Evaluation of fish pots as a feasible fishing method in Irish waters, with specific reference to the physiological effects of common and alternate pots on the lesser spotted dogfish *(Scyliorhinus canicula)*.

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Abstract

Finfish pots have emerged as a "responsible" gear, when used in combination with conservational and technical measures to sustain fisheries. Previous trials in Irish waters have offered no published reported data and so three designs tested in the current study provide new information on this gear. The most successful traps in terms of fish catch were rigid steel framed rectangular pots used to target Conger eel. Although commercial yield was low (0.2 per trap haul), potential existed for a viable pot fishery. Deployment and storage of Norwegian floating pots was conducted with relative ease but performance in the water was poor resulting in loss of gear. Catch returns were notable even though effort was restricted as mega-faunal by-catch was a problem, which lead to ending this trial. From these initial trials it was evident that catch rates were low compared to established Norwegian fisheries (3.6 cod per pot), which resulted in the utilisation of pots, already established in the crustacean fishery, to find species readily accessible to pot capture. Although fished and designed differently, these gears provided an opportunity to establish the benefits of pot fishing to fish quality and to determine the effects on by-catch. The fishing effects of three catching methods (pots, angling and trawl) and the effects of air exposure on the physiological status of a common by-catch, the lesser spotted dogfish *Scyliorhinus canicula* (L.) were examined using a range of physiological biomarkers (plasma catecholamine, glucose, lactate, muscle pH and muscle lactate). Physiological responses of fish to an emersion stress regime resulted in a significant metabolic disturbance in groups, but may not have weakened the overall health of these fish, as signified in the revival of some metabolites. Plasma glucose and lactate concentrations did not however recovery to baseline levels indicating that to achieve an accurate profile, responses should be determined by a suite of biomarkers. Responses did not demonstrate that samples from the pots were significantly less stressed than for the other two methods; angling and trawling, which are in contrast to many other studies. Employment of finfish potting therefore in Irish waters needs further consideration before further promotion as a more responsible method to supplement or replace established techniques.

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Chapter 1

Introduction

An assessment of common fishing gears and fishing practices in inshore waters with particular reference to the use of experimental fish pots and the physiological effects of fishing on catch.

1 Introduction

Fishing gears considered ecologically friendly have been characterised as species and size selective, non-destructive to all parts of the marine ecosystem in which they are deployed as well as being cost effective and efficient. These characteristics are desired and necessary to promote sustainable fisheries and have been defined in an ICES report (The International Commission for the Exploration of the Seas) by the working group on fish technology and fish behaviour (WGFTFB) (ICES, 2006). This is an approach also preferred by the Irish seafood industry where the development of 'environmentally friendly and fuel-efficient fishing gears that return a high quality product', has been encouraged in the inshore fishing sector (Anon, 2007a). A review of inshore Irish fisheries (Anon, 1999a) and a report in Eno *et al.* (1996) detail the composition of the Irish inshore fishing sector, paying special attention to pot fisheries. The Irish inshore sector provides vital employment in rural coastal communities and is defined as those fisheries that are conducted within 12 miles offshore including demersal, pelagic, shellfish, salmon and sea angling fisheries (Anon, 1999b; Anon, 2007c). The main challenges to this sector are to ensure sustainable fishing resources, increase the income to fishers by reducing fuel needs, improve the quality of fish retained, minimise discarding and to develop and implement technical conservation measures including restricted access and closed areas (Anon, 1999b). This sector has major advantages that may sustain the industry if managed to its full potential (Anon, 2005). The inshore sector has the potential to return a better quality of product as most catch can be brought ashore alive on the day of capture thus increasing shelf-life (Anon, 2007c). This sector primarily uses low impact gears and has lower by-catch rates of non target species has the ability to reduce mortalities as deck sorting is rapidly achieved.

Historically, Irish fishers have alternated their gear with the seasons, e.g. tangle nets for crayfish, driftnets and gillnets for salmon in the summer months (Anon, 1999a; Eno *et al.*, 1996). In 2006, drift-netting was banned in Irish waters in response to depleted stocks of Irish Atlantic salmon (*Salmo salar*). This has had a negative impact not only for the drift-net fishers but also food processors that specialised in this wild product, local co-ops who are dependent on this sector and gear manufacturers (Collins *et al.*, 2006). Static gear, predominantly crustacean pots are the main gear used in inshore fisheries (Fahy *et al.*, 2008). As there is a current ban on salmon fishing anecdotal reports suggest that there is now pressure on fishers to increase effort for other target species to maintain financial viability. However fishers have been advised to reduce fishing efforts to sustain these crustacean stocks (Anon, 1999a) therefore alternating fishing methods to replace and sustain current resources would be advantageous.

1.1 Fishing methods

Several gear types are fished in Irish waters such as crustacean pots, seine nets, otter trawl and gillnets; these are dependent on seasons and target species (Anon, 1999a; Fahy *et al.,* 2002,). Modifications of various gears have been extensively examined in order to reduce unwanted catch. Stoner & Kaimmer (2008) used a misch-metal on their gear to deter dogfish from bait while Furevik *et al.* (2008) rigged fish pots in a way that does not allow by-catch of crab into cod pots. Other efforts to make gear more selective and reduce impacts on the marine ecosystem have also had success (Valdemarsen & Suuronen, 2001) e.g. turtle excluder devices (Brewer *et al*., 2006; Watson *et al*., 1986,), Nordmore grids (Broadhurst, 2000) and drop out panels (Glass *et al*., 2001; Revill & Jennings, 2005, van Marlen *et al*., 2001). Further efforts however need to be made in local waters in order to improve fishing gear performance, the health of catch and to sustain future stocks and healthy ecosystems.

Discard rates in Ireland are still high for some gears; Borges *et al.* (2005) estimated that 20,000 tons of fish were discarded every year by the Irish demersal fisheries, one third of the total catch estimated for this fishery. Estimated discard rates were around 1,806 tons for beam trawls, 2158 tons for seines, and approximately 285 to 4966 tons of fish annually from otter trawl fleets (Borges *et al*., 2005). Trawls are nonselective and depending on duration of the tow, catch may be either dead or damaged once discarded. EU data collection regulations require few species catch data to be recorded from rod and line fisheries which has resulted in catch data for this fishery to be scarce. Vas (1995) however, reported that approximately 5.4 dogfish are caught per vessel from recreational angling from 1978 to 1992 in Irish waters. Mortality rates are thought to be low and rates of release of catch high. To date, no Irish studies have examined the by-catch of fish in crustacean pots or modifications of these gears in order to eliminate unwanted catch. Brown *et al.* (2005) have reported that, in general, bycatch rates are low compared to other gears, but the incidental bycatch of marine mammals and reptiles may occur (Pierpoint, 2000).

The European Union (EU) are now considering expanding current policies to reduce discards by introducing supplementary measures or banning discards completely (Anon., 2007a). Discarding occurs due to the unselective nature of gear, the failure to restrict fishing efforts, the practice of high grading and the result of damage to fish during the capture process. There are numerous negative impacts and discarding threatens future spawning populations due to the landing of juvenile undersized fish, which may not survive or may be damaged in the process (Davis, 2002; Davis & Ryder, 2003). The International Council for the Exploration of the Sea (ICES) (2006a) have reviewed the impacts of each of the major gear types in terms of their effects on all components of the ecosystem. A more comprehensive review has been completed by Johnson (2002) who examined global literature on fishing gear activities and effects on benthic habitats.

Fishing processes are complicated and may have several impacts on catch, depending on practices used. On deck sorting practices vary with fishers and may impact catch more than the fishing gear due to crushing on deck, lengthy exposure times and exposure to the elements (Davis, 2002). Quantifying these impacts and the response of catch across species is also complex. Determination of mortality and long-term damage to discards or survival poses a problem for fisheries managers. Retained fish may lose quality as a direct effect of harvesting techniques and reduce the shelf life of the product (Hattula *et al.*, 1995; Olafsdottir *et al.*, 1997). A short review of the impact of fishing methods is covered in the following sections.

1.2 Impact of common fishing methods on fish health.

1.2.1 Trawling

Trawls are tunnel shaped nets that have a closed off tail where the fish are collected and the opening on the top end acts as the mouth. Bottom trawling involves dragging a trawl or net along the seabed and the horizontal spread of the net is provided by trawl doors or "otter boards". Size selectivity is controlled by the mesh size of the "cod-end" or the end region of the trawl where fish are retained. Trawling, particularly beam trawling and otter trawling have a reputation as high impact methods exposing catch to several stresses during a tow. These include: mechanical abrasion against the net, crushing and overcrowding in the net and cod-end due to catch volume (Suuronen *et al.*, 1996; Kaiser *et al.*, 1998; Kaiser *et al.*, 2001). These stressors may be intensified as catch volume increases and other studies report that deck exposure (Parker *et al.*, 2003; Ridgeway *et al.*, 2006) and sorting processes effects are also responsible for the majority of mortalities and injuries. Hattula *et al.* (1995) reported that increasing the tow time also increases mortalities, but that gillnetting (a static gear) returned more mortalities than trawling due to post capture treatment of fish.

1.2.2 Recreational angling

Angling is the principal method of recreational fishing in Ireland, but commercial fisheries such as long-lining also use angling methods. The hook and float are usually attached by a line to a fishing rod. The rod is usually fitted with a reel that acts as a mechanism for retrieving and releasing out the line. Lures or bait are used on the hook to attract the catch. Catch and release fishing is increasingly practiced by recreational fishermen. In many European countries, size restrictions apply to certain species where fish below or above a minimum landing size must be released. The practice in theory allows the released fish to survive and therefore avoiding depletion of future population. There has been substantial interest in the survival rates and stress responses of angling caught fish (Cooke *et al.*, 2005; Meka & McCormick, 2004; Schreer *et al.*, 2005) which are usually highly valued but are subject to a variety of management regimes. Fish captured by catch-and-release angling are often subjected to many impacts such as intense struggling during the landing process, hooking injuries, handling, air exposure during the hook removal process and weighing (Cooke *et al.*, 2002; Cooke *et al.*, 2005; Suski *et al.*, 2004). The majority of studies investigating elasmobranch responses to fishing have examined specimens from longlines and trawls and they use data from hook and line specimens to provide condition data as it presumed to be a non stressful method (Hoffmayer & Parsons, 2001; High *et al.*, 2007; Mandelmann & Farrington, 2006). Other studies documenting the physiological disturbance of fish from hooking and landing stress have found minimal mortality (Cooke *et al.*, 2002; Pankhurst & Dedual, 1994). Repeated capture however may impose cumulative effects of stress and further disrupt fish metabolic processes.

1.2.3 Crustacean pots

Pots are a type of trap used to capture fish, crustaceans, or molluscs. They are usually composed of a rigid frame covered in a net and attached by a rope to a buoy at the surface. The main pots used in Irish waters are inkwell, creel, shrimp and whelk pots and most are baited with salted or fresh fish to attract catch. Lobster and crab pots are mainly of a D shaped design and are fished in areas of rocky ground. Pots can be fished singly or attached on a line or string. Stressors can be imposed on catch in a similar manner to finfish pots such as confinement, starvation, abrasion from the pot and injury from other catch. By-catch of several species of finfish is a common occurrence in crustacean fisheries e.g. dogfish, wrasse, cod, conger and ling (Anon, 2007a; Eno *et al.,* 1996) and may be retained. Unwanted by-catch can however be returned to sea rapidly as sorting and re-baiting would take place immediately once catch has been landed. These traps however tend to ghostfish or continue fishing when lost by fishers as they normally are composed of robust materials that remains intact (Brown *et al.*, 2005).

1.3 Experimental finfish pots

A recently formed study group on the development of fish-pots for commercial fisheries and survey purposes (SGPOT) is promoting and exploring new research into the commercial use of experimental finfish pots in European waters (ICES 2007a; ICES, 2008a). Traps or pots are of a similar form as crustacean pots but are usually larger in size with larger entrances. Many forms have evolved such as the collapsible two chambered Norwegian parlour pots (Furevik, 1997) and the rigid Atlantic cod pots (Zhou & Kruse, 2000). Finfish pot fisheries account for approximately 1,500 tons of the total discards estimated worldwide, which is considerably less than discarding quantities from other fishing methods (Kelleher, 2005); as such, these gears have a reputation for being low impact. Studies have reported that creel and trap caught fish return a superior quality product to the market, have minimum impact on benthic habitats, have reduced the levels of discards (Cole *et al.*, 2003; Eno *et al.*, 1996; O'Brien & Dennis, 2008). The impact of this fishing process would have the same effects on stress response as the crustacean pots described above. Species have been recaptured alive after the potting process (Nichol & Chilton, 2006) and larger individuals seem to recover better from barotraumas. However, certain additional factors may reduce quality and survival rates of catch; optimal soakage times, depth, emersion times, handling and processing of fish meat. One of the main problems with static gear is the interaction with mega-faunal species e.g. seals, particularly in inshore areas causing a reduction of the quality of catch, damage to gear and mortality of the predator (Moore, 2003). Acoustic Harassment Devices (AHD) and seal safe net traps have been used with some success (Konigsten, 2007; Lunneryd *et al.*, 2003). Pots can contribute to unaccounted mortality through persistent fishing after gear loss and through a cycle of rebaiting and capture of target and non-target species (Breen., 1990; Eno *et al.*, 1996; Smolowitz, 1978a). However, simple and effective measures can reduce the damage to fisheries by ghost pots if incorporated into the design e.g. incorporating time-release devices and biodegradable panels into the design which allow the eventual escape of fish eliminating an ongoing cycle of fishing and rebaiting (Al- Masroori *et al.*, 2004; Scarsbrook *et al.*, 1988; Smolowitz, 1978b Brown *et al.*, (2005) report that pot ghost-fishing is insignificant compared to lost nets in EU waters and that preventative and curative measures could reduce any impacts further.

1.4 Landing, air exposure and recovery

Numerous studies have shown that capture, landing, air exposure and killing procedures are responsible for intense stress response in fish (Bagni, 2007; Hattula *et al.*, 1995; Parker *et al.*, 2003).

1.4.1 Landing

Eliminating by-catch is not always possible even when reduction measures have been established. Before landing the fishing method initiates a stress response and once the fish has been removed from the water additional stress responses are experienced. While fish may escape injury during capture, fish handling and processes on deck cause a decrease in fish health (Davis, 2002, Davis & Parker, 2004). If released, short-term consequences could be the impediment of swimming and feeding capabilities, potential vulnerability to predators and reduction of the potential for successful migration due to sensory impairment. Landing consequences may be numerous e.g. exposure to the elements such as high or cold temperatures and lack of oxygen due to air exposure.

1.4.2 Air exposure

Air exposure occurs after the catching process is complete and fish are removed from water and landed onto the fishing vessel. The duration of exposure to air may last from a few seconds to a few minutes which normally occurs in recreational angling (Davis & Parker, 2005) or fish could be subjected to several hours of air exposure on deck as is a common occurrence in trawling practices (Revill *et al.*, 2005). Studies that looked at air exposure as a major disturbance report that this aspect of fishing alters the homeostasis of fish (Schreer *et al.*, 2005; Suski *et al.*, 2004; White *et al.*, 2008). Air exposure studies have shown that flesh quality in sea bass and sea bream deteriorated when fish died through asphyxia, a condition where there is an insufficient supply of oxygen to the gills and normal respiration cannot occur (Bagni *et al.* 2007). Ridgeway *et al.* (2006) and Suski *et al.* (2004) report that emersion stress elicits a major secondary disturbance just as stressful as the capture process itself by driving alterations in secondary metabolite responses.

1.4.3 Recovery effects after release

Unwanted fish which are returned to the sea undergo a physiological and biological recovery process which may have an impact on their individual survival. Chronic or long-term stress, however, could result in a reduction in growth, impairment of immune system and or depressed appetite (Schreck *et al*, 1997). The immune suppression may increase the risk of infection and any additional physical injuries from capture may prevent a full recovery. If sub-lethal stress levels are not present, fish which are returned to their original environment may recover fully, however this is species dependent. Low mortality rates in response to capture and transport suggest that dogfish recuperate quickly when returned to their normal environment (& Farrington, 2006). Recovery time for elasmobranchs has been reported from 3 hours up to 72 hours (Mandelmann & Farrington, 2006). This was observed through blood chemistry alterations making them an ideal species to gauge capture stress (Mandelmann & Farrington, 2006; Revill *et al.*, 2005).

1.5 Fish physiology

Fish physiology is very complex and depending on the study being undertaken will require an in-depth understanding of the target organ's biology and any potential impact in secondary responses. For this particular project, studies were undertaken to determine the effect of different fishing methods on biological and physiological mechanisms. This involved examining stressors such as aerial exposure (emersion) and different fishing methods through evaluating recovery mechanisms. In order to achieve this, muscle tissue and the circulatory system (metabolites such as lactate and glucose) were examined in detail.

The gill has been defined as a multipurpose organ that is the site of aquatic gas exchange; it plays a role in osmotic and ionic regulation, acid regulation, metabolism and excretion of substances such as ammonia (Evan *et al.*, 2005). Gills play a central role in the physiological condition of the lesser spotted dogfish *Scyliorhinus canicula* (Wright *et al.*, 1973). Pavement cells and mitochondrial rich cells are responsible for the main physiological responses of the epithelia of the gill e.g. pH regulation and excretion of excess nitrogen. Expansion of the gill filaments increases the gill surface area facilitating oxygen absorption during a stress event (Evans *et al.*, 2005). Once exposed to air an emersed fish usually dies because its gills dry and collapse, reducing the area of the respiratory surface, effectively preventing the passage of oxygen into the blood (Wright *et al.*, 1973).

Changes in environmental or blood gas tensions as a result of emersion initiate cardiovascular responses. Fish have a 2-chambered heart in which a single-loop circulatory pattern takes blood from the heart to the gills and then to the body. An increased flow of blood by the heart is suggested to accelerate recovery in elasmobranchs in response to oxygen debt (Opydyke *et al.*, 1982). Hypoxia can cause a reflex bradycardia (reduced heart rate) and decreases cardiac output, therefore decreasing blood pressure. This reflex may protect the heart from hypoxic impairment (Butler and Taylor, 1975; Taylor, 1992).

Removing a fish from its aquatic environment causes a flight response which encourages the fish to struggle to escape. The action of swimming depends on the species and motive. Intense swimming away from a perceived or real danger involves the undulatory side-movements of the trunk and tail by vigorously contracting the axial muscle fibers (Thébault *et al.*, 2005). Muscle exhaustion, characterised by a reduction in pH and depletion of ATP stores (Hatulla *et al.*, 1995), may follow as the result of strenuous exercise during the fishing event up to capture and landing which may undermine the quality of the fish flesh.

1.6 Biochemical metabolites in physiological monitoring

Wendelaar Bonga (1997) defines stress"as disturbance to organisms' homeostasis resulting in a corresponding series of behavioral and physiological responses in an effort to compensate and reinstate stability". The primary response is the release of stress hormones such as adrenaline into the blood stream (Barton, 2002). Secondary responses include an increased blood supply to the respiratory surface of the gills, leading to a breakdown of glycogen in the liver and muscle tissues and an increase in glucose concentrations in the blood or hyperglycaemia. Increased activity in white swimming muscle can produce an elevation in anaerobic metabolites resulting in elevated levels of muscle and blood lactate (Wardle, 1981; Wedemeyer *et al.,* 1990). Measuring alterations of these metabolites is complex (Wendelaar Bonga, 1997) and measuring these indicators at more than one level of the organism's biological organization is necessary to determine a true picture of physiological health (Adams, 1990; Barton, 2002). As this project involved both off shore and land based studies the following suite of metabolites were selected to reflect the sampling procedures and practical considerations.

1.6.1 Catecholamines

Catecholamines are "fight-or-flight" hormones that are released in response to stress. Two of the most commonly measured catecholamines are noradrenaline and adrenaline. These are recognized as the principal hormones distributing energy and targeting organs provoking specific changes in metabolism. At the primary level, intense increases in catecholmaines have been measured in elasmobranchs (Butler *et al.*, 1986) and teleosts (Whitely *et al.*, 2006) due to activity and heat stresses. Comparing these levels to a normal, or presumed resting state, is somewhat difficult as most elasmobranchs used in studies were caught by hook and line (Mandelmann *et al.*, 2006) and teleosts were held in captivity which in itself may alter the normal balance of the organism (Whitely *et al.*, 2006). Catecholmines reach the gill tissues due to the stimulation of chromaffin cells in the elasmobranch interrenal gland, which is connected with the head kidney (Wright *et al.*, 1973). Hypoxic conditions can cause an increase in plasma catecholamine levels which increases gill perfusion to maximize oxygen transfer to the tissues (Reid *et al.,* 1998; Wright *et al.*, 1973).

1.6.2 Glucose

Glucose levels (the amount of glucose present in an organism's blood) are stringently regulated as a part of metabolic homeostasis. Glucose is the main source of energy for cells and is transported via the bloodstream from the intestines or liver to cells. Failure to maintain blood glucose in the normal range leads to conditions of persistently high (hyperglycemia) or low (hypoglycemia) blood sugar. Elevated levels of glucose in the blood as a secondary response are indicative of both acute and chronic stress responses, primarily as the result of catecholamine release (Barton & Iwama, 1991; Bracewell *et al.*, 2004; Farell *et al.*, 2001). Stress related hyper-glycaemia is promoted by the liberation of glucose from the liver into circulation. Hyperglycemia is also indicative of chronic secondary level stress responses and can eventually result in hypoglycemia as the metabolism becomes maladaptive in the organism and can result in depletion of liver glycogen (Barton, 2002; Reid *et al.*, 1998).

1.6.3 Plasma and muscle lactate

Lactate is created from pyruvate via the enzyme lactate dehydrogenase (LDH) in a process of fermentation during normal metabolism and exercise. Increases in concentrations occur when lactate production exceeds the rate of removal. During intense exercise aerobic metabolism cannot produce adenosine triphosphate (ATP) quickly enough to supply the demands of muscle. Therefore, anaerobic metabolism becomes the main energy producing pathway as it can form ATP at higher rates, causing a shift of the buffering systems of tissues, resulting in a fall in pH (Bracewell *et al.*, 2004; Turner *et al.,* 1983; Wells & Baldwin, 2006).

Studies confirm that plasma lactate concentration is a good indicator of capture stress in elasmobranchs and confinement stress in teleosts such as salmon (Hoffmayer & Parsons, 2001; Skjervold *et al.*, 1999). Species exhibiting high rates of lactate production are suggested to have a 'high aerobic scope' which enables them to metabolize the lactate and re-synthesize glycogen (Pritchard *et al.*, 1997; Wells & Baldwin, 2006). This is in contrast to species that are less active and have a low aerobic capacity (Turner *et al.* 1986) and may retain lactate in the muscle. As a result of burst swimming, the main part of muscle becomes hypoxic and accumulates lactic acid as the end product of glycolysis. This lactic acid may clear into the circulation and the post-exercise rise in lactate may continue and persist for several hours until the oxygen liability has been decreased (Well & Baldwin, 2006).

1.6.4 Blood ammonia

Ammonia is a nitrogen end-product and it diffuses from the gills and is excreted as urea (Ip *et al.*, 2003). High blood ammonia concentration elevates blood pH which affects enzyme-catalysed reactions in turn affecting metabolism (Evan *et al.*, 2005). If the function of the gill is altered the osmotic balance may be disrupted, which may result in osmotic shock, affecting the fish's capability to remove ammonia. Exposure to hypoxic conditions promotes the elevation of fish respiration rates which in turn promote ionic imbalance and possibility of osmotic shock (Evan *et al.*, 2005). Depolarisation of the muscle has been reported in teleosts with accumulation of ammonia, particularly in circulation, leading to a decrease in swimming performance (De Boeck *et al.*, 2006).

