University of Southampton

September 2012

FACULTY OF NATURAL AND ENVIRONMENTAL SCIENCES

OCEAN AND EARTH SCIENCE

RESEARCH AND DESIGN OF ESCAPE GAPS FOR A MIXED CRUSTACEAN FISHERY

-FOR THE SOUTHERN INSHORE FISHERIES AND CONSERVATION AUTHORITY

Author: Miss Naomi Josephine Hyland

Research and design of escape gaps for a mixed crustacean fishery.

A dissertation submitted in partial fulfilment of the requirements for the degree of M.Sc. Marine Resource Management by instructional course (see University leaflet).

As the nominated University supervisor of this M.Sc project by Miss Naomi Josephine Hyland, I confirm that I have had the opportunity to comment on earlier drafts of the report prior to submission of the dissertation for consideration of the award of M.Sc Marine Resource Management.

Signed:…………………………………………..

Supervisor's name: Dr Antony Jensen.

ABSTRACT

Escape gaps can help create sustainable fisheries, they release non target individuals with no commercial value from fishing gear. In some UK fisheries districts escape gaps are compulsory in crustacean pots where the target species are the European lobster (*Homarus gammarus*) and the Brown crab (*Cancer pagurus*). The Southern Inshore Fisheries and Conservation Authority (IFCA) does not currently require escape gaps in fishing pots, but it is interested in identifying the most suitable escape gap designs. The three aims of the project were to find the optimum escape gap designs for: 1. *H.gammarus* and *C.pagurus*, 2. Velvet swimming crabs (*Necora puber*). 3. *N.puber* and small *H.gammarus*; based on the Southern IFCA MLSs.

Significant differences (P=<0.05) were found in the efficiencies of current, commercially available, escape gaps for undersized *H.gammarus*, with significantly smaller individuals escaping from a 44x79mm escape gap compared those escaping from a 46x86mm design. All escape gaps tested retained the majority of undersized *C.pagurus*, but all (except a 44x79mm escape gap) released in excess of 80% of undersized *H.gammarus*. Based on these results a new design with a gap 45x87mm was evaluated, results showed that this released significantly more (P=<0.05) undersized *C.pagurus* than the two smallest commercially available escape gaps.

A rectangular escape gap with a height of 21mm or less would release under MLS but retain *N.puber* above minimum landing size (MLS).

A circular escape gap of 48mm diameter retained 100% of undersized and legal sized *N.puber.* An assessment of a novel escape gap design, integrating the 48mm diameter circle and a 20mm rectangle, showed that 100% of *N.puber* and 44.4% of undersized *H.gammarus* could pass through this escape gap when manually manipulated. There were significant differences (P=<0.0.5) observed in results obtained by manual manipulation through the escape gap compared to those observed by natural escape (where animals escaped on their own accord). There were no significant differences between results obtained by natural escape of *N.puber* or *H.gammarus* when the novel escape gap was positioned horizontally or vertically.

Results indicate that the 45x87mm design for *C.pagurus* and *H.gammarus*, and the 21mm escape gap height for *N.puber* are near optimum designs for the Southern IFCA. Both designs need to be scientifically tested in the field, and more work is needed to determine an *N.puber* and *H.gammarus* escape gap design.

AKNOWLEDGEMENTS

This project has been absolutely amazing, and I am very honoured to have been able to take it on. Not only has this projected challenged me, it has taken me out on two fishing trips, tested my woodworking skills, thrown me in at the deep end with animal husbandry and brought me up close and personal to some very beautiful lobsters.

However I could not have done this project without the support, advice and kind words of the following people…

Firstly I would like to thank my supervisor Dr. Antony Jensen for entrusting me with this project and being so supportive throughout. I would also like to thank Neil Richardson- the Deputy Chief Officer of the Southern IFCA for his advice and all his help in obtaining correct documentation to allow this project to be possible.

Next I would like to thank Richard Stride and his crewmate Gill for allowing me to join them on board the fishing vessel 'Carlee' for my data collection days, and for their efforts in collecting the lobsters and crabs for my project. Also thanks to Jim down at Mudeford for giving me his views on escape gaps.

I would like to thank Chris Sturdy, the aquarium technician at the National Oceanography Centre for helping me learn how to look after all the animals involved, and for helping me cope with my first brown crab moult!

I would like to thank Rob Clark from the Sussex IFCA for giving me access to some of the resources they have there, and I would like to thank Dominic Bailey from the Essex IFCA for his efforts.

I would like to thank my BSc tutor Dr. John Williams and my MSc tutor Dr. Duncan Purdie for all their advice, support and input during this project, and during my time at Southampton.

I would like to thank my wonderful parents and sister, and my wonderful boyfriend Matthew Couldrey. They have all have helped me cope with the ups and downs, the stress, the tears and the smiles that this project has brought.

One last thank you goes to all the lobsters, brown crabs and velvet swimming crabs who were involved with this project, I definitely couldn't have done it without them.

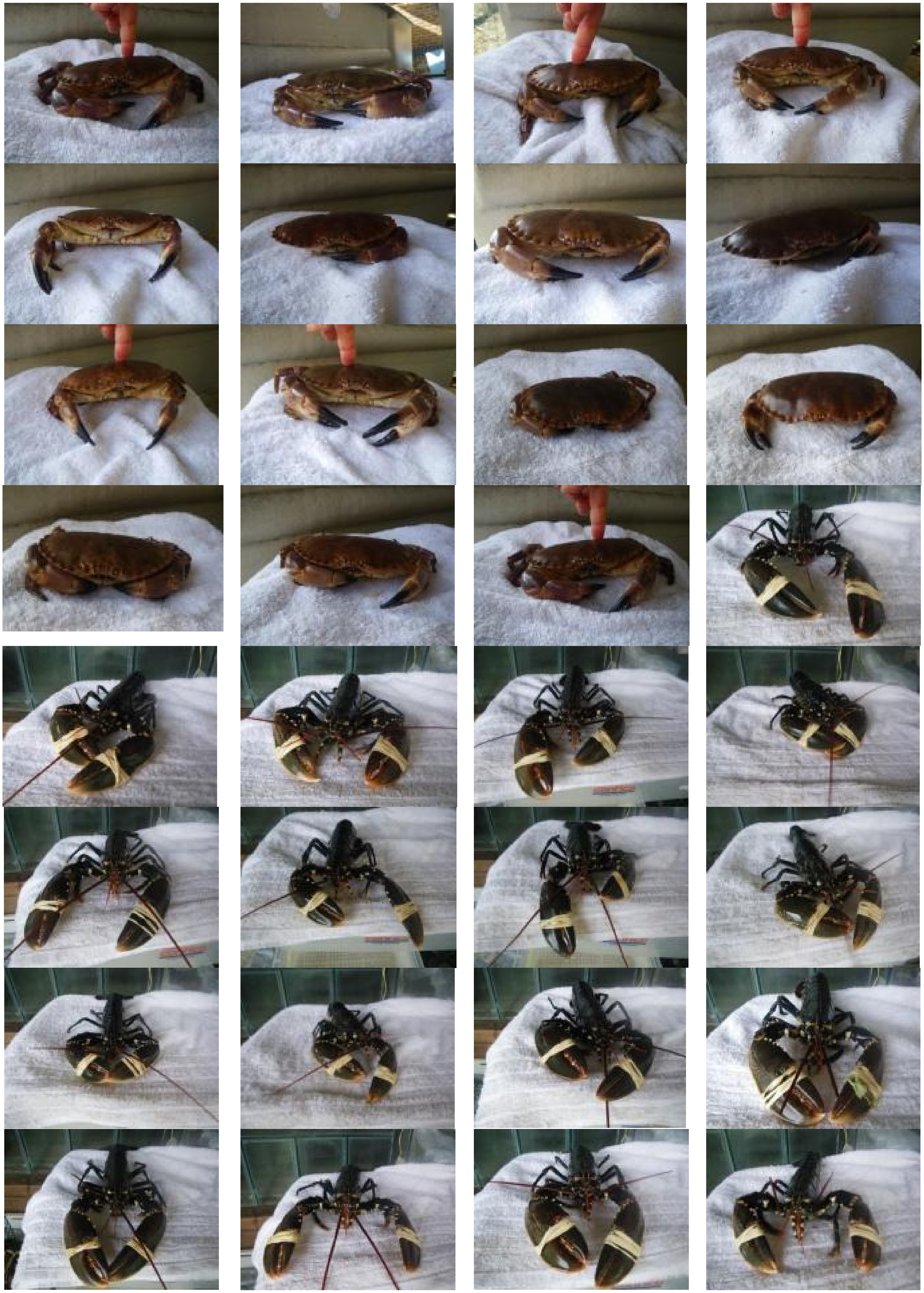


TABLE OF CONTENTS

SECTION 1. INTRODUCTION

1.1. Fisheries management and fisheries management tools

Fisheries act as important resources for many countries (Botsford *et al*., 1997). However as the worlds population grows, there is an increasing pressure on fish stocks. With the increasing demand for fish, there is investment into fishing technology to improve efficiency of fishing vessels. As a result of trying to maintain fisheries as profitable, there have been stocks which have been over exploited leading to stock failure. Botsford *et al*., (1997) report that nearly half of fish stocks are exploited fully, and a further 22% are overexploited. Fisheries practices can have direct and indirect impacts on fisheries, resulting in changes and weakening of ecosystem structure (Botsford *et al*., 1997). Direct effects occur when target species are removed from the fishery, and indirect impacts occur as a result of fishing practises. Crustacean fisheries will remove the larger sizes of commercial species from the environment, but they will also have indirect impacts on other non-target species which may become caught in the pot. Impacts from these indirect effects can cause a greater damage to the structure and dynamics of marine ecosystems than just removing one species.

Fisheries management decisions in part, aim to maintain stocks sustainably for future exploitation. Ideally fisheries are managed using information given from stock assessment techniques, which helps to determine how healthy stocks are in relation to the current rate of exploitation. If stocks are predicted to become vulnerable, then fishery management actions can be taken. These actions include using quotas for target species, using gear restrictions on vessels and restricting effort levels (Cadima, 2003). Technical measures can also be put in place as a way to manage stocks, these techniques can include mesh size regulation for nets, instating seasonal restrictions on catch of certain species, use of minimum landing sizes for certain species and use of escape gaps. Quantification of stocks is quite difficult, in the English Channel, the crustacean fisheries are managed by a range of technical measures which are used to reduce impacts of fishing on juveniles of the target species, so that the target species are able to reproduce, before becoming available for capture in the future. Minimum landing size (MLS) is the most common technical measure which is used in fishing districts, followed by gear restrictions. Escape gaps can be used as technical measure, where an escape gap of a certain size and shape is mandatory for each pot used in a fishery.

1.2. Escape gaps as a fisheries management tool

In many fisheries across the world, minimum landing sizes are stated for different species, this is a measure in which to prevent small individuals from being removed from the fishery. Individuals under the MLS are not allowed to be landed legally by the fishermen. If a person is found to be selling undersized individuals, fines or prosecution can be incurred. Consequently if small individuals are caught, in normal practice they are thrown immediately back into the sea.

Escape gaps can be used to allow fish and crustaceans which are of a size less than the MLS to escape from gear, including nets, pots and trawl devices. In potting fisheries, escape gaps can be beneficial to both the fishermen and the fishery. If small animals are able to escape from the pot, then less time is spent clearing the pot, saving the fishermen both time (and so money). Escape gaps of the correct dimensions will allow under MLS individuals of the target species to escape, this could help to make the fishery more sustainable; if undersized individuals become trapped in a pot without an escape gap, larger individuals can injure or kill the smaller, vulnerable individuals such as *H.gammarus* (Clark, 2007). Escape gaps will allow undersized individuals to escape and therefore they will not be handled whilst the pot is being sorted- handling can damage small individuals, and once thrown back into the sea the animal may be displaced.The less impact the fishing practise has on small individuals, the more likely the animal is to successfully reproduce and recruit into the fishery in the future and help towards the aspiration of a sustainable fishery.

Escape gaps may also help to reduce the impacts of ghost fishing, particularly for potting gear. Ghost fishing occurs when fishing gear becomes abandoned or lost, but the gear remains intact and continues to catch fish. Animals which are caught and cannot escape are likely to die in the pot and act as bait for other individuals which may become trapped- causing a cycle which may last months or sometimes even years (Matsuoka *et al*., 2005). If escape gaps are fitted to pots which become lost, small individuals will be able to escape back into their natural environment.

1.3. Escape gaps around the world

Examples of using escape gaps as a tool to manage and ensure sustainable fisheries are found all over the world. Often escape gaps will be considered as part of a new design, or when a problem is observed such as declining catch rates or high levels of by-catch.

Escape gaps were considered for use in the South African crustacean trap fishery, after a reduction in catch of *Jasus lalandii* during the early 1990s. Although the reason for this decline was mainly thought to be caused by reduced growth rates, it was thought damage was caused by the handling of undersized animals before they were placed back into the sea. As a result, the optimum escape gap design was found to be an 44mm grid spacing integrated into part of the crustacean pot design (Schoeman *et al*., 2002).

Research and design of escape gaps for a mixed crustacean fishery.

Escape gaps have been used as part of the design of trawl efficiency devices for the Australian prawn fishery. When escape gaps are used in these devices, they allow larger objects (including turtles) to escape from the trawl, but they will retain the target species of prawns, maintaining the level of catch observed when escape gap not used (Robins-Troeger *et al.,* 1995).

Another example for the use of escape gaps in fisheries is seen in a report by Campos and Fonseca (2004). In a similar example, a high level of fin fish by-catch from the crustacean trawl fishery in the Algarve caused concern for the fisheries managers of the region. To resolve the issue of by-catch, escape gaps were considered and researched. A new design of trawl which used escape gaps in the gear was found to significantly reduce the by-catch of three different types of fin fish (*Capros aper, Micromesistius poutassou,* and *Trachurus trachurus*), however the complexity of the design means that they are unlikely to be used commercially (Campos and Fonseca, 2004).

Escape gaps have also be used to overcome more bizarre problems. In the *Jasus edwardsii* fisheries in South Australia, octopus regularly predate lobsters are caught in pots. To reduce the mortality rates, a new pot was design incorporated lobster escape gaps into it, and helped to reduce lobster mortality by nearly 50% (Brock *et al*., 2006).

1.4. Considerations for escape gap design

An optimum escape gap size and shape will release most of the undersized individuals and maintain all of the legal sized catch (Treble *et al*., 1998). The design of escape gaps differ between fishery regions, as minimum landing sizes and target species will vary. As a result, escape gaps will come in all shapes and sizes, and designs will be based on the morphometric characteristics of the target species in the local region

It is important to consider how escape gaps work and the parameters which they are based on. In the case of *H.gammarus* the minimum landing size is based upon the carapace length, but an escape gap cannot select for this dimension, instead the escape gap will select for the carapace width and carapace height of the *H.gammarus*, since there is a well defined relationship between the length and width of *H.gammarus*. For *C.pagurus* the minimum landing size is based on the carapace width, which is related to the carapace width which is the dimension that the escape gap will select for.

A variety of shapes have been used in escape gaps for different fisheries. In the Hawaiian crustacean fisheries a circular escape gap was used to select for the body width of *Scyllarides squammosus* and the height of *Panulirus marginatus*, this allowed the sublegal sizes of both species to escape (Polovina *et al*., 1991). However in the American lobster (*Homarus americanus*) fishery in the USA, it was found that a circular escape gap was just as efficient a rectangular escape gap (Krouse, 1978) when considering lobster only fisheries. Circular escape gaps were considered to be more efficient in pots where crabs were also being targeted.

Nulk (1978) aimed to determine a method for finding an optimum escape gap size for *H.americanus* for a fishery in New England where there was a variable minimum landing size. Tests for the investigation were carried out in aquarium tanks, which were partitioned into sections. A *H.americanus* individual was placed one side of the partition which had an escape gap fitted to it, and several different methods were used to get the lobster to go through the escape gap, including food being placed on the other side of the partition, lights, intimidation by other lobsters and making the starting partition small. Results from the study showed there was a relationship between carapace length and carapace width, to the extent that the escape of lobsters of different sizes could be predicted from an escape gap of a certain size. The study developed a method to calculate the theoretical catch size distribution for any sized escape gap (Nulk, 1978).

Shape is an important consideration for escape gaps in the Caribbean Antillean trap fisheries. Again, escape gaps are being considered as a management tool to help fish stocks in the region recover. These escape gaps are designed for fin fish, and in the report rectangular and diamond shapes are considered. A rectangular shape would select for fish of a particular body shape, whereas diamond escape gap shapes would select for body height, width and body shape dimensions, undersized or some non target species of fish would be able to swim through the escape gap (Munro *et al*., 2003)

A lot of research has been carried out on escape design for the *H. americanus* fisheries. Krouse (1978) suggested that the carapace height is one of the key parameters which will determine whether a lobster can escape, Krouse (1978) highlighted that the depth of the walking legs from the lower carapace, needed to also be considered in design considerations.

For crustaceans there are marked differences between male and female morphometrics. These differences should to be considered with regard as to how, the installation of escape gaps as part of fishery management will impact the selectivity of that escape gap on a fishery. In a study of *H.americanus* by Fogary and Borden (1980), more females were caught in pots installed with escape gaps than males. The cause was that the carapace width of the female *H.americanus* is greater than the width of the male. Shermerdine and

White (2011) also highlighted that the morphometrics of a species will change through their reproductive status; in the case of *H.americanus* berried female lobsters will increase their carapace height and width.

The position of the escape gap within the pot is also an essential consideration. Location of the gap will depend on the movement characteristics of the target species. In the case of designing an escape gap for crabs, the best position for an escape gap would be low in the pot, so they can move continuously sideways (Bouston *et al*., 2009). In the UK, escape gaps are a byelaw requirement in five IFCA fisheries districts, in most cases there are requirements regarding the position and orientation of the escape gap in relation to the bottom of the pot (Devon and Severn IFCA, 2011; Kent and Essex IFCA, 2011), there are also requirements as to how much room there is for the animal to manoeuvre through the escape gap from inside the pot.

