A dissertation submitted in partial fulfilment of the requirements for the Master of Science (MSc) in Marine Biology

PRIFYSGOL BANGOR UNIVERSITY

Choke species and the Landings Obligation: Survivability of plaice in the Isle of Man queen scallop trawl fishery

By Alexis Elias
B.A. Biology University of California State Northridge

Supervisors: Stuart Jenkins, Isobel Bloor and Jack Emmerson

Collaborating Institutions:
The Isle of Man Government's Department of Environment Food and Agriculture (DEFA)
The Manx Fish Producers Organisation (MFPO)

School of Ocean Sciences Bangor University Gwynedd, LL57 2UW, UK

Submitted on 9 September, 2019

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Candidate

Date: 09/09/2019

STATEMENT 1

This dissertation is being submitted in partial fulfilment of the requirements for the degree of Master of Science.

Candidate:

Date: 09/09/2019

STATEMENT 2

This thesis is the result of my own work/investigations, except where otherwise stated.

Candidate:

Date: 09/09/2019

STATEMENT 3

I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available to outside organizations.

Candidate:

Date: 09/09/2019

Abstract

In January 2019, the reformed European common fisheries policy enacted the landings obligation which prohibits discarding any quota species, with the possibility to receive an exemption where species demonstrate high survivability. Among the common quota species caught in the Isle of Man queen scallop fishery, plaice (*Plueronectes platessa)* is one of the most common species caught as bycatch. Plaice is identified as a potential “choke” species and a great concern for the Isle of Man fisheries managers. However, in several studies plaice has presented an elevated survival potential. The objective for this study was to provide estimates on the survivability of plaice after the point of discarding, and to identify the variables that effect the discard survival in the trawl and on deck in the queen scallop fishery. A captive observation experiment was conducted in July and August to assess the discard survival as a function of a semi quantitative index of fish vitality and a reflex and injury score. The vitality index and reflex and injury scores were used to analyze the influence of several factors on the discard survival. The estimated survival rates were 11%, only fish in vitality 1 survived. These rates are comparatively very low to other studies. Air exposure on deck had a significant effect on the immediate survival and condition the fish. There was a positive correlation between time deck and vitality scores. In practice, plaice survival could be enhanced if fisherman were to releases the fish within 10 minutes or as early as possible during the sorting method to avoid prolonged air exposure. It is believed that the survival rate presented in this study is an underestimate of the actual discard survival rate for plaice. In order to validate these results, further investigation is required.

Acknowledgements

I would like to express my gratitude to my supervisors, Professor Stuart Jenkins, Dr. Isobel Bloor and Jack Emmerson, for their excellent guidance and support throughout the project, from the beginning to the completion.

I would also like to thank the Manx Fishing Producers Organization for the cooperation and efforts, in particular Dr. David Beard for organizing and assisting with logistical challenges.

I would like to thank Nicky Horne, skipper of F.V. Benolas, and his crew for their guidance and assistance at sea.

I would also like to give thanks to my family and friends for their constant support and encouragement throughout the duration of my MSc and this project.

Table of Contents

List of Tables

List of Figures

Abbreviations

ANOVA Analysis of variance

CFP Common fisheries policy

DEFA Department of Environment, Food & Agriculture

EDS East Douglas

EU European Union

GIS Geographic information systems

GLM Generalized linear model

ICES International council for the exploration of the seas

ISF Isle of Man Seafood

IoM Isle of Man

MCRS Minimum Conservation Size

MFPO Manx Fish Producers Organisation

MLS Minimum Landing Size

QSC Queen Scallop (*Aequipecten opercularis*)

SE Standard error

TL Total Length (mm)

1. Introduction

1.1 Bycatch and Discarding

Bycatch and discarding are significant issues that affect the ability to manage fisheries effectively and sustainably worldwide (Hall et al., 2000). Bycatch is defined as the portion of the catch that are unwanted or non-target species (Szostek et al., 2016). Whereas discarding is the proportion of the catch that is rejected onboard and returned to the sea (Hall et al., 2000). The issues associated with bycatch and discarding practices within fisheries have many ethical, economic and ecological ramifications (Alverson et al., 1996).

Primarily, bycatch and discarding are perceived as extremely wasteful. As fish products are the main source of protein for 3.2million people (FAO, 2018), wasting potential consumable resources is not only unethical, but also extremely unpractical in an economic sense. The practice of discarding fish wastes potential economic resources. Ecologically, the practice is detrimental to studies such as population dynamic calculations, whereby discards create an unknown factor in fish mortality. Without accurate records of discards, stock assessments will not be accurate and will result in an unsustainable fishery (Alverson et al., 1996). Without the accurate estimates of fishing mortality, fish community structures can collapse with severe impacts on the local environment (Alverson et al., 1996).

Bycatch is a specific problem within demersal fisheries. The gear used within these fisheries like trawls and dredges, chosen for its ability to catch a target species, is unselective (Stiles et al., 2010). This ensures a large percentage of bottom trawler catch is bycatch. Specifically, bottom trawlers have contributed to 58% of the total discards since the 1950s and is the largest contributor of unwanted discarding worldwide (Cashion et al., 2018).

1.1 Landings Obligation

The EU Common Fisheries Policy underwent refrom in 2012 with a goal to minimize the practice of discarding unwanted catches at sea (SEAFISH, n.d.). In 2015, the Landing’s Obligation was implemented strictly for pelagic species, then in 2016 for specific demersal species, and in January 2019 all catches of quota species or commercially valuable species were required to be landed. Quota species are all fish and shellfish that are managed by catch limits (EU Regulation No. 1380/2013 Article 26; EC 2013).