1.6.5 Muscle pH

A rise in pH levels, as has been previously mentioned, has a direct effect on the capability to eliminate ammonia from circulation. Measuring pH is also a reliable indicator to establish pre-mortem muscle fatigue stimulated by fishing (Cole *et al.*, 2003; Law, 1997). A relationship exists between lactate, pH and ATP depletion (Eassianen *et al.*, 2004; Lowe *et al.*, 1993). Muscle pH concentrations can measure the physiological conditions of fish pre-rigor as a result of stress (Korhonen *et al*,. 1990). Lower muscle pH pre mortem may indicate a more stressed fish and can also be related to a quicker onset of rigor mortis compared to unstressed fish. Acidosis facilitates the easier dissociation of oxyhaemoglobin and removal of oxygen from the blood. A muscle pH of 7.0 to 7.1 has been suggested to characterise an accumulation of lactate acid in salmon (Jerrett *et al.*, 1996; Jerrett *et al.*, 1998). Unstressed fish tend to have a higher pH and experience the onset of rigor later.

1.7 Meat quality

Numerous tests on the onset of rigor mortis and ATP stores in fish pre-slaughter have been used to determine the quality of meat which is dependent on the physiological status of fish at death (Esaiassen *et al.*, 2004; Hatulla *et al.*, 1995; Skjervold *et al.*, 1999). Due to the flight or fight response fish increase their activity to an extent where oxygen supply to the muscle ceases, and the muscle creates energy by anaerobic glycolysis. An accumulation of lactic acid ensues with a consequent reduction in pH. Amines such as (ATP) are quickly degraded resulting in accumulation of inosine and hypoxanthine. Rigor mortis develops once ATP is completely depleted from the muscle and this can be a reliable measure of the quality of fish flesh and physiological status of fish if sampled immediately. The rate of nucleotide degradation is known to differ in fish species and is also dependent on pre-death physiological condition, handling, season, and storage conditions (Hatulla *et al.*, 1995; Kennish & Kramer, 1986). Hattula *et al.* (1995) found that the stress experienced during the capture process was directly proportional to time rigor mortis occurred. Cole *et al.* (2003) used this biomarker as well as muscle pH to gauge a decrease in stress as a direct result of modifications to fishing gear thereby indicating that even small changes in the gear can affect meat quality.

1.8 The organism study

The lesser spotted dogfish *Scyliorhinus canicula* (L.) is from the family Scyliorhinidae or small catsharks. It is found in abundance on all Irish coasts (Henderson & Dunne, 1998; Henderson & Dunne, 2000) at depths up to 400m; (Compagnu, 1984; Wheeler, 1978). Reproduction is oviparous and its typical reproductive period is in the summer months (Henderson & Dunne, 1998). Together with other coastal sharks, spurdog (*Squalus acanthias*), nursehound (*Scyliorhinus stellaris*) and the smooth-hounds (*Mustelus* spp.), these groups comprises approximately half the total weight of elasmobranches taken from the northeast Atlantic (FAO, 1999). *S. canicula* is an important part of demersal fish communities and ecosystems as a whole and more information concerning their physiological profiles and responses to local fishing techniques is important. The commercial value of landings is difficult to determine, as undetermined quantities of this small dogfish are poorly documented in landings that are retained for use as bait in the Irish Sea and Bristol Channel whelk fishery (Anon, 2009). Survey catches are reported to be increasing or stable (ICES, 2007b) and focus is now being directed at accumulating more information on this species as there is limited information on their exact contribution to total catch (Anon, 2007b; FAO, 1999). The retaining and targeting of the north Atlantic spurdog, north Atlantic porbeagle and basking shark is prohibited by law from 2008 (Anon, 2007b) as species such as the spurdog are now deemed to be on the verge of collapse (Anon, 2007b). Few mortality or stress studies have investigated the response of lesser spotted dogfish to infection by parasites (Henderson & Dunne, 1998), and few studies have examined fishing or sorting practices (Revill *et al.*, 2005), all of which may affect long-term survival. The recovery times for other elasmobranchs in response to catching methods in terms of the blood metabolites have been measured however from 3 hours up to 72 hours (Mandelmann & Farrington, 2006). Low mortality rates to capture and transport suggest that dogfish are able to resist and recuperate from blood chemistry alterations (Mandelmann & Farrington, 2006; Revill *et al.*, 2005) making them an ideal species to gauge capture stress.

1.9 The aim of the project

The overall aim of this project was to broadly examine the performance of fishpots in Irish waters. In order to fully understand the impact of these methods it was important to examine the responses of fish to these methods and to determine the effects on by-catch. The following studies were undertaken in order to gain insight into this:

1. Evaluate the feasibility of fish pots as a fishing method to supplement or sustain established inshore fisheries.

   Several small trials were undertaken to determine the potential of various forms of this gear by giving fish-pots to fishers and by using their knowledge of the local fisheries. A separate trial targeting conger eel was conducted in conjunction with BIM (Bord Iascaigh Mhara; Project No. 08.SM.T1.01) through partnership with a local fisher and the use of pots from the current project alongside some newly designed pots (see Appendix II). Direct observations to determine the performance of entrances and fish retention devices or triggers were conducted in tanks as a means to choose an appropriate design. Once entrance designs had been assessed, observations were made concerning the size of the pot to ensure manageability on board smaller inshore vessels. Further studies examined finfish by-catch from a brown crab fishery over a brief period in inshore and offshore areas.

2. Investigate the physiological effects of three fishing methods on *S. canicula.*

   The response of a test species to three fishing methods was determined. Commercial crustacean pots are commonly used in Ireland and these were used in comparison studies with other established gear in field trials in order to gauge the stress response to a gear regarded as low impact. As *S. canicula* is a common bycatch species from most fishing techniques, it was used as a model species for other elasmobranchs which are in decline. *S. canicula* is an important part of demersal fish communities and the ecosystems as a whole, therefore the physiological profiles and responses to local fishing techniques were also examined.

3. Examine the response and recovery of *S. canicula* after an emersion event.

As emersion occurs in all fishing methods it is important to understand its effect on survival and physiological response in fish. A controlled experiment was carried out to determine the impact of aerial exposure (emersion) and recovery on *S. canicula.* As a common by-catch species particularly from fish pots an understanding of the resilience and recovery potential of this species is necessary to gauge the effect of this aspect of fishing. Metabolites such as lactate and glucose have been used in many studies to gain a better understanding of physiological response in fish. A suite of metabolites were measured in the lesser spotted dogfish in order to determine the impact of fishing gear, by-catch survival and commonly experienced stressors such as aerial exposure on physiological response.

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Chapter 2

Evaluation of fish pots as a feasible inshore fishing method.

2 Introduction

Although pot fisheries are established worldwide for crustacean and fish species (Agar *et al.*, 2005, Cole *et al.*, 2004; Collins, 1990; El-Etreby *et al.,* 2001; Munro, 1974; Whitelaw *et al.*, 1991) fish pots have emerged only in relatively recent research in European waters as an alternative efficient gear for finfish (Furevik, 1997: ICES, 2008). Fish pots are portable pots or traps, designed specifically to target finfish (excluding crustaceans and including eels) and characteristically have a lower CPUE (catch per unit effort) compared to other gears such as seine, trawl, gillnet, hook and line, and dredge (ICES, 2008). Numerous forms of fish pots have evolved reflecting target species behaviour, environmental conditions of the fished area and availability of local materials; ranging from eel traps, beehive traps and Caribbean traps to Atlantic cod pots (Zhou & Kruse, 2000). Metal pots are more advantageous than wooden pots as they do not corrode and degrade, are lighter out of water (handling ease), heavier in water (better anchorage), are more resistance to storm damage and move less in currents than wooden pots (El-Etreby *et al.*, 2001; Smolowitz, 1978). A comprehensive description including illustrations has been completed by von Brandt (1984) and FAO (2001).

In Europe, experimental fish pots are being extensively tested in an attempt to improve their performance, minimise unwanted impacts to ecosystems and to move towards more fuel efficient and sustainable practices (ICES, 2008). Successful trials undertaken using finfish potting in Norwegian waters (Furevik, 1997; Furevik & Lokkeborg, 1994; Furevik & Skeide, 2003; Furevik *et al.*, 2008; Nostvik & Pedersen, 1999) have examined a two chambered buoyant pot that was modified from a commercial pot (Furevik & Lokkeborg, 1994). Recent additional research has used Norwegian floating pots in several countries e.g. Faroe Islands, Norway, Sweden, France and Germany (ICES, 2008). These pots are collapsible, lightweight and can be stored on smaller vessels with ease. Furevik *et al.* (2008) altered the position of these pots in the water column to reduce and eliminate crustacean by-catch. Other designs have been tested by Seslavinsky (2005), who reported the use of pots to catch deepwater species in Russia; while Adamidou (2007) tested ellipsoidal steel weaved pots in Greek waters. Many recent studies concur that pot fisheries are a relatively selective fishing method (Cole *et al.,* 2003; Furevik, 1997; Furevik, 2008) enabling the release of live undamaged fish with minimal impact to benthic habitats (Eno *et al.*, 2001). The study group on the development of fish-pots for commercial fisheries and survey purposes (SGPOT) report a toothfish fishery which has a special quota for pots as an alternative for longlines that have caused bycatch problems as they interact with cetaceans and birds (ICES, 2008). Nostvik & Pedersen (1999) captured, tagged and released undamaged cod using pots in areas unsuitable for seines and trawls, e.g. rocky substratum, and ninety percent of tagged fish survived when fished with handline and fishtrap. Pots can however contribute to unaccounted mortality through relentless ghostfishing after gear has been lost through a succession of rebaiting and trapping of target and non-target species (Brown *et al.*, 2005; Eno *et al.*, 1996; Smolowitz, 1978).

Currently there is no direct pot fishery targeting finfish in Irish waters and the author has not found literature to date on trials with this experimental gear. Pots currently used in Irish fisheries catch and target crustaceans and molluscs and the limited amount of finfish landed in pots are usually treated as by-catch. These fisheries occupy approximately 13,250 km^2 (11%) of state waters (Fahy *et al.*, 2008). An introduction of a new gear should not, in theory, create major problems or disincentive the inshore sectors as fishers are already capable of alternating gear in different seasons. Polyvalent licences or vessels engaged in more than one fishing method, are held by approximately 1,744 vessels, switching to alternative target species, e.g. lobster to oysters and gears e.g pots to dredges, to maximise fishing opportunities (Anon, 1999a). The majority of successful finfish trap fisheries use pots that are larger than crustacean pots which are used in Ireland. Inshore boats are normally less than 15m long (Anon, 1999) which means space is a limiting factor. The size of the pot and entrance are one factor that can influence catch (Furevik, 1997; Munro, 1974), so reducing size may not be a solution to the availability of deck space. Collapsible pots would allow smaller vessels to carry larger numbers of pots safely without reducing deck space and causing interference with operations of the vessels when not in use (Munro, 1973). A disincentive to introducing finfish pots to Ireland would be initial startup expenses in order to cover any necessary modification of fishing vessels and the purchase of new gear.

The current study looked at the potential of using fish traps in inshore Irish waters to supplement or sustain existing fisheries by conducting small scale investigations. Pots used in this study included several experimental designs: an experimental rectangular trap with an 'Aqua-mesh' frame; previously manufactured by BIM (Bord Iascaigh Mhara) pots which were generously loaned to conduct the current studies and other commercially fished floating fish-pots imported from Norway. Before experimental pots could be tested an adequate entrance design was necessary. Visual observations to determine the performance of entrances and fish retention devices or triggers were conducted in tanks as a means to examine their performance and choose an appropriate design. A brown crab pot fishery was examined over a brief period in inshore and offshore areas to determine potential finfish species that tended to enter pots. Trials were conducted to examine the performance of three experimental fish traps in local waters and assess the potential of a new inshore fishery. Observations were also made concerning the size of pots to ensure the design was manageable on board for smaller inshore vessels. A separate trial targeting conger eel was conducted in conjunction BIM (Bord Iascaigh Mhara; Project No. 08.SM.T1.01) through partnership with a local fisher, using newly manufactured pots and pots from the current study.

2.1 Methodology

Pot designs tested

2.1.1 Crustacean pots

Lobster and crab pots were a D-shaped design measuring 0.6m by 0.4m by 0.8m with a soft eye entrance (*see plate 2.1, appendix I*) composed of nylon netting with an extended upper portion of the entrance that falls over the lower portion of the entrance, allowing the extra netting to cover the entrance. Entrances were placed in an offset position on the side of each pot and were approximately 22cm by 17cm. The bases of the pots were made of 10mm steel rods dipped in plastic for corrosion protection and most were bound at the base with polypropylene rope to prevent abrasion with seafloor.

2.1.2 Aqua-mesh Design (GMIT)

Aqua-mesh pots were made in two sizes using rigid mesh (4cm by 4cm) and were of rectangular in shape. The pots weighed approximately 7kg (smaller) and 10kg (larger) and measured 1.2 meters by 0.9 meters by 0.9 meters and 1.2m by 1.2m by 0.9m respectively (Plates *2.2-2.7, appendix I*). Bait boxes were fitted into the top of each pot and secured with twine and closed with a hook and cord. Bridles were attached to each corner which was then secured to a rope and buoy. Oak runners were placed on the base of each pot to give support and stability and prevent sinking into soft substrates. The entrances were modified by removing sections of mesh and attaching the new entrances at the gable end of each pot. Three sets of entrances (*Neptune triggers, hard eye, soft eye, section 2.1.7*) were used on these pots.

2.1.3 Rectangular Design (BIM)

This rectangular design (*Plate 2.8-2.9, see appendix I*) had a frame made from 10mm steel bars, covered with polypropylene twine net, with a mesh size of 4cm by 4cm. The pot measured 1.8m by 0.6m by 0.9m. Neptune triggers were replaced by a 'soft eye' entrance and a door was attached to the side and secured with a cord.

2.1 Methodology

Pot designs tested

2.1.1 Crustacean pots

Lobster and crab pots were a D-shaped design measuring 0.6m by 0.4m by 0.8m with a soft eye entrance (*see plate 2.1, appendix I*) composed of nylon netting with an extended upper portion of the entrance that falls over the lower portion of the entrance, allowing the extra netting to cover the entrance. Entrances were placed in an offset position on the side of each pot and were approximately 22cm by 17cm. The bases of the pots were made of 10mm steel rods dipped in plastic for corrosion protection and most were bound at the base with polypropylene rope to prevent abrasion with seafloor.

2.1.2 Aqua-mesh Design (GMIT)

Aqua-mesh pots were made in two sizes using rigid mesh (4cm by 4cm) and were of rectangular in shape. The pots weighed approximately 7kg (smaller) and 10kg (larger) and measured 1.2 meters by 0.9 meters by 0.9 meters and 1.2m by 1.2m by 0.9m respectively (Plates *2.2-2.7, appendix I*). Bait boxes were fitted into the top of each pot and secured with twine and closed with a hook and cord. Bridles were attached to each corner which was then secured to a rope and buoy. Oak runners were placed on the base of each pot to give support and stability and prevent sinking into soft substrates. The entrances were modified by removing sections of mesh and attaching the new entrances at the gable end of each pot. Three sets of entrances (*Neptune triggers, hard eye, soft eye, section 2.1.7*) were used on these pots.

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2.1.4 Norwegian two chambered pot design

A collapsible two-chambered pot constructed of one steel frame and two aluminum frames covered in nylon mesh. A zip was placed in both compartments allowing easy access to catch. The entrances were also made from nylon mesh measuring 26cm by 16 cm (*see plates 2.10-2.11, appendix I*) similar to a soft eye design (*see section 2.1.7*). The panel between the upper and lower compartments was designed to allow access to the upper chamber, preventing the catch returning to the lower chamber and escaping. Floats were placed on the top of the pot to lift the gear upwards and open the pot in the water column. When fully expanded these pots reach 110cm in height, 130cm long and 60cm wide. Bait bags were placed in both compartments i.e. upper and lower.

2.1.5 Shrimp pots

During the course of initial trials the by-catch of shrimp pots were also examined. These were a traditional 650mm x 360mm cylindrical pot and were covered with 3mm plastic net. An 8 inch plastic entrance was attached on the gables of the pot.

Pot entrance designs tested

2.1.6 Pot entrance designs

Hard eye entrances used metal and plastic rings acting as the inner apex of an entrance funnel. The funnel is held taut by twine attached to the netting or pot frame. The diameter of the entrance opening was 15cm and the lead into the pot measures 30cm.

Soft eye entrances were made entirely of netting, with an entrance opening 40cm by 40cm and a lead funnel into the pot measuring 55cm. The funnel is also held taut by twine attached to the netting or pot frame and the upper section is being deeper than the lower allowing a section of netting to cover the entrance. This acts a type of non return device.

Neptune trigger entrances were sourced from Neptune® marine products and are "one way" entrance devices composed of plastic interlocking fingers. The rigid fingers are placed facing inwards towards the inner chamber allowing ingress into the pot exit (*plate 2.4, see appendix I*). Triggers used in the current study measured 30cm by 10cm with 10 interlocking fingers.

2.2 *Trial methods and fishery observations*

2.2.1 Effectiveness of three entrance designs.

In order to determine appropriate entrance types to use on new experimental pots, visual observations of pots placed in fish tanks were recorded on video camera. Sessions lasted for 10 minute intervals, after which bait was replaced and new entrances were observed. Hard eye, soft eye and Neptune triggers entrances, described in section 2.1.7, were attached to smaller experimental Aqua-mesh pots and placed in a tank with cod. Thirty eight sessions were recorded observing the performance of three entrance designs and the most effective was chosen for field trials. Effectiveness in this instance was defined in terms of not acting as a disincentive for ingress and retaining fish once captured in the pot. Fish were not fed for a period of one day before the procedure to attract fish to gear once baited, which consisted of diced herring, squid, salmon and mackerel. Approaches, entries and exits of fish in relation to each entrance type were noted during the 10 minute intervals and recorded via video camera. Size was not considered in this study as these were general assessments of pot entrance performance. From these observations, broad inferences were made about the performance of each entrance, which were then used in field studies.

2.2.2 Observations of brown crab pot fishery by-catch, Malin Head, County Donegal.

Offshore

Observations were made of the by-catch species that were discarded from a brown crab fishery on the *MFV* Lady Heather Jane off the coast of North Donegal over a period of a week. On the 25th of July 2006 the first string of standard brown crab pots were hauled and fishing ended on the 30th of July 2006. Bait comprising 1kg frozen salmon and whiting was used in all pots. One hundred and sixty pots were set on each string with approximately fourteen strings hauled per day. Total number of finfish caught per day was recorded together with length and fish condition. The aim was to assess the species composition and length distribution of fish by-catch that entered pots.

Inshore

Observations were made from the 22nd of May until the 25th of May 2006 of the by-catch species that were discarded from a brown crab fishery off the coast of Malin Head, Donegal. Pots were deployed in strings of 55 pots and hauled after a twenty four hour period. Twenty-three strings were fished over a four day period. Total catch per string, fish length, weight and condition were also recorded. The aim was to assess the general species composition and length distribution of fish by-catch that entered pots in an inshore area.

2.2.3 Observations of by-catch from an inshore crustacean fishery, County Cork.

In March 2007 the Skipper of the *MFV* Susan Maria, recorded the incidental by-catch landings of finfish in crustacean pots for a period of seven months (Map 1). In June 2007 the skipper of the *MFV* Myross-CSA fished two pots, the BIM steel framed pots and Aquamesh GMIT pots (larger size) in the same area for a period of two months (Map 2). Entrances were modified from a Neptune® trigger to soft-eye entrances as a result of observations made of entrance performance in previous tank studies. These field studies aimed to provide information on the incidental by-catch that occurred in a common area from standard crustacean pots and larger experimental fish pots. Bait and soak-time were not standardized in this trial.

2.2.4 Small scale trials of larger aqua-mesh fish pots in the inshore area of Clew Bay, County Mayo.

Small scale trials commenced with larger Aqua-mesh pots on the 25th of May 2006 until the 26th of June 2006 on the *MFV* Murrisk Lass in Clew Bay, County Mayo, situated in the west coast of Ireland (53.50.03.13N, 09.47.59.10W). Sites fished are shown in Map 3. As this is the first instance of use here, target species were unknown and many methods of setting the pots were tried. The fisher targeted rocky grounds that were rarely fished by trawl as the area was not suitable for this method (Quinn *pers. comm.*). Rugged substratum of stone and weed were mainly chosen as areas where certain species tended to aggregate. Baits used were mainly dogfish, mackerel and crab (*Table 4*) and pots were fished up to 20m in depth. Pots were hauled when weather permitted but were given a 1-5 day soak period. Pots were conditioned for a 24 hour period before being deployed.

2.2.5 Small scale trials of collapsible Norwegian floating fish pots.

Field trials: Connemara, County Galway.

Prior to conducting more extensive trials these pots were set in a sheltered inshore area in order to find an efficient rigging configuration and to determine suitability for further sea trials. On Friday 29th June 2007 one of these traps was set on the eastern side of Treh Island at the mouth of Bertach Bui bay, Connemara. The other was deployed on the North-eastern side of the same island. Depth was approximately 5m-6m for both traps. The bait holder was placed in the upper compartment of the trap in one and in the lower compartment in the other. The traps were retrieved on Tuesday the 3rd of July. Crab (*Carcinus maenas*) bait was used for both soak periods. Traps were redeployed on the 3rd of July 2007 in the same areas in depths of approximately 2-3m and soaked for two days. Results for both deployments are shown in Table 2.1.

Field trials: Clew Bay, County Mayo.

Further field trials were conducted through partnership with a local fisher who agreed to trial the pots on a voluntary basis and through donation of the experimental gear from the Norwegian manufacturers (Refa Frøystad Group As. No-6095 Bølandet, Norway). All fishing was carried out on the prawn boat *MFV* Murrisk Lass (12m in length). A variety of baits used throughout the study were dependent on what fish were available at the time. The fisher rigged the pots in order to float them off the seabed, similar to methods employed by Furevik *et al.* (2008) where pots were floated at depths off the seabed to reduce crab by-catch. As this is the first instance of use here, target species were unknown and many rigging methods were trialed.

2.2.6 Commercial application of experimental fish traps in Irish inshore waters

In July 2008 a survey was conducted off County Cork; it involved targeting Conger eel (*Conger conger*) to extend a small scale investigation to a more comprehensive study. One hundred and fifty experimental pots were hauled over a consecutive ten-day period. These pots were based on an Alaskan design and were used in conjunction with BIM rectangular pots and Aquamesh pots from the current study. The soak time for these fish traps was standardised at 24 hours and the bait consisted of frozen mackerel. Conger eel were targeted as they were a non-quota species of commercial value which are not yet as overexploited as other commercial species.

2.3. Results

2.3.1 Effectiveness of three entrance designs.

Thirty eight sessions were conducted, of which 14 were with soft eye entrances. Out of the 10 fish that entered the soft eye entrances, no escapes occurred despite numerous attempts. Twelve sessions were conducted with Neptune triggers. Out of the 4 fish that entered, 3 escaped. A further twelve sessions were conducted with hard eye triggers. Only 7 fish entered through this entrance in total and there was one incidence of escape. It was noted that in all cases of ingress that bait was ignored and fish actively attempted to escape.

2.3.2 Observations of brown crab pot fishery by-catch, Malin Head, County Donegal.

Offshore trial move tables into appendix

A total of 51 fish were caught over a six day period from approximately several hundred pots. Cod (25.5%), whiting (23.5%) and white pollack (25.5%) were the majority of species caught during the seven days fishing (Table 2.1a & b). (All species of fish caught in the current study are listed in Appendix IIII of this thesis). Twelve species of by-catch caught ranged in size from pollack (14 cm) to conger eel (98cm) and the average length of fish caught was 31.4 cm (Table 2.1b). Cod, whiting and pollack were the main commercial species of by-catch. Several fish showed signs of barotraumas and other mortalities may have been due to longer soak-times, increasing the periods of stress. Some fish had injuries and skin damage caused by crustacean presence or possibly abrasion against the side of the pot.

Species	**Present in 13440 trap hauls (No)**	**Catch Per Unit Effort (No/trap haul)**
Conger eels	2	0.00015
Orange roughy	1	0.00007
Whiting	12	0.00089
Pollack	13	0.00097
Cod	13	0.00097
Four-spotted /megrim	2	0.00015
Lemon sole	2	0.00015
Dab	1	0.00007
Ling	2	0.00015
Norway Pout	1	0.00007
Scad	2	0.00015
Total		
Vertebrates (fish)	51	0.00379

Table 2.1a By-catch species and size range from fish pots from an inshore crustacean fishery, Malin head.

