rapidly decrease reaching 9.9°C by the end of November.

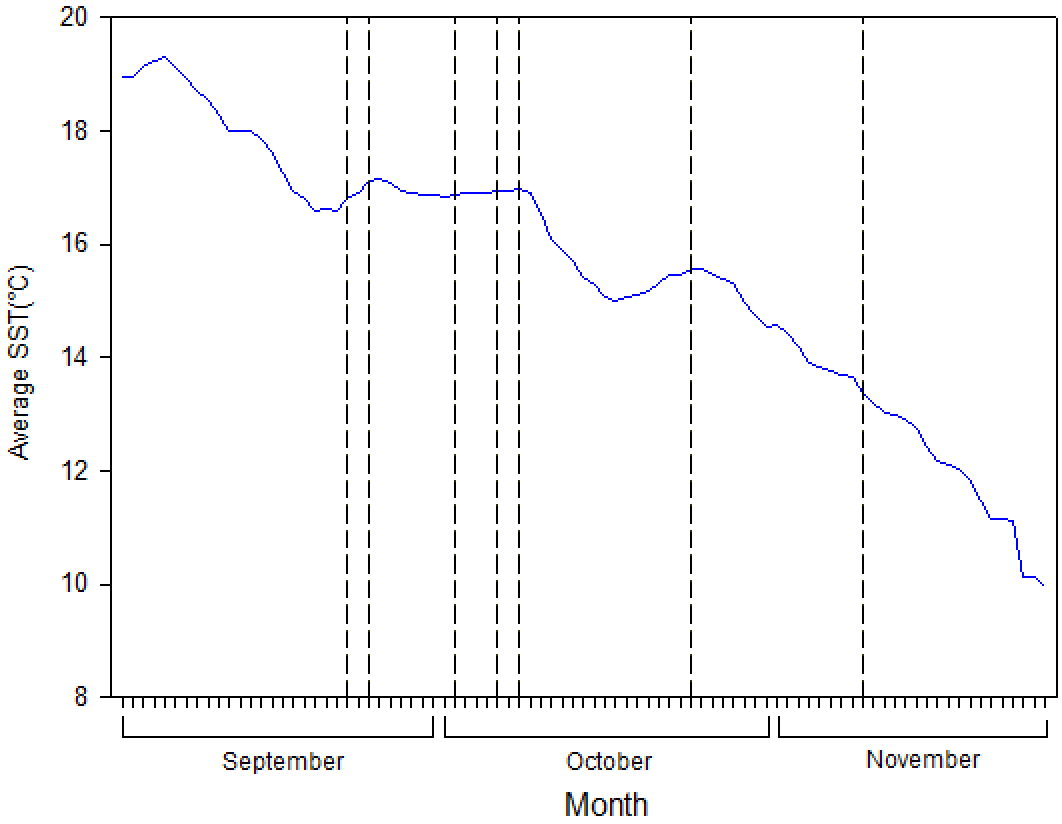


Figure 3.2. Sea surface temperature (SST) (°C) for September to November 2013 recorded at the Boscombe Wave Buoy. Dashed lines indicates when field trial data was collected.

During field trials, a total of 122 *H. gammarus*, 177 *C. pagurus* and 156 *N. puber* were collected. Over the first five trips, 28.6% of all pots fitted with escape gaps were empty and in all of these cases the bait in the pot had been removed, suggesting animals had entered the pot.

3.2.1. Homarus gammarus

The pooled data on lobster catches over all seven trips revealed a clear exclusion of smaller carapace lengths between 64 and 82 mm from pots fitted with escape gaps, with the exception of one individual (73 mm CL) (Figure 3.3a). The proportion of individuals caught above the MLS were maintained in pots fitted with escape gaps, with increases in size classes 95 and 96 mm CL. The average CL of lobsters caught in escape gap pots was significantly greater than those in control pots ($U=481.5$, $T=2926.5$, $p<0.001$), with an increase of 9.1 mm (Table 3.4). This means that the null hypothesis ‘retained individuals in parlour pots fitted with an escape gap will not have a significantly larger average size than those without an escape gap’ can be rejected. The frequency of lobsters in 1 mm size classes from 64 to 100 mm CL significantly differed between control and escape gap pots ($U=320$, $T=1752$, $p<0.001$). The largest differences were observed in carapace lengths between 74 to 85 mm, with higher frequencies occurring in control pots in this size range. The largest difference in frequency was as high as 7 individuals at a CL of 85 mm. This means that the null hypothesis ‘pots fitted with an escape gap will retain the same number of undersized (<MLS) individuals as pots without an escape gap’ can be rejected. With respect to carapace width, the majority (93.8%) of individuals caught in escape gap pots were 45 mm and above in size, whilst the majority (55.6%) of individuals caught in control pots had a carapace width less than 45 mm, illustrating escape gap height had a strong influence on selection (Figure 3.3b).

The retention of undersized (<MLS) lobsters decreased by 52%, from 74% of the catch in control pots to just 22% of the catch in pots fitted with escape gaps (Figure 3.3c; Table 3.4). Both the percentage and frequency of undersized individuals making up the total catch were found to be significantly lower in pots fitted with escape gaps than control pots (percentage: $t(12)=4.130$, $p=0.002$; frequency: $U=0.000$, $T=21$, $p=0.001$). This was subsequently reflected in the CPUE of undersized lobsters which significantly decreased from an average of 0.87 lobsters per pot haul in control pots to 0.09 in escape gap pots ($U=104$, $T=923$, $p<0.001$). Such large reductions in undersized individuals were achieved whilst maintaining catches of legal-sized (>MLS) lobsters. The total number of legal-sized (>MLS) lobsters caught over all 7 trips totaled 23 in control pots and 25 in escape gap pots, thereby revealing a slight increase of 8.6% in legal catch. There were however no significant differences in the frequency ($t(11)=0.332$, $p=0.746$) or CPUE ($U=314$, $T=665$, $p=0.648$) of legal-sized lobsters caught in control and escape gap pots.

Table 3.4. Catch composition of *Homarus gammarus*, *Cancer pagurus* and *Necora puber* in pots with and without escape gaps with details on the size range, average size, number of indivduals (N), number of individuals above and below the minimum landing size (MLS) and catch per unit effort (CPUE)(number of lobsters per pot haul).

Species	**Pot Type**	**Size Range (mm)**	**Average Size (±SD) (mm)**	**N**	**No. <MLS**	**No. >MLS**	**CPUE <MLS**	**CPUE >MLS**
H. gammarus	Control	64-98	81.6 (±8.0)	90	67	23	0.87	0.30
	Escape gap	73-100	90.7 (±5.3)	32	7	25	0.09	0.36
C. pagurus	Control	78-185	120.8 (±25.8)	127	97	30	1.33	0.42
	Escape gap	86-181	145.8 (±20.8)	50	12	38	0.17	0.52
N. puber	Control	55-85	70.7 (±5.1)	142	20	122	0.27	1.56
	Escape gap	56-78	66.6 (±5.3)	14	3	11	0.04	0.23