1.5. Escape gap use in the UK

In the UK there is a particular interest in using escape gaps for the 'mixed' crustacean fisheries that are typical of inshore fisheries, particularly for the brown crab (*Cancer pagurus* Linnaeus 1758) and the European lobster (*Homarus gammarus* Linnaeus, 1758). Although the European Union states the minimum landing sizes for some species, these MLSs can be increased within fishing districts if the authority finds it necessary. There are various different escape gap designs which are used around the UK in different regional fishery districts. The size of escape gap will relate to the minimum landing sizes of the region. In most cases the escape gaps currently used in the UK are rectangular, where the width of the escape gap selects for the body length of *C.pagurus* and the height of the escape gap selects for the carapace width of the *H.gammarus*.

In the UK, very few studies have been published that attempt to determine the optimum escape gap design for *H.gammarus* and *C.pagurus*. Results from a study by Brown (1982) showed that the carapace depth and carapace width are the most important dimensions for *C. pagurus*, and carapace width and carapace height are most important parameters for *H.gammarus*. Brown (1982) suggested that the optimum escape gap height would be 1mm less than the corresponding carapace width for the MLS (distance from the posterior edge of the carapace to the eye socket) of *H. gammarus*. At the time the study was published, the minimum landing size sizes were 115mm for *C. pagurus* and 80mm for *H.gammarus*- far smaller than it is today where the MLS for *C.pagurus* is 140mm carapace width and *H.gammarus* is 87mm carapace length. Consequently we cannot use the numbers derived for this study to determine the optimum escape gap size for current regulation, but we can build upon the theory.

Addison and Lovewell (1991) have also attempted to describe the optimum escape gap sizes in the UK, for *H. gammarus* and *C. pagurus*. At this time the minimum landing sizes were smaller than they are today; 85mm for *H.gammarus* and 115mm for *C. pagurus*, and this study suggested that an escape gap of 35mm by 74mm would allow crabs of 102mm carapace width and below to escape.

Clark (2007) found that escape gaps (of dimensions 80x45mm)reduced the number of small lobsters retained in the pots, reduced the mortality of undersized lobsters and reduced the time spent fishers spent clearing the pots.

Today the MLS for the EU are set out in Annex XII of the Council Regulation 850/98 (Council Regulation (EC) No 850/98). If animals are caught and they are under the minimum landing size, they must immediately be returned to the sea. In the English Channel the MLS for *C.pagurus* is 140mm carapace width, and for all EU regions apart from Skagerrak/Kattegat, the MLS for *H.gammarus* is 87mm carapace length. There are also local variations in MLS brought about in by different IFCAs.

In the UK there is also commercial interest in velvet swimming crabs (*Necora puber*). However the carapace height and length of this species are much smaller than that of *C.pagurus* and *H.gammarus* and so they are likely to be able to escape through escape gaps designed for *H.gammarus* and *C.pagurus.* A study by Shermerdine and White (2011) investigated the optimum escape gap design for *N.puber* in the Scottish fishery. The study showed that millimetre differences in escape gap height made significant differences to the sizes of animals being retained and released. The carapace height of the velvet swimming crab was found to be key to designing escape gaps for velvet swimming crabs. Results of the study by Shermerdine and White (2011) found that an escape gap with a height of 20mm would be the optimum height which would ensure the majority of oversized crabs did not escape. In the Scottish fishery the minimum landing size at the time of this study for *N.puber* was 70mm carapace width.

1.6 Southern Inshore Fishery and Conservation Authority and escape gaps

Fisheries management in the England is carried out by Inshore Fishery and Conservation Authorities (IFCA). There are ten IFCA districts along the English coast, and each is responsible for managing an area of England’s fisheries resources. An IFCA is responsible for management and enforcement of regulations for the coastline and up to six nautical miles from the regional baseline (DEFRA, 2012).

Research and design of escape gaps for a mixed crustacean fishery.

Five of the IFCAs around the UK have made escape gaps in fishing pots mandatory. These regions include the North Eastern IFCA, Devon and Severn IFCA, Eastern IFCA, Kent and Essex IFCA and the Cornwall IFCA. The fisheries management authorities for the Isle of Man and Jersey also use escape gaps. The Sussex IFCA is providing fishermen with escape gaps to use on a voluntary basis.

Currently the Southern IFCA does not use escape gaps as a fisheries management tool, although some fishermen are using them under their own initiative. The Southern IFCA manages fisheries for the coastline and up to six nautical miles from the baseline for the counties of the Isle of Wight, Hampshire and Dorset (Southern IFCA, 2012). The Southern IFCA are interested in using an evidence based approach to identify the escape gap designs which can contribute to improving the sustainability of the crustacean fisheries in the region.

The current (2012) minimum landing size within the Southern IFCA region for *C.pagurus* is 140mm carapace width, for *H.gammarus* is 87mm carapace length, and for *N.puber* is 65mm carapace width. *C.pagurus*, *H.gammarus* and *N.puber* are the main target species for the crustacean fishery in the Southern IFCA district. As such there is an interest in finding two escape gap designs which would suit this fishery. The first escape gap would be the optimum design where *C.pagurus* and *H.gammarus* are the key target species; the second escape gap would be the optimum design for where *N.puber* is the target species of the fishery.

In the UK, five of the fishing districts which use escape gaps have minimum landing sizes for *C.pagurus* and *H.gammarus* which are equal to or greater than the MLS currently used in the Southern IFCA. This study has determined the efficacy of these existing escape gap designs, by determining how effective each escape gap is at releasing undersized individuals and retaining individuals of MLS and above for *C. pagurus* and *H. gammarus.* The study then defines an optimum design for the Southern IFCA *N. puber* fishery, and finally it investigates the possibility of an escape gap design which would allow the escape of *N.puber* individuals which are less than MLS, but also release some undersized *H.gammarus* individuals as well.

It is important to note that this study recognizes that there needs to be certainty that no animals above the minimum landing size will be lost to the fisherman through the use of escape gaps. Consequently the 'design brief' for new escape gaps included the requirement to retain any animal 5mm below the appropriate MLS (MLS-5mm).

1.7. Aims and objectives of the project

AIM 1: To determine the effectiveness of escape gaps currently used in UK fisheries for *H.gammarus* (MLS 87mm) and *C.pagurus* (MLS 140mm)

- All escape gaps which are used in fisheries where the MLS is the same or greater than the MLS of the Southern IFCA will be identified.
- These current escape gaps will be tested with a range of individuals above and below the MLS for the species *H.gammarus*, *C.pagurus* and *N.puber*. Each animal will be tested as to whether it can escape naturally (of its own accord) through the escape gap.
- Results showing the percentage of escaped individuals above and below a MLS-5mm will be displayed for each species, allowing a visual comparison of their effectiveness. Statistical tests will help to determine how significant the differences are.
- To determine the optimum escape gap size which would suit the current MLSs which the Southern IFCA have in place for the *H.gammarus* and *C.pagurus* fishery.

Aim 1. Null Hypotheses

$H_0$1. There is no significant difference (P=0.05) between the effectiveness of the escape gaps currently used in the UK.

$H_0$2. All escape gaps will retain all individuals of each species which are over MLS-5mm, MLS-5mm is equal to 135mm carapace width for *C.pagurus*, 82mm carapace length for *H.gammarus*, and 60mm carapace width for *N.puber*.

AIM 2: To determine the optimum escape gap height for the *N. puber* fishery (MLS 65mm).

- The optimum escape gap height will be determined to allow *N.puber* below MLS to escape, but which will retain oversized *N.puber* individuals within the pot.
- Morphometric data for *N.puber* carapace depth and carapace width will be plotted and used to determine which heights to test.
- Results for the percentage of escaped *N.puber* above and below MLS escape gap will be compared visually, then statistically, to determine the optimum escape gap height.

Aim 2. Null Hypothesis

$H_0$1. The *N.puber* escape gap height retains all *N.puber* individuals above 65mm, and releases *N.puber* individuals below 65mm.

AIM 3: To determine an escape gap which can release undersized *N. puber* and *H. gammarus,* but which will retain *N.puber* individuals above MLS.

- The hybrid escape gap will incorporate the escape gap height for *N.puber* determined from Aim 2, with a circle of which the diameter will be based on the carapace length of *N.puber*.
- The design will be tested using *N.puber* and *H.gammarus* individuals testing them both manually and for natural escape through the escape gap. Results will then be statistically compared to see if there are significant differences (P=0.05) between the replicates.
- The hybrid escape gap will be tested using *N.puber* and *H.gammarus* individuals in two different positions- horizontally and vertically. Results will be statistically tested for significant differences (P=0.05).
- Finally the results from two different escape mechanisms- of natural escape (where the animal escapes from the pot on its own) and manual escape (where the animal is manipulated through the escape gap by hand) will be tested to see if there are any significant differences in results. These results will help to determine the optimum method of testing escape gaps.

Aim 3. Null Hypotheses

$H_0$1. The new escape gap design will retain all *N.puber* individuals above 65mm carapace width and all individuals for *H.gammarus* above 82mm carapace length.

$H_0$2. The new escape gap design will release some of the smaller *H.gammarus* individuals.

$H_0$3. There is no difference between results obtained manually and results obtained naturally for *N.puber* or *H.gammarus.*

$H_0$4. There is no difference between results obtained from the escape gap when it is positioned horizontally and when it is positioned vertically.

SECTION 2. MATERIALS AND METHODS.

2.1. Data Collection for Aim 1: Testing escape gaps currently used in UK fisheries.

Methods were based loosely on those described by Nulk (1978), but to gain the high quantity of data needed for this experiment, some changes were made. Four large plastic aquaculture tanks were designated for the project experiments. One rectangular tank of dimensions 1.05m x 0.75m x3.6m and a volume of 2.835m^3 was used as a storage tank for animals which were not being tested. Three square tanks of dimensions 1.2m x 1.2m x 0.75m and a volume of 1.08m^3 were used for the location of the tests. Each square tank had a different number of partitions (4, 6 and 8), were created using mesh which was attached to the walls of the tank using silicone sealant. Partitions were created to limit interaction between the animals during testing. After the tanks were set up, they were each filled with post-ozone treated sea water and provided with an air flow. The oxygen levels and air temperature were monitored daily, and tanks were cleaned once a week.

Twenty three pots were created from plastic garden mesh, the sides of the pots were tied securely with cable ties and twine. A range of pot sizes were produced to suit the variety of sizes of animals that would be tested in this project. Each pot was designed so an animal could be placed through the lid, the lid was then securely tied to the body of the pot using a length of twine, the only exit for the individual would be through the escape gap. Pots were designed so that multiple escape gap types could be tested on each pot.

Five different sized escape gaps were tested to meet the first aim of the project. Escape gap sizes were chosen if they met the following criteria:

1. They are currently used within UK waters.
2. The fisheries in which they are used have either the same or larger minimum landing size for *H.gammarus* and *C.pagurus* as that of the Southern IFCA.

Those which matched are described in Table 2.1.

Table 2.1. Escape gap sizes to be tested within this project, regions where they are used and the relationship to the regional MLS and the Southern IFCA MLS

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

Three of the escape gap designs were available to order from the GT Marine Products website (www.**gtproducts**marine.com/), this company is currently the main supplier of escape gaps to the fishing community. Twenty two units of each escape gap size (45x80mm; 46x80mm; 46x84mm) were ordered. Figure 2.1 shows photographs of the escape gaps used

Figure 2.1a: 46x86mm

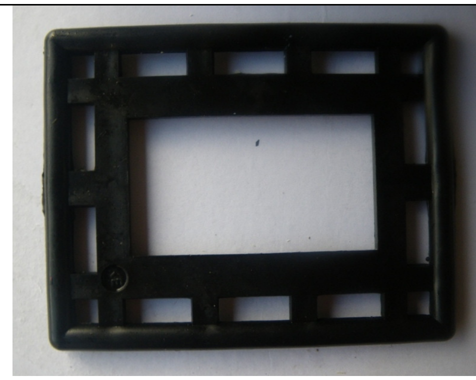


Figure 2.1b: 80x46mm

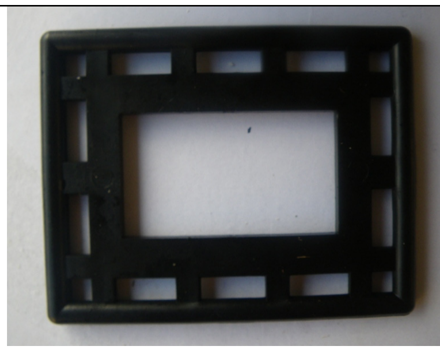


Figure 2.1c. 80x45mm

Figure 2.1d: 44x79mm

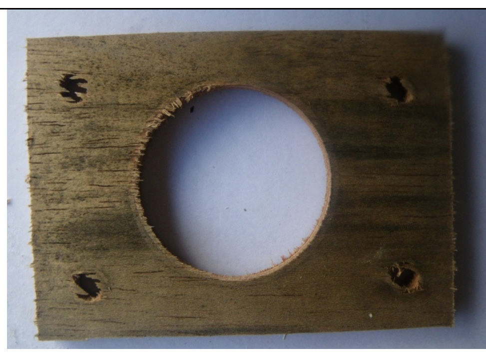


Figure 2.1e: 57mm Diameter Circle

Figure 2.1f: 45x87mm

Figure 2.1. Photographs of each escape gap tested for Aim 1 of the project, dimensions are labelled for each design. Where the escape gaps were not available commercially, the escape gap design was hand crafted.

However the escape gap size currently used in Jersey (44x79mm) was not available to purchase. Escape gaps of this size were made manually from plywood strips and water resistant wood glue (See Figure 2.1d). Holes were drilled in each side of the plywood so the escape gap could be attached to the pot using cable ties and twine, without reducing the area where the animal could escape through. The final escape gap to be tested was a design currently being trialed in the Southern IFCA region by an individual fisherman, the escape gap was a 57mm circle (see Figure 2.1e), which was created using a drill bit and plywood.

A dispensation letter from the Marine Management Organisation was required to allow sublegal sized animals to be collected for the project. After this letter was received, undersized animals could be collected. A range of animals both above and below the minimum landing sizes were collected for the species *H.gammarus*, *C.pagurus* and *N.puber*. Animals were collected from Mudeford Quay near Christchurch courtesy of Richard Stride, a local fisherman who sits on the Southern IFCA Committee. In total 17 lobsters, 16 brown crabs and 10 velvet swimming crabs were brought back to the tanks which were located in the research aquarium of the National Oceanography Centre, Southampton. Testing of the escape gaps started on the 14th June 2012.

To test an escape gap, an escape gap was fitted into the pot, and an animal was placed into the pot through the lid, the lid was then tied. It was found that when the lid was tied only in several places, animals were able to push their way out through the lid giving erroneous results. Looping a long measure of twine through the lid and the body of the pot was far more secure, and animals could not escape through the lid.

The fixture of the escape gap onto the pot was also checked to make sure it was tight. The animal in the pot was placed into one of the partitions of the test tanks and its location and species type was recorded. There were two methods of enticing the animal out of the pot (based on study by Nulk (1978) first was using a small amount of raw fish, secondly in each of the compartments a 'shelter' was present where the animal could hide if it escaped. The animals were left for a soak period of 24 hours. The following day, results were recorded with regard to whether the animal had escaped from the pot or not, then the morphometrics were recorded for each individual. Morphometrics included the carapace width, carapace length, carapace height and sex.

For *H. gammarus* the carapace length was measured from the posterior edge of the eye socket to the posterior edge of the carapace, parallel to the medio-dorsal line. The carapace width was taken at the widest part of the carapace. The carapace depth measurement was taken from the highest part of the dorsal surface of the carapace to the lowest protruding part of the ventral surface of the thoratic region (Brown, 1982). To help safeguard other *H.gammarus* individuals, all individuals (and the researcher!) remained banded during testing.

For *C.pagurus* the carapace width measurement was taken at the widest part of the carapace and the carapace length was taken from the anterior edge of the carapace in the region of the eyes to the proximal part of the abdominal flap. The carapace depth of *C.pagurus* was not taken. Consideration was given as to whether the tendon of the claw should be "nicked" or broken during the experiment. Eventually it was decided against, as there was concern over the changed behaviour of individuals during the experiment and also the risk of infection may have been greater.

For *N.puber* the carapace width was measured as the distance between the two outermost carapace thorns, the carapace height was measured as the greatest distance between the ventral and dorsal surfaces and the carapace length was measured from the anterior edge of the carapace in the region of the eyes to the proximal part of the abdominal flap.

Four replicates were taken for each escape gap using the method as described above. This number of replicates made sure to allow the results to be viable for statistical analysis.

2.2. Data Analysis of Aim 1.

Results were written up into a spreadsheet using Microsoft Office Excel 2003, for each escape gap replicate, for each species scatter plots were created to show the sizes of animals which were escaped or retained by the escape gap.

To test out the null hypothesis of Aim 1- the first being 'there is no difference between the efficacy of escape gaps currently used in the UK for *C.pagurus* and *H.gammarus*', and the second being 'all escape gap types retain individuals above MLS-5mm' the following methods were used. Percentage escape bar charts were created for each replicate of each escape gap type, for each species and size groups for the species. The two size groups were based on minimum landing size minus 5mm, where one size group was above, and the other below. For *H. gammarus* MLS-5mm would equal 82mm (where MLS in the Southern IFCA is 87mm) and for *C.pagurus* MLS-5mm is equal to 135mm (where MLS in the Southern IFCA is 140mm). MLS-5mm could not be used for *N.puber* as no individuals available to test were under 60mm carapace width. So for *N.puber* the two size groups were split into above 65mm carapace width (where 65mm is the MLS) and below 65mm carapace width.