Inshore trial

Five different species of fish were caught in 57% of trap hauls; codling (42%), cuckoo wrasse (9.5%), rockling (19.4%), pollack (4.7%) and ling (23.8%). Twenty-one fish in total were caught from approximately 1265 pots over four days.

Lengths ranged from the smallest at 10cm (rockling) to the largest at 60cm (ling). Average length of fish was 22cm and the average weight was 266g (Table 2.2a & b). Depths fished ranged from 6.8 meters to 16.4 meters over sand, cobble, pebble & shell and kelp.

Species	**Presence in 1265 trap hauls (No)**	**Catch Per Unit Effort (No/trap haul)**
Vertebrates		
Codling	9	0.00711
Rockling	5	0.00395
Wrasse	2	0.00158
Ling	5	0.00395
Pollack	1	0.00079
Total		
Vertebrates (fish)	22	0.00001

Table 2.2a Pot bycatch from crustacean pots, County Cork.

2.3.3 Observations of by-catch from an inshore crustacean fishery using crustacean pots and experimental Aqua mesh pots, County Cork.

Seven finfish species were caught from these pots: codling, poor cod, ling, octopus, whiting, coalfish and pollack (*see table 2.3a*). Sizes ranged from 10cm (poor cod & codling) to 90cm (conger). On the 08/10/2007, 22 whiting ranging from sizes 12cm to 19cm were caught from 80 shrimp pots fished over mud. These pots also caught 4 ling ranging from 20 to 24 cm and 17 codling ranging from 10 to 17cm. Side entry crab pots caught 2 cod that ranged up to 76cm, 8 ling that ranged from 39cm to 66cm, 19 codling that ranged 25cm to 41cm, and 11 poor cod that ranged from 10 to 13cm. Rectangular BIM pots caught 3 dogfish (50-70cm) and 1 wrasse (30cm). Experimental Aqua-mesh pots caught 4 wrasse (20-30cm), 1 conger eel (80cm) and 1 dogfish.

Species	Presence over 26 days (No)	Catch Per Unit Effort (No/Day)
Vertebrates		
Conger eels	1	0.04
Dogfish	3	0.12
Codling	26	1.00
Wrasse	5	0.19
Pollack	1	0.04
Poor cod	11	0.42
Ling	12	0.46
Coalfish	2	0.08
Whiting	2	0.08
Cod	2	0.08
Invertebrates		
Edible Crab	11	0.42
Lobster	6	0.23
Octopus	1	0.04
Total		
Vertebrates (fish)	**65**	**2.50**
Invertebrates (Shellfish)	**18**	**0.69**

Table 2.3a Pot by-catch from crustacean pots, County Cork.

2.3.4 Small scale trials of larger aqua-mesh fish pots inshore area Clew Bay, County Mayo.

Forty-one fish and crustacea were caught over the period these pots were deployed, (*see table 2.4a & b*). Dogfish were the most common by-catch species caught with 21 fish caught during the study. Pollack was the only commercial fish species caught in this area. Many of the fish species were alive upon hauling of the gear even after a few days soak-time, however it was not possible to tell when the fish entered the pot and hence the actual soak period.

Species	**Presence in 14 trap hauls (No)**	**Catch Per Unit Effort (No/trap haul)**
Vertebrates		
Dogfish	21	1.50
Pollack	2	0.14
Pouting	6	0.43
Spurdog		
Invertebrates		
Edible Crab	4	0.29
Lobster	9	0.64
Total		
Vertebrates (fish)	29	2.07
Invertebrates (Shellfish)	13	0.93

Table 2.4a Catch from Aqua-mesh pots in Clew bay, County Mayo.

2.3.5 *Small scale trials of collapsible floating fish pots.*

Field trials: Connemara, County Galway.

Reports from fishers revealed that the traps were easy to handle and deploy and that they floated upright in the appropriate manner in the water. Recommendations to add a handle to the roof of the trap to facilitate hauling was suggested. The results for the first soak periods are presented in table 2.5. Trap 1 caught a total of 2 dogfish, 1 conger eel, 1 topknot, 5 pollack, 1 ballan wrasse, 1 lobster, 1 spider crab, 7 velvet crab and 1common seal, over the two soak periods. Trap 2 caught a total of 2 dogfish, 2 pollack, 2 ballan wrasse, 1 lobster, and 2 common seal, over the two soaktimes. All dogfish were alive after hauling. The 2 common seals retrieved were juveniles and dead.

Species	Presence in 4 trap hauls (No)	Catch Per Unit Effort (No/trap haul)
Vertebrates		
Conger eels	1	0.25
Dogfish	4	1.00
Wrasse	3	0.75
Pollack	7	1.75
Seal	3	0.75
Top Knot	1	0.25
Invertebrates		
Lobster	2	0.5
Spider Crab	1	0.25
Velvet Crabs	1	0.25
Total		
Vertebrates (fish)	19	1.19
Invertebrates (Shellfish)	4	1.00

Table 2.5a Catch from collapsible floating pots, Connemara, Galway.

Field trials Clew Bay, County Mayo.

One of these pots was lost due to bad weather during first deployment. Due to gear loss and gear damage while in storage before deployment, this study was discontinued in the Clew-bay area.

2.3.6 Commercial application of experimental fish traps in Irish inshore waters

In addition to the work described in the foregoing thesis the author contributed to the following report as seen in Appendix II: **"Commercial application of experimental fish traps in Irish inshore waters"**. From the one hundred and fifty traps that were hauled over the ten days survey, 7 species of fish were retrieved alive in approximately one third of traps. Conger eel were the most abundant caught in 20% of trap hauls. Spotted dogfish were present in 6% of trap hauls followed by Wrasse (2%), Pollack (0.7%) and Spurdog (0.7%).

2.4 Discussion

2.4.1 Effectiveness of three entrance designs.

The role of the entrance in the catching power of pots has been reported as important by many other studies (Munro, 1974; Zhou & Kruse, 2000). Two entrance types showed promising results retaining fish that entered. The 'Neptune triggers' were the least effective entrance at retaining fish. These entrances also deterred fish from entering when contact was made with the trigger fingers. This is contrast to Salthaug *et al.* (2002) who found that the probability of fish ingress is not decreased, when triggers are incorporated into the design. The interlocking fingers in this experiment were too flexible and permitted fish to exit the pot. The 'hard eye' entrance was effective at retaining fish, maintaining an easy route for fish ingress; there was however one incidence of escape. These entrances did not physically deter escape as a non return valve was not incorporated into the design. The 'soft eye' entrances were the most effective entrance, retaining all fish that entered during the trial. Although this was the largest entrance and fish actively attempted to escape the entrance did not physically allow fish to get out. Tank studies like these allow observations to be conducted that would not be possible in the field. However there are disadvantages as fish are not being observed in their natural environment, behaviour may be altered by captivity and densities may be lower than in the field.

2.4.2 Observations of the brown crab pot fishery by-catch, Malin Head, County Donegal.

Offshore trial.

Results from this trial suggested that pots can catch a range of commercial fish species. Although a total of 51 fish were caught over the six day period, commercial yield was not viable as this was from approximately several hundred pots. These pots are designed to target crustacea and are smaller than finfish traps used elsewhere. However, the largest fish caught was a conger eel (98cm) and the average length of fish caught was 31.4 cm, which is considerable considering the entrances are not designed for fish ingress. The main species of by-catch caught were categorised as quota commercial species. Some of these teleosts showed signs of pressure traumas and physical injury possibly due to crab and lobster attacks. Damaged fish will lose value so eliminating this in experimental finfish pots is favourable.

Inshore trial

By-catch rates were low in this trial and species caught were similar to other species examined in pots that were ghostfishing (Eno *et al.*, 1996). Ling were the largest fish retrieved and were caught over kelp in this trial (*Table 2.2*). The majority of codling caught were fished over pebble and shell. Certain fish are known to be in greater numbers on the ground at different times of year and observing discard records over a larger geographical and temporal range in pots may be beneficial to finding suitable hotspots throughout the year from which to fish. Compared to bycatch from offshore crab pots (above) there is a low range of commercial species caught in inshore pots. This should be treated with caution as both trials were not standardised and cannot be compared directly.

2.4.3 Observations of by-catch from an inshore crustacean fishery, County Cork.

These pots were shot over rock and near wrecks in an attempt to fish areas of ground that may have provided shelter for certain species and also in areas not normally trawled. Species caught in the Aqua-mesh pots were larger than in smaller crustacean pots fished in the same general area. This may have been because entrances in these pots were larger and may have allowed smaller size classes to escape (Cole *et al.,* 2001). The fishing period for this project was short; the trial was aimed to investigate the performance of these new fish-pots and their entrances. The lobster pots were suitable for retaining substantial sized fish, but due to their small size and more secluded form, large amounts of finfish catch are not likely. The larger Aquamesh pots and BIM pots may be easier to enter but the large entrances may also allow a large number of fish to escape. Small fish may leave through the floor and other fish may have found their way out of the entrance (Cole *et al*., 2003). Entrances that are too large also may result in incidences of marine mammal capture (Anon, 1997).

2.4.4 Small scale trials of larger aqua-mesh fish pots in the inshore area of Clew Bay, County Mayo.

There were very low catch rate across this study with low commercial yield. Conger eel were suspected to have entered and escaped from the pots during the soak-time and possibly consumed the fish retained (Quinn *pers comm*.). Dogfish were plentiful, which is a common by-catch species in this area in standard crustacean pots (Quinn *pers. comm*).

Clew bay is relatively sheltered but during a storm a pot was damaged and had to be brought ashore, even though these larger pots are far more durable and robust than other collapsible designs (Furevik, 1997). There was also a problem with the small size of inshore boats and lack of deck space for this gear. Deck space would have to be reconsidered on smaller vessels if regular fishing with this potting gear is to be attempted. Few of these can be hauled and stored onboard at anytime due to their size and weight. Hauling was awkward and another modified winch and platform would need to be added to existing boats if these were to be fished in the future. This type of pot needed to be anchored with large weights, which makes the use of the gear more labour intensive

Skinners or isopods were a problem for bait also which reduced the life of the fish used. To overcome problem of scavengers, Kallayill *et al.,* (2003) used small meshed bags used in Norwegian trap fisheries for cod. From discussions with local fishermen (Quinn *pers comm.*), it was reported that isopods 'skinners' are regarded as a nuisance and reduce the durability of bait in pots.

2.4.5 Small scale trials of collapsible floating fish pots.

Field trials Connemara, County Galway.

This was the first time these traps have been used in this area. A major problem with the 'Norwegian pot' design is mega-fauna by-catch. Unfortunately due to the large size of the entrances of these pots and the inshore areas in which they are set, seal capture incidences occurred. The author recommends that further trials incorporating seal deterrent devices be conducted before further trialling of this gear (Anon, 1997; Lunneryd, 2001). Seals unable to escape will settle to the base of the trap putting extra weight on the gear which may cause it to sink from its floating position. Seals will eat, injure or stress the catch in the pot which decreases the fish quality. It is not known whether other marine mammals would be susceptible to capture from this gear and without proper investigation this may be detrimental to marine mammal populations.

A major advantage with 'Norwegian pots' is the ability of fishers to eliminate or target crustacean by-catch by simply changing floating level in the water column (Furevik, 2008). If these pots target a high priced fish, crustacean exclusion would reduce damage or injury to catch ensuring a good quality product. The potential to target crustaceans if desired makes this design very adaptable. The collapsible design allows many to be stored on deck without compromising space. When deployed the floats on the roof of the pot cause the pot to expand to full size, therefore collapsibility does not compromise volume size of the pot.

Field trials Clew Bay, County Mayo.

Due to gear loss and gear damage while in storage before deployment, this study was discontinued in the Clew-bay area. Storage of this gear in a dry secure place is important as gear was damaged in this trial by rodents when stored ashore. The materials in these Norwegian floating pots were not as durable as some other metal traps.

2.4.6 Commercial application of experimental fish traps in Irish inshore waters

In this project, soft eye entrances were used instead of the Neptune trigger entrances. These fish traps used soft eye entrances which were successful in targeting conger eel and other fish species of commercial interest. The total catch that was retrieved did not however represent a viable commercial return to the fisher during this season. The authors had intended to conduct this trial in the winter or autumn months as this would have been a more suitable time for surveying when beam scallop fisheries were not in operation in the area. The most interesting modification that was used on these traps was a crustacean segregation device in the form of fitted perforated plastic pipe, which separates crustacean and fish that are retained in the pot. This may reduce the risk of damage or mortality to lobster bycatch and between individual species.

2.5 Conclusion

From the above trials conducted one could conclude that there is some potential for further trials with experimental pots in Irish waters. Comparisons with other static gear or trawls would be necessary to ensure that fish targeted are in dense aggregations or present on the ground. Information from fishers revealed that fish are caught in crustacean pots in greater numbers at certain times of the year (Power *pers comm*) which needs to be investigated further. Further trials may also benefit from the extensive collection of information from lobster and crab fishers who have experienced increased fish catch in pots and may know better areas to fish at certain times of the year.

As Catch per unit effort (CPUE) is lower than with other gears fish that are targeted either need to be highly prized such as Turbot, or alternatively fish caught from these pots need to be of the highest quality to ensure better market value. The three pot designs used in the current study had catch rates that were very low. However further trials and modifications should be carried out before concluding on the potential viability of the gear.

The initial start up cost to implement this type of fishery on a large scale may be significant, with boat alterations such as the addition of winches and platforms for hauling pots necessary on some boats. The initial purchase and transport of these pots needs to be considered due to their size. Norwegian floating pots were however inexpensive, easy to import as they were lighter and compact enough to transport. For both these pots there would be potential for gear losses which would add an extra expense in terms of replacement or recovery of gear and/or loss of future earnings by depletion of stocks through ghost-fishing. Strict management controls would be necessary to control fishing practices.

Collapsible pots were far superior in terms of manageability and safety onboard smaller vessels, and can be modified and rigged in numerous ways to target various types of fish. They are lightweight and can be carried by hand unlike the larger rectangular and Aqua-mesh fish pots. They are light enough to be carried by one person and hauled out of water without a winch. However the durability of this type of design has to be tested for longer periods. Organism growth on this floating pot or 'bio-fouling' may be an issue in the long-term; these pots need to float in the water column to be effective and so the extra weight of bio-fouling may undermine performance during soaktime. Full scale fishing trials are needed to evaluate whether floated pots could become a commercially viable method of catching whitefish.

Even when fish are not targeted and pots are built for crustaceans, by-catch of larger fish such as conger occurs. Mortalities from pot fishing also are deemed to be small with fish still alive many days after capture. Shrimp pots have also caught variable sized fish and further examination of these pots might be beneficial. It may be possible to modify existing pots e.g. make lobster pots larger and refit entrances with fish retention devices (FRDS) and triggers to reduce initial start cost as boats would already be capable of fishing these gears. Some pots have been fitted with escape panels that allow species such as lobsters to fall out of the pot when hauled. Incorporating devices to segregate fish from crustacea would be beneficial to the quality of catch.

Further trials to compare fish pot catches with gear such as gillnets may be advantageous to compare the actual catch in relation to another gear at times of year when fish are present on the ground (Cole *et al.,* 2001; Fahrig *et al*., 1998). It would also be very useful to compare by-catch rates and composition to investigate the effectiveness of devices such as escape panels and non return entrances. Concurrent studies comparing the quality of fish returned and mortality rates from pots with other gear such gillnetting would be invaluable.

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3.1 Introduction

The lesser spotted dogfish, *Scyliorhinus canicula*, although not targeted directly, makes up a sizeable proportion of the by-catch of the commercial Irish fishery (Anon, 2007; Borges *et al*., 2005). Survival studies from trawling have shown the lesser spotted dogfish *Scyliorhinus canicula* is an enduring species that have high survival rates (Mandelmann & Farrington, 2006; Revill *et al*., 2005). Trawling has reportedly enriched their food supply, as a result of their survival and the mortality of other species returned as discards and may be indicative of their stable or increasing status (Anon, 2007; Olaso *et al*., 2005). However, trawling is considered a higher impact method as catch may be confined in the cod-end for several hours, damaged by abrasion with net, crushed by other fish and subjected to hypoxia due to mucus of other fish on deck (Davis, 2002; Suuronen, 1996). As this species is then frequently exposed to such activities it is important to determine their physiological responses which may determine their long-term recovery.

Dogfish are frequently landed in crustacean pots as by-catch, discarded or used as bait for other fisheries (Fahy, 2001, Fahy, 2008; Vas, 1995). Potting is regarded as a low impact fishing method (Cole *et al*., 2003; Ridgeway *et al*., 2006) returning a higher quality product (O'Brien & Dennis, 2008) and in most cases a live return of catch. Depending on the type of pot and fishing regime there may however be stress effects e.g. confinement for periods, long soak-times, predation from other confined fish, and abrasion with gear and increased stress levels during the hauling stage (Cole *et al*., 2003; Eno *et al*., 1996).

Syliorhinus canicula, like other elasmobranches are targeted in recreational angling and a report by Vas (1995) indicated that large numbers are caught and released in this sector. The duration on the hook is usually short but there may be tearing of the mouth due to intense struggling or due to the de-hooking process. Hook size and design has been suggested as being important in minimising damage (Cooke *et al*., 2005; Meka & McCormick, 2004; Schreer *et al.,* 2005) where optimal hook sizes minimise injury and can be size selective. In addition to these fishing processes, emersion times and subsequent hypoxic conditions onboard act as cumulative stressors which may intensify the stress response.

Stress and mortality in discarded and landed fish may be imposed by several interacting stressors (Davis, 2002). For many multi species fisheries these impacts on returned catch are uncontrolled and unmeasured (Davis, 2005). As a common by-catch species from these catching methods, *Scyliorhinus canicula* is frequently exposed to stressors that result in physiological responses, muscle activity that induces the release of catecholamines (Opdyke *et al.* 1982) causing cardiovascular changes and metabolic substrates to be mobilised (Barton, 2002). Many European countries consume and export this species and it accounts for a substantial part of shark catches from bottom fishing methods (FAO, 1999). Ireland exports this meat to the European community e.g. UK, Netherlands, France and Belgium (FAO, 1999). Approximately 1029 tonnes of spotted dogfish (2.3% demersal live weight) were landed from the Irish inshore fisheries sector in 1997 valued at approximately 238,536 Irish Punts (Anon, 1999). Borges *et al.* (2005) reported that the large quantities of juvenile dogfish are discarded and even though they are reported to have good survival rates, this may still have unknown impacts on this species population dynamics.

Scyliorhinus canicula (Linnaeus, 1758) is found in abundance on all Irish coasts (Henderson & Dunne., 1998) from 10m up to 400m (Compagnu, 1989). Reproduction of *Scyliorhinus canicula* is oviparous and its typical reproductive period is in the summer months (Henderson & Dunne, 1998). Size at maturity is estimated between 50cm and 60cm in females (; Henderson, 2000; Leloup & Olivereau, 1951) and at approximately 5 to 6 years old, maturing at a younger rate than other elasmobranchs. Males mature at a younger age and smaller size than females (Ivory *et al.*, 2004). Barotraumas are not a problem for this species as they lack a swimbladder. Gorbi *et al.* (2004) indicated that this species compared to other teleosts may not be efficient in metabolising enzymes and may be susceptible to several chemical pollutants. Smaller juvenile fish may be affected more by fishing regimes due to their higher metabolic rates (Sims, 1996) and survivorship and physiological recovery change with environmental variables and size class.

Numerous biochemical markers have been utilised in aquaculture (Barnett & Pankhurst, 1998; Svobodova *et al.*, 1999) and discard trials (Davis *et al.*, 2001) in order to evaluate the response of fish to such processes. These markers can be used to examine catching and handling methods in order to determine the sustained quality and condition of fish caught (Essaiassen, 2004; Hattula *et al.* 1995) and potential survival rates of fish released (Davis *et al.*, 2001: Mandelmann & Farrington, 2006). Few methods have been used to compare the effects of different gears and the response of by-catch to emersion times (Davis *et al.* 2001; Hattula *et al.* 1995; Parker *et al.*, 2003). The monitoring of endocrinal and metabolic substrates post capture has been used as an indicator of the level of stress endured by elasmobranchs (Harms *et al.*, 2002; High *et al.*, 2007; Mandelmann & Farrington, 2006) and teleosts (Davis & Schreck, 2005; Parker *et al.*, 2003).

The aim of the study was to examine the effects of fishing methods such as potting, angling and trawling on the biochemical response in the lesser spotted dogfish over two emersion periods. Changes in plasma catecholamine, glucose, lactate, muscle pH and muscle lactate were measured.

3.2 Materials and methods

3.2.1 Materials

Adrenaline/ Noradrenaline kits were obtained from Labor Diagnostics Nordhom, Germany (BA 10-1500, 2 CAT EIA). Lactate reagent (Catalogue no. 735-10) and lactate standard solution (Catalogue no. 826-10) were obtained from Trinity biotech, Dublin, Ireland. Glucose standard (Catalogue no. G6918), glucose oxidase peroxidise reagent (Catalogue no. G3660) was purchased from Sigma Aldrich, Ireland. Vacuette® serum tubes were obtained from Cruinn diagnostics Ltd, Dublin, Ireland. All other reagents were purchased from Sigma Aldrich Ltd, Dublin, Ireland and were of analytical grade.

3.2.2 Methodology

One hundred and eighteen adult fish (>40cm) were sampled in June 2007 and August 2007 in Clew Bay, County Mayo (53.50.03.13N, 09.47.59.10W) using two commercial methods: crustacean pots, demersal otter trawls and recreational angling. Mean dogfish length ranged from 43-73cm. Clew Bay is a shallow water bay reaching 10m at its inner reaches and increasing seawards to an average depth of 20m. Tidal range is c. 5m.

Pot samples were taken in June 2007 using traps comprising a metal frame covered in mesh. A concrete weight was attached to the base and two netted or soft eye entrances were placed on both sides of the pot. A combination of baits was used such as salmon, dogfish and crab. Forty eight dogfish were sampled ranging from 54cm to 68cm from commercial crustacean pots, depths ranged from a minimum (D1) 6m to (D2) 20m, and soak-time was two days.

Rod samples were taken in June 2007 using a rod, line and hook set attached with bait. Thirty nine fish were sampled ranging from 59cm to 73cm with rod and line at depths of 5-6m. Mackerel bait was used and the time of capture on the rods was for durations less than 30 seconds. Depths were approximately (D1) 6m.

Trawl samples were taken in August 2007 from a commercial fishing vessel using a bottom otter trawl that was towed along the seabed. Trawl samples were caught at a depth of (D3) 48 to 50m on sandy ground. Ten fish were sampled from three tows lasting 30 to 40 minutes. Due to the small catch size only 10 fish were sampled on this occasion from these three tows. An additional 21 fish ranging from 43cm to 68cm were used from tows on the *rv* Celtic Voyager in February 2007 to supplement the sample size used in this study. Tow time was approximately 30-40 minutes and depth ranged between (D4) 110m and 130m.

3.2.3 *Emersion times*

Emersion times were recorded from time of landing to time of sampling. Times were defined from this initial time onboard until time of sampling and were grouped into T0 (0-5 minutes) and T1 (5-10 minutes).

3.2.4 *Sample processing*

Fish were removed from the various gear and immediately sacrificed by spiking through the brain followed by cervical dislocations. Blood samples were taken by caudal puncture via the caudal vein using 19G needles (Black *et al.*, 2000; Congleton *et al.*, 2001; Cooper & Morris, 1998). This sampling procedure has been deemed as a method that distorts the results the least (Cooper & Morris, 1998; Korcock *et al.*, 1988). For blood glucose and lactate determinations 0.5ml of blood was deproteinised by the addition of 0.5ml 6% perchloric acid in a chilled Vacuette® serum tube. These samples were stored at – 20 ° C until further analysis. A further 1ml of blood was placed in Vacuette® EDTA K2 tubes and centrifuged immediately (3000 g for 5 minutes) for catecholamine analysis. The supernatant was then removed, flash frozen in liquid nitrogen and stored at – 80 ° C. Catecholamines in plasma are suitable for storage for up to one year at – 70 ° C provided that preparation of the plasma has been undertaken within 1 hour of sampling (Boosma *et al.*, 1993).