The Landings Obligation (LO) was introduced to incentivize fisherman to be more selective when fishing. Before 2015, it was illegal to land undersized fish (Minimum Landing Size, MLS) and it was illegal to land fish without proper licensing or quota. As a result of these regulations, fish that fell into either of those categories had to be discarded at sea. With the LO in effect in January 2019, these fish are now required by law to be landed. The minimum conservation reference size (MCRS) replaced the MLS. Fish that are caught under the MCRS cannot be sold for human consumption, however still have to be landed. The new restriction is in place so that fishermen actively try to reduce the catch of underdeveloped and undersized marine species (SEAFISH, n.d.).

The LO was created to eliminate discarding as whole, and incentivize fishermen to use more selective modes of fishing. However, when bycatch quotas are reached, it can cause major issues for the fishery. If bycatch quotas are fulfilled before the target fish quota us reached, the fishery will have to close early regardless of the targeted catch's numbers i.e. choking the fishery.

In light of the LO, it is up to industry to be proactive if they want avoid an early closure of their fishery. Fisheries managers and industry have a few options:

a. They must buy or retain a sufficient quota for their fleet to land the bycatch of quota species.
b. Try to implement strategies to fishing practice to reduce the amount of bycatch caught.
c. Apply for an exemption to continue discarding if circumstance are favorable.

The LO does recognize that under specific circumstances (regional variations, quota exemptions, and species that have shown evidence of high survivability) exemptions from the landing law can be permitted (SEAFISH, n.d.). Many studies have shown evidence that certain species have the ability to survive the process of capture and discard (Morfin et al., 2019; Kraak et al., 2018; Benoit et al., 2013). Discarding can be beneficial to species of fish that have a high survival rate after being discarded back to the sea (Catchpole et al., 2015).

The LO is fairly new and experimental; a numerical standard of high survivability has not been defined. According to the European Commission's Scientific, Technical, Economic Committee for Fisheries (STECF) high survivability can depend on the species in question and the specific fishery

(Catchpole et al., 2015). There are many factors which can affect the survivability of a discarded species. To be considered for an exemption, a proposal must include clear and defensible scientific evidence on fishery specific survival rates. The exemption will acknowledge factors like the gear, fishing practices and the specific ecosystem (Catchpole et al., 2015).

The LO has sparked major interest in research that contributes to finding the factors that can influence the potential for a higher probability of survival after discarding. European plaice or *Plueronectes platessa* is a species of great concern for European fisheries. Plaice is one of the most common species of fish caught indiscriminately. In certain demersal trawl fisheries, the large quantities of bycatch that have been traditionally caught pose a threat to the status of the fisheries each season (Rihan, 2018)

1.2 Survivability

In order to measure the survival rate of a species or organism, a sample of individuals must be recorded/monitored until they have died after certain treatments (Wassenburg & Hill 1993; Catchpole et al., 2015; Morfin et al., 2017; Morfin et al., 2018). When measuring the survival rate after being caught and discarded, the mortality rate or the number of individual that die over a period of time are quantified. Mortality rate is measured because it is the inverse of survival, and can be easily measured.

Research on the survival rate of bycatch and discards has been prevalent since the 1970's. In the 1970's researchers assumed that the animals that were caught in trawls, faced imminent mortality. The trauma of being captured and the air exposure were severe enough stressors, that fish could not survive (Maclean 1972; Seidel, 1975; Juhl and Drummond, 1977; Saila, 1983). However, a few years later research found that some animals can survive the process of trawling (Wassenberg and Hill 1989, 1993). Since the ban on discarding in 2015, considerable amounts of research on the survivability of discards has been completed. Estimates for survival can be difficult logistically and difficult to obtain (Depsteele et al., 2014). Death is not usually instantaneous; generally, time will elapse between the exposure to the stressor and the mortality incident (Catchpole et al., 2015). Currently there is not a standardized process or time frame to conduct an assessment on survival rates. The survival assessment will depend on the species and specific conditions and stress present (Wassenberg and Hill, 1993). When conducting survival assessments Catchpole et al. (2015) recommended that the survival estimates should be presented with in the timeframe that they were observed.

The probability of survival can be affected by many factors in each phase of the capture and discard process. The three phases are capture by the fishing gear (trawling), handling at the surface (sorting process), and returning the organism back into the water (discarding). Within each of these phases there are an abundance of factors that can greatly influence the probability of survival. These factors can be separated into three general categories biological, environmental, and technical (Catchpole et al., 2015). Biological factors include the species (Wassenburg and Hill, 1993), the length and weight, the age, the physical condition and the injuries the animal has sustained (Catchpole et al., 2015). The environmental factors include the change in temperature in the sea to the surface (Catchpole et al., 2015), the change in pressure when the catch is brought to the surface (Feathers and Knable, 1983) and light conditions (Davis, 2002). The technical factors include fishing methods, haul duration, volume of catch, catch handling, and air exposure (Davis, 2002). All of these factors can interact and influence the survival rate for the organisms captured and discarded (Figure 1).