Percentage escape bar charts for the natural escape of were produced for *N.puber*, *H.gammarus* and *C.pagurus* for the escape gap designs- 44mmx79mm, 80x45mm, 80x46mm and 84x46mm. However due to time constraints, only *H.gammarus* and *N.puber* were tested through the 57mm circle, the dimensions of the 57mm circle would likely to retain most *C.pagurus* individuals within the pot.

Statistical routines were used to analyse the data which had been considered during data collection, to further help to determine if there were differences in the efficiency of escape gaps. SigmaPlot 11.0 was the statistical package used to statistically analyse the data. For each escape gap, results for each replicate were tested for differences- for each species. First the size of individuals (carapace width for *C.pagurus* and carapace length for *H.gammarus*) which were retained by the escape gap were statistically compared. Next, the size of individuals which escaped through the escape gap were statistically compared. The type of test used was dependent on whether the data were parametric or non-parametric; for parametric data the use One Way ANOVA was used, and for non parametric data the Kruskal Wallis One Way ANOVA on Ranks test was used.

If replicates for the escape gap showed no significant difference ($P>0.05$), then results from the four replicates were combined and tested against the other combined replicate results for the other escape gap designs. Using Sigmaplot11.0 the Kruskal Wallis One Way ANOVA on Ranks was then used to test for differences between the sizes of animal which were retained/ which escaped from the escape gap types.

The averages of all percentage escape replicates were then found and average percentages were plotted as a bar chart for each escape gap, to provide a visual comparison of escape gap effectiveness for *H.gammarus* and *C.pagurus.*

The results for percentage escape for each replicate of the escape gaps were then compared for differences, for the two different size groups of *H.gammarus* and *C.pagurus.* To test for differences, the One Way ANOVA or Kruskal Wallis ANOVA on Ranks tests were used, depending on whether data were parametric or non-parametric.

The sizes of animals which escaped were then tested against the sizes of animals which were retained for each escape gap for each species using the Mann Whitney Rank Sum test. This allowed the results from the project to link in with the Clark (2007) study.

Velvet swimming crabs (*Necora puber*) were tested manually and naturally through all the escape gaps currently used in the UK, the average percentage escape results were plotted and compared on bar charts.

Replicates for individual escape gaps, were tested for differences for results regarding the size of *N.puber* which manually passed through the escape gap, using the One Way ANOVA or Kruskal Wallis One Way ANOVA on Ranks depending on data type. This was carried out for each escape gap.

If no significant differences were found between the replicates, the results from each replicate for an escape gap was merged and compared with the other merged results from the other escape gaps. Statistical analysis was carried out using Kruskal-Wallis One Way ANOVA on Ranks for both natural and manual escape results.

The results for percentage escape of *N.puber* from each replicate were merged and then these merged results were tested for significant differences ($P=0.05$) against the results from other escape gap types. This was done for natural and manual escape results and results for animals above and below the MLS.

The results gained from manual manipulation and natural escape of *N.puber* through escape gaps were tested to see if there were any statistical differences, this was achieved using the Mann Whitney Rank Sum Test.

2.3. Data Collection For Aim 2: Optimum Escape Gap Size For Southern IFCA *N.puber*.

No morphometric data were available for *N. puber* in the Southern IFCA region, so this had to be collected first hand. Data were collected during two fishing trips with Richard Stride on his vessel 'Carlee FY847'. For each *N.puber* individual which was retrieved from the pots, the carapace length, carapace width, carapace depth, sex and ovigerous state was recorded.

The optimum *N.puber* escape gap will be dependent on finding the correct height of the escape gap, which will be determined by the carapace height of *N.puber*. Morphometric data for carapace width and carapace height of male and female *N.puber* was plotted to determine a number of escape gap heights to test. One of the plastic escape gaps was modified (see Figure 2.2) to give variable escape gap heights, but maintain a constant width (80mm).

It was found that *N.puber* did not cope well in the aquarium conditions, and numbers were limited, so fifteen more *N.puber* individuals were collected from the Solent region from Mudeford Quay. These new animals were kept in tanks on the dockside where fresh seawater circulated in an attempt to keep the animals cooler, however cannibalism between these individuals meant that many mortalities occurred in the first 24 hours. For the remainder of the experiment, the surviving individuals were kept in individual mesh pots.

Methods for tests in Aim 2 were based on the methods used in the study by (Shermerdine and White (2011). *N.puber* were tested manually through a control escape gap height, followed by six different heights of the escape gap, with four replicates per escape gap. The *N.puber* morphometric sizes were recorded, as were whether the individual was retained by the escape gap size or not. Data were entered into a spreadsheet, then data were statistically analysed using Sigmaplot 11.0 software.

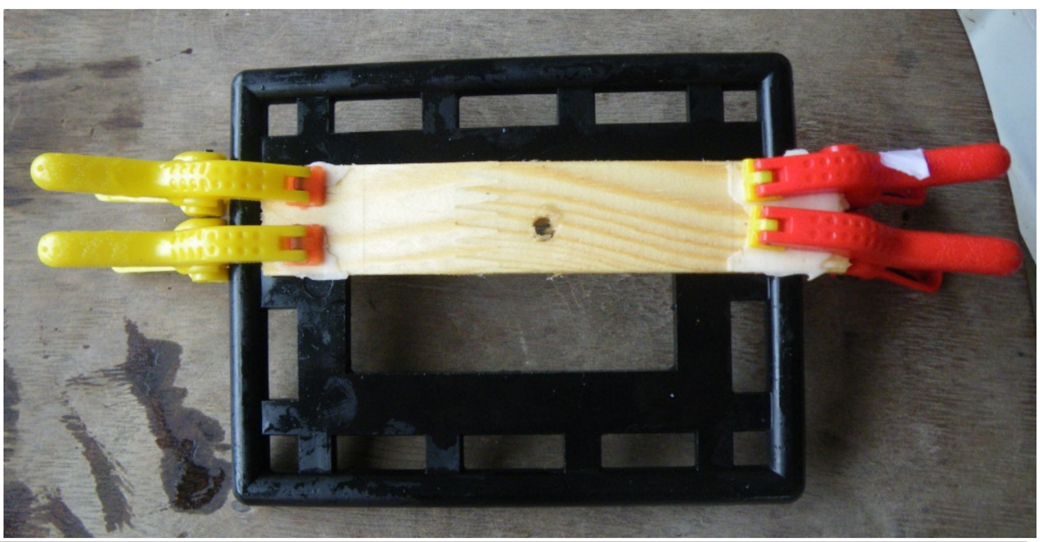


Figure 2.2. Modified escape gap, used to test different heights to find the optimum escape gap size for *N.puber*.

2.4. Data Analysis of Aim 2.

The null hypothesis for Aim 2 was that the escape gap design would not let any individual above 65mm carapace width through the escape gap, and it would release all *N.puber* which had a carapace width less than 65mm. To fine the escape gap height which fitted the null hypothesis the following was carried out. The percentage escape of velvet swimming crabs (one group above MLS, and one group below MLS) which could manually pass through each escape gap height were averaged plotted together as a bar chart, so that results could be visually compared.

The replicates for each escape gap were tested for statistical differences using the results of the carapace widths of animals which escaped (or if data were few/insufficient for animals which escaped to perform statistical analysis, then the sizes of animals retained were used). The Kruskal Wallis ANOVA was used to test results for animals above, and animals below MLS.

If there was no significant difference between replicates then the percentage escape results for the replicates from each escape gap type were merged. Then the results were tested for statistical differences between results obtained by the different escape gaps for the two size groups (above and below MLS). The Kruskal Wallis One Way ANOVA on Ranks was used to perform this function.

2.5. Data collection for Aim 3: Hybrid Escape Gap Size for *N.puber* and *H. gammarus*

Using results from Aim 2, the optimum escape gap height of was determined; this was then used as the main shape of the escape gap. To make the hybrid shape, a circle was required to be integrated with the objective of allowing small *H.gammarus* to escape. To find the diameter of this circle, the morphometric relationship between carapace width and carapace length for *N.puber* was investigated for male and females. The carapace length for 60mm was estimated using the linear relationship equation y=mx+c, where carapace length was 'y' and carapace width 'x'. A value could then be determined as the maximum diameter for the circle.

Velvet swimming crabs were manually tested through the 48mm circle, and results were plotted and analysed. The hybrid escape gap of a circle and letterbox shape was created using plywood. *N.puber* and *H.gammarus* were tested manually through the hybrid escape gaps.

To test the null hypothesis that 'the new escape gap design will retain all *N.puber* individuals above 65mm carapace width and release all *N.puber* individuals below 65mm carapace width', eight hybrid escape gaps were then fitted into the pots, and tested using *N.puber* and some smaller *H.gammarus* individuals using the same method as described in Section 2.1. This also tested the second null hypothesis that 'the new escape gap design will release some of the undersized individuals'. Morphometric parameters of each species and escapement of the individual was then recorded after a 24hour soak period. The hybrid escape gap was tested in two positions- horizontally and vertically, both positions had results for four replicates for the natural escape of *H.gammarus* and *N.puber*. This analysis was carried out to test the null hypothesis that 'there is no significant difference between the results obtained whilst the escape gap was in a horizontal and vertical position'. The hybrid escape gap was also tested with *N.puber* and *H.gammarus* by manually manipulating the two species through the escape gap. The results were then compared to test the null hypothesis that 'there was no difference between the results obtained by manually manipulating the animals through the escape gap compared to the results obtained for them escaping through the escape gap out of choice (naturally)'.

Due to deaths of *N.puber* (of which the cause remains unknown) over the time period when these experiments were run there were variations in the numbers of individuals tested for each hybrid escape gap position. This should be considered when observing results.

2.6. Data analysis for Aim 3.

The percentage escape values for each escape gap were plotted in bar charts, to allow visual comparisons between results obtained for manual and natural escape of both *N.puber* and *H.gammarus* from the hybrid escape gap. The percentage escape values for horizontal and vertical positioned hybrid escape gap could also be observed for both species. The percentages for each replicate were averaged to allow for an easier visual comparison once plotted together, as a separate chart.

Statistical analysis was run using a Mann Whitney Rank Sum Test (where data were non parametric) and T Test (where data were parametric) to determine if differences were significant between several parameters. The statistical tests tested for differences between results from manual and natural escape for *N.puber* and *H.gammarus.* Finally the percentage of escape between horizontal and vertical positioning of the hybrid escape gap were tested for significant differences for both *H.gammarus* and *N.puber*.

SECTION 3. RESULTS

3.1. Aim 1 Results: *H.gammarus* and *C.pagurus* Escape Gap

3.1.1. Results for *H.gammarus* and *C.pagurus***.**

Detailed data visualisations for the results of each species and each escape gap design can be found in Appendix 1. Bar charts which showed percentage escape of each species for each replicate through each escape gap were found to be a more concise way to view the data, the first percentage bar chart can be seen in Figure 3.1.

The results were planned to meet the aims and to test the null hypothesises for the project. The null hypothesises for Aim 1 were:

$H_0$1. There is no significant difference (P=0.05) between the effectiveness of the escape gaps currently used in the UK.

$H_0$2. All escape gaps will retain all individuals of each species which are over MLS-5mm, MLS-5mm is equal to 135mm carapace width for *C.pagurus*, 82mm carapace length for *H.gammarus*, and 60mm carapace width for *N.puber*.

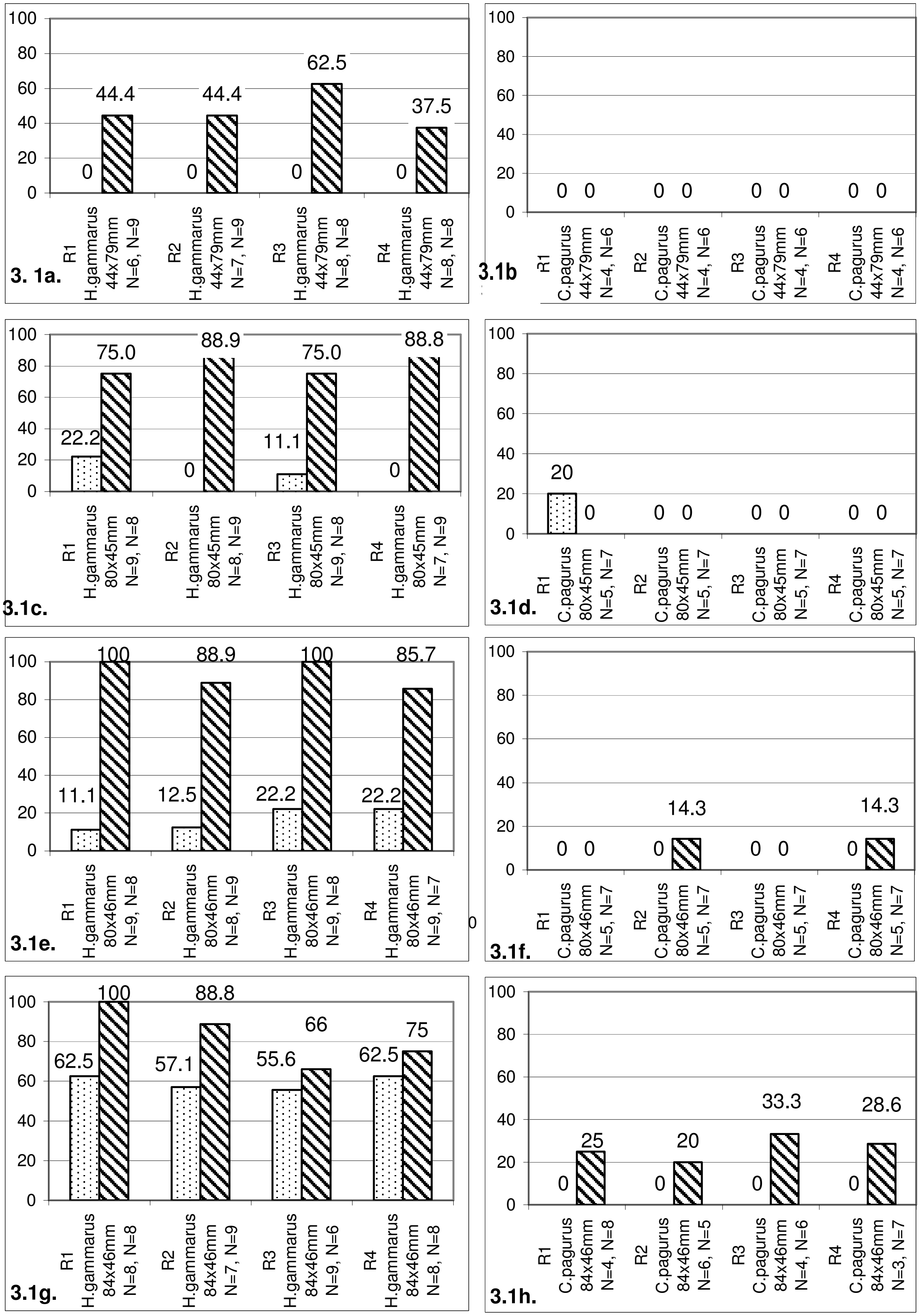


Figure 3.1. Percentage of escaped *H.gammarus* and *C.pagurus* for each replicate of the four escape gap sizes currently used in UK fisheries. Hashed bars show results for <MLS-5mm, dotted bars show results animals for >MLS-5mm, Y axis shows percentage escape (%) Bars are labelled with the percentage value (%). N relates to the number of animals that were tested per replicate; the first N relates to the number of >MLS-5mm animals tested, the second N is animals < MLS-5mm.

To test both the first and second null hypotheses for Aim 1, percentage escape bar charts were produced, this gave a visual indication of how well the different escape gap types were performing and differences between them. It also indicated what sizes of animals were escaping from the escape gaps.

The 44mm x 79mm escape gap retained all *C.pagurus* of all sizes (Fig 3.1b) and it retained all *H.gammarus* which were above 82mm Carapace Length (CL) (Fig 3.1a). There was found to be a limited release of *H.gammarus* with a carapace length less than 82mm from this design (Fig 3.1a), with percentage escape values ranging between 37.5% and 62.5%. The number of undersized *H.gammarus* which were retained was less for the 80x45mm escape gap design (Fig. 3.1c), where percentage escape values for individuals with a carapace length less than 82mm ranges from 75% to 88.8%. All percentage escape values for *C.pagurus* with a carapace width less than 135mm were 0% (Figure 3.1d), and very few *C.pagurus* with a carapace width above 135mm could escape (between 0% and 20%).

As the height of the escape gap increased, more *C.pagurus* which had a carapace width less than 135mm were able to escape through the 80x46mm escape gap (Fig. 3.1f). All *C.pagurus* above 135mm carapace width were retained in each replicate. For the 80x46mm escape gap there was an increase in the percentage of *H.gammarus* above 82mm carapace length escaping (between 11.1% and 22.2%) as seen in Figure 3.1e. There were very high percentages of *H.gammarus* with a carapace length above 82mm which were able to escape (with values for replicates ranging from 85.7% to 100%).

The escape gap with the greatest area (84x46mm) showed to release high numbers of *H.gammarus* both above and below 82mm carapace length (Fig. 3.1g). Percentage escape for animals with a carapace length less than 82mm ranged from 66% to 100%, and percentage escape for animals with a carapace length above 82mm ranged from 55.6% to 62.5%. This escape gap design retained all *C.pagurus* with a carapace width above 135mm, but released the highest percentage of undersized *C.pagurus* of all escape gaps- with percentage escape values ranging between 20% and 33.3%.