White muscle fillets were sampled at the anterior dorsal region. pH was recorded immediately using a Mettler Toledo pH probe which was placed in the muscle cut surface (Cole *et al.*, 2003). Approximately 1g of the muscle tissue was flash frozen in liquid nitrogen and stored at -80 ºC for muscle lactate determinations. These biochemical metabolites were chosen for investigation based on their importance highlighted in Section 1.6. Fish length measurements were taken from the tail to the tip of the nose and measurements are expressed to the nearest centimetre.

3.2.5 Glucose and lactate determinations

Blood samples in perchloric acid were defrosted on ice and centrifuged at 3000g for 10 minutes to allow separation of precipitated proteins. The supernatant was neutralised with 8N KOH, centrifuged and the resulting supernatant used for glucose and lactate analysis. The concentration of plasma glucose was measured using the glucose oxidase method (Glucose kit) (Sigma, Catalogue no. G3660). Lactate determinations were performed using lactate reagent (Catalogue no. 735-10) and standard (Catalogue no. 826-10) from Trinity Biotech. Analysis was in duplicate and measurements were made on a Multiskan UV Spectrophotometer at 540nm.

Muscle samples were taken from the same individuals used for blood samples. One gram of white muscle was homogenised on ice with 5ml of 0.6M of perchloric acid. Homogenates were centrifuged at 3000g for 10 minutes to remove undisrupted tissue and precipitated protein. A 2 ml sample of supernatant was immediately neutralised with 8 N KOH. Samples were aliquoted and stored (–70 °C) until required for lactate determinations as described previously.

3.2.6 Catecholamines

Determination of adrenaline and noradrenaline (Manz *et al.,* 1990) in dogfish plasma was performed using Labnor Diagnostic kits. Samples were extracted using a cis-diolspecific affinity gel, then acylated to N-acyladrenaline and N-acylnoradrenaline which is converted enzymatically to N-acylmetanephrine and n-acylnormetanephrine respectively. The amount of antibody bound to the solid phase catecholamine is inversely proportional to the catecholamine concentration of the sample. Measurements are made on a Multiskan uv spectrophotometer at 450nm.

3.2.7 Statistical analyses

Statistical analysis was performed using Minitab® version 15. All data were checked for normality using the Anderson-Darling test for normality with $p<0.05$. All data were checked for equal variances using Levenes test of equal variance. Based on these results analysis of variance (ANOVA) was then performed on normally distributed or transformed data to evaluate variations in metabolic and enzymatic activities at different emersion times. Separate analyses were conducted for each of the three survey gears to determine if there was an effect for depth. A tukey's test was used to separate significant mean difference at a significance level of $p < 0.05$ level. Berferroni corrections were applied when multiple comparisons using Anova were conducted.

The effect of emersion times between gears were further investigated with the use of separate one way analysis of variance to see if there was a direct influence of the fishing on each variable. All tests for significance were at the $p < 0.05$ level.

3.3 Results

3.3.1 Responses due to depth and fishing method

Before a comparison of the three fishing methods was made, variables within each fishing group were examined independently to eliminate confounding influences. All samples for rod and line were caught at approximately the same depth so analysis of emersion times and depth was not performed.

Two depths (6m and 20m) were compared at two emersion times for pot samples before all responses could be pooled. Plasma glucose concentrations were significantly lower at 6m (40.61mg/dl) ($p<0.05$) than at 20m (99.11mg/dl) at the shorter emersion times T0 (0-5 minutes), see figure 3.1. No significant difference occurred in variables due to the potting method at emersion time T1 (5- 10 minutes) as a result of depth.

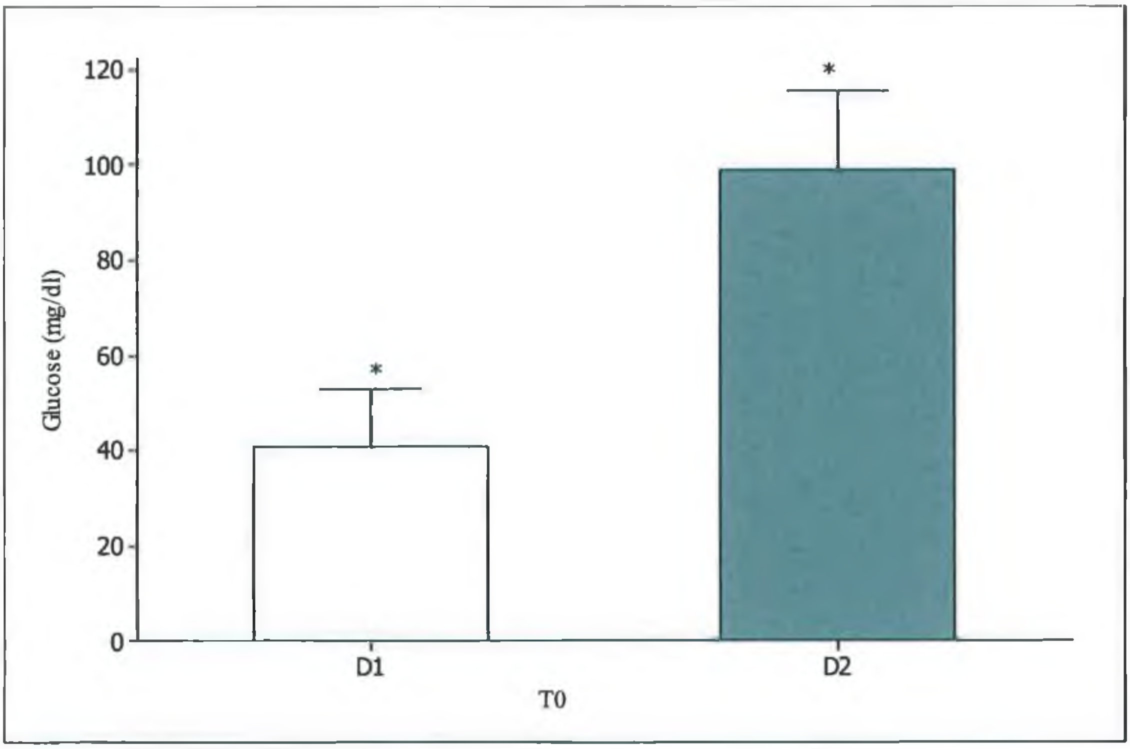

Figure 3.1 Concentrations of plasma glucose (mg/dl) for the potting method at depth D1(6m) and D2 (20m) at emersion time T0 (0-5mins). The bars and error bars denote means and standard error of the means (n=12). Significant differences ($p>0.05$) between treatments are indicated by asterisks (*).

As no significant differences were observed for the trawl method at the shorter emersion times (T0) influenced by two depths, these measured variables were pooled for further examination. A significant difference ($p<0.05$) was observed in white muscle lactate concentrations following the trawl method at D3 (57.9 mg/dl) and D4 (27.9 mg/dl) at the shorter emersion time, see figure 3.2. Responses that showed a significant difference due to depth were pooled for further examination, but should be treated with caution.

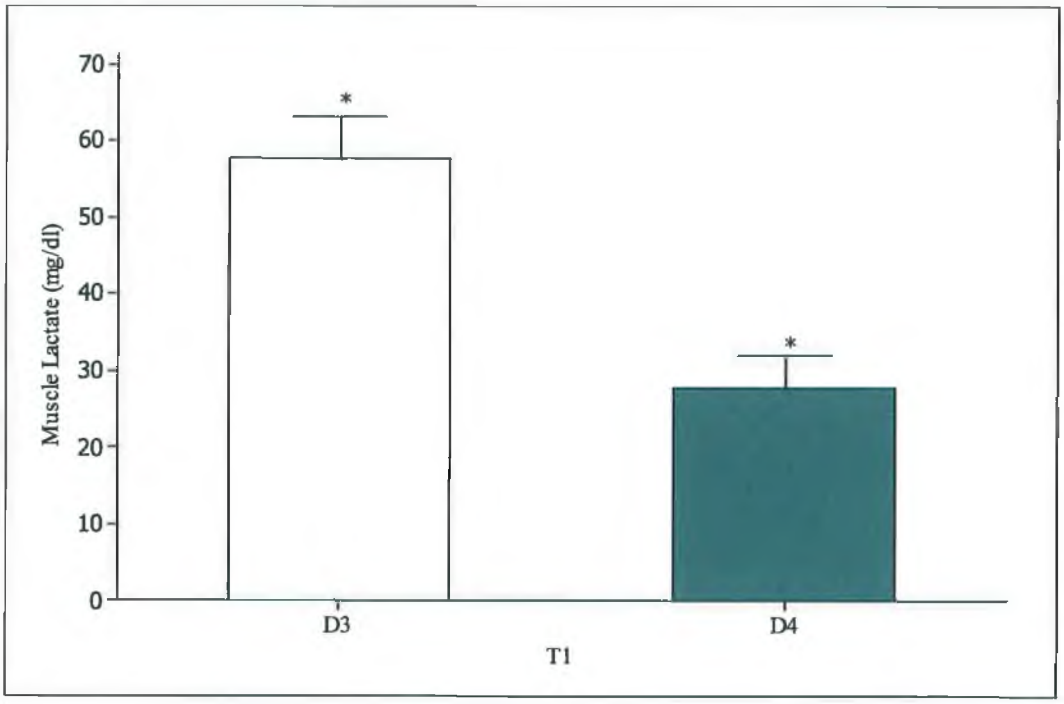

Figure 3.2 Concentrations of muscle lactate (mg/dl) at depth D3 (50m) and D4 (110m) at emersion times T1 (5-10mins) for the trawl method. The bars and error bars denote means and standard error of the means (n=4). Significant differences ($p<0.05$) between treatments are indicated by asterisks (*). No significant differences ($p>0.05$) between emersion treatments were observed.

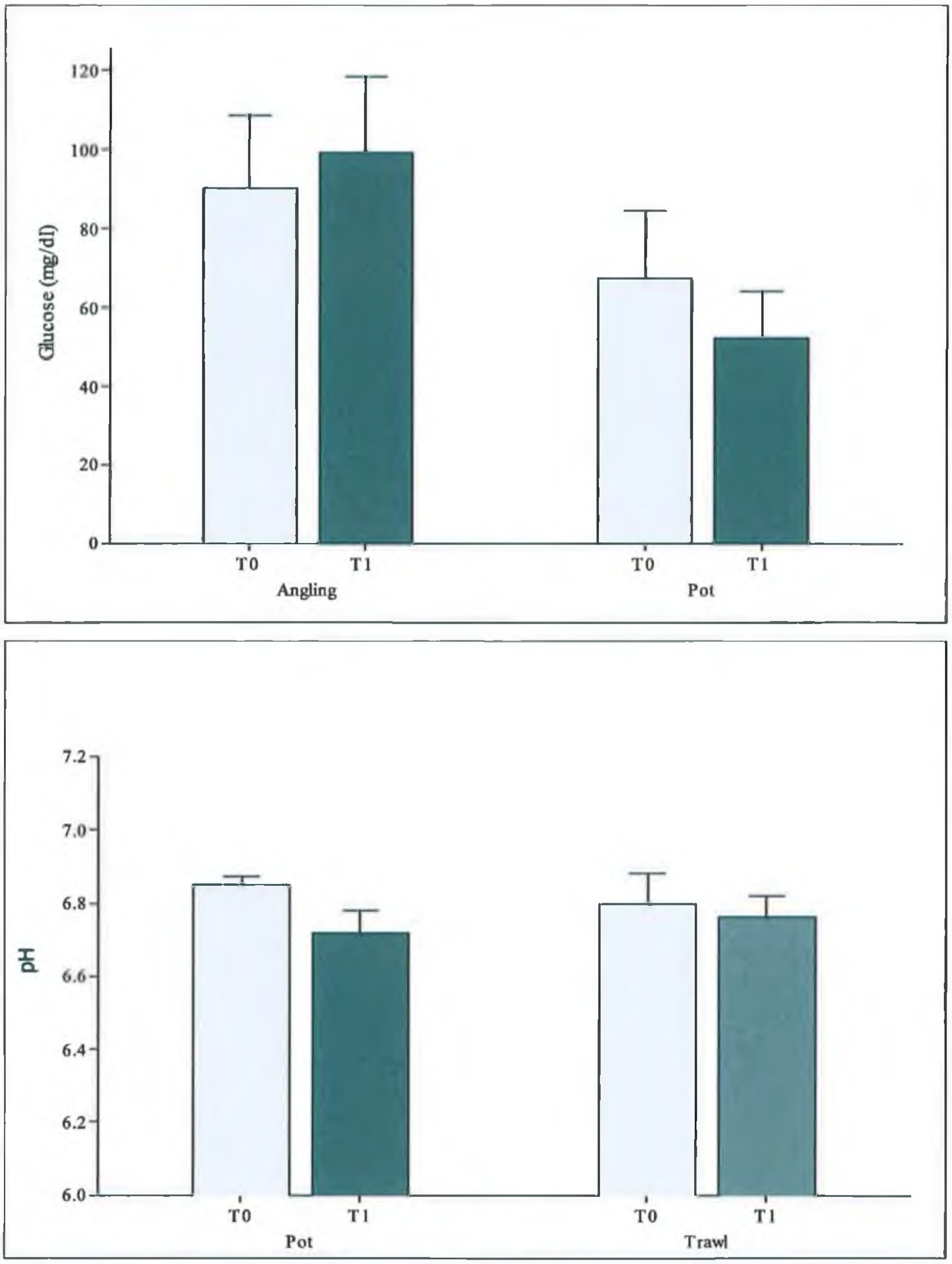

Fig. 3.3 Effect of emersion on concentrations of plasma glucose and pH for fish sampled by angling n=12, pot n=6 &Trawl n=8. The bars and error bars denote means and standard error of the means (n=4). Significant differences ($p<0.05$) between treatments are indicated by asterisks (*). No significant differences ($p>0.05$) between emersion treatments were observed.

3.3.2 Responses due to emersion times.

Physiological responses i.e. glucose, muscle and plasma lactate, muscle pH and plasma adrenaline, were unaffected significantly for the pot method by the two emersion times examined i.e. T0 & T1.

No significant differences occurred for the trawl method between the two emersion times examined for white muscle pH, white muscle lactate and blood lactate. There was however a significant difference ($p<0.05$) in plasma adrenaline due to longer emersion times for the trawl method T0 (3.9ng/ml) and T1 (10.2ng/ml), see figure 3.4.

While there was a difference in physiological variables from T0 to T1 for the angling method, it was not a significantly different response.

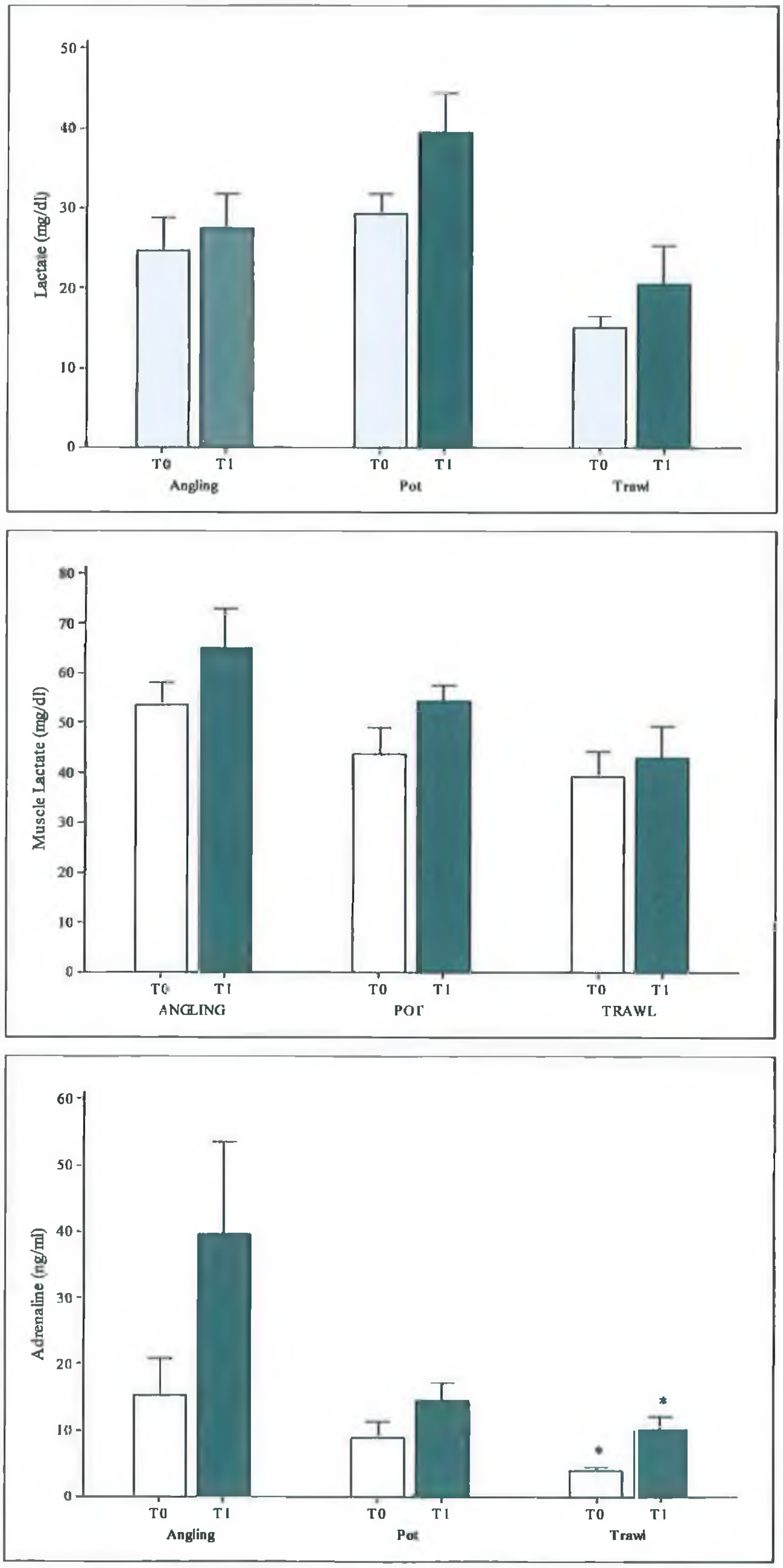

Fig. 3.4 Effect of emersion on concentrations of plasma lactate, plasma adrenaline and white muscle lactate for fish sampled by angling n=12, pot n=6 &trawl n=8. The bars and error bars denote means and standard error of the means (n=4). Significant differences ($p<0.05$) between emersion times are indicated by asterisks (*). No significant differences ($p>0.05$) between emersion treatments were observed.

3.3.3 Comparison between the three catching methods and emersion times.

Significant differences were determined ($p<0.05$) between the 3 catching methods at shorter emersion times and then at longer emersion times. For emersion time T0, four stress variables were analysed. Plasma lactate concentrations were significantly lower for the trawl method than angling and pot results ($p=0.001$), see figure 3.5. The results also demonstrated that levels of adrenaline are significantly lower ($p=0.014$) for angling than levels of adrenaline for the pot method at shorter emersion times, see figure 3.5.

The results demonstrated that at longer emersion times (T1) no significant differences in concentrations of plasma lactate and plasma adrenaline between the three fishing methods were observed. For angling, adrenaline levels increased from 3.31ng/ml to 52.9ng/ml, trawling from 3.9ng/ml to 9.7ng/ml and potting from 12.6 to 14.4ng/ml. Lactate responses demonstrated different trends with angling decreasing from 27.5 mg/dl to 24.9 mg/dl, trawling increasing from 15.13mg/dl to 25.2mg/dl and potting increasing from 30.2 to 39.5 mg/dl.

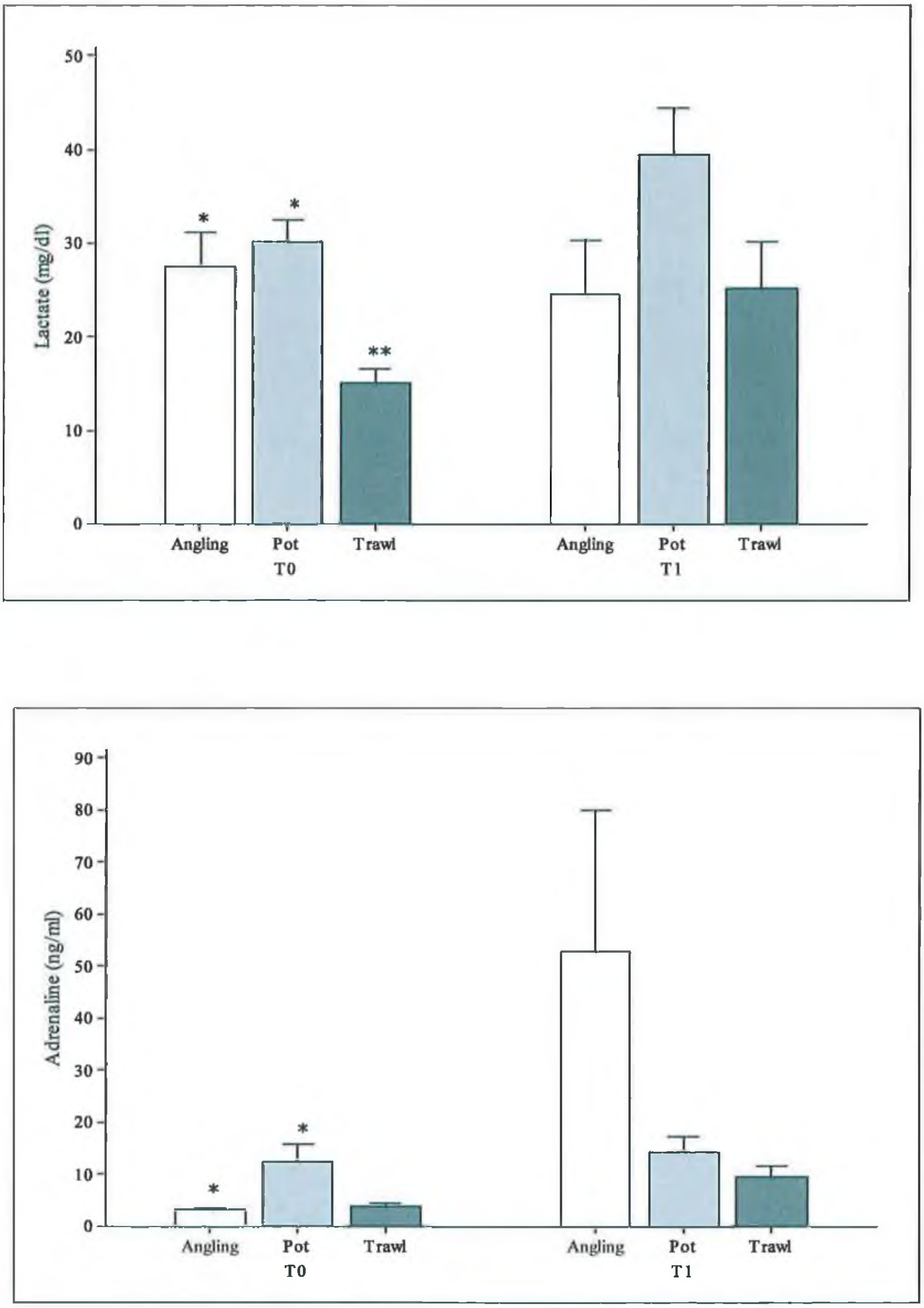

Fig. 3.5 Effect of emersion (T0 n=8, T1 n=6) and the catching method on concentrations of plasma lactate and plasma adrenaline for fish sampled by angling n=12, pot n=6 &trawl n=8. The bars and error bars denote means and standard error of the means (n=4). Significant differences ($p<0.05$) between treatments are indicated by asterisks (*). No significant differences ($p>0.05$) between emersion treatments were observed.