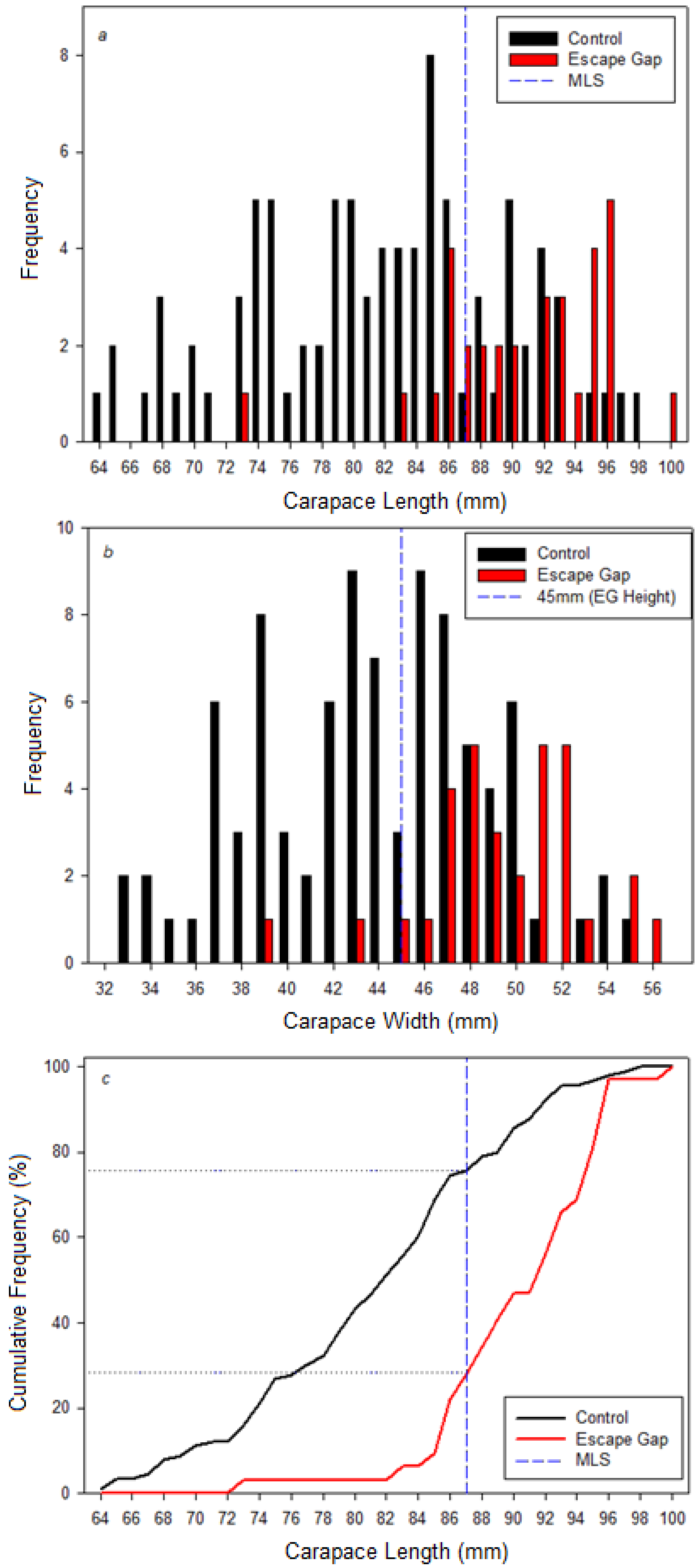


Figure 3.3. Size frequency distribution of *Homarus gammarus* caught in pots with (red) and without (black) escape gaps for (a) carapace length and (b) carapace width (critical body dimension) and (c) cumulative percentage curve for carapace length. The blue dashed line represents the minimum landing size (a & c) and the height of the escape gap (b).

3.2.2. Cancer pagurus

To a large extent there was an exclusion of crabs with carapace widths below 134 mm from pots fitted with escape gaps, with the exception of 16 individuals whose carapace widths ranged from 86 to 125 mm. In pots fitted with escape gaps, the most frequently (8 individuals) occurring CW was 145 mm (Figure 3.4a). Conversely, in the control pots, the highest frequencies (6 individuals) occurred at 100 and 110 mm CW and beyond this size, catches did not exceed more than 3 individuals at any carapace width. The frequency of edible crabs in 1 mm size classes from 78 to 185 mm CW significantly differed between control and escape gap pots ($U=4567$, $T=12983$, $p=0.003$). The greatest differences in frequency were observed at carapace widths of 97-111 mm and 144-155 mm, particularly at 100 and 110 mm CW. This means that the null hypothesis 'pots fitted with an escape gap will retain the same number of undersized (<MLS) individuals as pots without an escape gap' can be rejected. The carapace widths of edible crabs caught in pots with escape gaps were significantly greater than those in control pots ($U=1453$, $T=6171.5$, $p<0.001$), with an increase of 25 mm in average CW (Table 3.4). This means that the null hypothesis that 'retained individuals in pots fitted with an escape gap will not have a significantly larger average size than those without an escape gap' can be rejected. Only a small proportion of individuals retained in escape gap pots had a carapace length less than 87 mm (18%) and body depth less than 45mm (16%); the dimensions corresponding to that of the escape gap design. In control pots however, the majority of retained individuals had a carapace length less than 87 mm (68.5%) and body depth less than 45 mm (70.9%), illustrating that both escape gap height and length have a strong influence on the selection of edible crab (Figure 3.4b & 3.4c).

There was a reduction of 54% in the retention of undersized individuals, making up 77% of the catch in control pots to just 23% of the catch in pots fitted with an escape gap (Figure 3.4d; Table 3.4). The percentage and frequency of undersized individuals was found to be significantly lower in pots with escape gaps than in control pots (percentage: $t(12)=5.668$, $p<0.001$; frequency: $U=0.000$, $T=77$, $p<0.001$). There were also significant reductions in the average CPUE of undersized edible crab from 1.33 individuals per pot haul in control pots to 0.17 in pots fitted with escape gaps ($U=50$, $T=826$, $p<0.001$). Such large reductions in undersized individuals were achieved whilst maintaining catches of legal-sized individuals. Over the seven trips, escape gap pots caught 8 more legal-sized individuals than control pots (Table 3.4). Increases in the average CPUE of legal-sized individuals were also observed however neither increases in the frequency ($U=17$, $T=45$, $p=0.383$) or CPUE ($U=249.5$, $T=549.5$, $p=0.412$) were statistically significant for legal-sized individuals (Table 3.4).

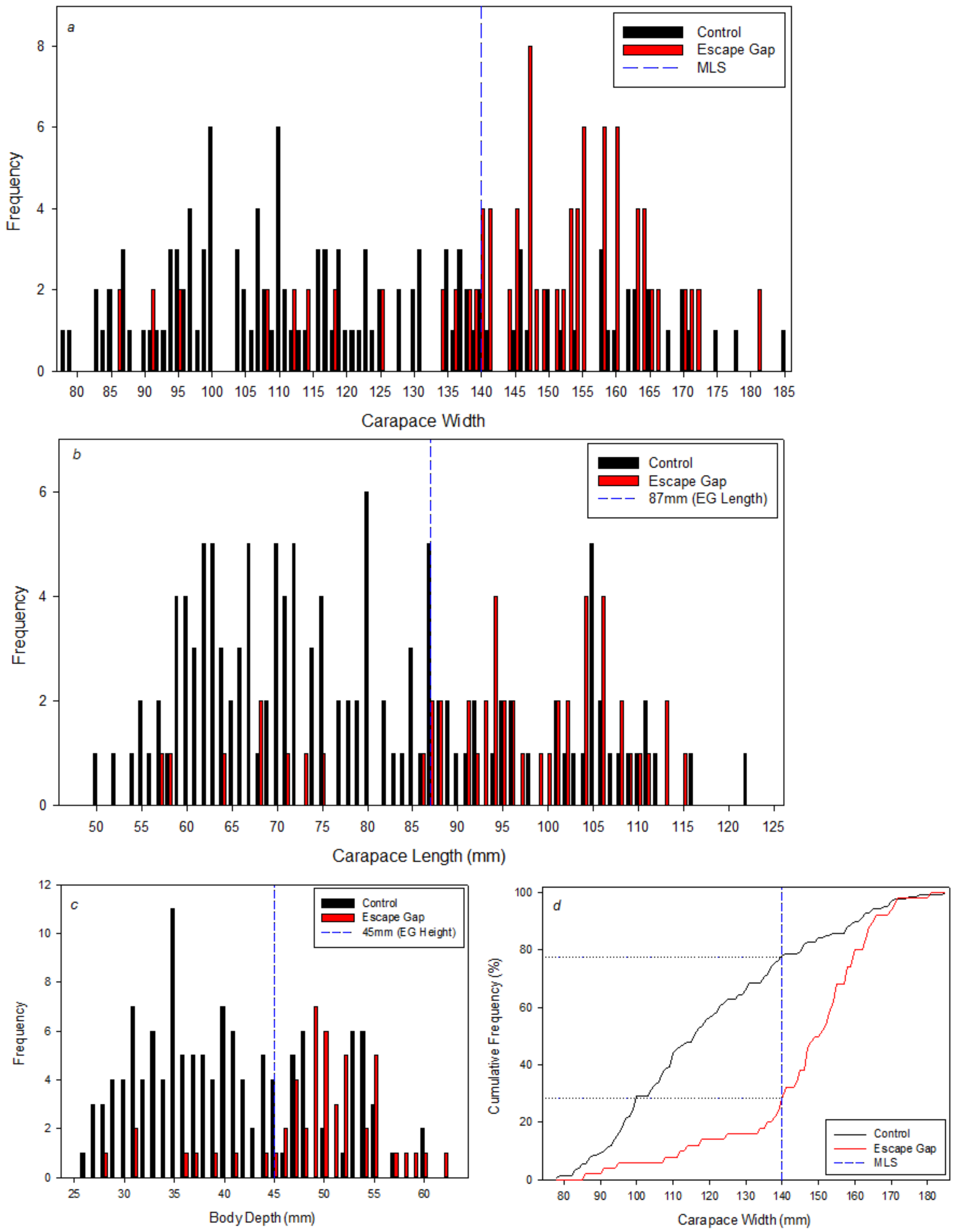


Figure 3.4. Size frequency distribution of *Cancer pagurus* caught in pots with (red) and without (black) escape gaps for (a) carapace width and (b) carapace length (critical body dimension) (c) body depth (critical body dimension) and (d) cumulative percentage curve for carapace length. The blue dashed line represents the minimum landing size (a & d), the length (b) and height of the escape gap (c).