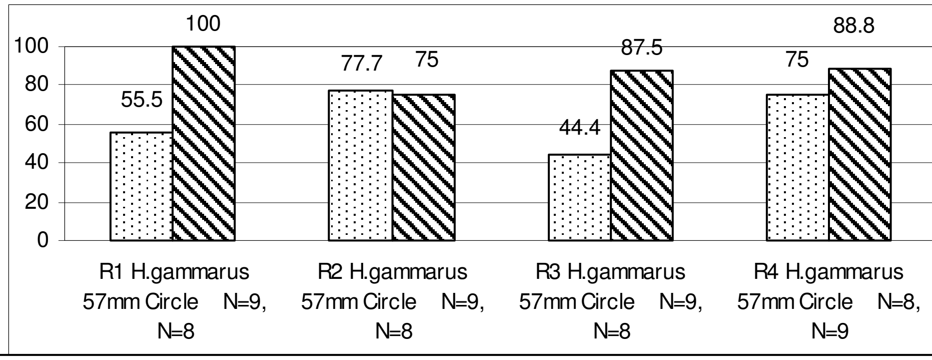


Figure 3.2. Results for percentage escape of *H.gammarus* from the 57mm circular escape gap. The Y axis shows percentage escape (%), hashed bar is <MLS-5mm and dotted bar is >MLS-5mm.N representes the number of animals tested, the first N represents animals >MLS, the second N <MLS.

A prototype escape gap design which is currently being tested in the Southern IFCA region by a local fishermen was then tested, this design was a circular escape gap with a diameter of 57mm. Due to its shape and size, this escape gap likely to retain most *C.pagurus* individuals and due to time restraints, only the *H.gammarus* were tested naturally through this escape gap. Results (Fig. 3.2) showed that for every replicate there was a percentage escape (ranging between 75% and 100%) of *H.gammarus* with a CL less than 82mm, but there was also a high percentage escape (ranging between 44.4% and 77.7%) of *H.gammarus* with a CL above 82mm.

Table 3.1. Statistical analysis testing for differences in replicates, based on size (CL for *H.gammarus* and CW for *C.pagurus*), of animals which were retained or escaped for each escape gap size. One Way ANOVA was used for parametric data and Kruskal-Wallis One Way ANOVA on Ranks for non parametric data. H_0: There is no significant difference between replicates.

Escape Gap Type	Species	Escaped/Retained	Result
44mm x79mm	*C.pagurus*	Retained	P=0.878
44mm x79mm	*H.gammarus*	Retained	P=0.909
44mm x79mm	*H.gammarus*	Escaped	P=0.836
80mmx45mm	*C.pagurus*	Retained	P=0.951
80mmx45mm	*H.gammarus*	Retained	P=0.818
80mmx45mm	*H.gammarus*	Escaped	P=0.810
80mm x46mm	*C.pagurus*	Retained	P= 0.966
80mm x46mm	*H.gammarus*	Retained	P=0.960
80mm x46mm	*H.gammarus*	Escaped	P=0.947
84mmx46mm	*C.pagurus*	Retained	P=0.997
84mmx46mm	*H.gammarus*	Retained	P=0.743
84mmx46mm	*H.gammarus*	Escaped	P=0.615
57mm Circle	*H.gammarus*	Retained	P= 0.462
57mm Circle	*H.gammarus*	Escaped	P= 0.308

To identify if there were any differences between the escape gaps with regard to the sizes of animals that they retained, statistical analysis was carried out. First, results from replicates of each escape gap were tested for statistical differences. As there were no significant differences (P=0.05) as seen in Figure 3.1, the results for each escape gap were combined and escape gap types were tested against each other.

Table 3.2. Statistical analysis testing for differences between all current escape gaps using sizes of animals (CL for *H.gammarus* and or CW for *C.pagurus*) which escaped or retained. One way ANOVA was used for parametric data, and Kruskal Wallis One Way ANOVA on Ranks for non parametric data. Dunn's method was then used to identify the cause of any significant differences. *C.pagurus* were not tested on the 57mm circle, but *H.gammarus* were. H_0: There is no difference between results obtained for all current escape gap designs.

Species	Escape Gap Type	Escaped/Retained	Results	Dunns Pairwise Comparison
H.gammarus	All Current EGs	Retained	P=0.066	
		Escaped	**P=<0.001**	84x46mm vs 44x79mm 57mm circle vs 44x79mm
C.pagurus	All Current EGs (excluding 57mm Circle)	Retained	P = 0.686	
		Escaped	P = 0.189	

No difference in the sizes carapace length (CL) of *H.gammarus* retained in all the escape gaps (Table 3.2), and there is no difference between the size of *C.pagurus* (CW) which were retained or which escaped from each escape gap (Table 3.2). There is a significant difference between the sizes of *H.gammarus* which escaped through the escape gap types (Table 3.2). Using a pairwise comparison, significant difference was found between the escape gap designs of 84x46mm and 44x79m, as well as the designs 44x79mm and the 57mm circle. These results would indicate that there is a difference in the efficacy of these escape gaps. These results would indicate that there are significant differences in the size selectivity of these escape gaps, so the first null hypothesis of Aim 1 would be rejected. Differences in percentage escape will be tested later in the results section.

Based on the observations and results so far, it was clear that very few *C.pagurus* could escape from any of the escape gaps which were currently being used. The reason for this was investigated. Morphometric analysis was carried out for *C.pagurus*, using a dataset from CEFAS (2004), the morphometirc relationships were analysed as follows.

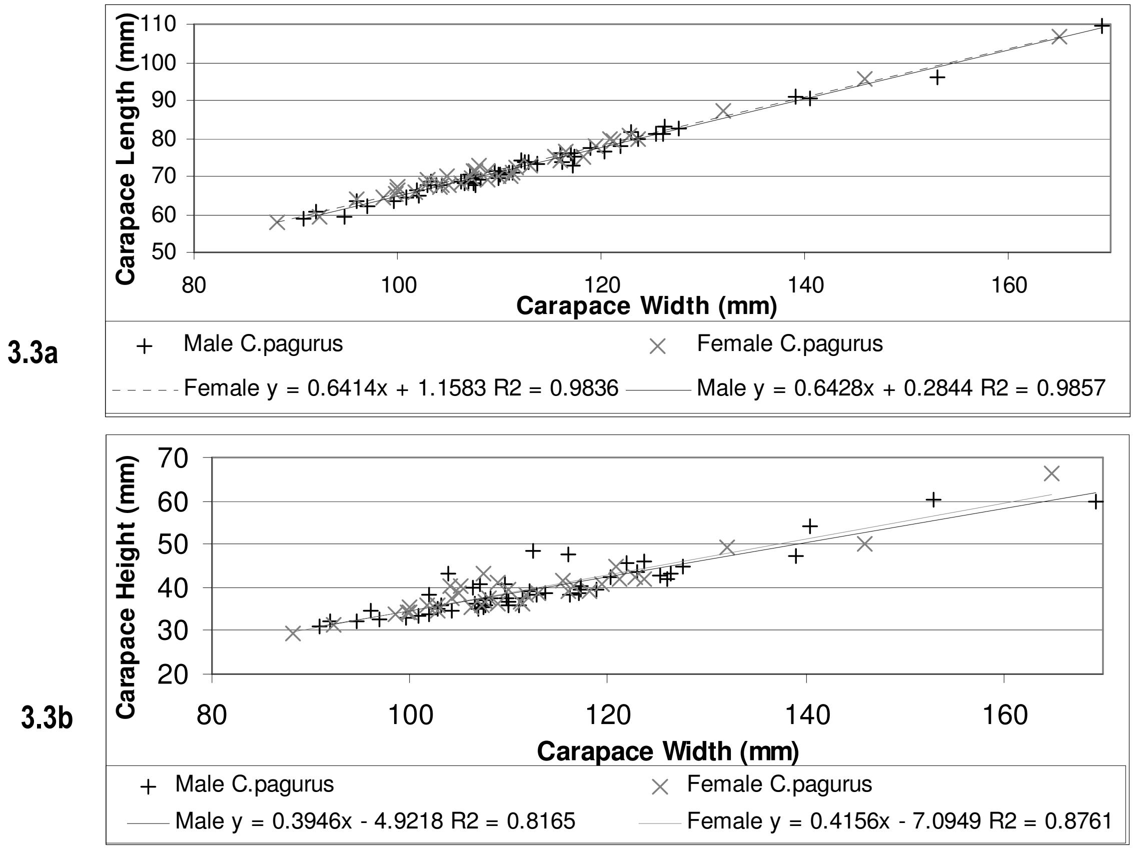


Figure 3.3. Morphometric data analysis using the CEFAS (2004) dataset, used to determine the optimum escape gap size for *H.gammarus* and *C.pagurus* . Figure 3a shows Carapace Width against carapace length, data has been fitted with a linear trend line for both male and female individuals. Figure 3b shows carapace width (mm) against carapace height (mm) with linear trend lines fitted for males and female individuals.

Based on the observations and results, it was clear that very few *C.pagurus* could escape from any of the escape gaps which were currently being used. The reason for this was investigated. Using the morphometric data from the CEFAS (2004) dataset, the morphometirc relationships were analysed. The linear equation (y=mx+c) was used for the width v carapace length (see Figure 3.3). Using the equation stated in Figures 3a and Figures 3b the theoretical sizes of *C.pagurus* able to escape from the current escape gap sizes was determined. The largest escape gap had a width of 84mm, would retain males with over 130mm CW and females 129.2mm CW. However results from figure 1h showed that very few *C.pagurus* individuals which were less than 135mm CW could escape from the 84x46mm escape gap.

The carapace width and carapace depth relationship was investigated (Figure 3b). The height of the escape gap was found to be more limiting than the escape gap width. The largest current escape gap height tested was 46mm. Using morphometric relationship analysis and the linear equation based on the CEFAS (2004) dataset, it was found that the maximum carapace width of a female *C.pagurus* to escape from 46mm escape gap height would be 127.8mm and for males 128.1mm. This would indicate that to allow more *C.pagurus* to escape from the optimum escape gap the escape gap height would need to be increased.

However results from results from the current study showed that changes in the height of escape gap (between 45mm and 46mm) resulted in more *H.gammarus* over 82mm CL escaping. Results showed that an escape gap with a height of 46mm let the majority of *H.gammarus* over 82mm CL out of the escape gap, and that 44mm retained many *H.gammarus* with a CL less than 82mm. However escape gaps with a height of 45mm gave the best compromise. Using the linear morphometric relationship equations described in Figure 3a, the carapace length of male and female *C.pagurus* at 135mm carapace width was estimated to be 87mm, based on these observations an escape gap of 87mm by 45mm was selected and tested.

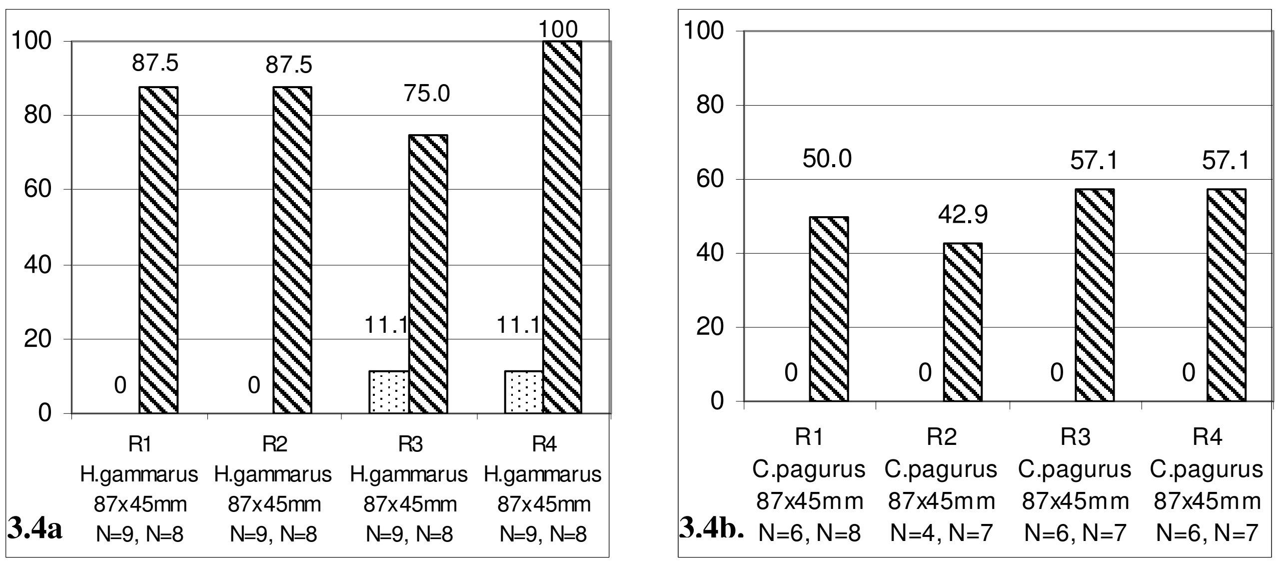


Figure 3.4. Results for percentage escape of *H.gammarus* (3.4a) and *C.pagurus* (3.4b) from the 87x45mm escape gap. The Y axis is percentage escape (%), hashed bar is <MLS-5mm and dotted bar is >MLS-5mm.N represents the number of animals tested per replicate, the first N indicates number of >MLS animals tested, the second N indicates the number of <MLS animals tested.

Table 3.3. Statistical analysis testing for differences in replicates, based on size (CL for *H.gammarus* and CW for *C.pagurus*), of animals which were retained or escaped for the 87x45mm escape gap. Using One Way ANOVA for parametric data and Kruskal Wallis One Way ANOVA on Ranks for non parametric data.
H_0: There is no difference between replicates.

Species	Escaped/Retained	Result
C.pagurus	Retained	P=0.281
C.pagurus	Escaped	P=0.308
H.gammarus	Retained	P=0.877
H.gammarus	Escaped	P= 0.880

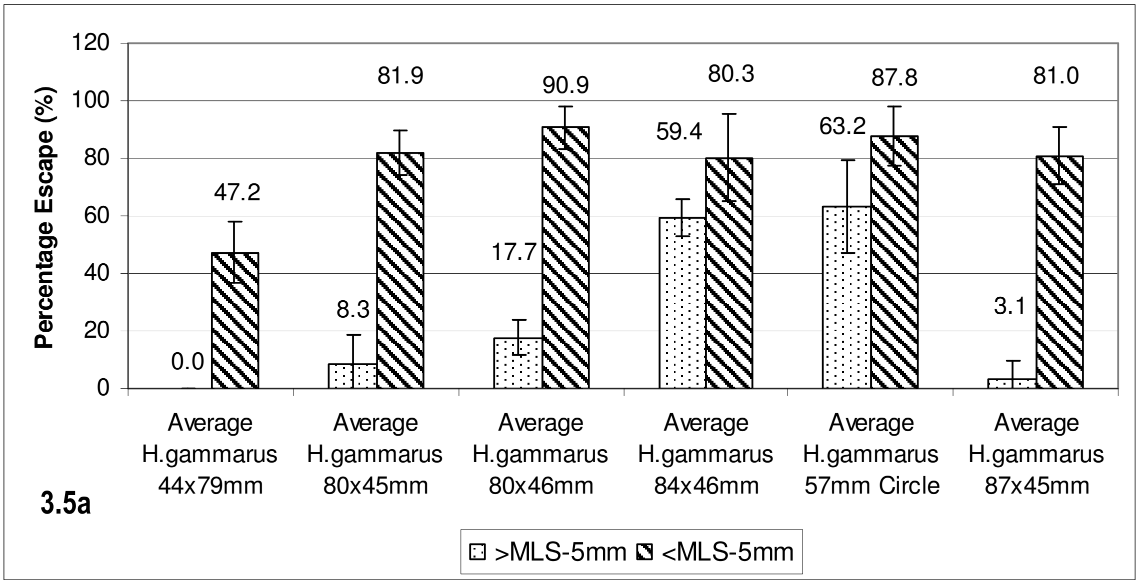
The 87x45mm escape gap was tested and results are shown in Figure 3.4. Results show that 0 to 11.1% of *H.gammarus* with a CL over 82mm escaped from the 87x45mm escape gap, but 75% to 100% of lobsters with a CL less than 82mm escaped (Figure 3.4a). Results for *C.pagurus* using the 87x45mm escape gap, show animals with a CW over 135mm were retained for all replicates, and between 42.9% and 57.1% of *C.pagurus* with a CW of less than 135mm escaped (Figure 3.4b).

To help to further test the null hypotheses of the first aim, size escape results were tested for the escape gaps including the new escape gap were tested for significant differences. First the size results for replicates of the 87x45mm escape gap had to be tested for significant differences before results could be compared with other escape gaps. There were no significant differences observed within replicates (Table 3.3). This allowed for all the escape gaps to be tested against each other.

Table 3.1a. Statistical analysis testing for differences between all escape gaps tested for the sizes of animals (CL for *H.gammarus* and or CW for *C.pagurus*) which escaped or retained. One way ANOVA was used for parametric data, and Kruskal Wallis One Way ANOVA on Ranks for non parametric data. Pairwise Comparison methods were then used to identify the cause of any significant differences. *C.pagurus* were not tested on the 57mm circle, but *H.gammarus* were.
H_0: There is no difference between results obtained for escape gap designs.

Escape Gap Types	Species	Escaped/Retained	Results	Pairwise Comparison
All Escape Gaps (including 57mm circle and 45mm x87mm)	*H.gammarus*	Retained	P=0.100	
		Escaped	**P=<0.001**	Dunns Method 84x46mm v 44x79mm 57mm circle v 44x79mm
All Escape Gaps (excluding 57mm Circle, but including 45x87mm)	*C.pagurus*	Retained	P=0.125	
		Escaped	**P=<0.001**	Holm-Sidak Method 44x79mm v 87x45mm 80x45mm v 87x45mm 80x45mm v 84x46mm 44x79mm v 80x46mm 44x79mm v 84x46mm

No significant difference was observed for sizes of *H.gammarus* retained in pots (the same as observed in Table 3.1), and there are no significant differences observed for the sizes of *C.pagurus* retained by escape gaps. However unlike in Table 3.1, there are statistical differences observed for the sizes of *C.pagurus* which escaped between 5 different escape gap pairs, these differences are observed between escape gaps with the largest area (80x46mm, 84x46mm and 87x45mm), and escape gaps with the smallest area (44x79mm and 80x45mm).