3.4 Discussion

Various gears are regarded differently in terms of perceived impact on fish quality and mortality rates (Davis, 2002). Ridgeway *et al.* (2006) reported that prawns caught in creel pots showed less stress compared to prawns from trawls. Potting has a reputation of being a low impact method returning a high quality product of finfish (Cole *et al.*, 2003; O'Brien & Dennis, 2008). In this study the trawl method demonstrated physiological responses significantly lower than potting and angling, at the shorter emersion times. Adrenaline results for angling were significantly lower than for the potting method but not significantly different to the trawl method at shorter emersion times. This may be due to the longer nature of the soak (up to two days) compared to angling as fish may have already experienced a rise in adrenaline in circulation which was cleared from the bloodstream due to a longer response time. Adrenaline is known to peak at the onset of the 'flight or fight' response (Barton, 2002). As potting is a passive technique, the hauling stage of this method has been reported to cause stress (Cole *et al.,* 2003). The response of the fish, demonstrated by the higher concentrations of adrenaline, may have primarily occurred during the hauling process just before landing. When adrenaline is measured at the longer emersion times all methods show an increased stress response. Angling seems to show a delayed response at the shorter emersion with adrenaline peaking intensely at the longer emersion period. Trawling adrenaline levels may have peaked previously during the tow which lasts up to 30 minutes, where adrenaline levels start to accumulate again due to a secondary stress response to emersion.

Most of the literature would deem trawling to be the most exhaustive and detrimental catching method. However, Ridgway *et al.* (2006) found that longer trawl soak-times do not result in an increase in lactate in prawns due to movement restrictions as a result of confinement in the net of the trawl. They also reported that emersion times may be more important than the trawling process. The weight of the total catch from the current study was not measured so it is hard to say whether the fish were restricted for the thirty minutes.

Plasma lactate was significantly lower for the trawl method compared to angling and potting. As has been mentioned previously, restriction in the trawl net may have prevented struggling and the subsequent onset of oxygen debt. This contrasts to angling which frequently involves prolonged struggling. A common trend in the three catching methods is a larger concentration of lactate in white muscle than in circulation. Lactate that accumulated in the muscle of fish sampled at shallower depths was significantly higher than at deeper depths for trawl samples. Lactic acid in the muscle of trawled fish in a study by Hattula *et al.* (1995) ranged from 85 to 211 mg/dl for trawls that lasted 2 hours to 5 hours. Mortality rates in the same study were lower with reduced tow times. Tow times in the current study were much lower lasting only 40 minutes, which is also represented by lower lactate levels. High concentrations of post exercise plasma lactate have been reported for teleosts (Lowe *et al.*, 1993) and some elasmobranchs (Hoffmayer & Parsons, 2001; Richards *et al.* 2003) where high levels may persist for hours to compensate for the oxygen debt until recovery. Wells & Baldwin (2006) found high lactate concentrations in circulation in Silver Trevally defining this species as 'releasers' which has been indicative of highly active swimmers. Gutierrez *et al.* (1988) characterises *Scyliorhinus canicula* as a low active species, staying close to the benthos and prey, therefore exhibiting lower circulating glucose that may retain higher levels of lactate in muscle for *in situ* glycogenesis (Wells & Baldwin, 2006). In this study, muscle lactate was retained in higher levels than was in circulation for all methods and emersion times, which indicates that this species is not a 'releaser' and supports the study of Wells & Baldwin (2006). However, it is known that lactate may take several hours to peak in the circulatory system and our study only measured emersion responses up to 10 minutes post capture, this may not have been long enough to gain the full profile response for this species. In another study by Richards *et al.* (2003) baseline levels of blood lactate for spiny dogfish were 19.8 mg/dl at rest and 73.3mg/dl after exhaustive exercise. They further reported that stress responses continued to rise to approximately 156mg/dl four hours post stress.

A substantial difference was evident in white muscle lactate following the trawl method when two depths were compared at the longer emersion time. *In situ* muscle lactate was significantly higher at the shallower depth than at the deeper depths for the trawl method. The reason for this may be that the shallower depth samples were taken in the summer months and that the deeper depths were sampled in spring. Gutierrez *et al.* (1986) found in this same species that plasma lactate levels were highest when sampled in July and that seasonal variations in metabolites occur and muscle lactate results should be treated cautiously. Adrenaline levels for the trawl method were significantly higher at the longer emersion time and this may indicate adrenaline had already peaked before the longer emersion time and the other metabolites were accumulating but had not peaked in the fish samples. These results when compared to other studies (Opdyke *et al.*, 1982) are close to presumed resting levels for elasmobranchs.

A significant difference in glycaemic (blood glucose) response occurred when pots were fished at two depths and at shorter emersion times. The hyperglycaemic response at the deeper depth may be indicative of a longer response time. When these two depths in the current study were compared at longer emersion times they returned glycaemic responses that were not significantly different from each but lower than the shorter emersion responses. The extra emersed time may have been substantial enough for the glucose levels to reach a plateau or to be used up during this high energy period and for anaerobic metabolism to commence. In a study by Torres *et al.* (1986) confinement evoked a stress response in *Scyliorhinus canicula* that resulted in a significant increase in glucose concentrations but at values of 10.74mg/dl, lower than the current study. Dogfish are suggested to have a depressed metabolism only feeding every two weeks and this has been suggested to be responsible for hyperglycaemia in this species directly after feeding (Sims *et al.*, 1996). Hoffymayer & Parsons (2001) found levels much higher of glucose which was suggested to be a result of recently ingested food. As pots use bait to entice catch, feeding could be a further explanation for high glucose levels. Walsh *et al.* (2006) found that after an initial increase glucose levels in spiny dogfish decreased several hours after feeding and remained relatively stable after that. Interpretation of this data is confounded by the fact that no absolute measure of time spent in the pot or when the bait is consumed is available.

As angling has a short soak-time i.e. only a matter of seconds on the line but an intense struggle which may become hyperactive, perhaps the stress of the landing process overrides the intensity of the exposure to air. There was no significant difference between the two emersion times but perhaps longer emersion times might have shown an increase in physiological responses. This however is in contrast to other studies, Parker *et al.* (2003) report that lingcod have improved survival rates if sorted on deck quickly and discarded upon capture. A survival rate of more than half of the fish caught occurred even after 30 minutes on deck regardless of tow times. A more recent study on Brook Trout has identified that longer air exposure time post capture result in higher stress responses. This species has a threshold of 60 seconds where fish can compensate for oxygen debt, but at 120 seconds of emersion fish are vulnerable to swimming performance impairment (Schreer *et al.*, 2005). There was a decrease in plasma lactate from the shorter to longer emersion time, which may have resulted from the intense need for energy while fish were struggling on the line. Lactate seems to be clearing from the blood for this method and is linked to catecholamine release to initiate the flight response. This catalysed glucose circulation in the blood which leads to an anaerobic switch and the release of muscle lactate to circulation. High levels of lactate in the blood are an indicator of an onset of anaerobic respiration. This may be in response to hypoxia and strenuous activity, often associated with acute stress responses. Lactate is retained in white muscle for *in situ* glycogenesis this may be due to the aggressive struggling on the line once captured. By contrast, muscle lactate and pH showed no significant difference in chemistry response for the three methods at the shorter emersion time. At the longer emersion periods adrenaline and muscle lactate showed no significant differences between the three methods.

Length data was not directly analysed in this study as only adult fish were used. However we can deduce from the lengths of fish caught that potting and angling have the potential to catch large sized species (Ziegler *et al.*, 2002; Cooke *et al.*, 2005). Parks (1973) found that specifically designed fish traps caught larger fish than trawl in the same trial. Trawling is deemed to be less size selective and tends to return a higher rate of smaller unwanted discards. The trawling sample size however was the smaller of the three and due to cost constraints a larger size was not used, therefore results here can only indicate that potting and angling have the potential to catch equal length fish.

The body size of *Scyliorhinus canicula* effects oxygen consumption (Sims, 1996); therefore larger sized fish may react better to emersion and have a better survival rate. As angling and potting tend to return larger sized fish and fewer undersized fish, these capture methods may be beneficial to populations as less pressure is imposed on the immature part of the population and larger fish would be affected less by the fishing process. As this species matures earlier than other elasmobranchs the capture of smaller fish may not be as much of a problem. In commercial trawlers, however, this species survival-rate was independent of the fish length or sex (Rodriquez-Cabello *et al.,* 2005).

3.5 Conclusion

Pinpointing an emersion threshold time for discard species may be important for survival post capture by minimising disturbance to homeostasis. In this study the physiological profile of *Scyliorhinus canicula* has been shown to be disturbed by depth and the capture method, air exposure times do not seem to be a determining factor on physiological biomarker alterations. However, further examination of emersion times for longer periods than the current study may determine other results.

Ideally larger sample sizes should be analysed but due to logistical reasons this was not possible in this study. Also, the fundamental process of each method was difficult to standardise. The three methods undertaken in this study aimed to compare a realistic approach to fishing rather than an idealised approach. The use of biochemical markers to determine stress effectively were analysed in order to build a more complete profile of fish physiological changes. This study used a range of such biochemical markers to determine the impact of three fishing methods on the status of this by-catch and its potential for recovery. However, while the current study gave a clearer profile of fish physiology further studies examining mortality, flesh quality and increased emersion times need to be considered. Further studies would aim to standardise the fishing methods to an extent where depth area and time of year would be comparable.

The resilience of this species makes it the ideal indicator of the impact of gear on the stress response of catch whether discarded or retained. As survival rates are high compared to teleosts especially when retained out of its aquatic environment for periods of time, modifications to gears to reduce stress imposed on fish and comparisons can be made deducing long-term recovery rates. Comparisons between same type gears and modifications of these gears may be more appropriate as standardising would be more achievable.

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Chapter 4

The physiological response and recovery of a bycatch species, lesser spotted dogfish (*Scyliorhinus canicula*), after an emersion event.

4.1 Introduction

Emersion represents a critical stage of stress in fishing activities and has raised considerable interest in commercial fishing (Ridgeway *et al*, 2006), aquaculture (Aceretea *et al*., 2004; Bagni *et al*., 2007; Bosworth *et al*., 2007) and recreational fishing (Suski *et al.,* 2004), in economic (Gollock *et al*., 2004) and fish survival terms (Davis & Schreck, 2005). Fish respond to stress in a relative manner that reflects the severity and duration of the stressor (Barton, 1991). Regardless of the severity of stress, the active response is considered to be mainly associated with activation of the adrenal medulla and the sympathetic nervous system. According to Wright *et al.* (1973) gills play a central role in the physiological condition of *Scyliorhinus canicula.* In addition to being the site of aquatic gas exchange, gills have a role in osmotic and ionic regulation, acid regulation and excretion (Evan *et al.,* 2005). Changes in environmental or blood gas tensions as a result of emersion elicit a suite of respiratory and cardiovascular responses. The primary stress reaction is represented by a rapid release of catecholamine into circulation in response to lowered pH (Iwama *et al.,* 1999). This subsequently activates the secondary responses, metabolic pathways resulting in blood chemistry alterations increase plasma glucose and may lead to hyperglycemia. In addition, the gill surface area is increased to increase oxygen absorption (Evans *et al.,* 2005).

The lesser spotted dogfish (*Scyliorhinus canicula*) (Linnaeus, 1758) forms a large part of total by-catch of the Irish Demersal fishery (Anon, 2007, Borges *et al.,* 2005). They are hooked frequently in recreational angling and are also caught in pot fisheries (Eno *et al.,* 1999) with fishers using these fish as bait for other fisheries e.g. crustacean pot fisheries (Fahy, 2002). Unspecified amounts which are poorly documented in landings are retained for use as bait in the Irish Sea and Bristol Channel whelk fishery (Anon, 2009). This makes the commercial value of such landings difficult to determine. They are frequently subjected to periods of emersion as the majority of landings are discarded after sorting (Revill *et al.,* 2001). Its role in the demersal fish communities has been reported by Olaso *et al.* (1998) as important, with other studies indicating that this species may be susceptible to chemical pollutants (Gorbi *et al*., 2004).

The aim of this study was to profile the physiological responses of this species to emersion stress independent of the fishing method, and to gain an insight into the impact exposure can alter on their physiological profile at the time of the stress event and following their return to an aquatic environment.

4.2 Materials and methods

4.2.1 Materials

Adrenaline/ Noradrenaline kits were obtained from Labor Diagnostics Nordhom, Germany (BA 10-1500, 2 CAT EIA). Lactate reagent (Catalogue no. 735-10) and lactate standard solution (Catalogue no. 826-10) were obtained from Trinity biotech, Dublin, Ireland. Glucose standard (Catalogue no. G6918), glucose oxidase peroxidise reagent (Catalogue no. G3660) was purchased from Sigma Aldrich, Ireland. Vacuette® serum tubes were obtained from Cruinn diagnostics Ltd, Dublin, Ireland. All other reagents were purchased from Sigma Aldrich Ltd, Dublin, Ireland and were of analytical grade.

4.2.2 Animal collection and aquarium acclimation

Sixty nine adult fish (>20cm) were collected from pots in Clew Bay, County Mayo (53.50.03.13N, 09.47.59.10W) at depths not exceeding 20 meters. Mean dogfish length ranged from 53-73cm and weight ranged from 430-1023g. Animals were transported for 90 minutes in aerated tanks containing seawater to an aquarium. Fish were placed in 3 tanks with approximately 1780 litres of seawater (14 fish per tank) at a density of < $6kg/m^3$ (Barnett & Pankhurst, 1998; Skjervold *et al.*, 1999; Trenzado *et al.*, 2006; Veiseth *et al.*, 2006;). Fish were randomly allocated to the tanks without consideration of sex or size class. Fish were acclimated for 14 days prior to the start of the experiment in a controlled environment (13 ± 0.5 ° C, 12hr light/dark cycle) and fed every second day with a mix of sprat and squid. Water ammonia levels were recorded and were below 0.1ng/litre, air temperature was maintained at 16 ± 1 ° C throughout the experiment. Fish were not fed 48 hours prior to the start of the experiment (Walsh *et al.*, 2006).

4.2.3 *Aerial exposure and recovery*

Prior to the start of the experiment 6 fish (n=6) were randomly removed from the 3 tanks to determine presumed physiological baseline levels (hereafter referred to as "T0"). Blood and tissue sampling procedures are described below. Six groups of fish (n=6) were removed from the holding tanks using a dip-net and three of these groups were exposed to air for 15 minutes and three groups were exposed for 40 minutes. Following this treatment two groups of fish (n=6) were sacrificed and blood and tissue samples were immediately taken (hereafter referred to as "E15 and E40"). Twenty four remaining fish were returned to the tank and allowed to recover for 4 hours and 8 hours (hereafter referred to as "R4 and R8"). Following 4 and 8 hour recovery, 4 groups of fish (n=6 per group) were sacrificed and blood and muscle samples were taken.

4.2.4 Sample processing

Fish were removed as gently as possible with a handheld net and immediately spiked through the brain, followed by cervical dislocations. Blood samples were taken by caudal puncture via the caudal vein using 19G needles (Black *et al*., 2000; Congleton *et al.,* 2001; Cooper & Morris, 1998). Studies examining this procedure have deemed it a method that minimises additional stress on physiological responses and fulfils animal handling recommendations (Cooper & Morris, 1998; Korcock *et al*., 1988). For blood glucose and lactate determinations 0.5ml of blood was deproteinised by the addition of 0.5ml 6% perchloric acid in a chilled Vacuette® serum tube. These samples were stored at – 20 ° C for further analysisA further 1ml of blood was placed in Vacuette® EDTA K2 tubes and centrifuged immediately (3000 g for 5 minutes) for catecholamine analysis. The supernatant was then removed, flash frozen in liquid nitrogen and stored at – 80 ° C. Catecholamines in plasma are suitable for storage for up to one year at – 70 ° C provided that preparation of the plasma has been undertaken within 1 hour of sampling (Boosma *et al*., 1993). A further 0.5ml of blood was stored in on ice for immediate blood ammonia determinations. Fish length measurements were taken from the tail to the tip of the nose and measurements are expressed to the nearest centimetre.

4.2.5 Plasma Glucose and lactate determinations

Blood samples in perchloric acid were defrosted on ice and centrifuged at 3000g for 10 minutes to separate precipitated proteins. The supernatant was neutralised with 7μl potassium bicarbonate, centrifuged and the resulting supernatant used for glucose and lactate analysis. The concentration of plasma glucose was measured using the glucose oxidase method (Sigma, Catalogue no. G3660). Lactate determinations were performed using lactate reagent (Catalogue no. 735-10) from Trinity Biotech. Both glucose and lactate concentrations were determined using known concentrations of standard. Analysis was performed in duplicate using a Multiskan spectrophotometer at 540nm.

4.2.6 White muscle pH and lactate determinations

White muscle fillets were sampled at the anterior dorsal region. pH was recorded immediately using a Mettler Toledo pH probe, placed in the muscle cut surface (Cole *et al.*, 2003). Approximately 1g of the muscle tissue was flash frozen in liquid nitrogen and stored at -80 ° C for muscle lactate determinations. One gram of white muscle was homogenised on ice with 5ml of 0.6M of perchloric acid. Homogenates were centrifuged at 3000g for 10 minutes to remove undisrupted tissue and precipitated protein. A 2ml sample of supernatant was immediately neutralised with 8N KOH. Samples were aliquoted and stored (–70 °C) until required for lactate determinations. Muscle lactate analysis was performed as per blood lactate measurements.

4.2.7 Blood ammonia

Blood samples stored on ice were analysed immediately for ammonia concentration using indophenol blue (Grasshoff & Johannsen, 1972). Twenty micro litres of blood was added to 380μl of deionised water followed by the addition of 200μl of 12N Sulphuric acid. After incubation for one hour at room temperature samples were analysed at 640nm using a Multiskan spectrophotometer (Thermolab Systems, Helsinki), results were expressed as mg/L.

4.2.8 Plasma Adrenaline

Determination of adrenaline and noradrenaline (Manz *et al.,* 1990) in dogfish plasma was performed using Labnor Diagnostic kits. Samples were extracted using a cis-diolspecific affinity gel, then acylated to N-acyladrenaline and N-acylnoradrenaline which are converted enzymatically to N-acylmetanephrine and n-acylnormetanephrine respectively. The amount of antibody bound to the solid phase catecholamine is inversely proportional to the catecholamine concentration of the sample. Measurements are made on a Multiskan spectrophotometer at 450nm.

4.2.9 Statistical analysis

Statistical analyses were performed using Minitab® software version 15. Data were checked for normality using an Anderson-Darling test for normality ($p<0.05$) and data were checked for equal variance using Levenes test for equal variances. Non-normally distributed data was transformed using a Johnson Transformation. Non-parametric data was analysed using the Kruskal Wallis test and followed by pair-wise analysis using a Mann-Whitney testA one way analysis of variance (ANOVA) and Tukey's post hoc tests were conducted on all normally distributed data to determine significant effects of emersion and recovery times. A $p<0.05$ value was considered significant in all analyses.

4.3. Results

4.3.1 Plasma Glucose

A one way ANOVA showed that there was a significant difference between the control and treatment groups ($p<0.05$). There was a significant difference between the emersion and recovery points for both treatment groups ($p<0.05$). Tukeys pair-wise analysis showed that there was a significant difference between T0 (28.03 mg/dl) and all points except the 15 minute emersion point (38.20 mg/dl), which differed significantly from the R4 and R5 period. The 40 minute emersion group significantly differed with the R4 group but not the R8 group. Glucose concentrations for E40 are significantly higher than T0, but for E15 concentrations are not significantly different, see fig 4.1. For both recovery points (R4 and R8) all concentrations for glucose remain significantly higher than T0. For this metabolite in this instance when exposed to air for 40 minutes or less, total recovery needs a period longer than 8 hours. There was no significant difference between the emersion treatments at 15 minutes and 40 minutes.

4.3.2 Plasma Lactate

There was a delay in peak concentrations at the treatment stage until the 4 hour recovery stage for both treatment groups. Plasma lactate concentrations for the 15 minute treatment did not peak as intensely as the emersion treatment for 40 minutes and remained relatively constant, even though all concentrations differed significantly from baseline concentrations ($p<0.05$), see fig 4.1. Median values for E15 were lower (58.11 mg/dl) compared with the E40 emersion group (71.5 mg/dl), but not significantly ($p=0.066$). Concentrations of plasma lactate at E15 were significantly different from R4 (94.8mg/dl) ($p=0.02$), but were not significantly different for R8 (89.14mg/dl) ($p=0.09$). Median values for E40 were significantly different for R4 at 204.46 mg/dl ($p=0.005$) but not significantly different for R8 at 155.9mg/dl ($p=0.09$). Recovery groups at the 8 hour point were not significantly different from each other ($p=0.298$). However the 15 minute treatment group had lower concentrations at 89.1mg/dl compared to 155.9 mg/dl. There was a significant difference between the recovery groups at four hours recovery ($p=0.005$)

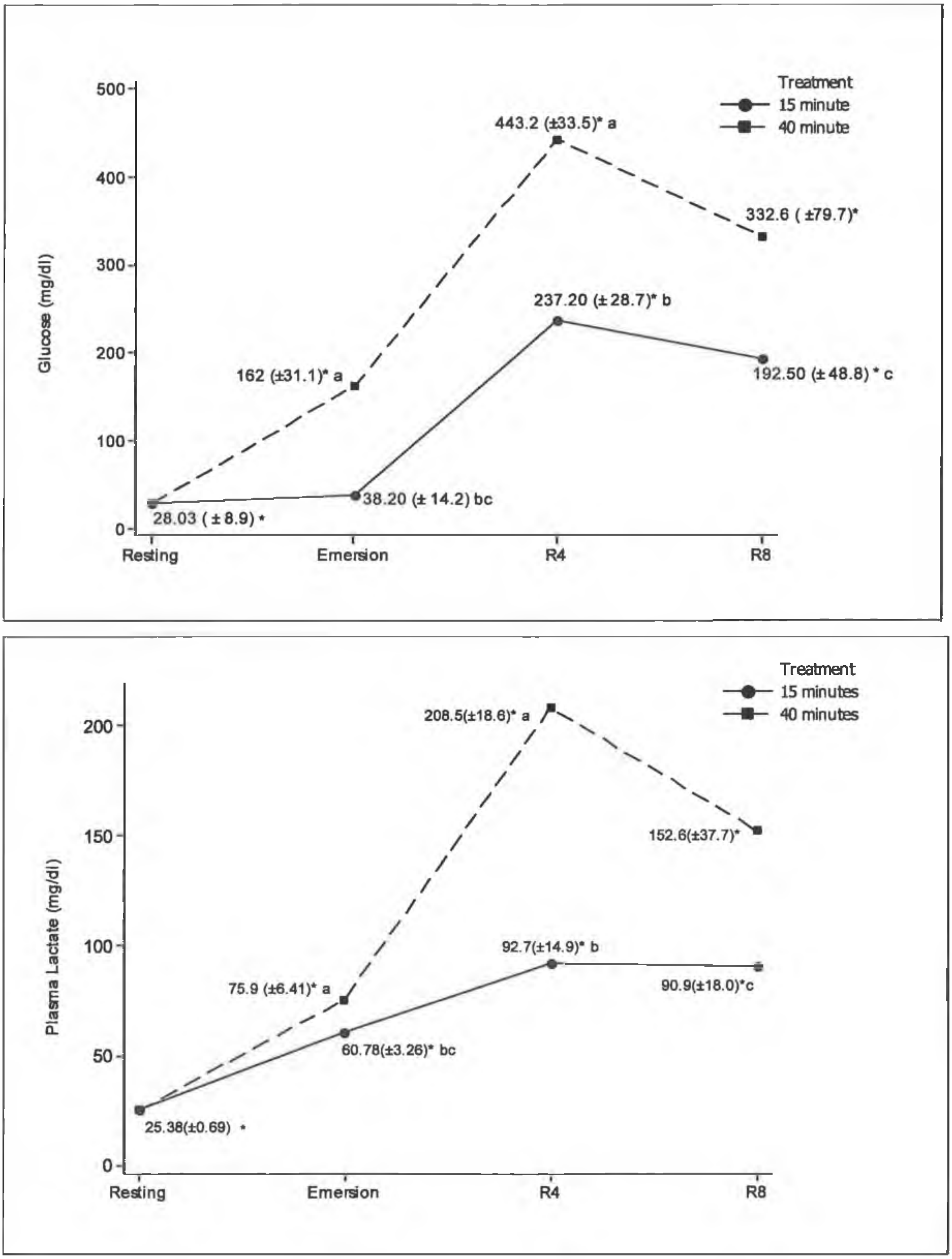


Figure 4.1 Effects of exposure to air for 15 and 40 minutes (Emersion) on plasma glucose (mg/dl) and on plasma lactate (mg/dl) at rest, emersion and recovery points. Mean values ±S.E.M, n=6. Significant differences (P<0.05) between treatments and resting levels are indicated by Asterisks (*). Smaller letters (P<0.05) denote significant differences between groups with the same letter.