3.2.3. Necora puber

A large proportion of the total catch was lost from pots fitted with escape gaps, with a total catch of only 14 individuals compared to 142 individuals in control pots. The size range of individuals caught showed a large overlap between both pot types however the highest frequencies only reached 3 individuals at 65 mm CW in pots fitted with escape gaps compared 17 individuals at 72 mm CW in control pots (Figure 3.5a). The frequency of velvet swimming crabs in 1 mm size classes from 55 to 84mm CW significantly differed between control and escape gap pots (U=141, T=1224, p<0.001). The greatest differences in frequency were observed between 66-77 mm CW, where the highest frequencies of velvet swimming crab occurred in control pots. In control pots, the majority (85.9%) of velvet swimming crabs caught were above the MLS, with an average CW of 70.7 mm; 5.7 mm above the current MLS (Table 3.4). The carapace widths of velvet swimming crabs caught in escape gap pots were significantly lower than those in control pots (t(154)=2.855, p=0.005), with a decrease of 4.1 mm in average CW (Table 3.4). This means that the null hypothesis ‘retained individuals in parlour pots fitted with an escape gap will not have a significantly larger average size than those without an escape gap’ must be accepted.

There were clear reductions in the number of individuals both above and below the minimum landing of 85% and 91%, respectively, in pots fitted with escape gaps compared to those without (Figure 3.5b; Table 3.4). In control pots, only 14.1% of individuals were undersized whilst in escape gap pots, 43% of individuals were undersized. Despite large differences in the percentage and frequency of undersized crabs in both pots types, no significant differences were found between the two (percentage: t(9)=0.560, p=0.589; frequency: t(9)=1.993, p=0.0774). This means that the null hypothesis ‘pots fitted with an escape gap will retain the same number of undersized (<MLS) individuals as pots without an escape gap’ must be accepted. In contrast to *H. gammarus* and *C. pagurus*, the frequency of legal-sized velvet swimming crab was greater in control pots (122 individuals) than in those fitted with escape gaps (11 individuals). The reductions in both frequency (t(9)=3.197, p=0.0119) and CPUE (U=78, T=872, p<0.001) of legal-sized velvet swimming crabs in pots fitted with escape gaps compared to those without were statistically significant.

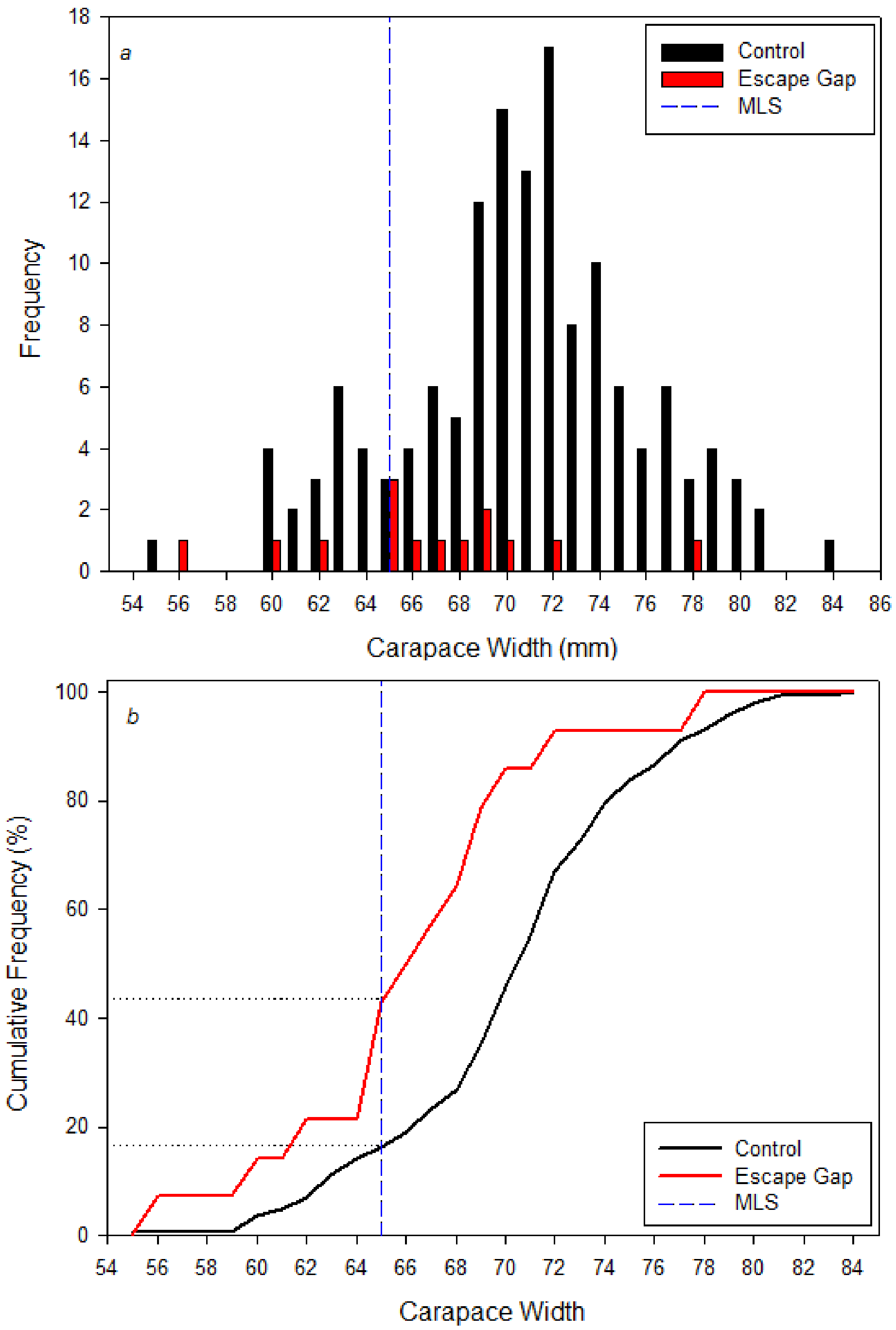


Figure 3.5. Size frequency distribution of *Necora puber* caught in pots with (red) and without (black) escape gaps for (a) carapace width and (b) cumulative percentage curve for carapace width. The blue dashed line represents the minimum landing size.

3.2.4. Bycatch Composition

Overall, there was a very low level of bycatch. In pots fitted with escape gaps there was no bycatch at all. Control pots had an average CPUE of 0.24 individuals per pot with the highest CPUE of 1.3 individuals per pot, which occurred only once. The species caught were either dogfish or wrasse and both occurred in equal amounts.

3.2.5. Morphometric Dimensions

All size data were pooled from control and escape gap pots to obtain a relationship between the critical body dimension and that used to base the MLS on. A total of 121 lobsters were measured, 38 female and 83 male. The relationship between CW and CL showed high R^2 values for both sexes confirming a close relationship to the line of best fit and minimal scatter of data points (Figure 3.6a). The corresponding CW to the 87 mm CL MLS was greater for females at 47.8 mm and 46.8 mm for males, thus confirming 45 mm as a suitable escape gap height in retaining individuals above the MLS. The relationship between the two body dimensions was significantly different between females and males ($t(119)=4.337$, $p<0.001$).

A total of 177 edible crabs were measured, 66 female and 111 male. The relationships between CL and CW and BD and CW revealed high R^2 values for both sexes, indicating both pairs of dimensions had a close relationship with the line of best fit and minimal scatter of data points (Figure 3.6b & 3.6c). The corresponding CL to the 140 mm CW MLS was 3 mm greater for females than males at 93.3 mm and 90.3 mm respectively. The corresponding BD to the 140 mm CW MLS was 2.4 mm greater for females than males at 48.4 mm and 46 mm respectively. Both confirm 45 mm and 87mm as a suitable escape gap height and length respectively. The relationship between both CL and CW and BD and CW were both significantly different between females and males (CL: $U=2159$, $T=7378$, $p<0.001$; BD: $U=2005$, $T=7532$, $p<0.001$).

A total of 155 velvet swimming crabs were measured, 31 female and 124 male. The relationship between BD and CW revealed intermediate R^2 values for both sexes indicating a moderately close relationship with the line of best fit but with evident scatter of data points (Figure 3.6d). The corresponding BD to the 65 mm CW MLS was slightly higher for females at 24.6 mm and 24.2 mm for males, thus confirming 20 mm as a suitable escape gap. The relationship between the two body dimensions was significantly different between females and males ($U=1387$, $T=2953$, $p=0.017$).