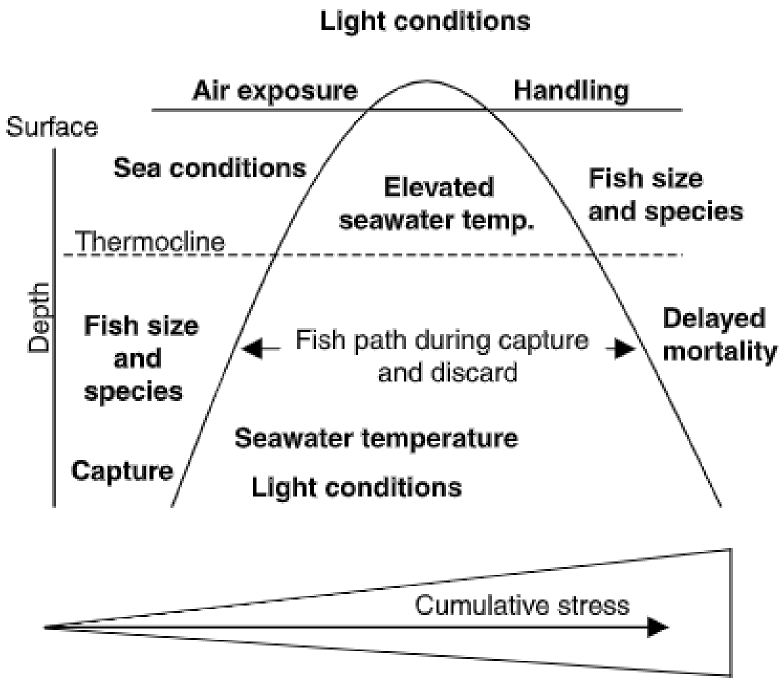


Figure 1 *A conceptual diagram adapted from Davis (2002), the diagram shows the relationship of interacting factors influencing the mortality of discards for fish caught with trawl, trap, and hook and line in deep water. The curved line represents the fish path at depth and surface during capture and discard. An increased stress level is illustrated at the bottom moving from left to right along the arrow, and the key stressors are indicated in bold lettering (Davis 2002).*

Research on discard mortality has been done on several different species of fish. Some species that have been studied are species that are more commonly caught as bycatch, that have a potential to choke a fishery. Whiting (*Merlangius merlangus),* pouting *(Trisopterus sp*.), Sole (*Solea solea*), cod (*Gadus morhua*), plaice (*Plueronectes platessa*) and skates (*Rajidae*) have all been studied extensively with hopes to bring more clarity to the probability of survival after capture and discard (Van beek et al., 1990; Wassenburg and Hill 1993; Depsteele 2014; Catchpole et al., 2015; Methling et al., 2017). Many of these studies have used the methodology of captive observation and a vitality assessment. According to the ICES workshop, there are three main techniques to conducting survival assessments to estimate discard survival (ICES, 2014). The first method is a vitality assessment. A vitality assessment assesses the health of an individual with a scoring guide using an array of indicators (i.e. reflex response, injuries, and activity levels) that are all incorporated into a single vitality score. The vitality scoring index has been shown to have a significant relationship with the probability of survival after discarding (Morfin et al., 2017; Morfin et al., 2019). The second method is through captive observation. The subjects are held for observation for a set amount of time after being captured. This method will give a probability of survival based on the incidents of mortality observed. The final method proposed by the ICES (2014) is tagging and biotelemetry. This method uses tagging technology to monitor the behavior and physiology of the fish after it has been discarded.

There are limitations to acknowledge for each methodology when completed in isolation, however, recent studies have shown that combining multiple methods can offer a greater chance at finding more accurate estimates for the probability of survival (Catchpole et al., 2015).

1.3 Isle of Man Queen Scallop Fisheries

The Isle of Man (IoM) is located in the Irish Sea between Ireland and England. The primary fisheries target king scallops, queen scallops, whelk, crab, and lobster. Historically the Queens Scallop (*Aequipecten opercularis*) fishery has been one of the more valuable fisheries. However, in the last couple of years its value has greatly decreased because of a decline in stock. As a result of the declining stock fisheries management has decreased the quota for the total allowable catch (TAC) (Bloor et al., 2019). The Isle of Man is not a member of the European Union; however, it is a Crown dependency of the United Kingdom (UK). The IoM and the UK hold a fisheries management agreement, and subsequently the IoM must comply with the EU common fisheries policy.

The queen scallop (QSC) fishery is the second most valuable fishery in the Isle of Man territorial sea. It is exploited by mainly Manx and a few UK vessels, predominantly using otter trawls and a few vessels using dredges. This fishery has been exploited for queen scallops around the Isle of Man territorial sea since the 1969 (Acoura Marine, 2016). The first quantified stock assessment was undertaken in 2013 (Murray, 2013).

Since 2010 there has been a declining trend in the mean abundance of QSC biomass. However, from 2006 to 2010 the mean abundance of biomass showed an annual increase, with 2010 reaching the highest recorded abundance since 1993 (Bloor and Kaiser, 2016). QSC landings were the highest in recorded history in 2012. In 2013, QSC were exploited over the recommended

TAC. Since 2010, there has been a rapidly declining trend in QSC average biomass. (Figure 2) (Bloor et al., 2019).