4.3.3 White muscle pH

White muscle pH differed significantly at the emersion points and both results were significantly different from T0 ($p<0.05$), see fig 4.2. No significant difference was detected from either of the recovery time groups (R4 and R8) with T0. The E40 group was significantly different from both recovery points at R4 and R8. The E15 recovered at R4 and R8 and both were not significantly different from T0. There was no significant difference between the emersion treatments at 15 minutes and 40 minutes.

4.3.4 White muscle lactate

The mean baseline white muscle lactate concentration (42.28 mg/dl) significantly differed from the E40 treatment group and subsequent 4 hour recovery (R4) treatment ($p<0.05$). There was no other significant difference between T0 and other groups. In the current study, lactate levels in both muscle and plasma started out at similar levels, see fig 4.2. However white muscle lactate peaked (instantly) at the emersion stage and then decreased gradually up to the R8. Plasma lactate rose significantly after emersion (for E40 & E15) and remained well above baseline levels at the recovery period of eight hours. There was no significant difference between the emersion treatments at 15 minutes and 40 minutes.

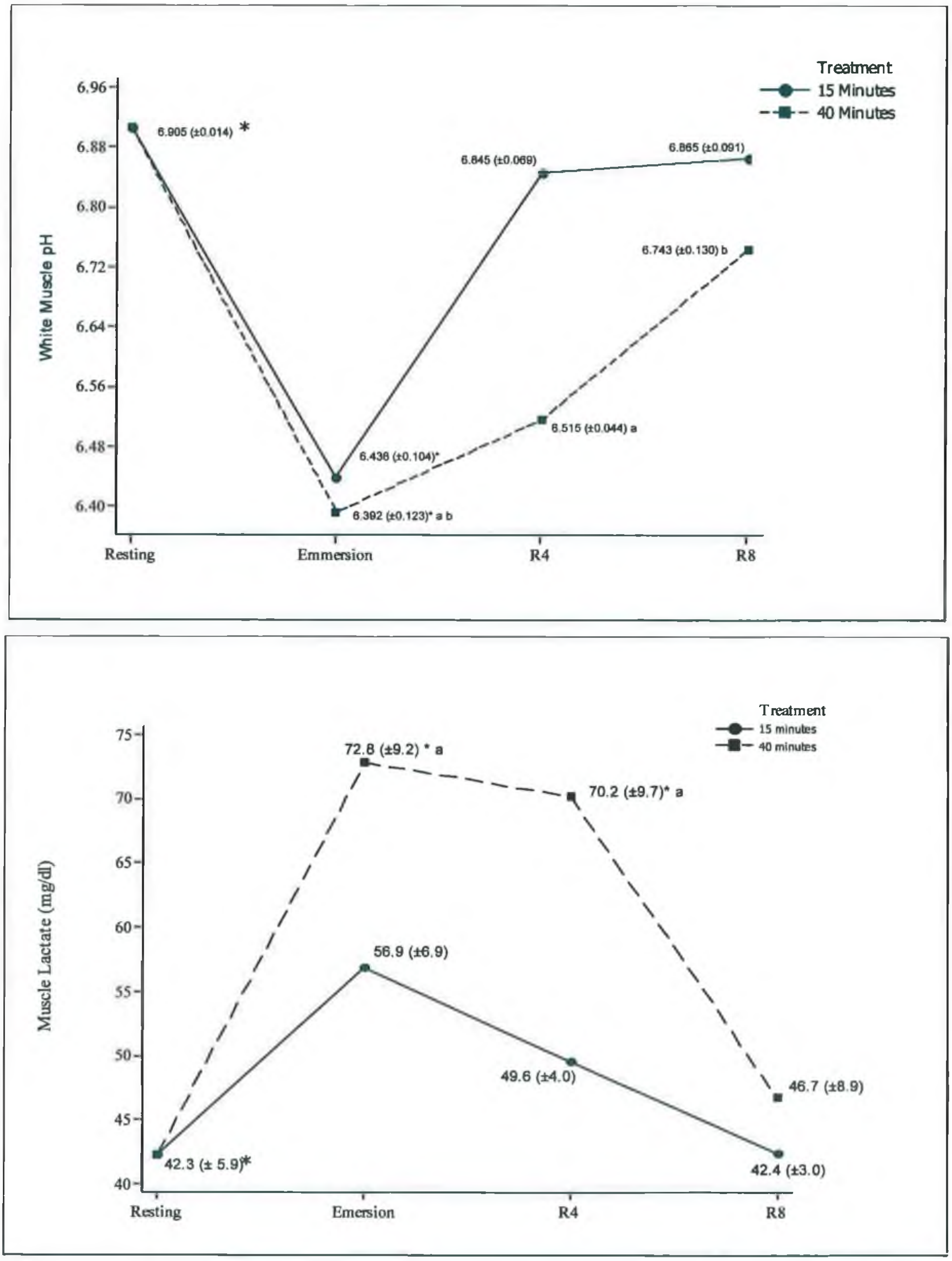


Figure 4.2 Effects of exposure to air for 15 and 40 minutes (Emersion) on white muscle lactate (mg/dl) and pH at rest, emersion and recovery points. Mean values ±S.E.M, n=6. Significant differences ($P<0.05$) between treatments and resting levels are indicated by Asterisks (*). Smaller letters ($P<0.05$) denote significant differences between groups with the same letter.

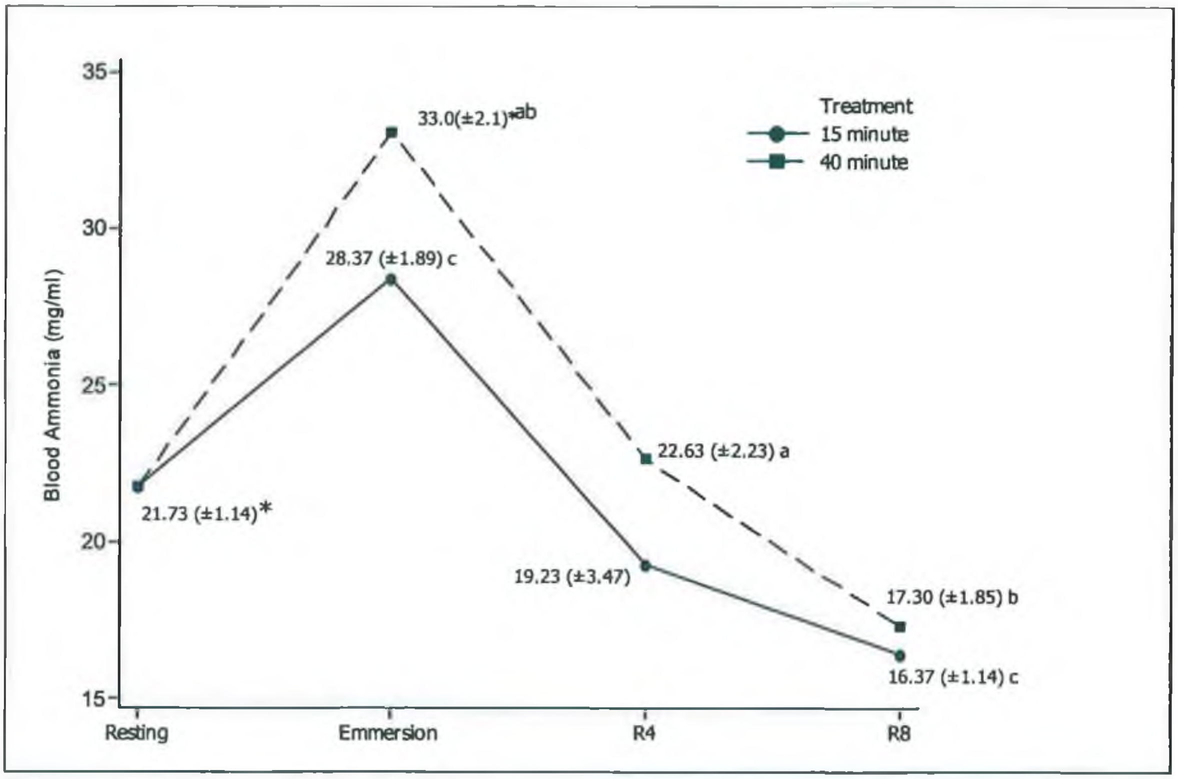
4.3.5 Blood Ammonia

A one way ANOVA showed that there was a significant difference between the control and treatment groups ($P<0.05$). The mean resting blood ammonia concentration (21.73 mg/ml) significantly differed (T0) to E40 minute emersion group. Blood ammonia for both E15 & E40 at R8 decreased below the resting concentrations (T0). R8 concentrations of blood ammonia were also significantly different to both E15 & E40 levels, see fig 4.3. Peak accumulations of blood ammonia occurred at the emersion point, with E40 being significantly higher than T0 and E15. For E15 at R4 blood ammonia concentrations were below those at T0 and also less than ammonia concentrations for E40 at R8. There was no significant difference between either of the emersion treatments at E15 and E40.

4.3.6 Plasma Adrenaline

A one way ANOVA showed that there was a significant difference in plasma adrenaline concentrations between the control and treatment groups ($P<0.05$). The mean resting plasma adrenaline concentration (2.8ng/ml) significantly differed from both emersion groups. For example adrenaline levels for E15 are approximately half those of E40 i.e. 57.2ng/ml and 110ng/ml respectively, see fig 4.3. Fish exposed for 15 minutes (E15) had adrenaline concentrations 4.18ng/ml (±1.6) at R4 and 4.9ng/ml (± 2.0) at R8. Plasma adrenaline concentrations at R4 and R8 were not significantly different from the mean resting concentration (control group) but significantly different from plasma concentrations post emersion for 15 minutes.

E40 fish had a plasma adrenaline concentration of 25.5ng/ml (±22.1) when allowed to recover for 4 hours (R4) after emersion. Levels declined to 22.1 ng/ml (± 12.8) when fish were allowed recover for a further four hours (R8), significantly different from the initial resting concentration (T0). There was a significant rise in plasma adrenaline concentration for both emersion groups. At R4 and R8 there was a rapid decrease in plasma adrenaline. There was no significant difference between either of the emersion treatments at E15 and E40.



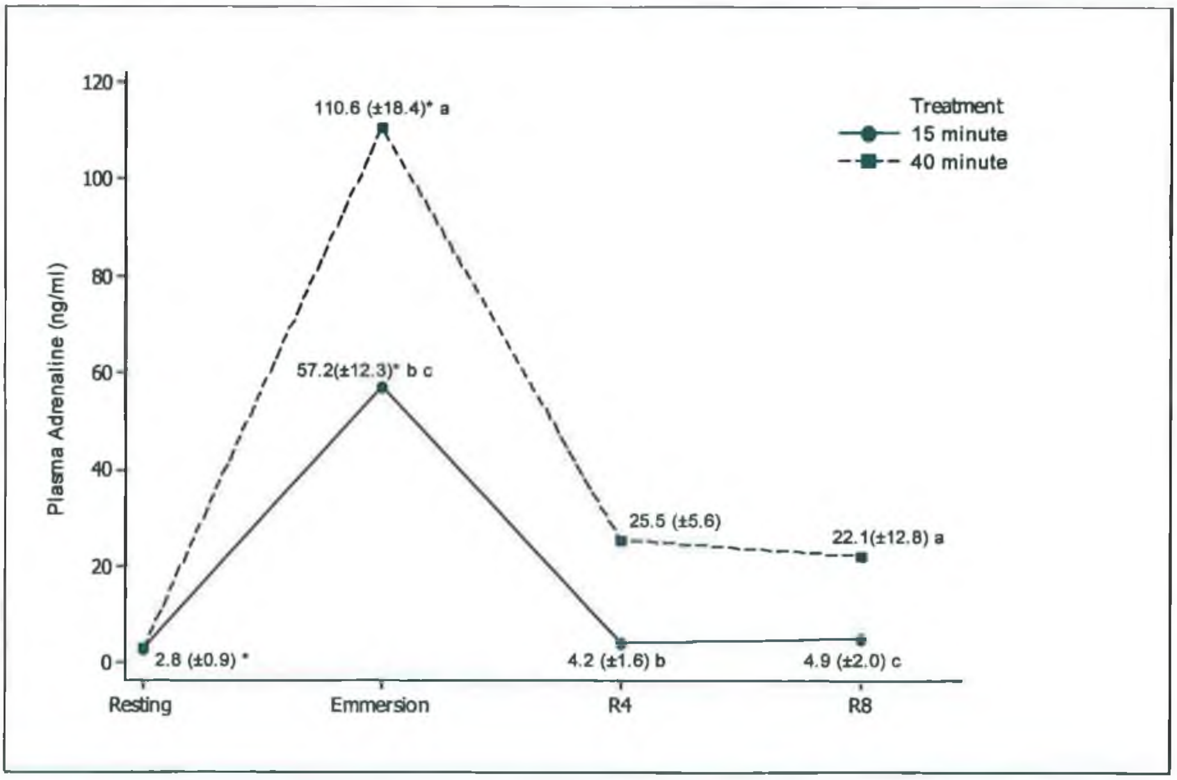


Figure 4.3 Effects of exposure to air for 15 and 40 minutes (Emersion) on plasma adrenaline (ng/dl) and on blood ammonia (mg/ml) at rest, emersion and recovery points. Mean values ±S.E.M, n=6. Significant differences ($P<0.05$) between treatments and resting levels are indicated by asterisks (*). Smaller letters ($P<0.05$) denote significant differences between groups with the same letter.

4.4 Discussion

The results from this study show that when fish are exposed to an emersion event that the duration of the emersion influences the magnitude of the response. Shorter emersion time elicited lower responses in metabolites compared to longer emersion times, but not to significant levels. Both emersion treatments distinctly coincided with each other but at different magnitudes, indicating that this species can cope with degrees of stressors at different intensities with response mechanisms proportional to the degree of stress.

Studies measuring the effects of fishing tend not to include the influence of emersion on the stress response. Emersion may be an important factor that might dictate the survival of fish and quality of fish flesh. Studies that have looked at air exposure as a major disturbance have agreed that this aspect of fishing alters the physiological homeostasis of fish (Schreer *et al.*, 2005; Suski *et al.*, 2004; White *et al.*, 2008). Ridgeway *et al.* (2006) found that fishing method might not always elicit a significant stress response in *Nephrops norvegicus* and that emersion onboard may drive alterations in plasma glucose and lactate. Suski *et al.* (2004) report that post angling, emersion time during the weigh-in period may elicit a secondary major disturbance just as altering as the capture process. Davis & Parker (2005) found that sablefish exposed to air for ten minutes experienced alteration of their normal behaviour and it was thought that this could lead to increased predation on the discarded fish, as smaller fish did not return to presumed normal behaviour 24 hours later.

Analysis of results taken just after the emersion events (E15 & E40) show that for all measured variables concentrations do not show significant difference from each other. The gill epithelium is the main site of plasma pH regulation and excretion of excess nitrogen. Exercise generates large amounts of muscle lactate and H^+ ions which may enter circulation. Greenback flounder studies show that H^+ ions in muscle coincide with a peak in plasma lactate after a controlled exercise event (Barnett & Pankhurst, 1998). In the current study plasma lactate remained relatively unchanged immediately post emersion to air whilst muscle pH and muscle lactate changed markedly. The additional 25 minutes that fish were emersed may have caused the pH to decrease. White *et al.* (2008) however, report that exercise and air exposure elicit biochemical alterations that are relative to the duration of stressor. This may be important when comparing studies as duration needs to be taken into account. Measurements of pH during the current study demonstrated a return to pre disturbance levels 4 hours after the event which is similar to a study by Mandelman & Farrington (2006) where pH reverted to pre disturbance levels 1-3 hours post capture.

Data from the current study shows that a recovery period of eight hours is not sufficient for all physiological variables to return to presumed baseline levels. Concentrations of glucose and lactate had not peaked at E15 and E40. Subsequently peaks in glucose and lactate occurred 4 hours into recovery. This increase at the delayed 4 hour recovery point represents a secondary stress response induced initially by catecholamines (which allow fish to withstand the stressful situation) (Mommsen *et al.,* 1999). When compared to baseline levels, an increase in blood glucose concentration was the most pronounced metabolic stress response after elasmobranch emersion; showing a significant increase that persisted for 4 hours until subsiding back to lower, but not original levels. To account for the maintenance of higher blood glucose during stressful situations fish normally breakdown glycogen from liver, mainly through glycogensis (Vijayan *et al.*, 1997). Feeding whilst confined was reported to be the cause of high levels of blood glucose in a study by Mandelmann & Farrington (2006). Walsh *et al.* (2006) found that feeding evoked a decrease in plasma glucose concentrations 4-8 hours post feeding and indicated that insulin production may have caused this. Atlantic salmon subject to active swimming post stress experienced peaks in plasma glucose 4 hours after stress and plasma lactate was restored 4 hours post stress (Veiseth *et al.,* 2006).

Plasma and white muscle lactate levels rose in response to the muscular activity associated with the physical reaction to stressors used in this experiment. Richard *et al.* (2003) found that spiny dogfish retained white muscle lactate during recovery as a source of fuel for *in situ* glycogen synthesis. This can be an important metabolic fuel product during stressful situations in elasmobranchs and may be used as substrate for glucose production.

During an acute stressful (in this case a hypoxic) event fish react with a flight or fight response (Barton, 2002) and switch from aerobic to anaerobic respiration. Lactate increases in the muscle and eventually diffuses into circulation and the pH of the system decreases. Lactate levels seem to be cleared from the muscle 4 hours into recovery but a rise in the plasma lactate was observed suggesting lactate was cleared into circulation from the muscle at this point. Ambient oxygen during an emersion event may have been reduced and fish resort to hyperventilation to increase oxygen supply. Aerobic respiration may not be maintained and the fish resorts to anaerobic respiration. Hoffmayer & Parsons (2001) report high lactate levels at 260.4mg/dl or 28.9mmol/l after capture and handling by hook and line. Lactate levels in specimens used during the current study peaked at the 4 hour recovery period at 208.5mg/dl (11.5mmol/l) for E40 which was well below this level. Butler *et al.* (1986) found resting levels of plasma lactate at 1.3±0.7mmol/dl (23.5mg/dl) and rose to just 1.4±0.3mmol/dl (25.3mg/dl) when swimming.

Plasma adrenaline, muscle pH and blood ammonia all returned to initial levels (not significantly different) or below (ammonia) but this might not necessarily indicate a full recovery in fish. Changes in environmental or blood gas tensions as a result of emersion elicit a suite of respiratory and cardiovascular responses. Plasma adrenaline increased as a primary response, released from the chromaffin cells directly following a stress event (Mommsen *et al.,* 1999), causing a series of metabolic changes to occur. Reid *et al.* (1998) detail these processes, where the hormones circulate into the bloodstream until they reach their target organ and initiate the efferent limb of the adrenergic response. In one study, plasma adrenaline ranged from 5.9±1.2 nmol/dl to 19.3±6.8 nmol/dl up to 96.3±28 nmol/dl after repeated exhaustive swimming for 3 to 4 minutes, 16 times the resting value (Butler *et al.,* 1978). Pichavant *et al.* (2002) found resting levels of 1.05±0.48 nmol in a teleost. In the current study there was a dramatic increase in adrenaline at the emersion event. Glucose at the same time point did not rise until 4 hours after emersion, coinciding with a marked decrease in adrenaline. High *et al.* (2007) found that longlined shark plasma adrenaline concentrations were sixteen times higher than control sharks. The basal levels reported in this study (2.8ng/ml) resembled those reported by Butler *et al.* (1986) and High *et al.* (2007): these authors also reported that shark whose level exceeded 90ng/ml or more had the greatest number of moribund or near dead specimens. Peak accumulations in the current studies for 15-min and 40-min exposure treatments peaked at the emersion event at 57.2 ng/ml and 110.6 ng/ml respectively which is higher than resulted reported by High *et al.* (2007).

Turbot, when exposed to hypoxic conditions demonstrated an increase in muscle lactate compared to a lower concentration of plasma lactate (Pichavant *et al.,* 2002) indicating that catecholamines may cause retention of muscle lactate by vasoconstriction. In our study this was not the case as there are similar concentrations of both plasma and white muscle lactate before emersion where plasma lactate increased dramatically compared to muscle lactate, peaking at the 4 hour recovery point. Plasma lactate did not return to original levels 8 hours post emersion and muscle lactate returned to lower concentrations. Muscle lactate was initially produced and catecholamines may have been responsible for its retention in order to inhibit loss of glucose production. However, eventually it seems that it was cleared and entered circulation. This coincides with a decrease in pH which slowly returned to original levels 8 hours post emersion. Barnet & Pankhurst (1998) attribute post exercise low level plasma lactate to muscle glycogenesis where instead of being released into the blood stream, lactate is retained to conserve glucose. *Scyliorhinus canicula* has a high aerobic capacity, as muscle lactate may be retained initially in the muscle but is cleared into the blood where plasma lactate peaks some 4 hours later.

De Boeck *et al.* (2006) found that peak accumulations of plasma and muscle ammonia occurred in the first hours of a stressor. If the stressful event was prolonged then the ammonia plasma levels were found to accumulate further in the following days. Results presented here show that blood ammonia peaked significantly post emersion but returned to base levels at least 4 hours after the emersion treatment and subsequently were suppressed below the original levels 8 hours into recovery. This seems to correlate with acidosis in white muscle where pH returns to near base levels 4 hours post treatment. Ammonia may be suppressed once anaerobic metabolism takes over as this type of respiration is suggested to reduce ammonia production (De Boeck *et al.*, 2006) reducing/suppressing depolarisation of muscle fibres and increasing performance of muscle. It seems that an initial surge in blood ammonia occurs during a hypoxic event but is suppressed and most of the ammonia excreted by the gills is produced in other tissues such as muscle and cleared from the blood. The liver appears to produce the majority of ammonia, with skeletal muscle, kidneys, and gills producing most of the remainder (Evans *et al.,* 2005).

4.5 Conclusion

The current study examined the time course of physiological recovery in the plasma, blood and white muscle of lesser spotted dogfish, *Scyliorhinus canicula*. Exposure to a stress regime resulted in an alteration in metabolites from presumed resting levels consistent with the hypotheses that alterations are relative to intensity of emersion period. Interestingly, most variables recovered to near resting values, with results that seem to be relative to the magnitude of the stress regime. The stress regime or periods of time fish were emersed resulted in a significant change in the physiological profile of the lesser spotted dogfish, but this may not have endangered that the overall wellbeing, as indicated from the recovery in the majority of metabolites. This was in a controlled environment where there was no risk of predation or disturbance from other sources. In reality, the spotted dogfish returned to sea post capture and exposure may recover after four to eight hours but during this time in its natural environment it may make them susceptible to inter or intra specific interactions such as predation, competition and in the case of females, harassment from males (Sims *et al.*, 2001). Elevated plasma adrenaline, blood ammonia, muscle pH and lactate may be more reliable indicators and direct measure of emersion stress as elevations occur directly after the stress event compared to plasma lactate and glucose which peak 4 hours later. Future studies would need to analyse a series of stress indicators in order to build up a precise picture of the reaction fish have to any stress event (physiological profile).