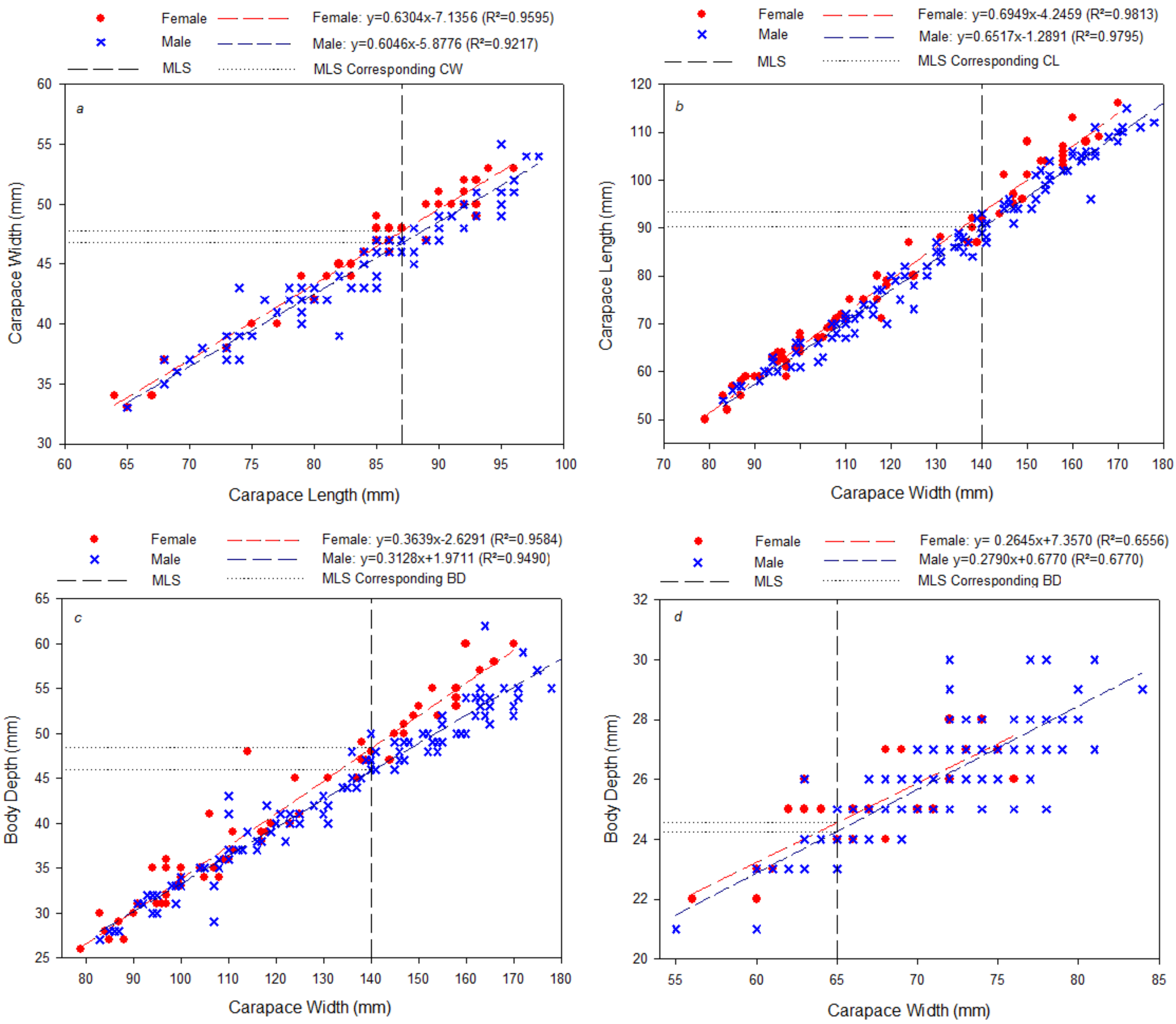


Figure 3.6. Morphometric dimension relationships between the body dimension on which minimum landing size is based (x-axis) versus the critical body dimension (y-axis) with the line of best fit for females (red) and males (blue) of (a) *Homarus gammarus* (b) *Cancer pagurus* (carapace length), (c) *Cancer pagurus* (body depth) and (d) *Necora puber*. Dashed lines represent the minimum landing size and dotted lines represent the corresponding critical body dimension. The y=mx+c equation for the line of best fit and R^2 value is given for each sex.

3.2.6. Size-selectivity Curves

In the size-selectivity curve analysis, similar AIC values were calculated for both curves for each species, indicating a comparable goodness of fit to the data (Table 3.5; Figure 3.7). Despite similarities, the AIC values for the logistic function were lower for both species, indicating a slightly better goodness of fit than the Richards curve. Both curves reveal a fairly gradual gradient and do not display a knife-edge retention, which would be characterized by an extremely steep gradient.

The size selectivity curves did not extend to the size at which full retention (100%) would be achieved. For both species, L_{50} was greater than the minimum landing size, occurring at approximately 91.9 mm CL for *H. gammarus* and 156.9 CW for *C. pagurus* (Table 3.5).

Table 3.5. Values of parameters; constants *a*, *b* and δ, L_{50}, selection range (SR) and Akaike's Information Criterion (AIC) for logistic and Richards curves fitted to retention data of European lobster (*Homarus gammarus*) and edible crab (*Cancer pagurus*) from field trials using the 87 x 45 mm escape gap. L_{50} is the size (mm) of an animal at 50% retention, this based on carapace width for *C. pagurus* and carapace length for *H. gammarus*. SR is L_{25}- L_{75}. AIC describes the goodness of fit of the model to the data, lower values indicate a better fit.

		Parameter					
Species	**Curve**	*A*	*B*	δ	L_{50}	SR	AIC
Cancer pagurus	Logistic	-6.34	0.04	-	156.89	54.35	67.15
	Richards	-3.64	0.03	0.43	156.75	60.77	68.60
Homarus gammarus	Logistic	-18.40	0.20	-	91.92	10.98	56.40
	Richards	-15.83	0.18	0.75	91.89	11.51	56.55