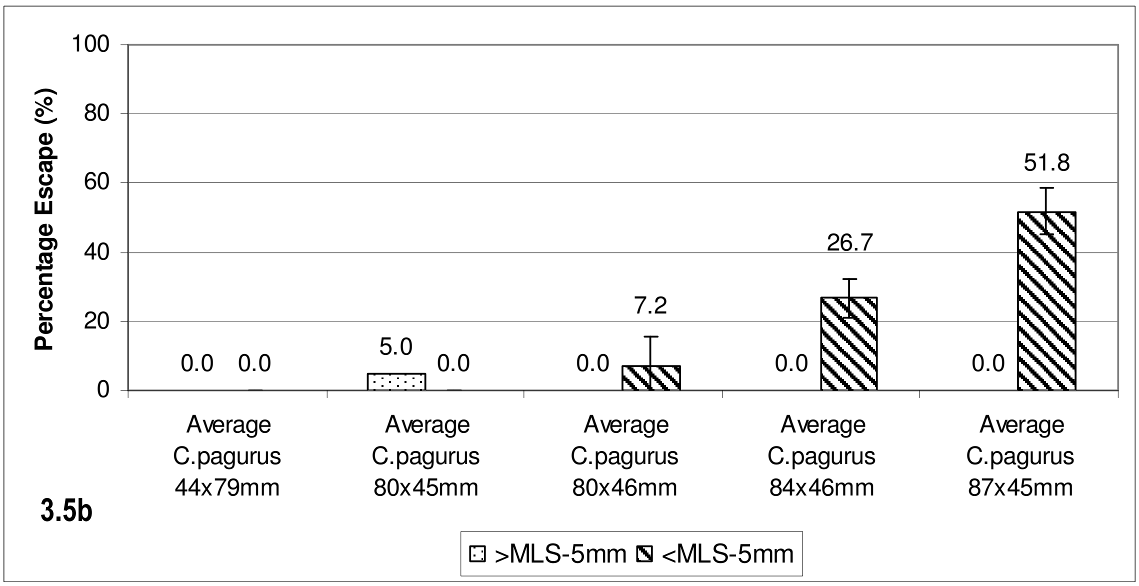


Figure 3.5. Results showing average percentage escape of *H.gammarus* (Figure 5a) and *C.pagurus* (Figure 3.5b.) for each escape gap tested, for the two size groups. Standard deviation has been applied.

Results for the first Aim are summarised in Figure 3.5. The first aim was to find the best escape gap size where *H.gammarus* and *C.pagurus* are the target species. The four escape gap types which are currently used in five UK fishing districts were compared and tested for differences (44x79mm, 45x80mm, 46x80mm and 46x84mm).

Results from the study suggest that there are marked differences between the effectiveness of these escape gaps with regard to the percentage escape of *H.gammarus* and *C.pagurus* for animals which are above and below MLS-5mm. The most restrictive escape gap for both species was the size of 44mmx79mm which is currently used in Jersey. Results for this escape gap show that on average only 47.2% of *H.gammarus* with a carapace length less than 82mm will escape (Fig. 3.5a). No legal sized animals for either species are able to escape, but results also show that no undersized *C.pagurus* individuals could escape (Fig. 3.5). The escape gap with the largest area had a size of 84x46mm, this escape gap let some of the smaller *C.pagurus* out of the pot (Fig. 3.5b), but also let on average 58.4% of *H.gammarus* individuals above 82mm escape (Fig. 3.5a).

The escape gaps of the sizes 80x45mm and 80x46mm showed better results with regard to the percentage escape of the two *H.gammarus* size groups; with both escape gaps releasing an average of 81.9% of *H.gammarus* with CL above 82mm, and 90.9% of *H.gammarus* less than 82mm CL (Figure 3.5a). However both of these escape gaps released very low numbers of the undersized *C.pagurus* as seen in Figure 3.5b, which shows that on average the 80x45mm escape gap releases 0% *C.pagurus* with a CW less than 135mm, and the 80x46mm escape gap releases only 7.2% of *C.pagurus* with a CW less than 135mm.

The 57mm diameter circle of the prototype escape gap did not work very well. Results showed that although there was a high average of percentage escape (87.8%) of *H.gammarus* with a CL less than 82mm (Figure 3.5a), but there was also a high average of percentage escape (63.2%) of *H.gammarus* with a CL above 82mm (see Figure 3.5a).

The new escape gap design of 87x45mm gave the most optimal results of all escape gaps. It had a high percentage release (81.0%) of *H.gammarus* with a CL less than 82mm, and released a very low percentage of *H.gammarus* with a CL above 82mm (Figure 3.5a). It retained all *C.pagurus* above 135mm carapace width, but unlike the other escape gaps tested it released above 50% of *C.pagurus* with a carapace width less than 135mm.

Results from the average percentage escape for animals above and below MLS-5mm would indicate that there are marked differences of percentage escape between escape gaps. Next, the percentage escape results for different escape gaps are tested, to help to further investigate the Aim 1's first null hypothesis.

Table 3.4. Testing for differences between percentage escape between all escape gaps, using all percentage escape data, for *H.gammarus* and *C.pagurus*. One way ANOVA or Kruskal Wallis ANOVA on ranks was used depending on data type.

Species	Size Group	P Value	Pairwise comparison results (using Tukey or Holm-Sidak method depending on data structure)
H.gammarus	<MLS-5mm	**P = <0.001**	80x46mm vs. 44x79mm 57mm Circle vs. 44x79mm 45x87mm vs. 44x79mm 84x46mm vs. 44x79mm 80x45mm vs. 44x79mm
H.gammarus	>MLS-5mm	**P = 0.002**	84x46mm vs 44x79mm 57mm Circle vs 44x79mm
C.pagurus	<MLS-5mm	**P = 0.002**	45x87mm vs 80x45mm 45x87mm vs 44x79mm
C.pagurus	>MLS-5mm	P = 0.406	

No significant differences (P=0.05) were found between the percentage escape of *C.pagurus* above 135mm carapace width, from all escape gaps (Table 3.4). But significant differences were found between percentage escape results for *C.pagurus* with a carapace width less than 135mm, these significant differences are caused by the percentage escape results between the smallest (44x79mm and 80x45mm) escape gap results and the largest escape gap results (87x45mm) (see Table 3.4).

Significant differences were observed between escape gaps for the percentage escape results of both *H.gammarus* above and below 82mm CL (Table 3.4). These significant differences were observed for *H.gammarus* above 82mm CL, between percentage escape results obtained for the 44x79mm escape gap (the most restrictive escape gap) and the two larger escape gaps 84x46mm and 57mm circle (the largest escape gaps). For *H.gammarus* with a CL less than 82mm, significantly lower values of percentage escape were found for the 44x79mm escape gap against the percentage release rate of every other escape gap type tested.

As part of this project, video footage of an undersized lobster escaping through a 45mmx87mm escape gap fitted to a pot was taken. This video can be viewed on the attached data CD or using the following link in a web browser:

http://y2u.be/GMk7eHdJc_4

Table 3.5. Statistical analysis testing for differences between the sizes of animal which escaped and the sizes which were retained for each escape gap. Using Mann Whitney Rank Sum test.
H0: There is no difference between the sizes of escaped animals and the sizes of retained animals from the escape gap.

Escape Gap Size	Species	Result
44x79mm	*H.gammarus*	**P=<0.001**
80x45mm	*H.gammarus*	**P=<0.001**
80x46mm	*H.gammarus*	**P=<0.001**
84x46mm	*H.gammarus*	**P=0.010**
45 x87mm	*H.gammarus*	**P=<0.001**
80x46mm	*C.pagurus*	P= 0.244
84x46mm	*C.pagurus*	P=0.009
45 x87mm	*C.pagurus*	**P=<0.001**

Statistical analysis was then carried out to test whether there were significant differences between the sizes of animals which were retained and the sizes which escaped through the different escape gap types for H.*gammarus* and *C.pagurus.* This part of the study was carried out to see if the results linked in with results were similar to those observed in the study by Clark (2007). For the all escape gap sizes tested there is a significant difference in the sizes of *H.gammarus* which escape and which are retained (Table 3.5). The

87x45mm escape gap is the only design showing a significant difference (P=<0.01) between the sizes of *C.pagurus* retained and released (Table 3.5).

3.1.2. Results for *N.puber*.

The next section of results was designed to test the first null hypothesis of Aim 1: 'There is no significant difference (P=0.05) between the effectiveness of the escape gaps currently used in the UK'

As well as the latter part of the second null hypothesis of Aim 1: 'All escape gaps will retain all individuals of each species which are over MLS-5mm, MLS-5mm is equal to 135mm carapace width for *C.pagurus*, 82mm carapace length for *H.gammarus*, and 60mm carapace width for *N.puber*.

N.puber were tested naturally (over a 24 hour soak period) through all escape gaps currently used in the UK, and then they were tested through all escape gaps manually, results are shown in Figure 3.6.

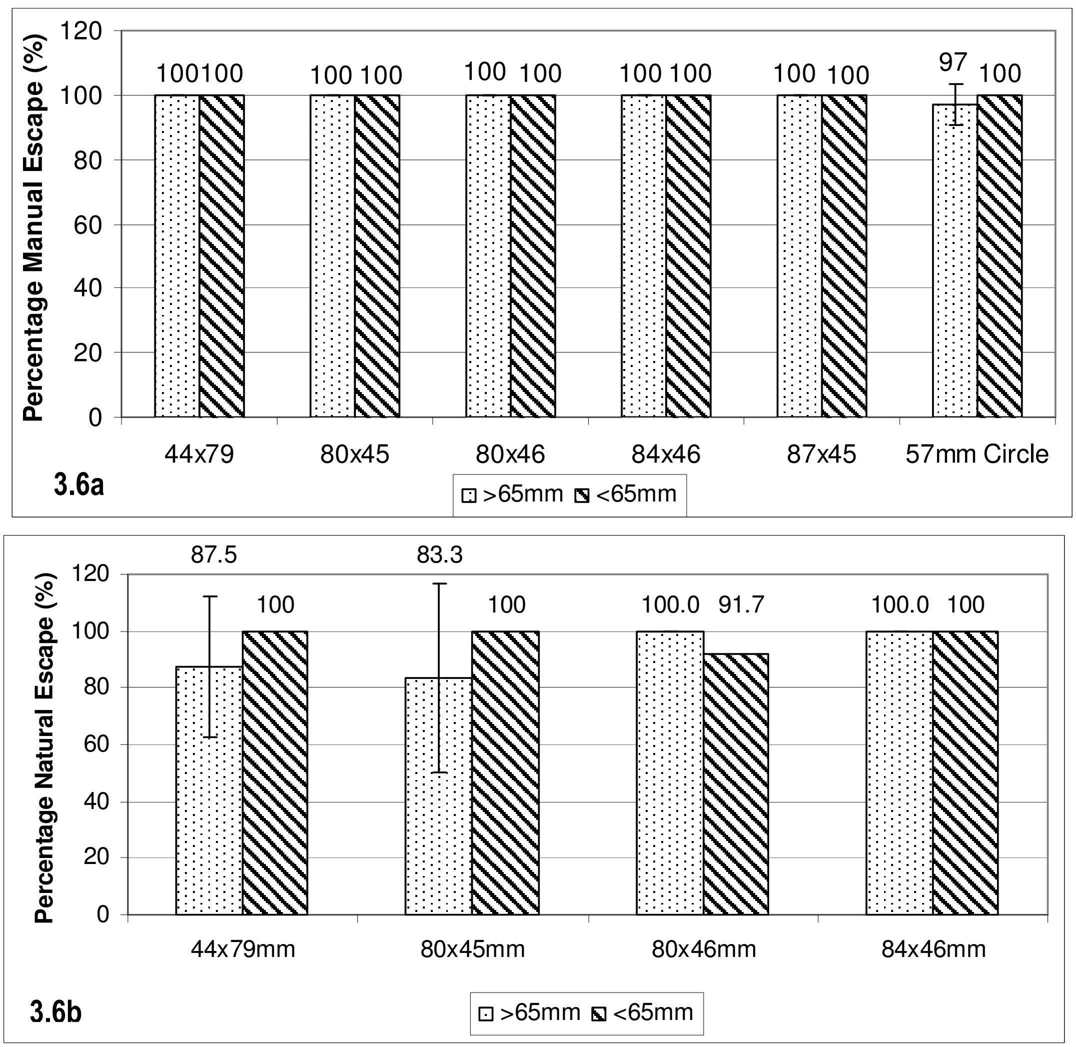


Figure 3.6. Figure 3.6a shows results for percentage of *N.puber* which could manually pass through all of the escape gaps tested.Figure 3.6b shows the percentage escape of *N.puber* tested for the natural escape through four escape gaps.

An average of 100% of *N.puber* above MLS were able to escape through all six types of escape gaps manually (Figure 3.6a). Similar results were observed for *N.puber* less than 65mm carapace width (CW), apart from results observed for the 57mm circle where the average percentage escape was 97% (Figure 3.6a). A lower rate of average percentage escape were observed for results obtained by the natural escape of *N.puber* (Figure 3.6b). For *N.puber* less than 65mm CW, percentage escape for each escape gap ranged between 91.7% and 100%, and for *N.puber* above 65mm CW, percentage escape ranged between 83.3% and 100%. These results for *N.puber* would indicate that these escape gaps are not able to retain animals above MLS, meaning that the second null hypothesis for Aim 1 would have to be rejected, next the results were tested for significant differences.

Table 3.6. Results from statistical analysis on replicates showing *N.puber* success at escaping through gaps, either naturally or manually, (using One Way ANOVA for parametric data and Kruskal Wallis One Way ANOVA on ranks for non parametric data), based on the sizes of individuals which were retained or which escaped for each escape gap type

Escape Gap Type	Natural Escape Result	Manual Escape Result
44mm x79mm	P=0.513	P = 1.000
80mmx45mm	P=0.295	P = 1.000
80mm x46mm	P=0.890	P = 1.000
84mmx46mm	P=0.969	P = 1.000
57mm Circle		P = 0.993
87mm x45mm		P = 1.000

Table 3.6a. Results from statistical analysis after results of sizes of *N.puber* which successfully passed from replicates were merged, using Kruskal- Wallis One Way ANOVA on Ranks

Escape Gaps Tested	Escape Type	Result
UK Current Escape Gap	Natural	P=0.585
All	Manual	P=1.00

There were no significant differences between results from *N.puber* replicates which were observed for the sizes of animals escaping through each escape gap type (Figure 3.6). Based on this result, size results from each escape gap could be merged for each escape gap and statistically compared against each other. No significant difference was found for the sizes of *N.puber* which successfully passed through the escape gaps either naturally or manually (Figure 3.6a)

Table 3.7. Test for differences between escape gaps, using percentage escape data for each replicate. Natural escape was tested only on the current escape gaps used in the UK. Using One Way ANOVA for parametric data and Kruskal-Wallis One way ANOVA on Ranks for non parametric data.
H_0: There is no difference for the percentage escape results of *N.puber* between escape gap designs.

Size Group	Type of escape	Result
<65mm	Manual	P = 1.000
>65mm	Manual	P = 0.416
<65mm	Natural	P = 0.392
>65mm	Natural	P = 0.542

The results for percentage escape were then tested for statistical differences, results showed there is no significant differences observed for the percentage escape results of *N.puber* through the escape gaps either manually or naturally (Table 3.7).

Table 3.8. Results for statistical analysis testing for differences between the percentage escape results of natural escape and manual escape for *N.puber*. Data for all replicates of all current escape gaps was tested for differences using the Mann Whitney Rank Sum Test,
H_0: There is no difference between results obtained for manual and natural escape of *N.puber* through the escape gap.

Size Group	Result
<65mm	P = 0.349
>65mm	P = 0.164

Finally the results obtained for above MLS and the results for below MLS were tested to see if there differences between the natural and manual escape of *N.puber* were significant. There was no significant differences (P=0.05) observed for either size group, between the results obtained by natural and manual escape.

Aim 1 was to find the optimum escape gap for the Southern IFCA fishery for *H.gammarus* and *C.pagurus*. Two null hypotheses were tested. The first null hypothesis stated that there would be no difference between the effectiveness of the escape gaps which are currently used in the UK. This hypothesis remained true for the *N.puber*, as all *N.puber* individuals could escape through all escape gaps both naturally and manually. However there were significant differences (P<0.05) in the effectiveness of escape gaps for *H.gammarus*, particularly with the sizes the animals retained by the largest and smallest escape gaps. This would indicate that the escape gap size 44x79mm restricts so much that it is preventing many of the undersized *H.gammarus* from escaping. All escape gaps currently in use around the UK retain most of the undersized *C.pagurus*. This was unexpected, but analysis showed *C.pagurus* are severely restricted by their carapace length and carapace depth- which the escape gaps currently used in the UK do not account for.

Based on these results it is clear that there is variability in the effectiveness of the escape gaps which are currently used in UK fisheries. All of these designs retain oversized *C.pagurus*, but none of the escape gaps let many (if any) undersized *C.pagurus* escape. There is more variability in the effectiveness of the escape gaps with regard to *H.gammarus*. It would appear that with as the heights and widths of the escape gaps increases, there is an increase in the successful escapes of *H.gammarus* both above and below the MLS. Therefore there needs to be a careful compromise between escape gap width and escape gap height to determine the optimum escape gap size, which is what the new design 87x45mm achieves. Therefore this study would suggest that the optimum escape gap design for the Southern IFCA is 87x45mm.

3.2. Aim 2 Results- *N.puber* Escape Gap Design

The second aim of the report was to find the optimum escape gap design for *N.puber*, for this aim there was one null hypothesis: 'The *N.puber* escape gap height retains all *N.puber* individuals above 65mm, and releases *N.puber* individuals below 65mm.'