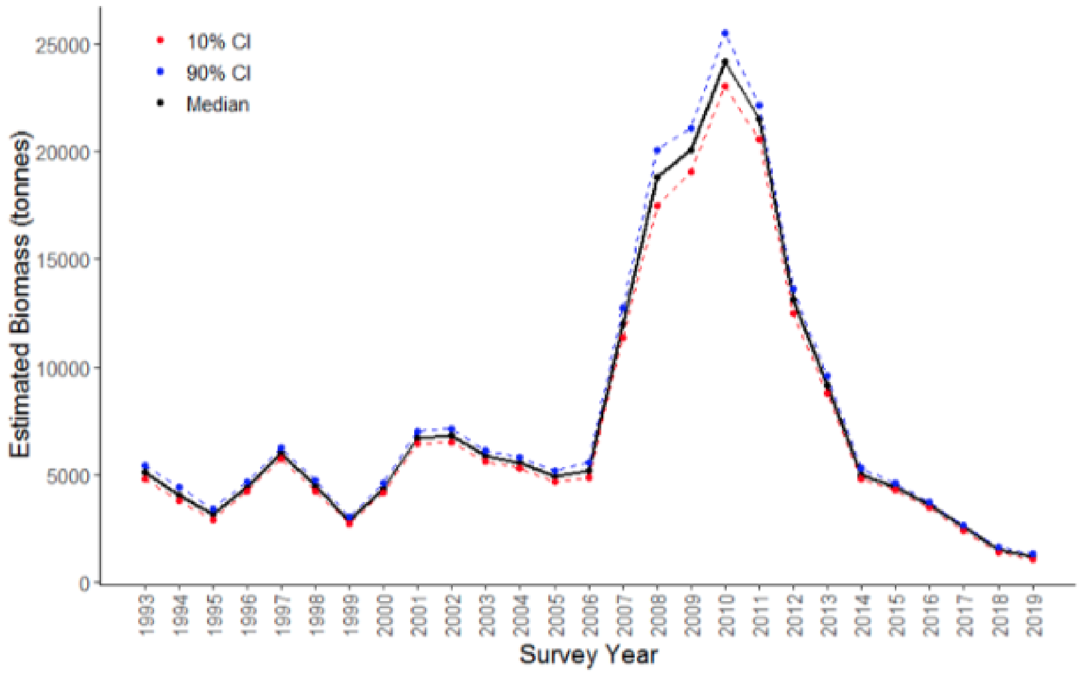


Figure 2 *Estimated biomass for QSC from 1993 to 2019 (Bloor et al., 2019).*

Since 2013, fisheries management measures have been put in place (i.e. TAC, closed areas etc). The landings from this fishery have decreased by around 89% from 2011 to 2018 (Bloor et al., 2019).

Typically, four fishing grounds are exploited each season: Targets, Point Ayre, Chickens and East Douglas. Depending on where fishing is most productive, single grounds will be exploited for that season (i.e. EDS in 2017, and Tar in 2015 and 2016). In 2018 there was relatively even split between the four main grounds (Bloor et al., 2019). During the current season, East Douglas was predominantly fished. The TAC this season was set at 557 T, the lowest TAC to date for otter trawling vessels.

Managing bycatch quota is a major issue for fisheries management. Quantifying and managing bycatch species catch rates is essential to reduce the risk of a fishery closure. In a 2012 bycatch assessment, 6.8% of the total catch was bycatch landed from four of the QSC fishing grounds. The most common species landed were Small spotted cat *shark (Scyliorhinus canicula),* Dab (*Limanda limanda)*, Haddock (*Melanogramus aeglefinus)*, Lemon Sole (*Microstomus kit)*, Red Gurnard (*Aspitrigla cuculus)*, Whiting (*Merlangius merlangus)* and Plaice (*Pleuronectes platessa).*

1.4 Objectives and Hypotheses

Ultimately the goal of this study is to find clear, defensible, scientific evidence for the survival rates of plaice to support a proposal for an exemption from the Landing Obligation. In order to achieve this goal this research project was structured with these objectives:

1. To assess the species commonly caught as bycatch in the QSC fishery as potential species for survivability studies
2. To assess the potential survival rates of *P. platessa* the Isle of Man territorial seas.
    a. To quantify the discard survival for *P. platessa* under normal commercial fishing procedures.
    b. To quantify the condition and health status plaice are in when brought on board.
    c. To investigate the discard survival rate for modified onboard handling operations with the aim to improve survivability.
3. To assess the potential methods for onshore captive monitoring onshore with an aim to estimate survival rates.

Each of these objectives will aid in assessing the hypotheses:

H1: Plaice have a high survival rate when discarded in the Isle of Man queen scallop fishery.

H2: Modifying onboard activity will enhance the potential for survival of plaice in the Isle of Man queen scallop fishery.

2. Methodology

2.1 Site Selection

The surveys were conducted during regular commercial fishing practices within the Isle of Man territorial sea. The sites that were selected were chosen based on discretion of the skipper. There are five main fishing grounds most commonly exploited in the Isle of Man QSC fishery Point of Ayre (North); Ramsey Bay (North-East); East Douglas (East); Chickens (South) and Targets (West). East Douglas, shown in figure 2, has been fished extensively this season by the entire fleet because of the high densities of queen scallops found throughout this season.