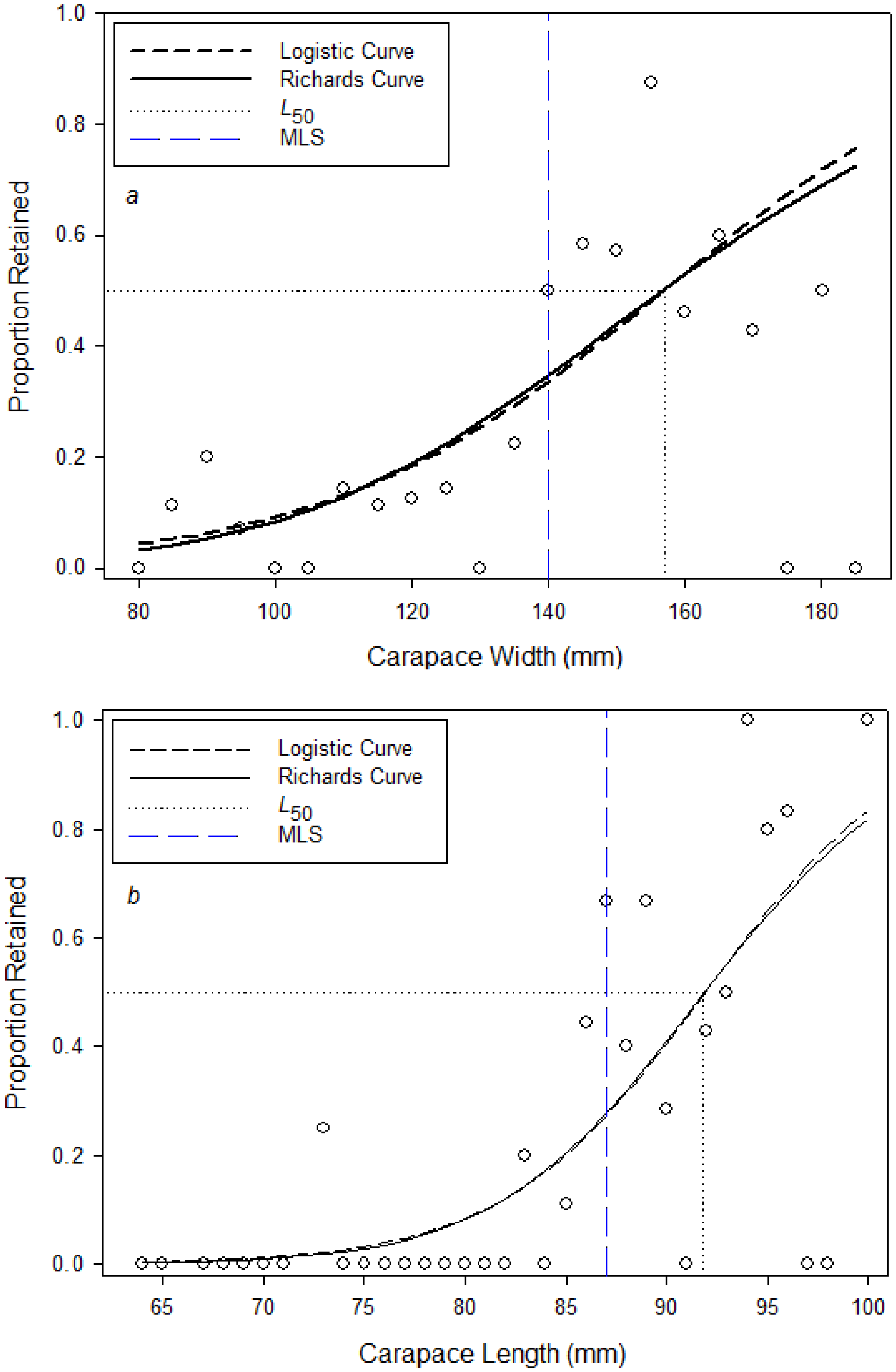


Figure 3.7. Size selectivity curves, Logistic (dashed lines) and Richards (solid lines) fitted to the proportion of retained (a) *Cancer pagurus* and (b) *Homarus gammarus* in escape gap field trials of an 87 x 45 mm escape gap design. *Cancer pagurus* frequency data was clustered in 5 mm size classes and *Homarus gammarus* frequency data was clustered in 1 mm 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}).

4. DISCUSSION

4.1. Field Trials

Field trials revealed that escape gaps can significantly reduce the percentage retention of undersized individuals in parlour pots. Parlour pots, used widely in the UK, are particularly efficient at retaining all individuals that enter a pot, with catches of *H. gammarus* reported to be twice that of a single chambered pot (Lovewell *et al*., 1979). The 87 x 45 mm escape gap was found to reduce sublegal retention of both *H. gammarus* and *C. pagurus* by over 50%; the magnitude of which is in line with, if not slightly lower than, than reductions achieved during other escape gap studies (Appendix 4). In general, fitting escape gaps has been shown to reduce the catch of sublegal crustaceans by over 50%, although in extreme cases can reach up to 90% (Appendix 4) (Brown, 1982; Everson *et al*., 1992; Brock *et al*., 2006). In the UK, Brown (1982) reported a reduction of 91% in undersized *C. pagurus*. Allowing over 50% more sublegal individuals to exit through an escape gap at the seafloor eliminates the negative effects associated with onboard handling procedures, such as an increased likelihood of appendage loss, predation, displacement and air exposure; thus increasing their chance of survival. If used in the Southern IFCA district, escape gaps could reduce the incidence of appendage loss, estimated to affect 10% of the population in the UK edible crab fishery, theoretically by half (Bennett, 1973). The 25% reduction in growth rate associated with severe appendage loss in edible crabs would therefore affect less of the population and prevent delayed entry into the Southern IFCA fishery (Bennett, 1973; Davis, 1981).

The level of reduction achieved in sublegal catch rates were very similar for *H. gammarus* and *C. pagurus*. This is unlike previous studies based in the UK whose results confirm the enhanced escape of *H. gammarus* over *C. pagurus* (Brown, 1979; Lovewell *et al*., 2002). Brown (1979) reported reductions of 84% and 34% in the number sublegal *H. gammarus* and *C. pagurus*, respectively, using a combined lobster and crab escape gap measuring 42 x 74 mm. Similar results were obtained in a more recent study, where reductions of 58% and 34% were achieved in the number of sublegal *H. gammarus* and *C. pagurus* respectively, using an escape gap measuring 84 x 46 mm; similar to the escape gap dimensions used in the present study (Lovewell *et al*., 2002). The latter study was conducted in the North Eastern IFCA district where the minimum landing sizes are 87mm CL for *H. gammarus* and 130mm CW for *C. pagurus*, similar to the Southern IFCA district (Lovewell *et al*., 2002). Hyland (2012) revealed that the length of commercially available escape gaps in the UK restricted the exit of sublegal edible crab, thus causing a bias towards the escape of sublegal lobsters. Field trials of the lengthened escape gap, recommended by Hyland (2012), demonstrated that the additional length was able to enhance the escape of sublegal edible crab and maintain the escape of sublegal lobster.

Overall catches of legal-sized lobster and edible crab were higher in escape gap pots than control pots by 8.6% and 26.7% respectively. Brown (1978) achieved similar increases in *C. pagurus* of 25%, using a single 38 x 74 mm escape gap. A smaller increase in the legal catch of *H. gammarus* is similar to the average increase of 5.9% observed to occur in *Homarus* and *Panulirus* lobster fisheries (Skillman *et al*., 1984). The aggressive behavior exhibited by *Homarus* spp. often limits the number of lobsters and crabs found in a fishing pot and may explain the smaller increase in legal catch (Addison *et al*., 1995). Agonistic interactions between conspecifics of *Homarus* spp. and other *Cancer* spp. within a fishing pot have shown to inhibit subsequent trap entry (Bell *et al*., 2001; Watson & Jury, 2013). In fishing pots off of the Welsh coast, only 2% of pots were found to contain more than one lobster; consistent with personal observations made during field trials that a single legal-sized lobster would occur in pots fitted with an escape gap (Bennett & Lovewell, 1977). This is well supported by results obtained in experiments using pots pre-stocked with one or more lobster (Richards *et al*., 1983; Addison, 1995). Pots pre-stocked with a single lobster (*H. gammarus*) reduced subsequent catch rates of lobster and crab (*C. pagurus*) by 54% and 60% respectively (Addison, 1995). Fitting an escape gap to the side of a pot is more likely to reduce the probability of agonistic interactions as sublegal individuals are able to egress before such encounters occur, this in turn increases the likelihood of a legal-sized individual entering a pot (Guillory & Hein, 1998). In non-vented pots however, a saturation effect may decrease the likelihood of a legal-sized lobster from entering a pot if other lobsters are already present (Krouse, 1978). Conversely, the presence *C. pagurus* is less likely to affect subsequent catch rates of conspecifics or *H. gammarus* (Bell *et al*., 2001). Pre-stocking traps with *C. pagurus* has proved to have no effect on the catch rate of *H. gammarus* and only a small effect on the catch rate of conspecifics, with reductions of up to 30% (Addison & Bannister, 1998). It is important to note these reductions were achieved by pre-stocking traps with three large edible crabs, averaging 142 mm CW and were thus more likely to have an influence on subsequent catch rates (Addison & Bannister, 1998). The limited influence of *C. pagurus* is likely to explain why legal catches of *C. pagurus* were higher than *H. gammarus*.

4.2. Two-Dimensional Escape Gap Designs

During aquarium trials, the elliptical escape gap was equally as effective as the 87 x 45 mm rectangular escape gap at releasing undersized *H. gammarus* and *C. pagurus*, despite a smaller opening area (Appendix 5). Escape gap opening area is an important variable for crustaceans in terms of locating an escape gap (Boutson *et al*., 2009). Paul (1984) concluded that escape gap designs with the largest opening area provided the highest level of escape. Blue swimming crabs have been observed to preferably select square escape gaps with a larger opening area over smaller circular escapes and rectangular escape gaps over elliptical escape gaps with similar opening areas (Boutson *et al*., 2009). This may be related to the fact that escape gap openings are located through random searching and so a larger opening is located more easily than a smaller one (Fogarty & Borden, 1980; Boutson *et al*., 2009). These observations however contradict current findings as the percentage retention did not considerably differ between the elliptical and rectangular design, with both achieving similar results. The reason for this is likely to be because both are based on the same 87 x 45 mm dimensions, with only a small difference in opening area. A larger reduction in the opening area of the rhombus however, largely influenced the egress of *H. gammarus* and *C. pagurus*. This is likely to be because of the lack of physical space available for passage through the escape gap rather than finding it more difficult to locate. A smaller opening area can also reduce the space in which an individual has to maneuver. For example, a lobsters passage through a circular escape gap is found to be more challenging than through a rectangular escape gap, due to the lack of space necessary for the insertion of the chelae (Estrella & Glenn, 2006).

The outcome of aquarium and field trials both highlight the 87 by 45 mm escape gap design, recommended by Hyland (2012), is extremely suitable for retaining *H. gammarus* and *C. pagurus* above the minimum landing size. The size-selectivity curves do however reveal that the selectivity of the escape gap is gradual and there is not a 'knife edge retention', whereby all individuals may escape until reaching a critical maximum size (Guillory *et al*., 2004). This is most likely confounded by the ability of lobsters to compress their carapace, as found by Nulk (1978) who reported escapee carapace widths up to 5 mm greater than the escape gap height in *H. americanus*. In the present study however, a lobster with a carapace width of 46 mm was able to egress, therefore only able to compress its carapace by 1 mm, as would be expected for a hard-shelled American lobster (Krouse & Thomas, 1975). The contrary was found for the edible crab, whose maximum dimensions of carapace length and body depth reflected that of the 87 x 45 mm escape gap, thus implying *C. pagurus* was not able to compress its carapace.