This species of elasmobranch has a high aerobic scope and has developed a high adaptive mechanism to cope with hypoxic events with a suite of physiological adaptations to return to a balanced internal state. Recovery seems to be relative to the duration of the emersion period, with concentrations proportional to the emersion time. Intensive detailed knowledge of characteristic elasmobranch physiological profiles and baseline normal levels may be important in the long term to determine the effect of disturbances. This study did not expose fish to lethal levels of stress which would give a good indication of the duration past which recovery was unachievable. The profile obtained should help to identify lethal stress limits in the post-capture period that promote altered behaviour, delayed recovery and potential mortality.

The physiological profiles examined in this study, provides a framework for future work with elasmobranchs. As part of fisheries management regimes, protocols may need to be put in place to avoid mortality to unnecessary exposure time onboard vessels. As this species is conspicuous it could be easily pulled from catch and returned to the sea more quickly, this may not be the situation for other by-catch species. The development of such protocol needs further research into the physiological response and survival of more than one species.

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Chapter 5

Discussion

Overall discussion

Sustainable fishing methods require the exploitation of fishing resources without undermining the ecosystem balance. As stated previously there are numerous financial, ecological and legislative pressures facing the Irish inshore fishing industry. A variety of initiatives are required to ensure the sustainability of the sector. These include the adoption of novel fishing gears that offer greater selectivity, reduced costs and alternate target species or grounds.

One of the most important aspects of this project was the examination of the use of experimental fish traps and their comparison with currently practiced methods. This aspect of the project required close collaboration with local fishers and provided invaluable information regarding the practical aspects of using such gear and where potential improvements could be made. As a result of initial trials it became evident that CPUE was lower than expected and this would need to be further examined before the promotion of finfish potting gear as a suitable alternative could take place. This result lead to the utilisation of crab, lobster and shrimp pots, already well established in the crustacean fisheries, to find species prone to pot capture even when gear was not designed for this. Although fished and designed differently, these gears could provide an opportunity to establish the benefits of pot fishing to fish quality.

Finfish traps come in numerous designs and the scope of experimental work to find a suitable choice was vast. Three designs were tested in the current study. The most successful traps in terms of fish catch were rigid steel framed rectangular pots used to target Conger eel *Conger conger*. Although commercial yield was low, potential existed for a viable pot fishery. All fish were landed alive and non commercial and undersized fish were released. Escape panels and a crustacean separation device were incorporated into the design which reduced injury to individual eels.

Unfortunately, the initial deployment of Norwegian floating pots revealed that mega-faunal by-catch was a problem that would need to be solved before future extensive scale trials could be run. In addition to this, although catch returns were promising, it was also evident that the rigging configuration would need more extensive investigation as the Irish waters in which they would be fished are harsher than in the fjord where they were originally devised. However, this type of pot should not be eliminated from future trials and their potential should be examined with other established gears i.e. gillnets, to further investigate their potential.

Entrance designs used worldwide are also not exhaustive and as with pot architecture, this is a significant factor in catch rates and retaining catch. When examined in a controlled environment soft eye entrances were determined to be the most efficient in terms of retaining catch and were used in further field trials. Observations in tank trials identified potential problems in unsuitable entrance types that would have been unobservable in the field.

While it is not a commercial species, the lesser spotted dogfish was selected as a model species against which the impact of fishing methods could be adequately assessed. This species, considered to be resilient, is immune to barotraumas (no swim bladder) with high survival rates and is a common by-catch in numerous fisheries. This permitted responses and recovery to catching methods to be measured without mortalities, which reduced sampling costs and time in the field. The sampling procedure also may have damaged the appearance of the fish; therefore the cost of more highly prized or marketable fish would need to be reimbursed to fishers.

This project further expanded the current physiological knowledge on this species which may be used in future comparative fishing trials. This was achieved by selecting a suite of commonly measured metabolites such as lactate, ammonia, glucose, pH and adrenaline. Some metabolite results demonstrated concentrations similar in magnitude to those previously reported for other elasmobranches. These metabolites were included in analysing the effects different fishing methods have on the stress response in the test species. However, catch numbers were not high enough to facilitate a sample size from experimental fish pots and therefore a similar gear (crustacean pots) in terms of its design and performance was utilised. Due to the dissimilar nature of the three catching methods, standardisation of soak-time, hauling times and depths were not achievable. However, catching methods remained typical so a realistic profile of a response to these catching methods was achievable. Responses did not, however, demonstrate that samples from the pots were significantly less stressed than for the other two methods, which are in contrast to many other studies. Additionally, as immature fish were not considered in these experiments, the author was not able to analyse the length data from each method. The average length of fish from the potting method however was greater than either the angling catch data or trawl catch data. This supports other studies that have highlighted the potential of pots to under sample smaller size classes. This characteristic that may be advantageous to more vulnerable teleost species, as smaller fish are more likely to have higher mortality rates and are more likely to be discarded due to minimum landing sizes.

Lesser spotted dogfish were chosen as the test species as they were frequently caught in pots and then discarded. The results showed that in response to two emersion times, the stress response and recovery of this species were influenced directly by the magnitude of the time emersed. Recovery was not achieved by all metabolites after an eight hour recovery period. Plasma lactate and glucose measurement did not recover fully 8 hours after emersion stress, but muscle pH and lactate, adrenaline and ammonia returned to near baseline levels. The effects of these alterations in physiological homeostasis in the field may be intensified as discarded fish returned to their aquatic environment may not be in a position to respond to typical dangers such as predation. Conditions on a vessel such as catch volume, temperature and injury from other individuals may act cumulatively with air exposure intensifying the physiological and recovery responses. The experiment identified only the physiological impact of exposure to air, and avoided the impact of external influences on the test species.

The use of these metabolites provides an interesting insight into understanding the physiology of the lesser spotted dogfish *(Scyliorhinus canicula)*. When using physiological metabolites to determine stress responses, it is useful to employ a collection of these biomarkers to gain a full profile of the status of the test species. From the emersion study, adrenaline peaked immediately at the treatment stage while lactate and glucose did not plateau until 40 minutes after the treatment. Scrutinising a single biomarker alone will not give an adequate picture of homeostasis and might distort physiological events. Strict control of sampling times from landing is necessary. The disadvantages of using a broad range of these biomarkers are that they are not easy to use in the field and do not give immediate results. All biomarkers except muscle pH were difficult to process and store onboard smaller fishing vessels. Overall, muscle pH was the most practical biomarker to use in the field as results were immediate and effects could be seen easily. While sample processing was time consuming and at time difficult, samples can be stored under proper conditions for extensive periods without compromising results. Furthermore, the selection of biomarkers needs careful considered as the cost of analysis can be quite significant. The correct biomarker selection for analysis can produce meaningful results and be very beneficial in understanding the physiological response to fishing methods.

From the current studies, it is obvious that determining the potential for a finfish pot fishery in Irish waters is a complex undertaking. Closed fishing areas and unsuitable terrain restricted for other gears potentially make this gear highly attractive. However, the implementation of any new gear must be managed appropriately. The impact to mega-fauna has proven to be a problem for some designs which must be corrected. Loss of gear needs to be avoided and the retrieval of gear that is lost by licensed fishers needs to be controlled. Measures that prevent ghost fishing by modifications and proper marking should be compulsory.

It is recommended that further trials examine and improve entrance performance on target species to establish the most efficient type. An interesting part of the eel trap trial was the use of segregation devices for crustaceans and deserves further attention. All trials should incorporate physiological studies into experimental design as fish quality is an attractive incentive which would improve fish prices for pot caught fish. The further use of a test species such as lesser spotted dogfish to determine the overall physiological advantage of incorporating these and other modification into pots might prove useful.

Appendix I

Plates

Plate 2.1 Standard crustacean pot, beside frozen bait blocks

Plate 2.2 Aqua-mesh pot with 'soft eye'.

Plate 2.3 Aqua-mesh trap with ‘soft eye’.

Plate 2.4 Aqua-mesh (larger) trap with ‘Neptune trigger’.

Plate 2.5 Aqua-mesh (larger) trap with ‘soft eye’ and runners.

Plate 2.6 Aqua-mesh (larger) trap with ‘Neptune trigger’ and runners.

Plate 2.7 Aqua-mesh (larger) trap with 'Neptune trigger' and runners.

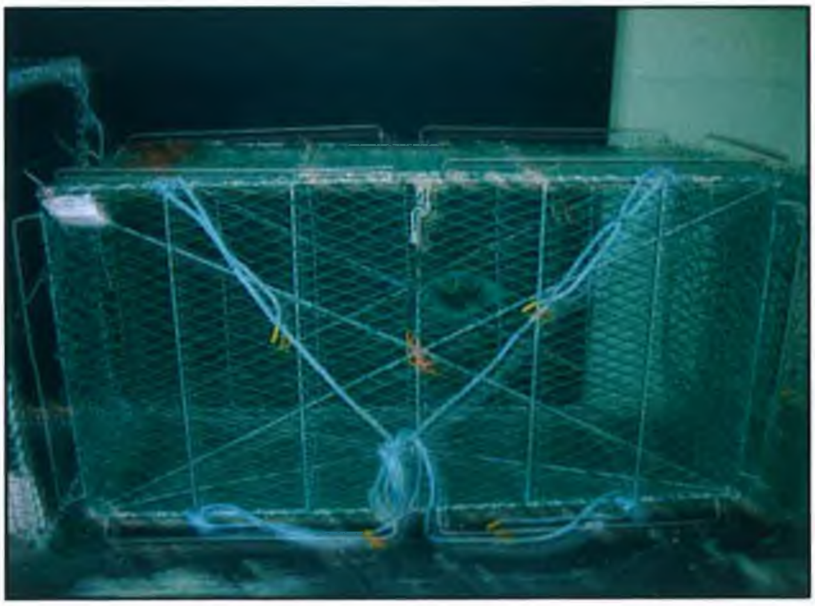

Plate 2.8 BIM rectangular steel framed trap.

Plate 2.9 BIM rectangular steel framed trap.

Plate 2.10 Collapsible 'Norwegian' fishpot.

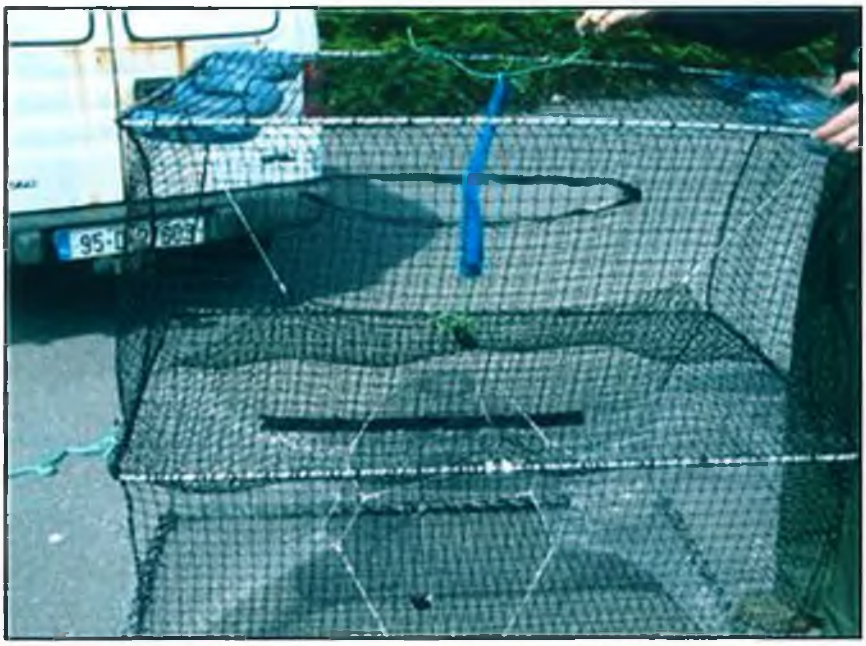

Plate 2.11 Collapsible 'Norwegian' fishpot.

Appendix II

Commercial application of experimental fish traps in Irish inshore waters

Bord Iascaigh Mhara
Irish Sea Fisheries Board

NATIONAL DEVELOPMENT PLAN

Commercial application of experimental fish traps in Irish inshore waters

Project No. 08.SM.T1.01
Final Technical Report

October 2008

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Introduction and project scope

Selective fishing is the successful capture of target species and size classes in a way that minimises by-catch, minimises damage to flesh and maximises post-mortem sale value (Cole *et al*., 2003). The trapping of live fish in specially designed fish traps is one such selective fishing method. This method of fish capture has the potential to be highly selective with the advantage of live return of unwanted catch. Fish capture using traps forms the basis of several successful directed fisheries worldwide, with examples including the New Zealand blue cod trap fishery and the Alaskan cod trap fishery.

At a more local level, ICES (The International Commission for the Exploration of the Seas) has recognised the potential of fish traps as a more environmentally friendly 'Alternative fishing gear'. Furthermore, in 2007 the ICES working group on the development of fish pots for commercial fisheries and survey purposes (SGPOT) identified the need for increased research in the area of fish trap application to both fisheries assessment and commercial fisheries in EU waters (Anon, 2007).

Anecdotal information from the Irish fishing industry identified the occurrence of several species of fish, such as wrasse, dogfish and conger eel as a by-catch in directed inshore crustacean fisheries. Acknowledging the need for information on the potential for fish traps in Irish waters, in 2006 the Galway/Mayo Institute of Technology initiated a M.Sc. research study to this end. Under this investigation, several fish traps were loaned out, on a small-scale experimental trial basis, to selected skippers around the coast. These fish traps were hauled on a voluntary basis by inshore vessels and targeted species such as Pollack, Ling and Conger Eel.

This proposal aimed to extend this GMIT fisheries development research study on a larger spatial scale. The target species was conger eel, larger individuals of which are known to undertake a post-spawning migration to Irish inshore waters during autumn and winter (Anon, 2006; O' Sullivan, 2002). Conger eel are considered an under-exploited species in Irish waters and historically utilized mainly as bait or landed for commercial scale in small quantities. However, the potential value of such non-quota species is currently of interest in light of increasing pressure on more traditionally exploited species. The potential to prosecute a localised experimental fishery for this species was reinforced by a projected seasonal export market value of between €0.70 to €3.00/kg (Fres Valdez, Spain).

Results from previous fish trap experiments off the southwest coast of Ireland.

During the winter of 1997, Mr. Paul O' Donovan of Glandore, Union Hall, Co. Cork undertook a private trial of fish cages on the vessel MFV Ross Anne (G120) on inshore fishing grounds south of Cape Clear Island and Baltimore harbour (Pers. Comm.). The target species was conger eel and cage design consisted of steel framed 6x4x3 foot cages with finger entrances attached. Cages were experimentally fished for about one month and when fished were hauled and baited several times per day with fresh mackerel. No survey report is available for this fishery trial but anecdotal evidence and personal communications suggests that a commercially viable biomass of conger eel was harvested. Individual pot hauls may have yielded in excess of 50kg per cage at times. However, poor market price at the time ultimately resulted in cessation of this experimental fishery trial.

Project Aims

The aim of this project was twofold:

1. To evaluate the potential for commercial application of experimental fish traps in Irish inshore waters.
2. To evaluate the potential for a directed seasonal conger eel trap fishery in Irish inshore waters.

It was envisaged that this project would support the ongoing fisheries development strategy of BIM by adding capacity for diversification from traditional inshore fisheries, as well as complimenting ongoing fisheries research at the Galway/Mayo Institute of Technology.

Materials & Methods - Survey design

A local commercial vessel was chartered to undertake approximately 15-20 pot hauls per day over a ten-day period (15 newly purchased fish traps, plus 5 existing GMIT provided fish traps). Soak times were standardised. Such a design facilitated a larger spatial coverage on proposed survey grounds. Data collection was undertaken through observer coverage (IS&WFPO/BIM External Staff) (Project No.05.SM.T1.02). A quantitative and qualitative analysis of all catches was undertaken. An evaluation of the potential of a small-scale fish trap fishery for the local inshore polyvalent sector was assessed. Catch per unit effort (CPUE) of target species and by-catch was recorded along with standardised survey catch and vessel information recordings. Trap design was modified to include escape panels and refuge areas for undersized commercially important species of crustaceans.

Figure 1. Experimental fish trap design with soft eye entrance.

Results

Trap Design

Trap design was modified from that of earlier trials using traps on loan from Galway - Mayo Institute of Technology. In initial trials experimental traps were fitted with plastic finger entrance grids, however catch rates of both fish and shellfish in traps fitted with such designs was negligible. It was felt that the incorporation of large soft eye entrances to trap design would improve target species catch rates (Figure 1). Furthermore, several sections of perforated four inch water pipe was fitted to the bottom corners of traps to provide lobster by-catch with refuge areas in an effort to avoid damage between individuals.

Survey Area and plan

Initially this project set out to focus on a more temporally optimal study period during autumn/winter, however the available funding timeframe resulted in the project being undertaken during the summer months (July). Exact planned survey areas were unsuitable at this time due to the activity of a beam-scallop fishing vessel in the area, resulting in an increased risk of gear loss. Accordingly, survey hauls were completed in areas adjacent to planned survey areas as outlined in Figure 2. One hundred and fifty trap hauls were completed in total over a consecutive ten-day period from 18/07/2008 to 27/07/2008. Soak time for fish traps was standardised at 24 hours and bait used was whole frozen mackerel.

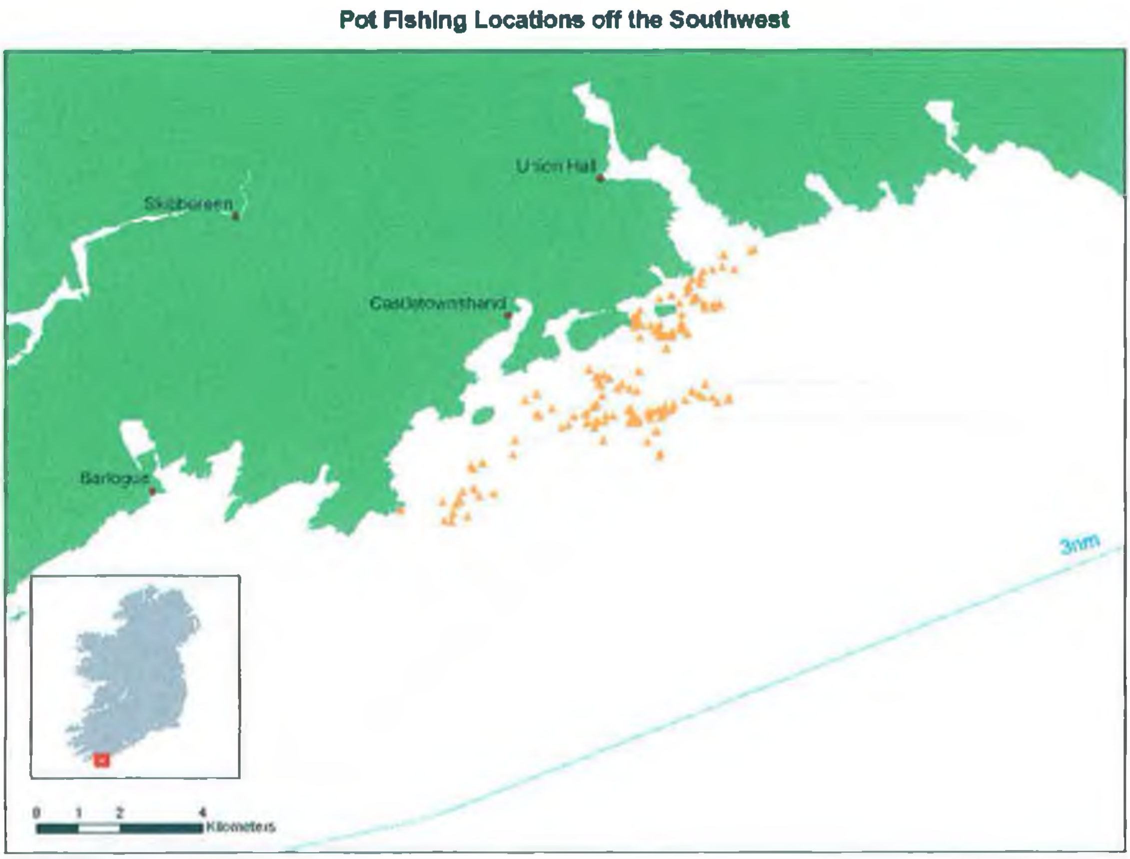

Figure 2. Fish trap haul locations off the southwest coast during the study period.

Catchability

Fish species were encountered in approximately 33% of trap hauls (Table 1). In total, seven species of fish were observed in catches. Conger eel were the most abundant species of fish observed and were present in 20% of trap hauls. Spotted dogfish were present in 6% of trap hauls followed by Wrasse (2%), Pollack (0.7%) and Spurdog (0.7%). All fish captured were alive in traps when retrieved by the vessel. Commercially undersized or unwanted species were returned alive to sea.

Catchability of target fish species (Conger eel) was considered quite low during this study (Figure 3). Although individuals were captured during daily hauls, catches of Conger Eel did not represent justifiably commercial quantities. This may or may not have been affected by the timing of the survey. However, modified trap entrance design was successful in capturing several species of fish and therefore represents an improvement in trap design and catchability in this area.

Invertebrate species were on average more prevalent in experimental trap catches (90%) compared to vertebrate species (33%). Edible crab was present in 48% of hauls followed by Lobster (21%), Spider (15%) and Velvet crab (6%). The abundance of shellfish in experimental catches can be explained by the trap entrance similarity to that of commercial crab or lobster pots i.e. large soft eye entrance.

Species	**Presence in 150 trap hauls (No)**	**Frequency in trap hauls (%)**	**Catch Per Unit Effort (No/trap haul)**
Vertebrates			
Conger eels	30	20	0.2
Spotted Dogfish	9	6	0.06
Rockling	4	2.66	0.0266
Wrasse	3	2	0.02
Pollack	1	0.66	0.0066
Pouting	1	0.66	0.0066
Spurdog	1	0.66	0.0066
Invertebrates			
Edible Crab	72	48	0.48
Lobster	32	21.33	0.2133
Spider Crab	23	15.33	0.1533
Velvet Crabs	9	6	0.06
Total			
Vertebrates (fish)	49	32.66	0.3266
Invertebrates (Shellfish)	136	90.66	0.9066

Market Price

Prices per kilo for conger eels on the Spanish fresh market in July ranged from €1.40 to €1.80/kg back to the vessel and €2.00 to €2.20/kg gross market price (Via Frez Valdez sales partner). Size of the catch was a deterministic factor for market price with 7kg + conger demanding highest prices i.e. €2.20/kg.

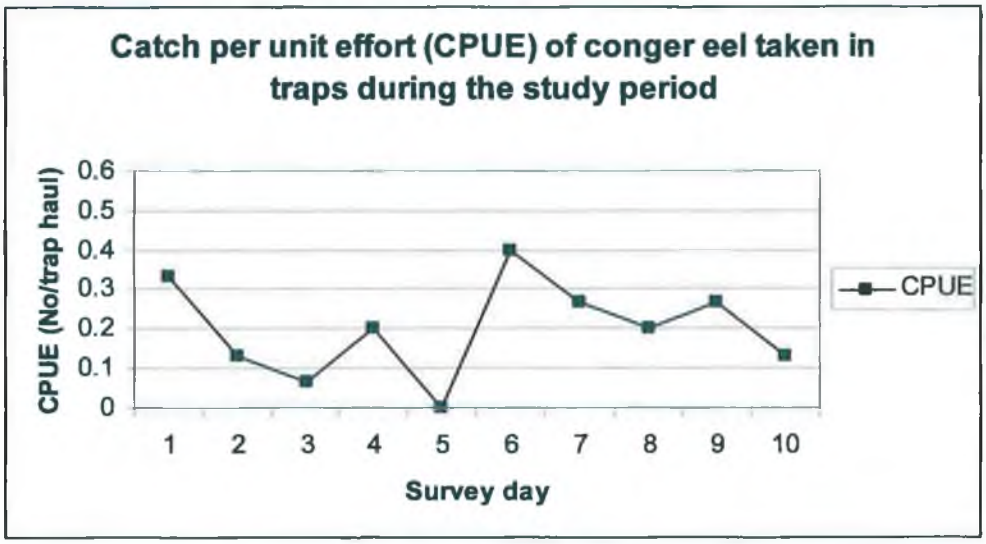

Figure 3. Catch per unit effort of Conger eel during the study period.