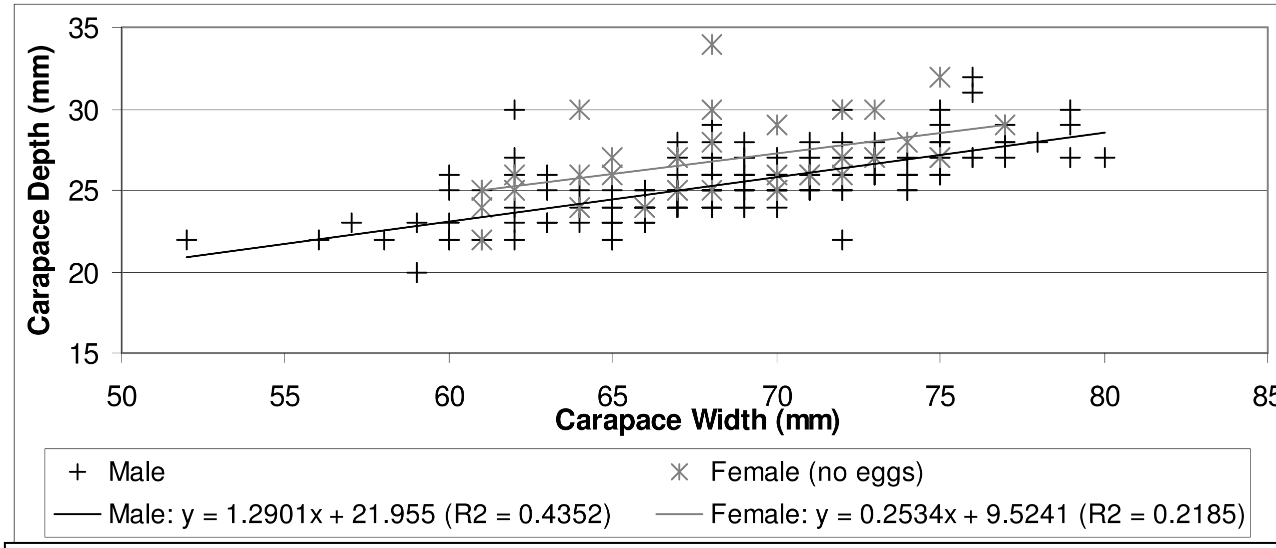


Figure 3.7. Morphometric Analysis on velvet swimming crab data carapace width against carapace depth, for male and females. The trend line for both sexes is plotted linearly, with the y=mx+c equation displayed.

Using *N.puber* morphometric data collected for this project, the heights of escape gap were determined for which *N.puber* should be tested. Data were plotted into a scatter-graph (Figure 3.7) and then analysed. Most *N.puber* with a CW less than 65mm have a carapace depth less than 30mm, and most with a CW less than 60mm CW have a carapace depth less than 25mm (Figure 3.7). From these observations seven escape gap sizes were determined to be tested (30mm, 27mm, 25mm, 23mm, 22mm, 21mm and 20mm).

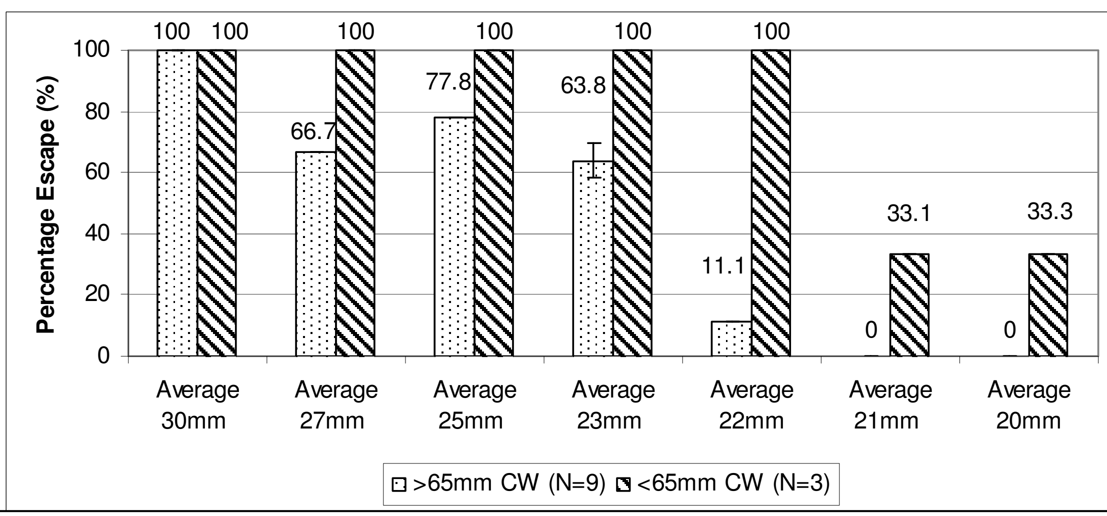


Figure 3.8. Results showing the average percentage escape of *N.puber* which could manually pass through seven different rectangles with different heights. The height was varied to find the optimum escape gap size where *N.puber* above MLS could not escape, and where small (<65mm) individuals could escape. Standard Deviation has been applied, but in the majority of cases SD=0.

The results for each escape gap height were analysed with regard to whether they achieved the null hypothesis for aim two. An escape gap height of 30mm was tested as a control test, this height was found to let 100% of animals above and below the MLS through (Figure 3.8). However as the height of the gap decreased, there was a decrease in the percentage of above MLS *N.puber* which could escape. The largest escape height where 0% of >MLS *N.puber* were able to escape was at 21mm (Figure 3.8). However the passing of animals less than 65mm CW was not impacted until the height of the escape gap became less than 22mm, where the percentage escape levels dropped from 100% (with an escape gap height of 22mm) to 33.1% (with an escape gap height of 21mm), as seen in Figure 3.8.

Table 3.9. Testing for difference between carapace widths of escaped/retained *N.puber* from each escape gap for two size groups. Where numbers became too low to statistically test the escaped sizes, retained sizes were tested for differences. The Kruskal Wallis One Way ANOVA on Ranks was used.
H_0: There is no difference between size of carapace width obtained for the replicates of each escape gap.

Rectangle Height	Results <65mm	Results >65mm
30mm	P = 1.000 (Escaped)	P = 1.000 (Escaped)
27mm	P = 1.000 (Escaped)	P = 1.000 (Escaped)
25mm	P = 1.000 (Escaped)	P = 1.000 (Escaped)
23mm	P = 1.000 (Escaped)	P = 0.952 (Escaped)
22mm	P = 1.000 (Escaped)	P = 1.000 (Retained)
21mm	P = 1.000 (Retained)	P = 1.000 (Retained)
20mm	P = 0.916 (Retained)	P = 1.000 (Retained)

The carapace widths of animals which escaped or retained by each escape gap height were tested for significant differences (Table 3.9). There were no significant differences (P=0.05) between any of the sizes of animals which escaped or which were retained by the different escape gaps (Table 3.9). This allowed the results for each escape gap to be combined and tested against each other for significant differences (P=0.05).

Table 3.10. Testing for statistical differences between the percentage escape results for all replicates of all escape gaps listed in Table 3.8. Tested using Kruskal Wallis One Way ANOVA on Ranks, pair wise tests are carried out to determine the cause of significant differences.

Size Group	Results	Pairwise Test Results
>65mm	**P = <0.001**	Tukey test found differences (P<0.05) between: 30mm vs 20mm 30mm vs 21mm 25mm vs 20mm 25mm vs 21mm
<65mm	**P = <0.001**	No significant differences found using Tukey Test. Mann-Whitney Rank Sum Test showed significant difference between % escape results for undersized *N.puber* for 22mm and 21mm height (P = 0.029)

The results for percentage escape replicates were then tested against the other replicate results for other escape gap types. Significant differences were found between percentage escape results for both size groups (Table 3.10). The cause of significant differences for the *N.puber* over 65mm in Table 3.10 were caused by differences between the smallest escape gaps which had a height of 20mm and 21mm and those with larger heights of 20mm and 25mm. There was a significant difference between the median values of which were produced for *N.puber* with a CW less than 65mm, but the Tukey test did not identify the source of the significant difference. A Mann-Whitney Rank Sum Test was used to test for differences between the percentage escape of <65mm *N. puber* from the 22mm escape gap and the percentage escape from the 21mm escape gap. A significant difference was found between the two escape gap replicates values for undersized *N.puber* ($P<0.05$).

The second aim for this report was to find the optimum escape gap size for an *N.puber* escape gap. The 21mm and 20mm escape gap heights were found to fit in with the second aims null hypothesis- where all *N.puber* above MLS are retained, but *N.puber* below MLS were able to escape. Results for 21mm and 20mm escape gap heights retained 100% of *N.puber* above MLS, and released 33.3% of *N.puber* below MLS.

3.3. Aim 3 Results- Design and testing of an Escape Gap design for *N.puber* and *H.gammarus*

The third aim of this study was to investigate an escape gap design which would release only *N.puber* above MLS, but it would also release some *H.gammarus* individuals. The results would test the null hypotheses stated for Aim 3. These are as follows:

$H_0$1. The new escape gap design will retain all *N.puber* individuals above 65mm carapace width and all individuals for *H.gammarus* above 82mm carapace length.

$H_0$2. The new escape gap design will release some *H.gammarus* individuals less than 82mm carapace length.

$H_0$3. There is no difference between results obtained manually and results obtained naturally for *N.puber* or *H.gammarus.*

$H_0$4. There is no difference between results obtained from the escape gap when it is positioned horizontally and when it is positioned vertically.

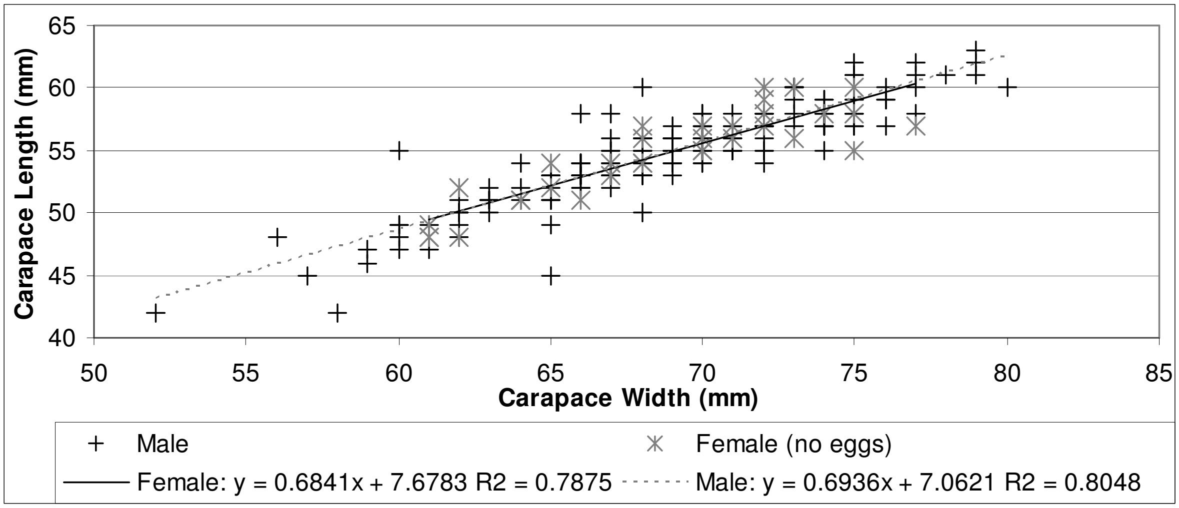


Figure 3.9. Morphometric relationship between carapace length and carapace width for male and female *N.puber*. Linear trend lines have been plotted and the y=mx+c equation is displayed.

Using the results from Aim 2, a 20mm rectangle was used, and combined with a circle. The size of the circle would be determined using the *N.puber* morphometric data collected for this project. A strong positive linear relationship was observed for the morphometric relationship between carapace length and carapace width for *N.puber* (Figure 3.9), R^2 values are 0.7875 for males and 0.8048 for females and males respectively, these values are high and close to +1 which suggest a positive correlation. Using the y=mx+c equation the optimum diameter of a circle can be determined for the hybrid escape gap. To determine the circles diameter, it was considered that no *N.puber* larger than 60mm carapace width should to be released from this gap, so the linear morphometric relationship equation (y=mx+c) was used with 60 as X. Results showed that for males at 60mm carapace width male *N.puber* were likely to have a carapace length of 48.7mm, females are likely to have a carapace length of 48.7mm. So a circle size of 48mm was chosen to be integrated with the 21mm rectangle.

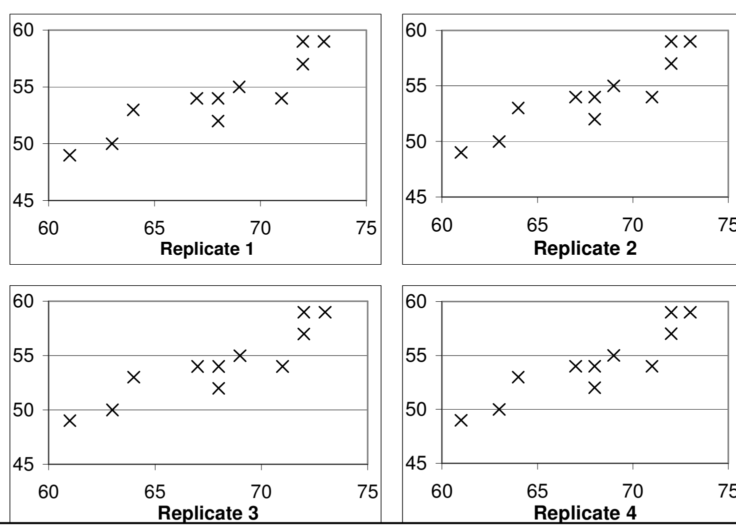


Figure 3.10. Plots showing the successful attempts of manually passing a range of different sized *N.puber* through a 48mm circle only. The X axis is carapace width (mm) and Y axis is carapace length (mm). Crosses indicate that the individual has been retained by the circle and cannot pass though.

A 48mm circle was tested to see if any *N.puber* could escape. No *N.puber* of any size available for testing was able to escape through this size of escape gap (Figure 3.10). A trial run of the 48mm circle with *H.gammarus* was run over night with the 48mm circle, however the gap was too small for any possible escapement of animals, and 100% were retained- even the smallest lobster of 68mm carapace length could not escape. Due to time constraints, testing of the escapement of the lobsters through the 48mm circle was moved on to testing the hybrid escape gap (where the circle and rectangle were integrated).

This suggested that a 48mm circle diameter and the 20mm rectangle could be integrated and tested as a potential design which would meet the third aim of the project.

Figure 3.11. Hybrid escape gap design. With 20mm height of rectangle, and 48mm diameter circle.

Eight escape gaps were made to the specifications of 20mm height of the rectangle and 48mm circle diameter (see example in Figure 3.11). *N.puber* and *H.gammarus* were tested manually and naturally through the design.

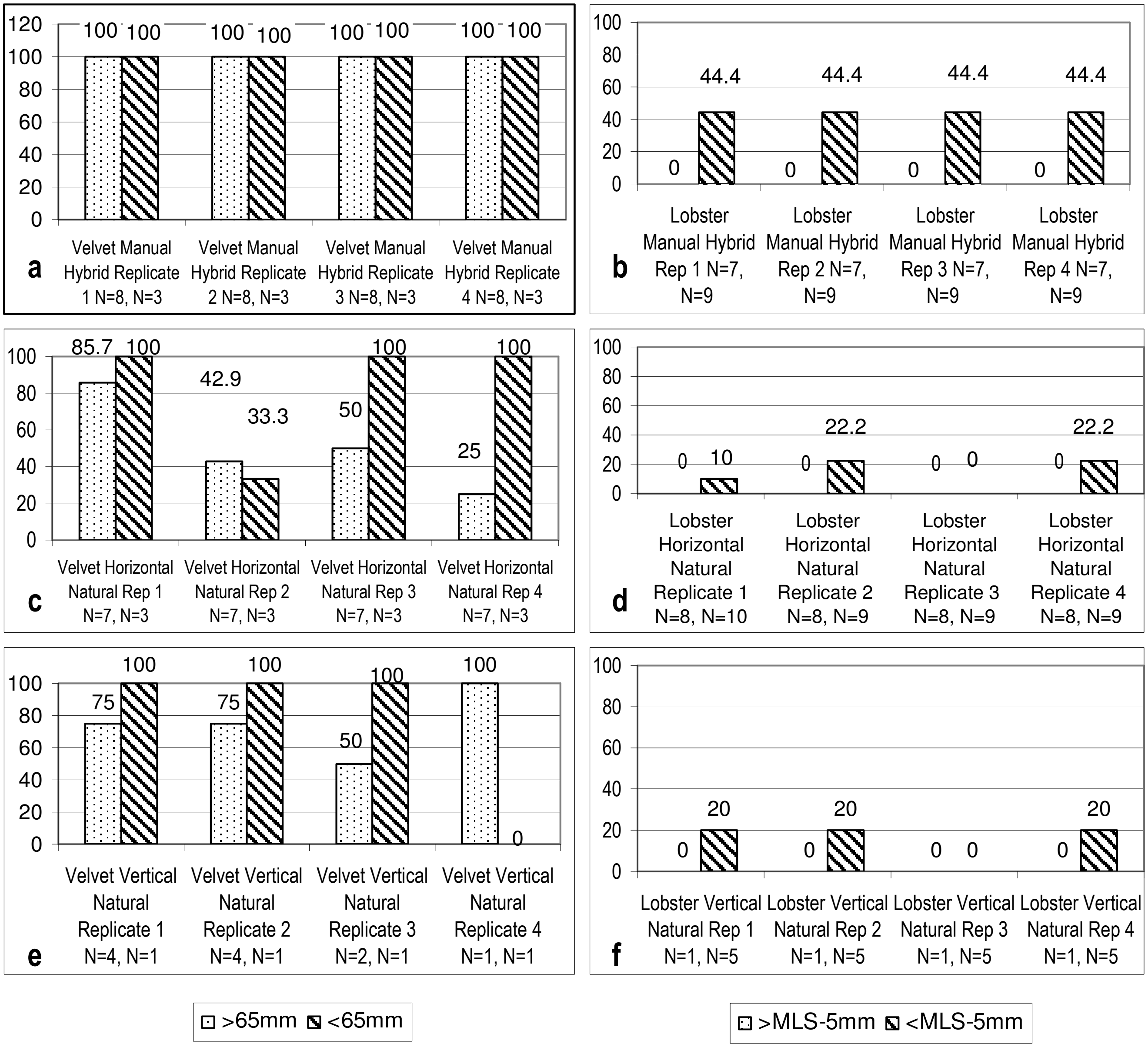


Figure 3.11. Figure shows the percentage escape for *H.gammarus* (labelled as 'lobster') and *N.puber* (labelled as 'velvet') through the hybrid escape gap. Figures a and b show results for manual escape, figures c and d show natural escape through the hybrid escape gap positioned horizontally, figures e and f show percentage escape through the hybrid escape gap positioned vertically. For each plot the Y axis is percentage escape, value of percentage escape is indicated for each bar.