Although aquarium trials revealed that the 87 x 45 mm escape gap retained individuals above the MLS it did not retain individuals above the precautionary MLS^{-5mm} size limit. In order to comply with the MLS^{-5mm} size limit, a conservative approach would be to recommend an 87 x 44 mm escape gap in order to minimise the escape of individuals between the MLS^{-5mm} and MLS. A 1 mm reduction however is likely to significantly affect the size of lobsters and edible crabs able pass through the escape gap (Brown & Caputi, 1986). Assuming lobsters have the ability to compress their carapace width by up to 1 mm, the carapace length of a female and male able to egress through an 87 x 44 mm escape gap would range between 81.1 to 82.7 mm and 82.5 to 84.2 mm, respectively. The carapace width of a female and male edible crab able to egress through an 87 x 44 mm escape gap would be 128.1 mm and 134.4 mm, respectively. The large decrease in carapace width of females able to escape is related to their significantly greater body depths and illustrates how a small change to the critical dimension can correspond to much larger changes in other body dimensions. These in turn correspond to large changes in the retention capabilities of an escape gap. For example, in the American blue crab fishery, a 1.6 mm increase in escape ring size, decreased the retention of sublegal males from 1.87 to 0.96 per trap; equivalent to 12.3 million individuals annually (Guillory *et al*., 2004; Rudershausen & Turano, 2009).

When deciding on an appropriate escape gap, a balance must be reached between retaining legal sized individuals and allowing undersized individuals to escape (Shelmerdine & White, 2011). An escape gap measuring 87 x 44 mm is likely to retain a greater proportion of lobsters and male edible crabs 5 mm below the MLS. The retention size of female edible crabs however, is likely to extend up to 12 mm below the MLS, which may represent a huge cost to the fishery. A higher proportion of undersized female edible crab would become vulnerable to the negative effects associated with onboard handling and return procedures. Additionally, females with a 128.1 mm CW are unlikely to have had a chance to reproduce as the size at maturity is estimated to range between 127 mm to 132 mm (Fish & Fish, 1996; Ungfors, 2008). Therefore removing undersized females would reduce future spawning stock, so protecting these individuals is of particular importance, as they are responsible for future recruitment to the fishery. The reassurance fishermen gain from retaining a higher proportion of individuals between the MLS and MLS^{-5mm} with an 87 x 44 mm escape gap, is likely to be offset by the potential cost to the fishery of retaining a higher proportion of undersized female edible crabs. Therefore an 87 x 45 mm escape gap is likely to be more suitable for catching *H. gammarus* and *C. pagurus* at the current minimum landing sizes implemented in the Southern IFCA region.

Out of all four two-dimensional escape gap designs that were trialed for *N. puber*, none were found to sufficiently retain individuals of legal size as dimensions were too large. Dimensions were primarily based on the principal 87 x 45 mm dimensions, as these are known to retain legal-sized *H. gammarus* and *C. pagurus* (Hyland, 2012). The reason for this is that *H. gammarus* and *C. pagurus* are the dominant target species. The fishery for *N. puber* is relatively new and the species still only represents 0.28% of the overall landings and 0.16% of the total value of the fishery. This explains why initial research into suitable escape gap dimensions largely concentrated on *H. gammarus* and *C. pagurus*, however finding a suitable escape gap for all three species is still the ultimate aim for the Southern IFCA.

4.3. Three-Dimensional Escape Gap Designs

The relatively recent interest in catching *N. puber* means an ideal escape gap would retain legal-sized individuals of *H. gammarus*, *C. pagurus* and *N. puber*. The disparity in body size and shape make this difficult, however promising results were generated from aquarium trialed escape gap designs that incorporated deformable material. The concept of the three-dimensional escape gap design was to create an escape gap opening area measuring 20 mm in height, to allow sublegal *N. puber* to escape but retain legal-sized *N. puber*, whilst still allowing sublegal *C. pagurus* and *H. gammarus* to exit through the escape gap by pushing their way through the deformable material. The expected outcome was observed for *N. puber* and *C. pagurus,* all be it with varying levels of success for each material type, but not *H. gammarus* who were unwilling to exit through any of the three-dimensional designs. The most suitable deformable material was found to be brush bristles. These were attached to the top edge of the escape gap frame, leaving the lower section of the escape gap open. This may be the reason it was the most successful as the attachment site for the other two material types was on the upper and lower edges of the escape gap, thus when exiting the individual would incur resistance on their dorsal and ventral sides.

The incorporation of deformable material into an escape gap appears to be an entirely new concept not reported in the literature before. It is however relatively similar to an anti-escape device which is fitted to trap entrances and are known as triggers (Krouse, 1989). Triggers generally consist of vertical wires that are loosely fixed to the top of a rigid trap opening, usually in traps with side entrances (Miller, 1990). The triggers are pushed up and in as an animal enters the trap and then fall after the animal is in the trap (Miller, 1990). The vertical wires cover the entire entrance and this allows individuals to only pass through in one direction (Miller, 1990). Their main use is as an anti-escape or non-return device, however the spacing between the vertical wires can be used to allow escape of sublegal individuals (Zhou & Shirley, 1997). A recent study fitted triggers to escape gaps to block the entry of crabs from outside (Puspito, 2013).

Entry of individuals into a pot fitted with triggers requires contact with the vertical wires (Barber & Cobb, 2009). This was found to not affect the probability of entry of edible crabs, as observed in the present study where edible crabs were found to exit through all types of deformable material (Salthaug, 2002). Other studies have revealed that triggers do not hinder catches of *C. pagurus* or *H. gammarus* (Miller, 1990). This indicates contact with triggers does not deter entry of *H. gammarus* into the trap; unlike observations made in the present study (Miller, 1990). Interestingly, no lobsters penetrated the deformable material, for which there is no obvious explanation. In rocky areas, the European lobster is known to burrow under rocks (Thomas, 1968), so it was unexpected that sublegal individuals were unwilling to push their way through the deformable material. Crustaceans possess a variety of sensory structures, known as sensilla, and these are involved in the detection of external mechanical and chemical stimuli (Derby, 1989). Sensilla are found on antennules, antennae and mouthparts and legs of *Homarus* spp. (Derby & Atema, 1982). Those on the antennal flagellum are involved chemoreception and mechanoreception (Tazaki, 1977; Derby & Atema, 1982). This makes them extremely sensitive to water movement and so such high sensitivity to mechanical stimuli may have deterred lobsters when making contact and incurring resistance from the deformable material (Tazaki, 1977). Alternatively, a chemical stimulus, released from the materials used to construct the escape gaps, may have acted as a deterrent. The escape gaps were not soaked before use, a practice often used for new traps or pots to eliminate the possibility of foreign odours that may leach from the materials used (Slack-Smith, 2001). It is rumoured that new fishing pots are less efficient that those that have remained in the water for long periods (Stride pers. comm.). Additionally, the artificial and homogenous environment of the aquarium may also be an important factor, as the degree to which animals exhibit natural behavior is unknown (Jury *et al*., 2001; Leland *et al*., 2013). A previous escape gap study using *N. puber* found individuals to exhibit depressed feeding rates and limited movement within the tanks, which led to no crabs passing through the escape gap (Shelmerdine & White, 2011).

The fact that *H. gammarus* failed to push their way through any of the three-dimensional escape gaps gives rise to the potential for an escape gap panel rather an a single escape gap that would be suitable for all three species. The escape gap panel would consist a crab only escape gap incorporating bristles positioned alongside a circular escape gap for *H. gammarus* (Appendix 6). Circular escape gaps are a commonly utilised escape gap shape, particularly in *Homarus* spp. lobster fisheries (Table 1.1). In the UK however, circular escape gaps are not used, despite being proven to be just as efficient as rectangular escape gaps in allowing the egress of sublegal American lobsters (Krouse, 1978). An appropriate diameter for the circular escape gap would need to be large enough to allow the egress of undersized lobster but retain legal-sized velvet swimming crab. The diameter should therefore be based on the carapace height of a lobster and carapace length of a velvet swimming crab, both of which represent the animals critical body dimension (Krouse, 1978; Guillory *et al*., 2004). Based on the morphometric dimensions obtained during the field trials, the diameter would need to range between 48 and 53 mm (Appendix 7). This size range is based on the body depth of an 82 mm CL lobster and 65 mm CW velvet swimming crab. The keyhole escape gap, which incorporated a 48 mm diameter circle, proved to be too small for the exit of undersized lobsters, therefore the minimum diameter to be trialed should be established at 49 mm. Additional consideration must be given to the height of the lobsters walking legs which increase body depth, potential for carapace compression and ability to maneuver through a smaller escape gap opening (Estrella & Glenn, 2006). It is recommended that circular escape gaps ranging from 49 to 53 mm diameter should undergo aquarium trials with *H. gammarus* and *N. puber*. Previous escape gap trials concluded a 58 mm diameter circle was appropriate for retaining American lobsters 81 mm CL and above (Krouse, 1978), whilst a 79 mm CL European lobster could be manually pushed through a 53 mm diameter circle (Brown, 1982). In Norway, 60 mm diameter circles are used to retain individuals 90 mm CL and above (Moland *et al*., 2013). Results from these studies and escape gap regulations in Norway suggest, a circle greater than 53 mm diameter may be necessary to allow the escape of individuals below 82 mm CL, however this warrants further investigation.