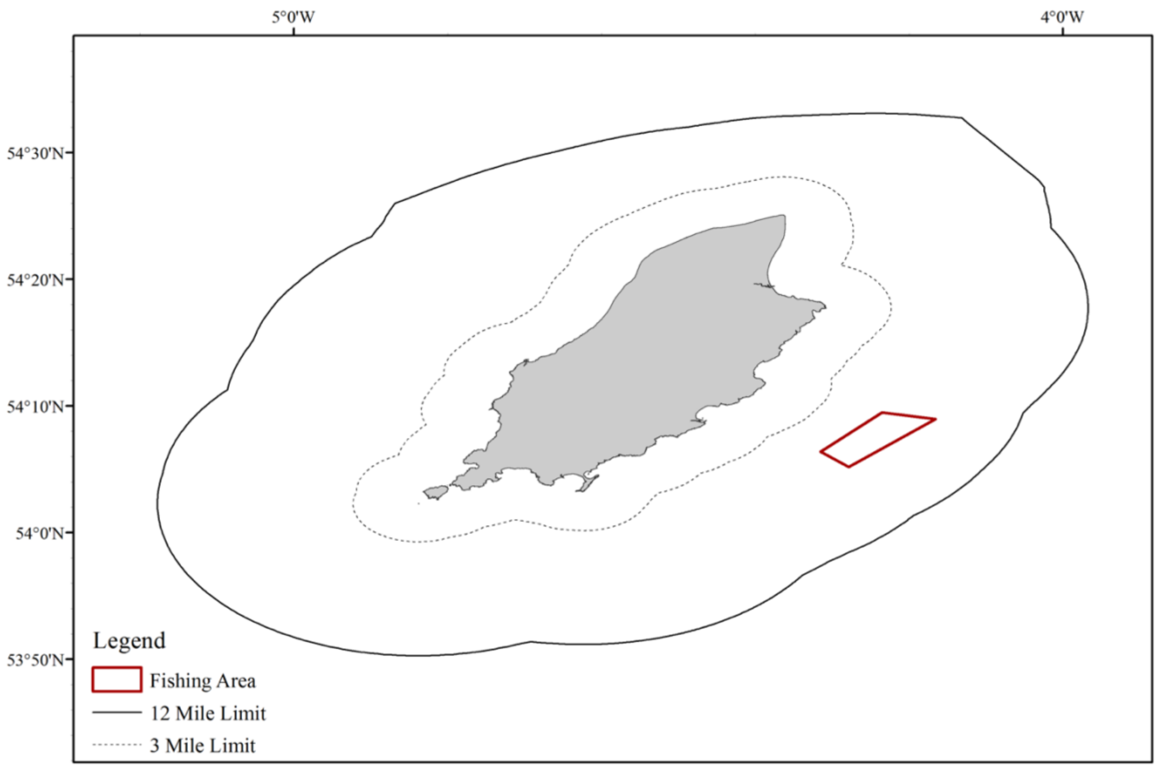


Figure 3 *Map illustrating the area surveyed in the East Douglas fishing area. The red box indicates the area that the tows were conducted. The Isle of Man territorial sea is shown within the 3 nautical mile and 12 nautical mile limit.*

2.2 Gear Description

The surveys were conducted on-board a commercial queen scallop vessel, the F.V. Benolas; it was operated under regular commercial fishing conditions representative of the fleet working in the Isle of Man territorial sea. The vessel assessed all fish in each haul for one day a week for the duration of 6 weeks beginning on July 1, 2019. Each haul was had a duration of up to 145 min and the trawl had a footrope length of 10 fathoms, and a mesh size of 85mm to 90mm codend. The vessels collected the samples in regularly fished fishing grounds at the skipper's discretion. The location of each survey were recorded and are shown on figure 2. The water depths were between 15m to 22.5 m and each hauling process took on average 111 minutes.

Figure 4 *Pictured on the left side is the F.V. Benolas, a local IoM fishing vessel. This vessel was used for the plaice survivability fishing trips*.

2.3 At Sea

Several parameters were recorded each trip, including environmental conditions, information specific to the haul, catch, and individual fish (Table 1). When the catch was brought on-board the vessel, the crew handled the catch as they would have done during normal commercial fishing operations for seven of the trips (F1-F7), and one of the trips was experimental (E1). The four tows during trip number E1, were performed under experimental procedure.

Table 1 *Haul details, environmental conditions and information on each individual fish assessed recorded during the fishing trips at sea.*

Haul Details	Environmental Conditions	Individual Fish
Tow Duration (min)	Depth (m)	Species
Longitude	Sorting Time	Length (cm)
Latitude		Vitality Score
Area		Reflex Assessment
Speed (knots)		Injury Assessment
Catch (bags)		

2.3.1 Commercial fishing procedure

Once the net was brought on to the deck and the cod-end was released, the catch was spilled on the deck after each tow. The crew redeployed the net before sorting the catch. Once the net was redeployed, the crew would then start the sorting process. First, passing the loose fish on top to the researcher, then shoveling the QSC into a riddle (Figure 5B). The riddle consists of a rotating cylindrical barrel made up of steel rings of certain width and diameter to eliminate the QSC under market size. The undersized QSC would fall through the holes into a metal shoot overboard. Once the catch had been processed, the QSC were bagged and the number of bags of marketable QSC per tow were recorded.

A.   **B.**

Figures 5A and 5B *The common fishing practices on board the F.V. Benolas. A. Crew member opening the cod-end on deck before sorting through the catch. B. Riddle used to sort undersized QSC.*

2.3.2 Experimental fishing procedure

The goal for the experimental tows was to minimize the time spent on deck as much as possible. For fishing trip E1, once the net was brought on deck and the cod-end was released. The net was secured, and the catch was immediately sorted. When the crew were sorting the catch, the flatfish and other quota species were prioritized first, then the rest of the catch were passed to the researcher. When all the visible fish were sorted and passed, the crew then began to shovel the QSC into the riddle. If they uncovered fish as they shoveled the QSC the fish would be passed at that point. Once the catch was sorted, the net would be redeployed.