All *N.puber* above and below MLS were able to pass through the hybrid escape gap design manually (Figure 3.11). A lower percentage of above and below *N.puber* were able to escape through the hybrid escape gap naturally whilst the escape gap was in a horizontal (Figure 3.11c) and vertical position (Figure 3.11f) compared to those able to escape by manual manipulation. But percentage escape values escape through the hybrid escape gap are still very high and would indicate that this escape gap does not prevent *N.puber* from escaping, suggesting that the escape gap design fails to meet the first null hypothesis of Aim 3.

On average 44.4% of undersized *H.gammarus* could pass through the hybrid escape gap design when manually manipulated (Figure 3.11b). Fewer *H.gammarus* with a CL less than 82mm were able to pass through naturally when the escape gap was in a horizontal (0-22.2%) or vertical position (0-20%) as observed in Figure 3.11d and Figure 3.11f. Even though only very low percentages could escape, these results would show that this escape gap design achieves the second null hypothesis for Aim 3 of this study- that some *H.gammarus* with a CL less than 82mm can escape.

No *H.gammarus* with a CL above 82mm were able to escape through this escape gap when it was placed horizontally (Figure 3.11d) or vertically (Figure 3.11f). This would suggest that the first null hypothesis for Aim 2 was achieved using this design (that no *H.gammarus* with CL above 82mm could pass through)

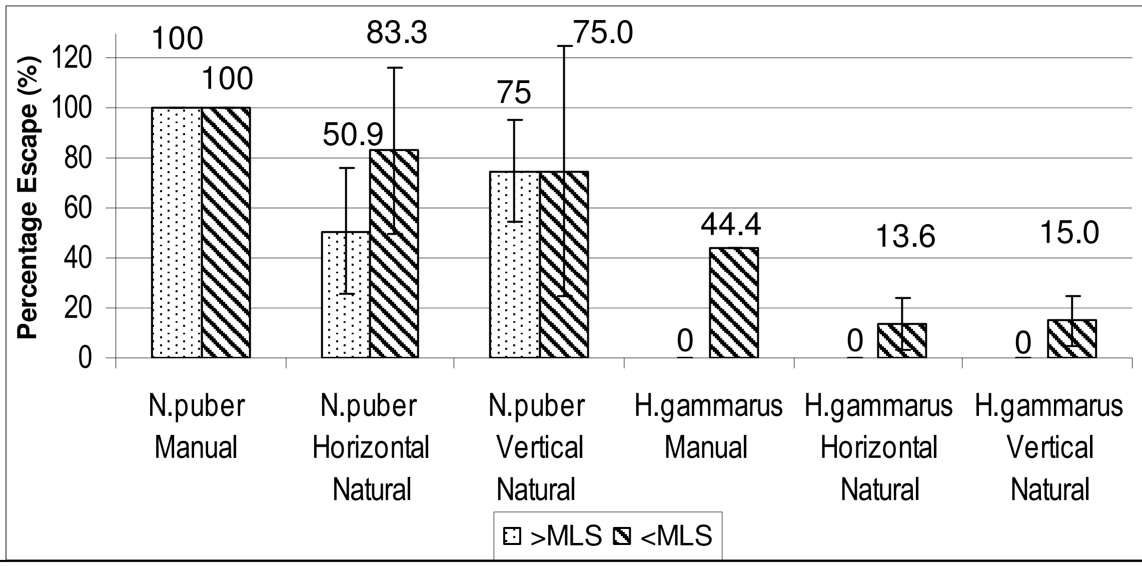


Figure 3.12. Averages of the percentage escape of *N.puber* through the Hybrid escape gap, for above and below MLS. For different types of escape (natural/manual) and different positions. Percentage values and standard deviation are placed on each bar.

To summarise all the results observed in Figure 3.11, replicate results were averaged to allow an easy comparison (Figure 3.12). The percentage escape of undersized animals for both species is of a lower percentage than when the animals are passed through the escape gap manually (Figure 3.12). The percentage escape of both *N.puber* and *H.gammarus* through the hybrid escape gap whilst it is in horizontal and vertical positions give very similar values for both size groups, for both species (Figure 3.12).

To test the third and fourth null hypothesises for Aim 3, statistical analysis was required. The third null hypothesises looked for differences between manual and natural results, and the fourth null hypothesis looked for differences between results gained for the escape gap when it was positioned horizontally and vertically.

Table 3.11. Table showing comparison tests on data for hybrid escape gap results using percentage escape data, including comparisons of results for natural and manual escape, and horizontal and vertical positioning of the escape gap. Mann Whitney Rank Sum Test or T Test used depending on whether data were parametric or non parametric.
H0: There is no difference between results obtained by the two escape types (natural and manual).
H0: There is no difference between results obtained when the escape gap is placed horizontally or vertically.

Test	Size Group	Result
N.puber Manual v *N.puber* Natural (Horizontal data used)	<65mm	**P = 0.029**
	>65mm	P = 0.686
H.gammarus Manual v *H.gammarus* Natural (Horizontal data used)	<MLS-5mm	**P = 0.029**
	>MLS-5mm	P = 1.000
N.puber Manual v *N.puber* Natural (Vertical data used)	<65mm	P = 0.686
	>65mm	**P = 0.029**
H.gammarus Manual v *H.gammarus* Natural (Vertical data used)	<MLS-5mm	**P = 0.029**
	>MLS-5mm	P = 1.000
N.puber Horizontal v *N.puber* Vertical (Natural escape data used)	<65mm	P = 0.886
	>65mm	P = 0.190
H.gammarus Horizontal v *H.gammarus* Vertical (Natural escape data used)	<MLS-5mm	P = 0.686
	>MLS-5mm	P = 1.000

A significant difference was found for percentage escape results obtained manually and naturally (see Table 3.11), for the *H.gammarus* with a CL less than 82mm and for *N.puber* with a CW less than 65mm, when horizontal data were used. No significant differences were found between the results of natural and manual escape for *H.gammarus* above 82mm CL and *N.puber* above 65mm, when horizontal natural escape data were used. However when vertical natural escape data were used and tested against the manual percentage escape, significant differences were found between the results obtained for *N.puber* above MLS, and for *H.gammarus* less than 82mm CL. No significant differences ($P=0.05$) were found between results obtained for when the escape gap was in a vertical and horizontal position for either species.

Therefore third null hypothesis: that there is no difference between the results obtained for natural escape through the escape gap and manual manipulation through the escape gap can be rejected There is a significant difference in results, therefore in future experiments the natural escape of *N.puber* and *H.gammarus* should be tested. The fourth null hypothesis was that there is no difference between results obtained for natural escape of *N.puber* and *H.gammarus* through a horizontally and vertically positioned escape gap. The results showed that this null hypothesis could not be rejected- there was no significant difference between results obtained for the escape gap when it was positioned horizontally or vertically.

Figure 3.13. Half Hybrid escape gap. The design is similar to the hybrid escape gap, as 48mm circle is used, but only one side of the circle has the 20mm rectangle shape.

Finally, a different version of the hybrid escape gap was tested. This version of the design was considered as results from the study showed that *N.puber* were able to easily escape through the hybrid escape gap design- where the circle was in the centre. The carapace depth is greatest at the centre of the body of *N.puber*, so when *N.puber* passes through the hybrid escape gap design the widest part of the *N.puber* will pass through the highest part of the escape gap. Based on this observation, it was considered if the circle only had one side with a 'letterbox' the centre of the *N.puber* would occur at the point where the circle and the letterbox shape meet which is only 20mm high (see Figure 3.13). However, due to time constraints of the project, this escape gap design could only be tested manually with *N.puber*.

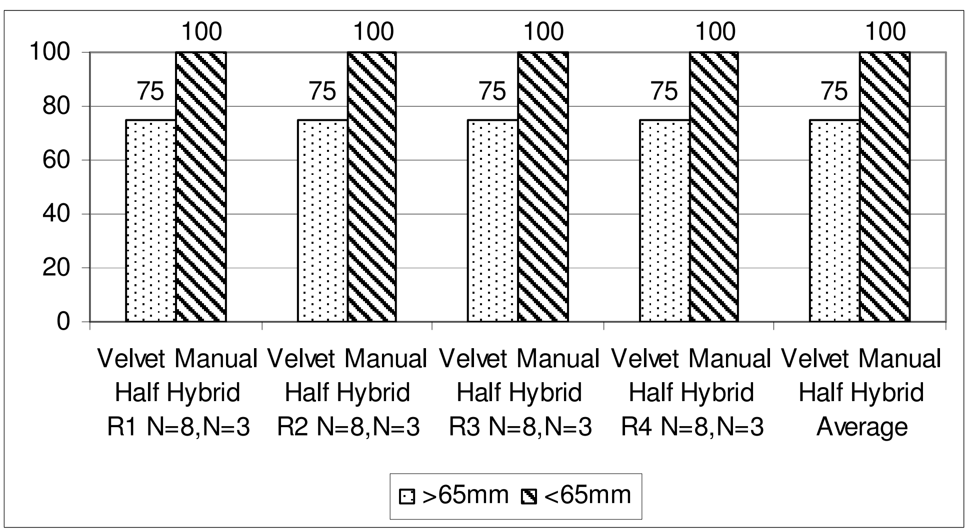


Figure 3.14. Results for *N.puber* for each replicate of Half Hybrid Escape Gap. Showing percentage escape (%) on the Y Axis. Each bar is labelled with the percentage escape. Standard deviation for averages is 0.

The half hybrid design released a very high percentage of *N.puber* above MLS, percentage escape values averaging 75% (Figure 3.14). This design therefore fails to meet the first null hypothesis of Aim 3, so should not be considered for optimum design for a *N.puber* and *H.gammarus* escape gap.

3.4. Summary of Results

Aim 1

Results with regard to the Null Hypothesis of Aim 1

$H_0$1. There is no significant difference (P=0.05) between the effectiveness of the escape gaps currently used in the UK.

$H_0$2. All escape gaps will retain all individuals of each species which are over MLS-5mm, MLS-5mm is equal to 135mm carapace width for *C.pagurus*, 82mm carapace length for *H.gammarus*, and 60mm carapace width for *N.puber*.

- All four of the escape gaps currently used in the UK (44x79mm, 45x80mm, 46x80mm and 46x84mm) retain all *C.pagurus* over 135mm CW.
- The 44x79mm and 45x80mm designs retain all *C.pagurus* with a CW less than 135mm. The 46x80mm escape gap released an average of 7.2% of *C.pagurus* with a CW less than 135mm and the 46x84mm design released 26.7% of *C.pagurus* less than 135mm CW.
- The 44x79mm design is the most restricting of all escape gap sizes for both *H.gammarus* and *C.pagurus*. It retained all *C.pagurus* individuals tested, it retained all *H.gammarus* with a CL over 82mm, and released 47.2% of *H.gammarus* with a CL less than 82mm.
- The 46x84mm design releases an average of 59.4% of *H.gammarus* with a CL over 82mm, this design releases the highest percentage of undersized *C.pagurus* escape of all the designs (26.7%).
- The 57mm diameter circular escape gap releases high percentage of *H.gammarus* of both size groups through the escape gap (63.2% >82mm CL, 87.8% <82mm CL), due to the shape it will select for all *C.pagurus*.
- Carapace height and carapace length restrict the *C.pagurus* from escaping through escape gaps currently used in the UK.
- A new escape gap design was derived, it aimed to release some of the undersized *C.pagurus*-which the current escape gaps fail to do. The escape gap width was determined by finding the carapace length of brown crabs at 135mm CW, the escape gap height was based on the results of testing the current escape gaps- results showed a height of 45mm was the best height to retain the larger *H.gammarus*. The new

design had dimensions of 45mm x 87mm, it was then tested. The design retained 96.2% of *H.gammarus* with a CL above 82mm, it released 81% of *H.gammarus* with a CL above 82mm. The design retained 100% of *C.pagurus* with a CW above 135mm, and released average of 51.8% of *C.pagurus* with a CL less than 135mm.

- There was a significant difference in the sizes of *H.gammarus* which escaped from the designs ($P<0.05$). The sizes released from the smallest escape gap (44x79mm) were significantly smaller than the sizes released from the largest escape gaps (84x46mm and 57mm Circle).
- There was a significant difference ($P=<0.05$) in the size of *H.gammarus* which were retained and escaped from <u>all</u> escape gap designs.
- There is a significant difference between the sizes of *C.pagurus* which were retained or escaped through the 87x45mm escape gap.
- *N.puber* could pass through <u>all</u> the escape gap designs nearly 100% of the time when they were manually manipulated. Results for natural escape through the escape gaps used in the UK were visually lower and more variable than results obtained by manual manipulation. There was no statistical difference ($P=0.05$) between the results obtained manually or naturally.

<u>Aim 2</u>

<u>Results with regard to the Null Hypothesis of Aim 2</u>

$H_0$1. The *N.puber* escape gap height retains all *N.puber* individuals above 65mm, and releases *N.puber* individuals below 65mm.

- An escape gap design with a height of 21mm or less retains 100% of *N.puber* with a CW above 65mm, it releases 33.3% of undersized *N.puber*.
- Results for an escape gap height of 21mm and 20mm give the same results- retaining 100% of >MLS *N.puber* and releasing 33.3% *N.puber* <MLS.
- An escape gap with a height of 22mm, releases 11.1% of >MLS *N.puber*, but releases 100% of <MLS *N.puber.* There is a significant difference ($P<0.05$) between the percentage release of <MLS *N.puber* from an escape gap with a height of 22mm and the percentage release from an escape gap with a height of 21mm.

<u>Aim 3</u>

- Using results from Aim 2, 20mm was chosen as the height for the rectangle which would form one of the two shapes making up the escape gap design. The other shape would be a circle.

- The diameter of the circle to be integrated with rectangle was determined by using the carapace width and carapace length relationship of *N.puber*. The 48mm circle retained 100% of >MLS *N.puber*.
- A rectangle of 20mm and a circle of 48mm were combined to form the hybrid escape gap, it was then tested using *N.puber* and *H.gammarus.*

<u>Results with regard to the Null Hypothesis's of Aim 3</u>

$H_0$1. The new escape gap design will retain all *N.puber* individuals above 65mm carapace width and all individuals for *H.gammarus* above 82mm carapace length.

- 100% of *N.puber* which were above and below the MLS could pass through the hybrid escape gap by manual manipulation.
- 100% of *H.gammarus* were retained by the hybrid escape gap.

$H_0$2. The new escape gap design will release some of the smaller *H.gammarus* individuals.

- An average of 44.4% of *H.gammarus* with a CL less than 82mm could pass through the hybrid escape gap manually, 100% of *H.gammarus* with a CL above 82mm were retained.

$H_0$3. There is no difference between results obtained manually and results obtained naturally for *N.puber* or *H.gammarus.*

- Significantly less ($P<0.05$) *N.puber* and *H.gammarus* (with CL <82mm) escaped naturally than manually, there was no significant difference between results for natural and manual escape for the oversized animals (apart from *N.puber* above MLS).

$H_0$4. There is no significant difference between the percentage of *N.puber* and *H.gammarus* which could escape through the hybrid escape gap when it was positioned horizontally or vertically.

- There is no difference between results obtained from the escape gap when it is positioned horizontally and when it is positioned vertically.

SECTION 4. DISCUSSION

This study showed that there are significant differences between the efficiency of escape gaps currently in use around the UK. It showed that the optimum escape gap size for the Southern IFCA where the target species are *H.gammarus* and *C.pagurus* would be 87x45mm. Results from this study also showed that the optimum escape gap for the Southern IFCA where the target species are *N.puber* would have a height of 21mm. Field trials are required for these escape gaps to show if they work in practise.

Results from this study showed that there were significant differences in the efficacy of escape gaps currently used in the UK, to some extent this would be expected as they each had different dimensions. But these escape gaps are all being used where the in regions where the MLS is equal to or larger than the Southern IFCA, where the MLS for *H.gammarus* is 87mm carapace length, and for *C.pagurus* it is 140mm carapace width. It is therefore surprising and unexpected that there should be significant differences between them.

Previous studies have tested how escape gaps change the size of animals caught in crustacean fishing pots (Clark, 2007; Brown 1978; Brown 1979), all of these studies found that with an escape gap installed into a pot, the average size of the *H.gammarus* increases. This was to be expected, if smaller animals are able to escape from the pot, the average size of animals which are caught in the pot increases. Results from this study showed there were significant differences between sizes of animals which were retained by the escape gap and the sizes of animals which escaped for all escape gaps tested. This would indicate that using *H.gammarus* and *C.pagurus* escape gaps in a pot (particularly those designs tested in this report) would see an increase in the average size of the target species within the pot. If the escape gap design was too small to release smaller individuals, then the average size of the animals would not increase. In this report the smallest escape gap of dimensions 44x79mm was shown to release significantly smaller individuals than the sizes of those retained, but still be significantly less effective than other escape gaps tested. So it could be questioned how well the method of measuring average sizes of animals retained in pots is really beneficial to research and finding the optimum size of escape gap for a fishery.