4.4. Limitations

Field trials were conducted under real life fishing conditions and this meant a number of variables could not be controlled for. It is however important to acknowledge and consider the effects these variables may have had on the final results. For example, soak time varied between 48 and 168 hours. Further analysis on the effect on soak time revealed that a soak time of 168 hours caught significantly larger edible crabs and velvet swimming crabs in control pots than those soaked for 48 or 96 hours (edible crab: $H(2)=14.047$, $p<0.001$; velvet swimming crab; $F_{2,139}=4.552$, $p=0.012$). An increase in the average size of crabs in control pots implies that a longer soak time may improve their chance of escape (Krouse, 1978; Breen *et al*., 1990). Similar analyses on CPUE revealed that a soak time of 168 hours also caught significantly more edible crabs <MLS in control pots ($F_{2,21}=4.305$, $P=0.027$) and >MLS in escape gap pots ($H(2)=6.127$, $p=0.047$). These results imply that CPUE increases with soak time. Catch numbers are often observed to increase with soak time until they reach an asymptote, reported to occur after approximately 7 days in the American lobster fishery (Miller, 1990). It has been reported that catches using parlour pots also increase with soak time (Lovewell *et al*., 1979; Kinnear, 1983). Conversely, for *H. gammarus* there was a lack of significant change in the CPUE with increasing soak times, largely agreeing with observations made by Bennett & Lovewell (1977) who found that CPUE of *H. gammarus* was independent of soak time for up to 5 days (120 hours). This is likely to be because of agonistic interactions with other conspecifics (Bell *et al*., 2001). It is important to consider the effects of variable soak times, as an increase in the average size of individuals caught or CPUE is likely to skew comparisons made between control pots and escape gap pots. For example an increase in average size may lead to an underestimation of the effectiveness of escape gaps, as the difference in average size between escape gap pots and control pots is likely to be less apparent.

In the present study it was assumed that individuals of all species would have an equal probability of entering a control or an escape gap pot, as in other escape gap studies (Shanks, 1997). This assumption may be defied if individuals that have escaped from an escape gap pots enter an adjacent control pot (Shanks, 1997). This may be possible as escape gap pots and control pots were alternated in each string. It is would be reasonable to assume a sublegal individual would re-enter the same pot rather than travel 20 m to the adjacent pot (Stride pers. comm.). Having said this, when escape gap pots were hauled to the surface no bait remained, indicating individuals had actively entered the pot and potentially exited through the escape gap or entrance. This may potentially lead to individuals being attracted by and entering into the adjacent pot whose bait is still intact. The American lobster has been found to approach a baited trap from 11 m away and the area of bait influence (ABI) for the edible crab has been found to be 48 m, thus strongly indicating the ABI of adjacent pots may overlap (Skajaa *et al*., 1998; Watson *et al*., 2009). It is important to consider the influence of adjacent pots, as this may enhance the probability of a control pot catching undersized individuals and would therefore not be representative of a 'normal' catch; potentially leading to overestimation of escape gap effectiveness.

Other factors such as bait type, changes in population and current strength and direction are unlikely to have such a large effect on the overall catch, as similar forces are acting on all pots (Salthaug, 2002). Fresh bait was used on each trip so is unlikely to bias the catch, as the bait acts to attract all species, known to be scavengers, regardless of their size (Lawton, 1989; Cefas, 2012). Changes in the population may be slightly more variable. European lobster undergoes minimal movement, with many studies documenting average distances ranging from 1 to 3.8 km (Smith *et al*., 2001; Agnatt *et al*., 2007). Edible crabs however do travel further. A tag recapture study found 90% of males and 76% of females remained within 18 km of their release site in inshore areas (Bennett & Brown, 1983). Female crabs however tend to migrate offshore, up to distances over 20 km, to spawn (Davis, 2007; Ungfors, 2008). This migration takes place during autumn and therefore may have removed large female crabs from the fishery at the time the study was conducted (Bennett & Brown, 1983). Whilst it is important to consider factors that may affect the catch rates, in reality these cannot be controlled. The results obtained in this study are therefore likely to provide an accurate reflection of the commercial fishery.

4.5. Future Research

Further research should concentrate on testing the feasibility of the suggested escape gap panel with the ultimate aim of developing an escape gap panel suitable for all three species. This work should aim to determine if an appropriate diameter for the circular escape gap is achievable and additionally retrial the three-dimensional escape gap design incorporating bristles. Particular attention should be paid to the attachment mechanism for the bristles, as this proved to be difficult in the present study.

The Southern IFCA have recently approved the manufacture of 500 87 x 45 mm rectangular escape gaps for commercial trial by pot fishermen within the district. Results from this future trial will allow views of the fishing industry to be gathered and the potential value of the 87 x 45 mm escape gap to be analysed in further detail. This is likely to be a valuable resource for the Southern IFCA and may help to aid future decisions on the recommendation of appropriate escape gap dimensions or on the implementation of a voluntary scheme or escape gap byelaw.

5. CONCLUSION

For fishermen only wishing to catch only *C. pagurus* and *H. gammarus*, the 87 x 45 mm rectangular escape gap design has proven to be extremely effective; releasing over 50% of undersized individuals from both species, whilst retaining all individuals above the minimum landing size in aquarium trials and slightly enhancing the catch of legal-sized individuals. The success of this escape gap was largely achieved by the increased length, recommended by Hyland (2012), which has allowed for a greater escape of undersized edible crab. Unfortunately the present study has been unable to find an escape gap for all three species found within the Southern IFCA region, however progress has been made in the development of a potential escape gap panel. Further investigation is needed into the suggested escape gap panel, although the current study has provided promising results for a crab-only escape gap using a three-dimensional escape gap design incorporating brush bristles.

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http://www.dfo-mpo.gc.ca/decisions/fm-2011-gp/atl-050-eng.htm - Rock Crab (Canada) Escape Gap Regulations

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http://www.fish.govt.nz/en-nz/Recreational/Most+Popular+Species/Rock+Lobster/default.htm - Spiny Rock Lobster and Packhorse Rock Lobster (New Zealand) Escape Gap Regulations

7. APPENDICES

Appendix 1 – New rubber attachment mechanism.

Appendix 2 – Dispensation letter.

Appendix 3 – Student-Newman-Keuls (SNK) output from SigmaStat.

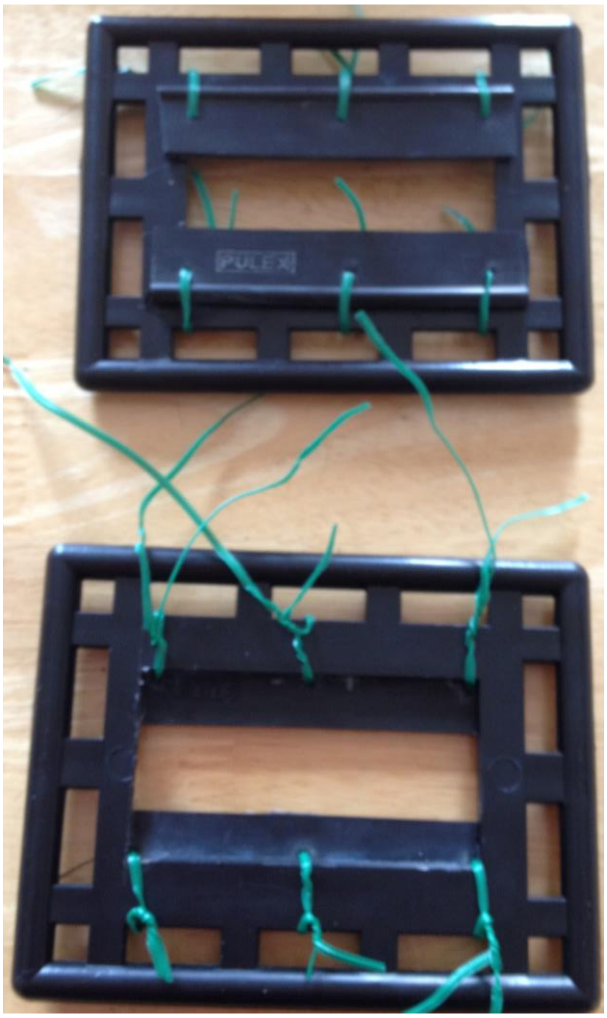
Appendix 4 – Table of reductions in sublegal retention in escape gap studies.