Figure 6 *Sorting through the catch, the skipper and a crew member sorting through QSC and the other crew member sorting the fish and shoveling the QSC into the riddle on the right.*

2.3.3 Assessment at the point of discarding

At the point where the fish would normally have been discarded before the landing obligation, scientists and crew separated plaice (priority species) and then other species to assess length, vitality, injury, and reflex impairment to get an estimate of the condition of the fish and the proportion of which are dead. Vitality was assessed using a scoring method from 1 Excellent to 4 moribund (Table 2). This method was used in Benoit et al. (2010), Catchpole et al. (2015), Morfin et al. (2017) and Kraak et al. (2018). The injury and reflex impairment assessment were scored based on presence and absence of each reflex response or injury (Table 3 and Table 4). If a fish did not exhibit a reflex response within 5 seconds, a score of 1 was awarded. If there was some uncertainty in the reflex response a 1 was awarded. Injuries were also assessed for presence or absence. A list of 13 possible injuries were assessed shown in Table 4. If the animal exhibited an injury, a 1 was awarded. All fish caught in the hauls were assessed using these methods. Rays were assessed in the same manner, however the index used to measure reflex impairment and injury were modified specific to rays (Table 3). During trips F6, F7 and E1 the time that each plaice was assessed (the time the fish would have been discarded) was recorded. A sample of 10 - 20 plaice were placed in on-board holding tanks per day, depending on the quantity of plaice caught per trip, retaining five plaice per 100L holding tanks and 3 plaice per 70L holding tanks. However, when space was limited on-board, we used a combination of 10 plaice per 200L bongo and 3 plaice per 75 L flexi-tub (Figure 7B). Using the flexi tubs and bongo were not ideal conditions; nevertheless, it was the only option with the limited space when working under normal fishing practices.

Fish were identified throughout the project by a combination of length and vitality score. Fish of the same lengths were not placed within the same holding tank (2cm intervals) unless it was unavoidable. Holding tank conditions (water flow, pH, salinity, temperature, ammonia) were monitored every hour to ensure that the conditions were as close to sea conditions as possible.

A. **B.**

Figures 7A and 7B *A. Researcher measuring/assessing the vitality of a plaice. B. The blue bongo, (pictured right) had a constant flow of running sea water, the plaice were kept in when there wasn't enough room onboard the vessel for the insulated tubs.*

***Table 2** The vitality score index that was used to assess the bycatch during on-board assessments. Minor injuries were defined as 'minor bleeding, or minor tear of mouth parts or operculum (≤10% of the diameter), or moderate loss of scales (i.e. bare patch)'. Major injuries were defined as 'major bleeding, or major tear of mouthparts or operculum, or everted stomach, or bloated swim bladder'.*

Vitality Assessment:	
1	Vigorous body movement; no or minor external injuries only
2	Weak body movement; responds to touching/prodding; minora external injuries
3	No body movement but fish can move operculum; minor or major external injuries
4	No body or operculum movements (no response to touching or prodding

***Table 3** The list of injuries assessed during onboard assessment of bycatch. An injury is scored as absent (0) when it is not present or there is doubt about its presence, and as present (1) when observed.*

RAMP	
Evasion	Attempts to actively swim away when placed on the palm of the hand
Fin Dive	Attempts to actively bury with rhythmical fin movements
Tail Grab	Attempts upward flexing of the tail when held between thumb and index finger
Head grab	Attempts upward flexing of the head when held between thumb and index finger
Righting	Attempts to dorsoventrally right itself within 5 s
Respiration	Attempts to actively move its operculum
Spiracle Closure (RAYS)	Actively opening and closing its spiracles
Body Flex (RAYS)	Attempts to actively flex its body
Startle Touch (RAYS)	Actively closes spiracles when touched with blunt object

Table 4 *The list of reflexes assessed for impairment during on-board assessments. A reflex is scored as not impaired (1) when it is strong or easily observed, or impaired (0) when not present, weak, or if there is doubt about its presence.*

Injury Assessment	
Bulging eyes	Eyes distended outwards abnormally from head
Corneal gas bubbles	Air bubbles present in eye or membrane covering eye
Subcutaneous gas bubbles	Air bubbles under tissue (fins, body surface)
Prolapsed cloaca	Intestine protruding out of the anus
Fin fraying	Fins damaged, with slight bleeding
Wounding	Nicks or shallow cuts on body
Deep wounding	Obvious deep cuts or gashes on body
Bleeding	Obvious bleeding from any location
Mucus loss	Obvious area of mucus loss
Scale loss	Obvious area of scale loss
Abrasion	Hemorrhaging red area abrasion
Predation by 'lice' or another, crab or seal	Predation event observed with lice actively present or notable predation damage (e.g. area of fish body eaten, bite mark)
Internal organs exposed	Internal organs exposed with wounds

2.4 Sea to Shore*:*

Each trip was for a maximum duration of 12 hours, the fish were kept on board for periods no longer than 12 hours, then were transferred to onshore facilities. The on-board holding containers were secured to the deck. There was a flow of sea water supplied into the tanks. The sea water was connected to the vessels wash system. Extreme care was taken to minimize the stress on the fish when transporting to the onshore facility.

A. **B.**

Figure 8A and 8B *The methods of transporting the plaice from the boat to the onshore facility in Peel. A. Using a crane, the fish were hoisted up to the truck on at the harbor. B. The truck used to transport the plaice. The tank in the back was built to transport fish, it was refrigerated and had an aerator to keep the conditions for transporting as optimal as possible.*

2.5 On Shore

The Holding tanks were setup at Lewis Seafood in Peel, supplied by the Manx Fishing Producers Organization (MFPO). The top three layers of the tanks were used for plaice survival observations. Each tank layer measures 418 x 114 x 16 L x W x D (cm). The tank used a recirculating sea water system with cascade flow, a protein skimmer and bio filter.