Conclusions

- In Irish inshore waters, modified soft eye entrances for fish traps represent a general improvement in catchability for both fish and shellfish compared to plastic trigger entrances.
- Fish trap design using soft eye entrances was successful in targeting Conger Eel and other fish species of commercial interest during summer. However such catches do not represent a commercially viable alternative for inshore vessels during this time of year (June/July/August).
- Fitting several plastic pipe sections (perforated) to large fish traps reduces the risk of damage or mortality to lobster by-catch.
- If the opportunity arises further investigations on commercial fish trap application for Conger Eel should be attempted, in particular during the winter months of October/November/December.

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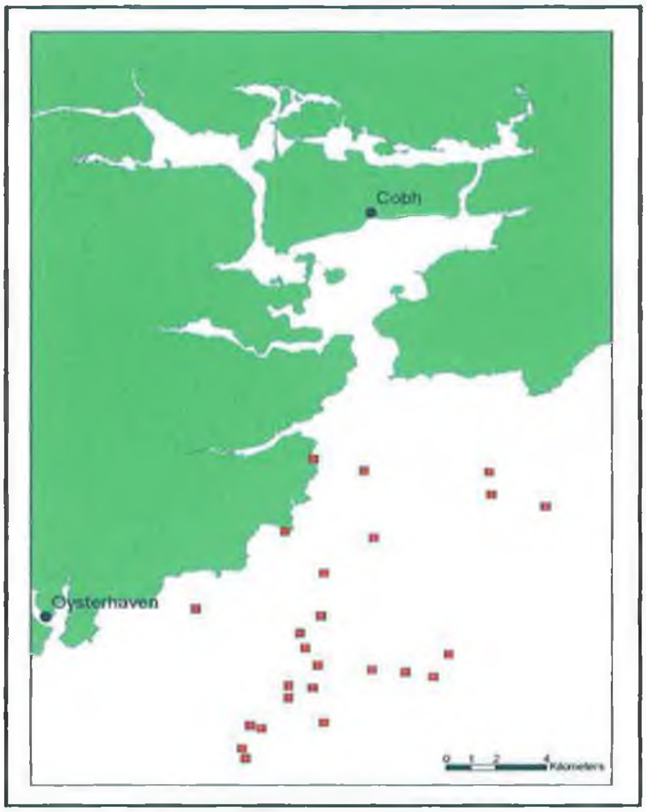
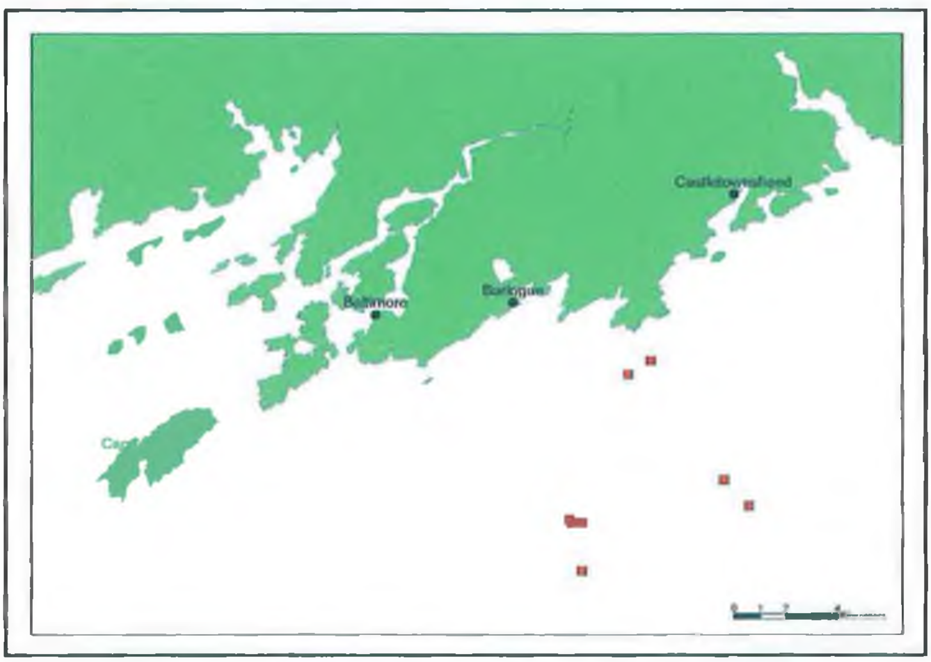
Appendix III

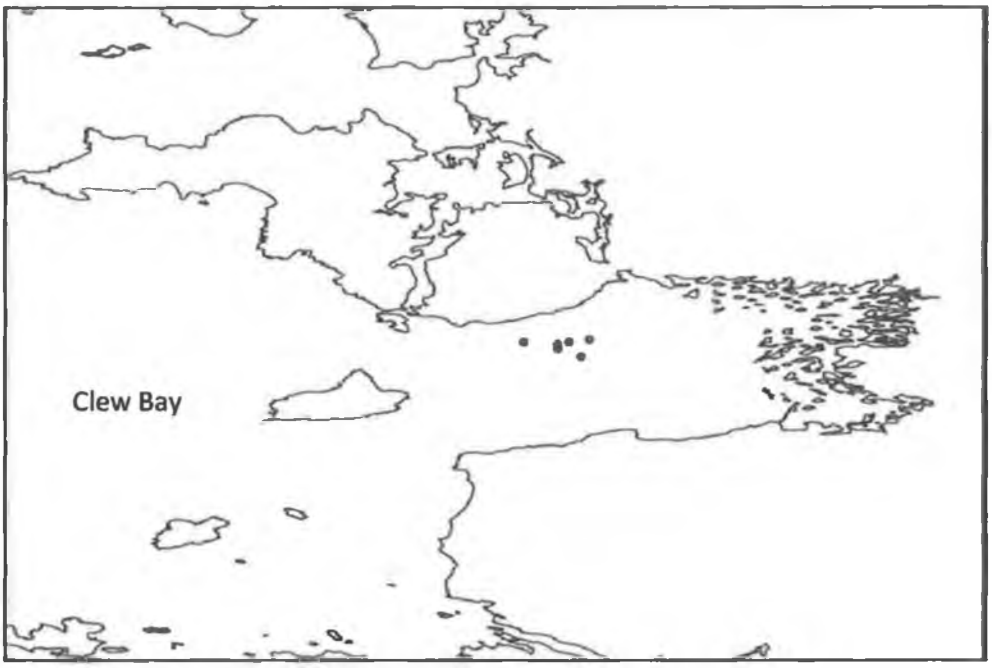
Tables



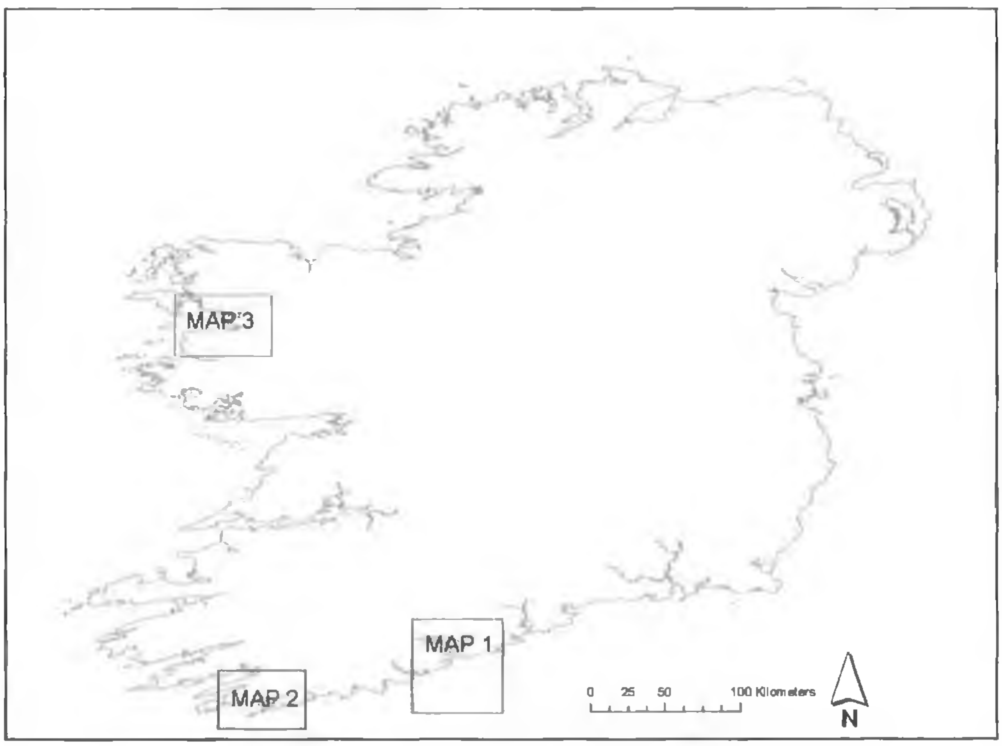
Map 1. Locations of pot hauling sites of South Cork Harbour, MFV Susan Maria.



Map 2. Locations of pot hauling sites off South Baltimore, Cork, MFV Myross CSA.



Map 3. Aqua-mesh trap deployment locations, Clew Bay County Mayo.



Map 4. Study area locations on the coast of Ireland.

Table 2.1b Length, species and condition of fish hauled from each day of fishing.

Day	Species	Substratum	Length (cm)	Condition
25/07/2006	Cod	Sand, rock.	17	Alive
25/07/2006	Cod	Sand, rock.	16	Alive
25/07/2006	Cod	Sand, rock.	23	Alive
25/07/2006	Cod	Sand, rock.	23	Alive
25/07/2006	Cod	Sand, rock.	21	Alive
25/07/2006	Whiting	Sand, rock.	14	Dead
25/07/2006	Whiting	Sand, rock.	17	Dead
25/07/2006	Whiting	Sand, rock.	16	Dead
25/07/2006	Conger Eel	Sand, rock.	46	Alive
26/07/2006	Orange Roughly	Sand, rock.	17	Dead
26/07/2006	Megrim	Sand, rock.	27	Dead
26/07/2006	Whiting	Sand, rock.	28	Dead
26/07/2006	Whiting	Sand, rock.	27	Dead
26/07/2006	Whiting	Sand, rock.	32	Dead
26/07/2006	Pollack	Sand, rock.	19	Dead
26/07/2006	Pollack	Sand, rock.	22	Dead
26/07/2006	Pollack	Sand, rock.	15	Dead
26/07/2006	Pollack	Sand, rock.	19	Dead
26/07/2006	Pollack	Sand, rock.	18	Dead
26/07/2006	Pollack	Sand, rock.	14	Dead
26/07/2006	Pollack	Sand, rock.	18	Dead
26/07/2006	Pollack	Sand, rock.	24	Dead
26/07/2006	Pollack	Sand, rock.	25	Dead
26/07/2006	Lemon Sole	Sand, rock.	25	Alive

Table 2.1 continued

26/07/2006	Dab	Sand, rock.	30	Alive
27/07/2006	Whiting	Sand, rock.	26	Alive
27/07/2006	Whiting	Sand, rock.	29	Alive
27/07/2006	Ling	Sand, rock.	50	Alive
27/07/2006	Cod	Sand, rock.	25	Dead
27/07/2006	Whiting	Sand, rock.	33	Alive
27/07/2006	Cod	Sand, rock.	39	Alive
27/07/2006	Whiting	Sand, rock.	29	Alive
27/07/2006	Cod	Sand, rock.	50	Alive
27/07/2006	Cod	Sand, rock.	48	Alive
27/07/2006	Pollack	Sand, rock.	36	Alive
27/07/2006	Cod	Sand, rock.	49	Alive
27/07/2006	Pollack	Sand, rock.	41	Alive
28/07/2006	Pollack	Sand, rock.	51	Dead
28/07/2006	Norway Pout	Sand, rock.	25	Dead
28/07/2006	Cod	Sand, rock.	63	Dead
28/07/2006	Scads	Sand, rock.	26	Alive
28/07/2006	Scads	Sand, rock.	27	Alive
28/07/2006	Whiting	Sand, rock.	28	Alive
28/07/2006	Whiting	Sand, rock.	32	Alive
28/07/2006	Ling	Sand, rock.	68	Alive
28/07/2006	Conger eel	Sand, rock.	98	Alive
28/07/2006	Lemon sole	Sand, rock.	26	Alive
28/07/2006	Pollack	Sand, rock.	35	Dead
29/07/2006	Cod	Sand, rock.	55	Dead
29/07/2006	Cod	Sand, rock.	35	Dead
30/07/2006	Four Spotted Megrim	Sand, rock.	24	Dead

Table 2.2b By-catch species and size range from fish pots from an inshore crustacean fishery in Malin head.

Date	Substratum	Depth (M)	Fish	Species	Length	Weight	String
22/05/2007	sand	16.4	1	Rockling	10cm	30g	1
22/05/2007	sand	15.2	0	NR	NR	NR	2
22/05/2007	sand	9.8	1	Cuckoo wrasse	18cm	180g	3
22/05/2007	cobble	13.8	0	NR	NR	NR	4
22/05/2007	cobble	11.3	1	Rockling	10cm	30g	5
22/05/2007	pebbles & shell	15.6	3	Rockling	10cm	30g	6
23/05/2007	cobble	13.1	0	NR	NR	NR	7
23/05/2007	cobble	6.8	0	NR			8
23/05/2007	pebbles & shell	16.2	0	NR	NR	NR	9
23/05/2007	pebbles & shell	14.5	1	Rockling	10	30	10
23/05/2007	pebbles & shell	10.4	2	Cuckoo wrasse	26cm	276g	11
				Pollack	34cm	287g	
23/05/2007	kelp	10.3	1	Ling	48cm	700g	12
24/05/2007	sand	15.6	1	Codling	24cm	199g	13
24/05/2007	sand	6.9	0	NR	NR	NR	14
24/05/2007	pebbles & shell	15.5	3	Codling	25cm	151g	15
				Codling	36cm	509g	
				Codling	24cm	150g	
24/05/2007	pebbles & shell	13.1	0	NR	NR	NR	16
24/05/2007	pebbles & shell	14.2	0	Codling	23cm	165g	17
24/05/2007	kelp	11.6	1	Ling	60cm	1250g	18
24/05/2007	kelp	11.6	1	Ling	35cm	359g	19
25/05/2007	cobble	14.4	0	NR	NR	NR	20

25/05/2007	pebbles & shell	14.7	4	Codling	21cm	178	21
				Codling	22cm	179	
				Codling	21cm	179	
				Codling	25cm	188	
25/05/2007	kelp	11.1	1	Ling	35cm	359g	22
25/05/2007	kelp	11.1	1	Ling	33cm	414g	23

Table 2.3b Pot bycatch from crustacean pots, County Cork.

Date	Vessel	Location	Species	No	Size cm	Pot type	Bait Used	Bottom
23/03/07	Susan Maria	South Cork Harbour	Codling	3	28-40	Side entry	Salmon Frame	Rock
27/03/07	Susan Maria	South Cork Harbour	Poor Cod	3	12-13	Side entry	Salmon Frame	Rock
27/03/07	Susan Maria	South Cork Harbour	Poor Cod	8	10-13	Side entry	Salmon Frame	Rock
27/03/07	Susan Maria	South Cork Harbour	Ling	1	39	Side entry	Salmon Frame	Rock
27/03/07	Susan Maria	South Cork Harbour	Coalfish	2	31	Side entry	Salmon Frame	Rock
06/04/07	Susan Maria	South Cork Harbour	Codling	2	30-40	Side entry	Salmon Frame	Rock
06/04/07	Susan Maria	South Cork Harbour	Octopus	1	20	Side entry	Salmon Frame	Rock
12/04/07	Susan Maria	South Cork Harbour	Codling	6	12-17	Shrimp pot	No bait	Mud
12/04/07	Susan Maria	South Cork Harbour	Ling	3	20-22	Shrimp pot	No bait	Mud
12/04/07	Susan Maria	South Cork Harbour	Codling	1	10-17	Shrimp pot	No bait	Mud
12/04/07	Susan Maria	South Cork Harbour	Ling	1	24	Shrimp pot	No bait	Mud
24/05/07	Susan Maria	South Cork Harbour	Codling	1	35	Side entry	Salmon Frame	Rock.
31/05/07	Susan Maria	South Cork Harbour	Pollack	1	28	Parlour	Salt-salmon	Rock
07/06/07	Susan Maria	South Cork Harbour	Codling	1	41	Side entry	Mackerel	Rock
16/06/07	Susan Maria	South Cork Harbour	Codling	2	26,38	Side entry	Mackerel	Rock

22/06/07	Susan Maria	South Cork Harbour	Ling	1	66	Side entry	Mackerel	Rock
26/06/07	Susan Maria	South Cork Harbour	Ling	2	51,61	Side entry	Wrasse	Rock
05/07/07	Susan Maria	South Cork Harbour	Cod	1	66	Side entry	Salmon Frame	Rock, stone.
14/07/07	Susan Maria	South Cork Harbour	Cod	1	76	Side entry	Salmon Frame	Rock
20/07/07	Susan Maria	South Cork Harbour	Codling	2	26,30	Side entry	Salmon Frame	Rock
28/07/07	Susan Maria	South Cork Harbour	Codling	3	25,26,3 6	Side entry	Salmon Frame	Rock
10/08/07	Susan Maria	South Cork Harbour	Ling	1	60	Side entry	Mackerel	Rock, stone.
11/08/200 7	Susan Maria	South Cork Harbour	Codling	2	38,41	Side entry	Salmon Frame	Rock
17/08/07	Susan Maria	South Cork Harbour	Ling	1	56	Side entry	Mackerel,Dogfi sh	Rock, stone.
04/09/07	Susan Maria	South Cork Harbour	Codling	2	28,31	Side entry	Salmon Frame	Rock
04/09/07	Susan Maria	South Cork Harbour	Codling	1	28	Side entry	Salmon Frame	Rock, stone.
26/09/07	Susan Maria	South Cork Harbour	Ling	1	59	Side entry	Mackerel, dogfish	Rock, stone.
29/09/07	Susan Maria	South Cork Harbour	Ling	1	61	Side entry	Wrasse, Dogfish	Rock
08/10/07	Susan Maria	South Cork Harbour	Whiting	2	12-19	Shrimp pot	Whiting Frame	Mud
05/06/07	Myross	South Baltimore	Crab	8	>13	Rectangular	Whiting Coalfish	Wreck
06/06/200 7	Myross	South Baltimore	Wrasse	1	20	Rectangular B	Whiting Coalfish	Wreck
06/06/07	Myross	South Baltimore	Crab	1		Aquamesh	Whiting Coalfish	Rock

Table 2.4b Catch from Aqua-mesh pots in Clew bay, County Mayo.

Deployed	Depth	Soak	Ground	Bait	Species	Number	Weight	Force	Comments
25/05/2006	12m	4	Rock stone	Whiting (salted)	Pollack	2	2kg	calm	2 Pollack alive.
				Prawns (Frozen).	Pouting	1	NR		Pouting alive.
					Lobster	1	NR		
29/05/2006	12m	2	Rock stone	Whiting, crab.	Dogfish	4	NR	strong	4 Dogfish alive.
					Lobster	1	1.5kg		
01/06/2006	20m	1	Rock stone	Fresh trout, crab	Dogfish	2	NR	calm	Dogfish alive.
					Pouting	1	NR		Good condition.
					Lobster				
01/06/2006	20m	1	Rough weed	Fresh Trout	Dogfish	2	NR	calm	Entrance slack.
					Crab	1	NR		Entrance changed.
02/06/2006	20m	4	Rock stone	Fresh trout, crab	Dogfish	2	NR	calm	Dogfish alive
					Crab	1	0.75kg		
					Lobster	1	0.5kg		
02/06/2006	15m	4	Rock stone	Fresh trout, crab.	Dogfish	2	NR	calm	Dogfish alive
					Lobster	1	NR		
					Crab	1	0.5kg		
06/06/2006	15m	1	Rough weed	Dogfish, Crab.	Dogfish	1	NR	calm	Dogfish alive
					Pouting	1	NR		
					Lobster	1	NR		
06/06/2006	10m	1	Rough weed	Dogfish, Crab	Dogfish	4	NR	calm	Dogfish alive
					Crab	1	NR		
06/06/2006	15m	1	Rough weed	Mackeral,mussel,crab	Dogfish	2	NR	calm	Horizontal triggers.
07/06/2006	10m	8	Rough weed	Mackeral,crab,dogfish.	Dogfish	2	NR	gale 8	Dogfish alive
					Pouting	2	5kg		
07/06/2006	15m	8	Rough weed	Crab, dogfish, whiting.	Pouting	1	NR	gale 8	
07/06/2006	15m	8	Rough weed	Dogfish, Crab	Lobster	3	NR	gale 8	no catch
15/06/2006	10m	9	Rough weed	Dogfish, Whiting	NR	NR	NR	gale 8	Pot damaged in storm.

11/06/07	Myross	South Baltimore	Dogfish	1	60-70	Rectangular	Dogfish	Rock
11/06/07	Myross	South Baltimore	Wrasse	2	20	Aquamesh	Dogfish	Wreck
11/06/07	Myross	South Baltimore	Dogfish	1	60-70	Rectangular	Dogfish	Rock
18/06/07	Myross	South Baltimore	Lobster,crab.	3&1		Aquamesh	Whiting	Wreck
18/06/07	Myross	South Baltimore	Dogfish	1	50-70	Rectangular	Whiting	Rock
18/06/07	Myross	South Baltimore	Wrasse	2	30	Aquamesh	Whiting	Rock
18/06/07	Myross	South Baltimore	Dogfish	1	50-80	Aquamesh	Whiting	Rock
07/07/07	Myross	South Baltimore	3 Lobster			Rect. BIM	Whiting	Rock
07/07/07	Myross	South Baltimore	Conger, Crab	1	80-100	Aquamesh	Whiting	Rock

Table 2.5b Catch from collapsible floating pots, Connemara, Galway.

Date	Trap	Depth	Ground	Chamber	Soaktime	Spp.	Comments
29/06/2007	1	5-6m	Rocky, mixed.	Upper	4days	Lesser spotted dogfish	10lbs Alive
						Lesser spotted dogfish	8lbs Alive
		5-6m		Lower	4days	Pollack	NR
						Pollack	NR
						Young adult common seal	NR
						Ballan Wrasse	NR
						Lobster	NR
29/06/2007	2	5-6m		Upper	4days	Lesser spotted dogfish	10lbs Alive
						Lesser spotted dogfish	8lbs Alive
		5-6m	Sandy, weed.	Lower	4days	Pollack	290g/31.9cm
						Pollack	160g /26.7
						Young adult common seal	Juvenile
						Ballan wrasse	70g 17.7cm
						Lobster	NR
				Upper		Conger eel	NR
03/07/2007	1	3m	Fine sand.			Topknot	210g/23.5cm
						Spider crab	690g /15cm
				Lower	2 days	Pollack	Small
						Pollack	Small
						Pollack	Small
						Velvet crab	7 individuals
03/07/2007	2	3m	Mixed, kelp, sand.	Lower	2 days	Ballan wrasse	None
						Common Seal	Juvenile

Appendix IIII

Appendix IIII: List of fish species caught from experimental and fish pots.

Pollack	*Polachius pollachius*
Whiting	*Merlangius merlangus*
Cod	*Gadus morhua*
Conger Eel	*Conger conger*
Orange Roughy	*Hoplostethus atlanticus*
Lemon Sole	*Microstomus kitt*
Dab	*Limanda limanda*
Ling	*Molva molva*
Norway Pout	*Trisopterus esmarki*
Scad	*Decapterus macarellus*
Four Spotted Megrim	*Lepidorhombus boscii*
Ballan wrasse	*Labrus bergylta*
Rockling	*Gaidropsarus vulgaris*
Poor cod	*Trisopterus minutus*
Coalfish	*Pollachius virens*
Octopus	*Octopus vulgaris*
Dogfish	*Scyliorhinus canicula*
Brown crab	*Cancer pagurus*
Lobster	*Homarus gammarus*
Spider crab	*Maja squinado*
Velvet crab	*Necora puber*
Topknot	*Phrynorhombus norvegicus.*