Appendix 5 – Table of escape gap opening areas of all two-dimensional designs.

Appendix 6 – Schematic diagram of the proposed escape gap panel.

Appendix 7 - Morphometric dimension relationships.

Appendix 1. New rubber attachment mechanism for the three-dimensional design incorporating rubber.



Appendix 2. Dispensation letter for the collection of undersized animals from the Marine Management Organisation (MMO).

Marine Management Organisation

Marine Management Organisation
Lancaster House
Hampshire Court
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NE4 7YH

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Dr A Jenson
Room 456/4
Ocean and Earth Science
University of Southampton
National Oceanography Centre
Southampton
SO14 3ZH

Your reference:
Our reference: 074

29th July 2013

Dear Dr Jenson,

DISPENSATION FROM THE PROVISIONS OF COUNCIL REGULATION 850/98

Thank you for your recent e-mail requesting dispensation from the requirements of Council Regulations 850/98 in order to evaluate pot escape gap design with a view to developing further a new escape gap within the area of Christchurch Ledge.

This letter will allow the skipper, **Richard Stride,** of the vessel **Carlee (C17889)** to land undersized lobster, edible crab and velvet crab at Mudeford Quay, transport to the aquarium at the NOC to be involved in escape gap assessment experiments, then return to the sea. Up to a maximum of 50 individuals of each species.

The Evaluation will be carried out using lobster pots fished over Christchurch ledges.This dispensation is valid for the period from **1st August 2013 – 28th February 2013,** please be aware that **no fish are to be sold as a result of this survey.**

This authorisation letter must be carried by the skipper on board the **Carlee (C17889)** for the duration of all fishing trips connected with this research work, and should be made available to any Marine Enforcement Officer (MEO) upon request. A printout of this letter will be acceptable.

We would ask that the Marine Management Organisation coastal office in the locale the **Carlee (C17889)** sails from be informed at least 1 day prior to the first departure.

Yours sincerely

B Byford

Beverley Byford
Fisheries Management and Control
Cc:Portsmouth Marine Office

POSITIVE ABOUT DISABLED PEOPLE INVESTORS IN PEOPLE

Appendix 3. Student-Newman-Keuls (SNK) outputs from SigmaStat showing where the differences exist in the percentage retention of undersized (a) *Homarus gammarus* and (b) *Cancer pagurus* (c) size of retained *Homarus gammarus* between two-dimensional escape gap designs.

a

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Student-Newman-Keuls Method) :

Comparison	Diff of Ranks	q	P<0.05
3 vs 5	25.500	3.292	No
3 vs 2	21.000	3.363	Do Not Test
3 vs 1	21.000	4.427	Do Not Test
3 vs 4	0.000	0.000	Do Not Test
4 vs 5	25.500	4.083	Do Not Test
4 vs 2	21.000	4.427	Do Not Test
4 vs 1	21.000	6.481	Do Not Test
1 vs 5	4.500	0.949	Do Not Test
1 vs 2	0.000	0.000	Do Not Test
2 vs 5	4.500	1.389	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.

A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

b

All Pairwise Multiple Comparison Procedures (Student-Newman-Keuls Method) :

Comparison	Diff of Ranks	q	P<0.05
3 vs 1	21.000	3.363	No
3 vs 4	17.500	3.689	Do Not Test
3 vs 2	3.500	1.080	Do Not Test
2 vs 1	17.500	3.689	Do Not Test
2 vs 4	14.000	4.320	Do Not Test
4 vs 1	3.500	1.080	Do Not Test

Note: The multiple comparisons on ranks do not include an adjustment for ties.

c

All Pairwise Multiple Comparison Procedures (Student-Newman-Keuls Method) :

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
Oval vs. Keyhole	4.222	5	3.015	0.219	No
Oval vs. Diamond	4.111	4	2.935	0.171	Do Not Test
Oval vs. Boomerang	0.577	3	0.383	0.960	Do Not Test
Oval vs. 87x45	0.0385	2	0.0256	0.986	Do Not Test
87x45 vs. Keyhole	4.184	4	3.059	0.144	Do Not Test
87x45 vs. Diamond	4.073	3	2.977	0.096	Do Not Test
87x45 vs. Boomerang	0.538	2	0.365	0.797	Do Not Test
Boomerang vs. Keyhole	3.645	3	2.665	0.151	Do Not Test
Boomerang vs. Diamond	3.534	2	2.584	0.072	Do Not Test
Diamond vs. Keyhole	0.111	2	0.0887	0.950	Do Not Test

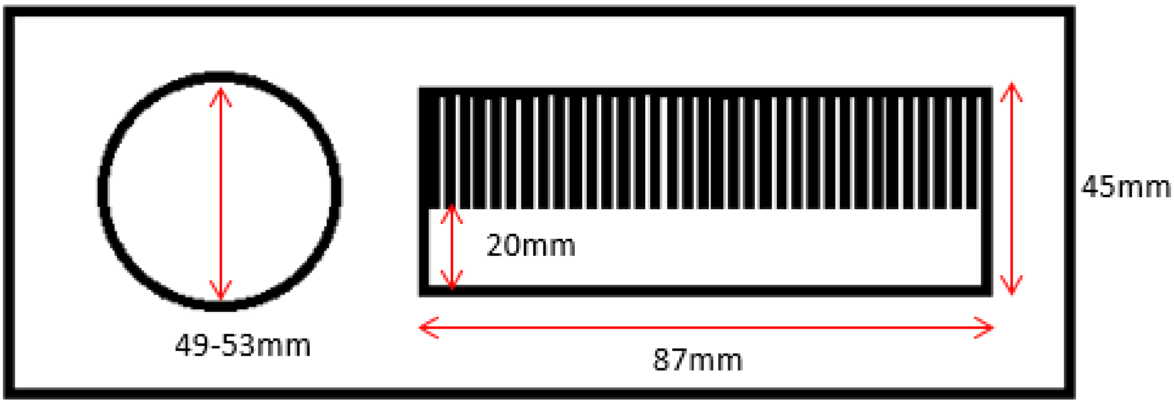
Appendix 4. Reductions in retention of undersized individuals achieved in escape gap studies conducted in crustacean trap fisheries worldwide. Sorted alphabetically by country.

Country	Region	Common Name	Scientific Name	Reduction in Sublegal Retention	Source
America	Rhode Island	American lobster	*Homarus americanus*	79%	Fogarty & Borden, 1980
America	-	Blue Crab	*Callinectes sapidus*	75-80%	Guillory *et al.*, 2004
America	Hawaii	Spiny lobster Common slipper lobster	*Panulirus marginatus* *Scyllarides squammosus*	83% 93%	Everson *et al.*, 1992
Australia	New South Wales	Giant mud crab	*Scylla serrata*	58-84%	Rotherham *et al.*, 2013
Australia	South	Spiny/ Southern Rock lobster	*Jasus edwardsii*	64-68%	Brock *et al.*, 2006 Linnane *et al.*, 2011
Canada	Newfoundland & Labrador	Snow crab	*Chionoecetes opilio*	38-47%	Winger & Walsh, 2011
Chile	-	Juan Fernández rock lobster	*Jasus frontalis*	61.2%	Arana *et al.*, 2011
Thailand	-	Blue swimming crab	*Portunus pelagicus*	59.5%	Boutson *et al.*, 2009
United Kingdom	-	Edible Crab European lobster	*Cancer pagurus* *Homarus gammarus*	38-91% 58-84%	Brown, 1979 Brown 1982 Lovewell *et al.*, 2002

Appendix 5. Escape gap opening areas of all two-dimensional designs.

Escape Gap Design	Opening Area (mm^2)
87 x 45 mm Rectangle	4785
Boomerang	3555
Ellipse	3074
Keyhole	2149
Rhombus	1958

Appendix 6. Schematic diagram of the proposed escape gap panel for all three species (*Homarus gammarus, Cancer pagurus* & *Necora puber*) in the Southern IFCA district annotated with dimensions.



Appendix 7. Morphometric dimension relationships between (a) body depth (y-axis) versus carapace length (x-axis) for *Homarus gammarus* and (b) carapace length (y-axis) versus carapace width (x-axis) for *Necora puber*, with the line of best fit for females (red dots) and males (blue crosses). The y=mx+c equation for the line of best fit and R^2 value is given for each sex.