Captive monitoring started directly after the fish were placed into the tanks on-board and onshore. The fish were monitored daily (every 24 hours for the 7 days) at the laboratory. During monitoring, tank conditions including pH, ammonia, dissolved oxygen levels, salinity and water temperature (°C) were monitored, as well as, water quality. The fish were fed defrosted rag worm ad libitum. Any leftover food and dead fish were removed from tanks and documented. Throughout the monitoring time period, if a fish started to show signs of being lethargic, i.e. the individual had no reflex response to a tail grab after 5 seconds, the fish was removed from the monitoring tanks, identified, recorded, then terminated using a schedule 1 procedure (See Appendix A). Monitoring continued for 7 days after capture. At the end of the monitoring period all fish were individually removed from the observation containers, measured, identified, assessed for a reflex response, and then were terminated or released. The fish were terminated following ethical guidelines using a schedule 1 procedure to anesthetize then destroy the brainstem (see Appendix A).

Figure 9 *Holding tank setup at Lewis Seafood in Peel. The top three layers of the tanks will be used for plaice survival observations. Each tank layer measures 418 x 114 x 16 L x W x D (cm). The tank uses a recirculating sea water system with cascade flow, a protein skimmer and bio filter.*

2.6 Data Analysis

2.6.1 Total Bycatch Landings

The total allowable catch (TAC) set by fisheries management is measured by weight (t) of the catch. In order to measure the percent of bycatch per haul, per trip, per vessel, and for the fishing fleet; the weight of each fish was calculated. The length of each species was recorded for each fish on board during the assessment. The function W = aLb where W is the weight (g), L is the TL (mm), and a and b are constants, was used to estimate the weight of each fish, total weight of each species, and total weight of the bycatch landed (Silva et al., 2013). The constants a and b were used from Silva et al. (2013).

2.6.2 Relationship between vitality index and survival drivers

In the vitality assessment there were many factors measured related to the fishing practices (depth, tow duration, weight of the catch, and deck time) and fish biology (length). These were tested for their potential influence on the vitality score for plaice using a parametric model that related these factors as linear or second order combinations of covariates to a response variable, the vitality index. To account for the ordinal nature of the vitality index, an ordinal logistic regression was tested. The ordinal nature of the vitality index was accounted for by scoring the Excellent to Dead/Moribund status by 1 to 4 values. Models were fitted with the 'Ordinal' R package (Morfin et al., 2017). The fixed effects were selected by the AIC score.

2.6.3 Effects of deck time and Vitality Scores

The mean vitality scores were tested against the time each fish would have spent on deck during the sorting process. The data did not meet the assumptions of a one-way ANOVA test; therefore, a non-parametric alternative test was conducted. The Kruskal Wallis test was carried out. There were three groups of 10 to 20 minute intervals of time on deck, therefore a post hoc Wilcoxon pairwise comparison test with a Bonferroni adjustment was carried out to determine the differences between groups. The R packages "dplyr", "ggpubr" and "devtools" were used. R version 3.3.1 was used for all statistical analysis.

2.6.4 Reflex and Injury Score

Thirteen injuries and six reflexes were assessed and recorded for reflex and injury score. The injuries were split into three categories (stomach reversion, eye bulging, and other injuries) (see appendix for the injuries found in each category). The presence and absence of the injury and reflex response was recorded for each of the categories, if an injury was present a 1 was recorded. If a reflex response was absent, a 1 was awarded.

The Reflex and injury score (RI score) was calculated by:

$$RI = \frac{(sum\ of\ injuries)}{3} + \frac{(sum\ of\ reflexes\ impaired)}{6}$$

2.6.5 Relationship between Vitality and RI Score

The mean RI scores were tested against the vitality score recorded for each fish. The data did not meet the assumptions of a one-way ANOVA test, therefore a non-parametric alternative test was conducted. The Kruskal Wallis test was carried out. There were four vitality groups, therefore a post hoc Wilcoxon pairwise comparison test with a Bonferroni adjustment was carried out to determine the differences between groups. The R packages "dplyr", "ggpubr" and "devtools" were used. R version 3.3.1 was used for all statistical analysis.

2.6.6 Survival Analysis

The Kaplan-Meier estimator was used to approximate the survival probability over time. The "survfit" package in R version 3.3.1 was used to produce weighted K-M curves. The survival estimates of plaice were derived at asymptote (ICES,2016). A log rank test was used to test for significance between the three survival curves. A post hoc test was used to test for significance between each curve.

3. Results

3.1 Fishing Practices

The average haul duration was 111 minutes, a maximum of 145 minutes and a minimum haul duration of 75 minutes. The amount of time fish spent on deck following landing and prior to being sampled varied among the 7 fishing where normal deck procedure was followed (Fishing trips F1-F7; Figure 10). As fishing trips progressed the average time on deck decreased. The time on deck varied between 23 minutes and 139 minutes. In the final fishing trip (E1) normal fishing procedure was not followed; the crew prioritized sorting the fish bycatch before redeployment of the net. Thus the deck time was lowest and varied between 3 minutes and 34 minutes.