A study by Murray *et al*., (2009) estimated that *H.gammarus* with a carapace length of 83mm could escape through an escape gap size of 84x46mm, and *H.gammarus* with carapace length of 81mm could escape through an escape gap of 80x45mm. These results fit in with the results of the current study, which show that the 84x46mm escape gap releases a much higher percentage of *H.gammarus* with a CL above

82mm than the 80x45mm escape gap. However the study by Murray *et al*., (2009) was based on field trials and only tested the effectiveness of two escape gaps, it did not take into consideration the efficacy of these escape gaps for *C.pagurus*. To date it would appear that no studies have compared the different escape gap types with regard to the MLSs of the fishery.

It remains unknown where the sizes of escape gaps which are currently used in the UK came from, it seems that they have been designed to release undersized *H.gammarus* and most (apart from the 44x79mm) escape gap do this well, however it does not seem that *C.pagurus* has been taken into consideration for these designs at all. Brown (1982) investigated the optimum escape gap size for a mixed fishery where *H.gammarus* and *C.pagurus* were the target species. The report indicated that the most suitable escape gap size where the MLS for *C.pagurus* was 115mm and MLS for *H.gammarus* is 80mm would be 42x74mm, the present MLSs for the Southern IFCA are far higher than those during the study for Brown (1982). Brown (1982) also highlighted that the escape gap selection for *C.pagurus* depends on the carapace height and width. This fact seems to have been overlooked with time, and as MLSs have increased within fisheries districts the escape gap designs have not been updated to suit these new MLSs.

This is reflected in amount of literature available on escape gaps for UK crustacean fisheries. In a search of the Aquatic Sciences and Fisheries Abstracts (AFSA) database in September 2012, a search with the keywords 'escape gap lobster UK' returned only five published studies, all of which were published over ten years ago. Many of the studies which have been carried out on UK escape gaps are unpublished grey literature, and so this indicates there is a clear need to investigate this sector of fisheries management further and to produce more peer-reviewed literature.

In the USA, crustacean escape gaps have been a mandatory part of fisheries management for many years, a lot of research has been carried out here on escape gaps, the interest in fisheries management here is particularly focused on maintaining the *Homarus americanus* population. Results from a study by Nulk (1978) found that an escape gap with dimensions of 45mm x152mm is the optimum escape gap size for *H.americanus* when the MLS is 81mm CL. Nulk (1978) suggested that with an increase in the length of the escape gap, there was an increase in the effectiveness of the escape gap. This would link into the results obtained from this study, but with regard to *C.pagurus* rather that *H.gammarus*. Further investigation into the width of an escape gap for a *C.pagurus* and *H.gammaus* maybe beneficial, as increasing the width may release a higher percentage of *C.pagurus* than the 87mmx x45mm escape gap does, so the efficacy of this new design could be increased.

Results from this current study found that the optimum *N.puber* escape gap would have an ideal height of 21mm. This is slightly different to the findings of the study by Shermerdine and White (2011), where the optimum design for *N.puber* with a MLS of 70mm was found to be 20mm. The MLS for *N.puber* in the Southern IFCA is 5mm smaller than the Scottish MLS, at 65mm carapace width. For a larger MLS it would be considered that a larger escape gap height would be required. However results from the current study were tested manually, *N.puber* have not been tested for their natural escape through a height of 21mm or in the field. It is possible that there are morphometric variations in *N.puber* around the UK, which has lead to the optimum escape gap heights being very similar for two different MLSs.

As described in the Introduction, the optimum escape gap will release the majority of undersized animals and retain all legal sized target species. This is achieved by the 87x45mm escape gap where the target species are *C.pagurus* and *H.gammarus,* and the 21mm escape gap height where the target species is *N.puber*.

However it should be considered as to whether the *N.puber* escape gap would really add to a sustainable fishery, particularly when it is fitted into parlour pots where the target species are *C.pagurus* and *H.gammarus*. As described earlier, for several fishing districts around the UK escape gaps are mandatory, these escape gaps are the larger escape gaps which are designed for *H.gammarus* and *C.pagurus*. In these fishing districts it is unlikely that *N.puber* will be retained in the pots where the *H.gammarus* and *C.pagurus* escape gaps are fitted, and so therefore fishermen in these regions are likely to have specific pots which are targeted at catching *N.puber*.

If the *N.puber* escape gap was fitted to a parlour pot where *C.pagurus* and *H.gammarus* are the key target species, then only the smallest *N.puber* could escape, no small *H.gammarus* or *C.pagurus* would be able to escape of any size. It is unlikely therefore that the 21mm escape gap for *N.puber* would really add to making a fishery more sustainable, as very few animals could escape through the escape gap.

As the results from this study have shown, it is very unlikely that there will be an escape gap design which will let undersized *C.pagurus*, *H.gammarus* through an escape gap, at the same time retaining above MLS *N.puber*. Therefore another, possibly more sustainable option for the Southern IFCA would be to designate the 87x45mm escape gap to be used in all parlour pots, this would allowing undersized *H.gammarus* and *C.pagurus* and some non-target species to escape. Then *N.puber* escape gaps could be used on *N.puber* specific pots, allowing the release of undersized *N.puber* individuals back into the natural environment.

The fisheries management authorities are in place to protect the fisheries resources of a region, this study along with others has shown that escape gaps can be an effective way to achieve this. But to be truly effective escape gaps have to be designed correctly and instated responsibly. This study has found two designs which are likely to be the optimum designs for the region.

To use the escape gaps responsibly it is strongly recommended that the Southern IFCA follow the other IFCAs in making the *C.pagurus* and *H.gammarus* escape gap (with a size of 87x45mm) mandatory in all parlour pots, but then make *N.puber* escape gaps mandatory in all *N.puber* pots. This would be the preferable and most effective way to use the escape gaps within the fishery; if crustacean pot users were given a choice between use of the smaller *N.puber* escape gap or the 87x45mm escape gap, it would seem unlikely that the larger escape gap will be chosen. Results from this study offer a great opportunity for escape gaps to be responsibly instated into a fishery, where the optimum designs have been determined using an evidence based approach.

There is a great amount of scope for further work in this field. Possibilities for further work include the following. There needs to be field trials of the 87x45mm and *N.puber* 21mm escape gap height. This could be carried out by fixing the escape gap sizes to pots and testing the sizes which are caught in pots with escape gaps compared to pots without escape gaps, as in the study by Murry *et al*., (2009), the results (species, morphometrics, sex, ovigerosity etc) for each escape gap type could be compared.

To date very little work has been carried out on *C.pagurus* and how well escape gaps work for releasing undersized individuals of this species. From the current study it would appear that most of the designs commercially available retain most undersized animals and so it would be expected that average sizes of *C.pagurus* would remain the same when escape gaps are used, compared to when they are not. To test this, the average size of *C.pagurus* caught in pots with and without escape gaps could be compared using the commercially available escape gaps, this could be done following the method of Clark (2007). The new escape gap (87x45mm) could then be tested in the same manner; in the current study, this design showed significant differences in sizes of *C.pagurus* which escaped compared to those which were retained.

It may also be worthwhile to look at if increasing the escape gap width increases the percentage escape of undersized *H.gammarus* and *C.pagurus* further as the study by Nulk (1979) suggests that with increasing width there is increasing effectiveness of an escape gaps, this could lead to an increase in the percentage escape of undersized target species from the pot.

It is important to note that the efficacy of these escape gap designs with changing MLSs of *N.puber*, *C.pagurus* and *H.gammarus* could be determined using the data collected from this report, as the data analysed could be changed to fit the new MLSs. It maybe useful and helpful to expand the database of this data (by increasing the number of individuals tested and testing more escape gap designs) so that the optimum escape gap design can be determined as the MLS changes, helping to keep escape gaps relevant and updated.

From this report it would seem that lab studies are the best starting point in testing the efficacy of an escape gap design. However as time and resources are often limited, so field trials are often run, but these studies also are limiting. When possible, lab trials should be run before field trials for escape gap testing.

SECTION 5. CONCLUSION

- This study has found that there are significant differences in the effectiveness of escape gaps which are currently used in the UK, all escape gaps which were tested released a very low percentage of undersized *C.pagurus*.
- In regions where the MLS of is equal or larger than the following: *C.pagurus* (140mm CW) and *H.gammarus* (87mm CL), the 87x45mm escape gap is the optimum design, as it increases the escapement of undersized *C.pagurus*, but maintains high release rate of the undersized *H.gammarus*. Field trials are needed to test that the design works in the fishery.
- The optimum escape gap for the *N.puber* fishery where the MLS is 65mm CW, is where the escape gap has a height of 21mm. Field trials to test this escape gap design are needed.
- A novel escape gap design which retains *N.puber* above MLS but releases some *H.gammarus* was shown not to work, so further development is needed for this design.
- Significant differences between results obtained by natural escape of animals from pots and manual manipulation. Based on these results it is therefore preferable that future work using escape gaps using the natural escape from pots, but further work in this field maybe required.
- Careful consideration of the use of escape gaps within the fishery is needed. To choose the smaller *N.puber* escape gap over the larger 87x45mm escape gap for use in parlour pots is unlikely to be beneficial to the fishery, as it will retain most animals which are caught in the pot. Ideally the 87x45mm escape gap would be mandatory in parlour pots and the 21mm *N.puber* escape gap would be mandatory in pots specifically designed for *N.puber*.

SECTION 6. REFERENCES

Addison J.T. and Lovewell S.R.J., 1991. Size composition and pot selectivity in the lobster (*Homarus gammarus* (L.)) and crab (*Cancer pagurus* (L.)) fisheries on the east coast of England. *International Council for the Exploration of the Sea Journal of Marine Science,* 48: 79-90.

Botsford L.W., Castilla J.C., Peterson C.H., 1997. The management of fisheries and marine ecosystems. *Science*, 277, 509- 515.

Bouston A., Mahasawasde C., Mahasawasde S., Tunkijjanukij S., and Arimoto T., 2009. Use of escape vents to improve size and species selectivity of collapsible pot for blue swimming crab *Portunus pelagicus* in Thailand. *Fisheries Science*, 75: 25-33.

Brock D.J., Saunders T.M., Ward T.M., and Linnane A.J., 2006. Effectiveness of a two chambered trap in reducing within-trap predation by octopus on southern spiny rock lobster. *Fisheries Research*, 77, 348-355.

Brown, C.G., 1978. Trials with escape gaps in lobster and crab traps. *International Council for the Exploration of the Sea*, Shellfish Committee.

Brown, C.G., 1979. *Trials with escape gaps in lobster and crab pots*. Fish. Not., MAFF Direct. Fish. Res., Lowestoft, 62.

Brown, C.G., 1982. The effect of escape gaps on trap selectivity in the United Kingdom crab (*Cancer pagurus* L.) and lobster (*Homarus gammarus* (L.)) fisheries. *International Council for the exploration of the sea*, 40: 127-134.

Cadima E.L., 2003. *Fish stock assessment manual.* FAO Fisheries Technical Paper, No.393. Rome, FAO, 161p.

Campos A. and Fonseca P., 2004. The use of separator panels and square mesh windows for by-catch reducation in the crustacean trawl fishery off the Algarve (South Portugal). *Fisheries Research*, 69, 147-156.

CEFAS, 2004. *Unpublished dataset of morphormetric characteristics for H.gammarus and C.pagurus, collected in Essex*. Centre for Environment, Fisheries and Aquaculture Science.

Clark R., 2007. Lobster escape hatches in Selsey. *CEFAS Shellfish News*, 24: 23- 25.

Council Regulation (EC) No 850/98 ANNEX XII of 30 March 1998 for the conservation of fishery resources through technical measure for the protection of juveniles of marine organisms. [Online] Official Journal L 125, Available at: < http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31998R0850:en:HTML > [Accessed 19th August 2012].

Department for Environment Food and Rural Affairs, 2012.Inshore Fisheries and Conservation Authorities (IFCAs). [online] DEFRA. Available at: http://www.defra.gov.uk/environment/marine/wwo/ifca/ [Accessed on: 30th August 2012]

Devon and Severn IFCA, 2011. *Devon Sea Fisheries Committee Byelaws*. [online] Devon and Severn Inshore Fisheries and Conservation Authority. Available at: < www.**devonandsevernifca**.gov.uk/sitedata/Misc/**byelaws**.pdf > [Accessed on 30th August 2012]

Fogary and Borden (1980) Effects of trap venting of gear selectivity in the inshore Rhode Island American lobster, *Homarus americanus*, fishery. *Fishery Bulletin*, 77: 925-933.

Kent and Essex IFCA, 2011. Kent and Essex Inshore Fisheries and Conservation Authority- Byelaws Area A. [online] Kent and Essex Inshore fisheries and Conservation Authority. Available at: < http://www.kentandessex-ifca.gov.uk/images/stories/KEpicts/repos/area_a.pdf > [Accessed on 19th August 2012].

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

Matsuoka T., Nakashima T., and Nagasawa N., 2005. A review of ghost fishing scientific approaches to evaluation and solutions. *Fisheries science*, 71, 691-702.

Murray L.G., Hinz H., and Kaiser M.J., 2009. Lobster Escape Gap Trials. Fisheries and Conservation report Number 9, Bangor University, pp11.

Munroe J.L., Sary Z., and Gell F.R., 2003. Escape gaps: an option for the management of Caribbean trap fisheries. *Proceedings of the annual Gulf and Caribbean Fisheries Institute,* 54: 28-40.

Nulk V.E., 1978. The effects of different escape vents on the selectivity of lobster traps. *Marine Fisheries Review*, 40: 50-58.

Polovina J.J., Everson A.R., and Kazama T.K., 1991. Evaluation of circular and rectangular escape vents in a multispecies lobster fishery in Hawaii. *Proceedings of the annual Gulf and Caribbean Fisheries Institute*, 40: 471-481.

Robins-Troeger J.B., Buckworth R.C., and Dredge M.C.L., 1995. Development of a trawl efficiency device (TED) for Australian prawn fisheries. II Field evaluations of the AusTED. *Fisheries Research*, 22, 107-117.

Schoeman D.S., Cockcroft A.C., Van Zyl D.L., and Goosen P.C., (2002). Changes to regulations and the gear used in the South African commercial fishery for *Jasus lalandii*. *South African Journal of Marine Science*, 24, 365-369.

Shermerdine and White (2011) SISP Report 01/11: Escape gaps for velvet crabs (*Necora puber*); stock and economic benefits for the catching sector [pdf] Available at: <http://www.scotland.gov.uk/Resource/Doc/295194/0117043.pdf> [Accessed on: 23rd March 2012].

Southern IFCA 2012. *About the Southern IFCA*. [online] Southern Inshore Fisheries and Conservation Authority. Available at: < http://www.southern-ifca.gov.uk/about> [Accessed on 30th August 2012]

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

APPENDIX I

Following is a list of all scatter plot files on the Data DC which is supplied with this report. Each scatter plot shows the size of individuals which were retained or which escaped from a particular escape gap size, for four replicates. Axes show combinations of Carapace Width (CW), Carapace Length (CL) and Carapace Depth (CD), all in millimeters.

Aim	File Name	Escape Gap Size	Figure	Species	Axis
1	Plots 79x44mm	79mm x 44mm	1	*C.pagurus*	CW v CL
			2	*H.gammarus*	CL v CW
			3	*H.gammarus*	CL v CD
			4	*N.puber*	CW v CL
	Plots 80x45mm	80mm x 45mm	1	*C.pagurus*	CW v CL
			2	*H.gammarus*	CL v CW
			3	*H.gammarus*	CL v CD
			4	*N.puber*	CW v CL
	Plots 80x46mm	80mm x 46mm	1	*C.pagurus*	CW v CL
			2	*H.gammarus*	CL v CW
			3	*H.gammarus*	CL v CD
			4	*N.puber*	CW v CL
	Plots 84x46mm	84mm x 46mm	1	*C.pagurus*	CW v CL
			2	*H.gammarus*	CL v CW
			3	*H.gammarus*	CL v CD
			4	*N.puber*	CW v CL
	Plots 45x87mm	45mm x 87mm	1	*C.pagurus*	CW v CL
			2	*H.gammarus*	CL v CW
			3	*H.gammarus*	CL v CD
	57mm Circle Results	57mm Circle	1	*H.gammarus*	CL v CW
			2	*H.gammarus*	CL v CD
	Velvet 44x79 Manual	44mm x 79mm	1	*N.puber*	CW v CL
	Velvet 45x80 Manual	45mm x 80mm	1	*N.puber*	CW v CL
	Velvet 46x80 Manual	46mm x 80mm	1	*N.puber*	CW v CL
	Velvet 46x84 Manual	46mm x84mm	1	*N.puber*	CW v CL
	Velvet 45x87 Manual	45mm x87mm	1	*N.puber*	CW v CL
	Velvet 57mm Circle Manual	57mm Circle	1	*N.puber*	CW v CL
2	20mm Velvet Manual	20mm	1	*N.puber*	CW v CL
	21mm Velvet Manual	21mm	1	*N.puber*	CW v CL
	22mm Velvet Manual	22mm	1	*N.puber*	CW v CL
	23mm Velvet Manual	23mm	1	*N.puber*	CW v CL
	25mm Velvet Manual	25mm	1	*N.puber*	CW v CL
	27mm Velvet Manual	27mm	1	*N.puber*	CW v CL
	30mm Velvet Manual	30mm	1	*N.puber*	CW v CL
3	Velvet 48mm Circle Manual	48mm Circle	1	*N.puber*	CW v CL
	Velvet Hybrid Manual	Hybrid	1	*N.puber*	CW v CL
	Velvet Natural Hybrid Vertical	Hybrid	1	*N.puber*	CW v CL
	Velvet Natural Hybrid Horizontal	Hybrid	1	*N.puber*	CW v CL
	Lobster Hybrid Manual	Hybrid	1	*H.gammarus*	CL v CW
			2	*H.gammarus*	CL v CD
	Lobster Hybrid Natural Horizontal	Hybrid	1	*H.gammarus*	CL v CW
			2	*H.gammarus*	CL v CD
	Lobster Hybrid Natural Vertical	Hybrid	1	*H.gammarus*	CL v CW