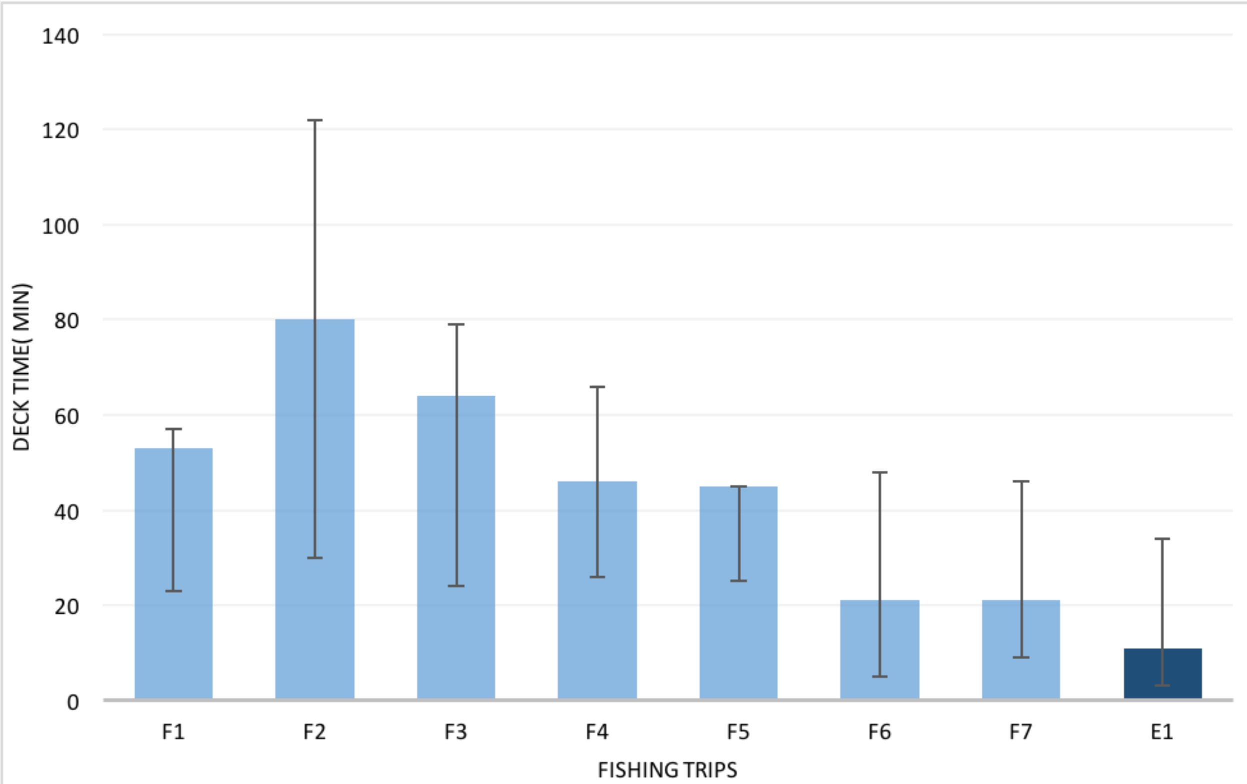


Figure 10 *The average time between the net being lifted and the end of sorting the catch per trip. The bars represent the minimum and maximum time on deck. Light blue represents the trips under normal fishing conditions. Dark blue represents the trip fishing under experimental conditions.*

3.2 QSC and Bycatch Landings

Across the 8 fishing trips 16.8t of scallops were landed. A total of .83t of bycatch were landed, equating to 5% of the total landings as shown in Table 1. Plaice accounted for 6% of the total bycatch, 0.05t. All ray species totaled at 0.05t, also 6% of the total bycatch (Table 5).

Table 5 *Total landings of QSC for the F.V Benolas, and the fishing fleet (Bloor et al., 2019). Total bycatch, plaice bycatch, and ray bycatch on the F.V. Benolas were landed during the 8 trips. Fishing fleet total bycatch, Plaice bycatch and Ray bycatch were a calculated proportion from the data taken from F.V. Benolas.*

	QSC (t)	Total Bycatch (t)	Plaice Bycatch (t)	Rays Bycatch (t)
F.V. Benolas	16.8	0.83	0.05	0.05
Fishing Fleet	557	27.6	1.6	1.7
MFPO Quota	**557**		**17.8**	

3.3 Landing Composition

There was a total of 21 species of fish caught throughout the eight fishing trips, 11 of those species were quota species in the Irish sea. Only 23% of the bycatch landings were quota species. Rays were 6% of total bycatch. Non-quota species accounted for 77% of the bycatch landings. The small-spotted catshark (*Scyliorhinus canicula)* was 65% of bycatch landings (Figure 11)

Table 6 *List of the quota and non-quota species landed during the 8 fishing trips.*

Quota Species	**Non-Quota Species**
Atlantic Cod *(Gadus morhua)*	Bull Huss (*Scyliorhinus stellaris*)
Cuckoo Ray *(Leucoraja naevus)*	Grey Gurnard *(Eutrigla gurnardus)*
Dab *(Limanda limanda)*	John Dory (*Zeus faber)* Poor Cod (*Trisopterus minutus)*
Dover Sole *(Solea solea)*	Red Gurnard *(Aspitrigla cuculus)*
Haddock *(Melanogrammus aeglefinus)*	Streaked Gurnard *(Trigloporus lastoviza)*
Lemon Sole (*Microstomus kitt)*	Small Spotted Cat Shark (*Scyliorhinus canicula)*
Monk Fish (*Lophius piscatorius)*	Smooth Hound *(Mustelus mustelus)*
Plaice (*Pleuronectes platessa)*	Starry Smooth Hound (*Mustelus asterias)*
Spotted Ray *(Raja montagui)*	Tub Gurnard *(Chelidonichthys lucerna)*
Thornback Ray (*Raja clavata)*	
Whiting *(Merlangius merlangus)*	

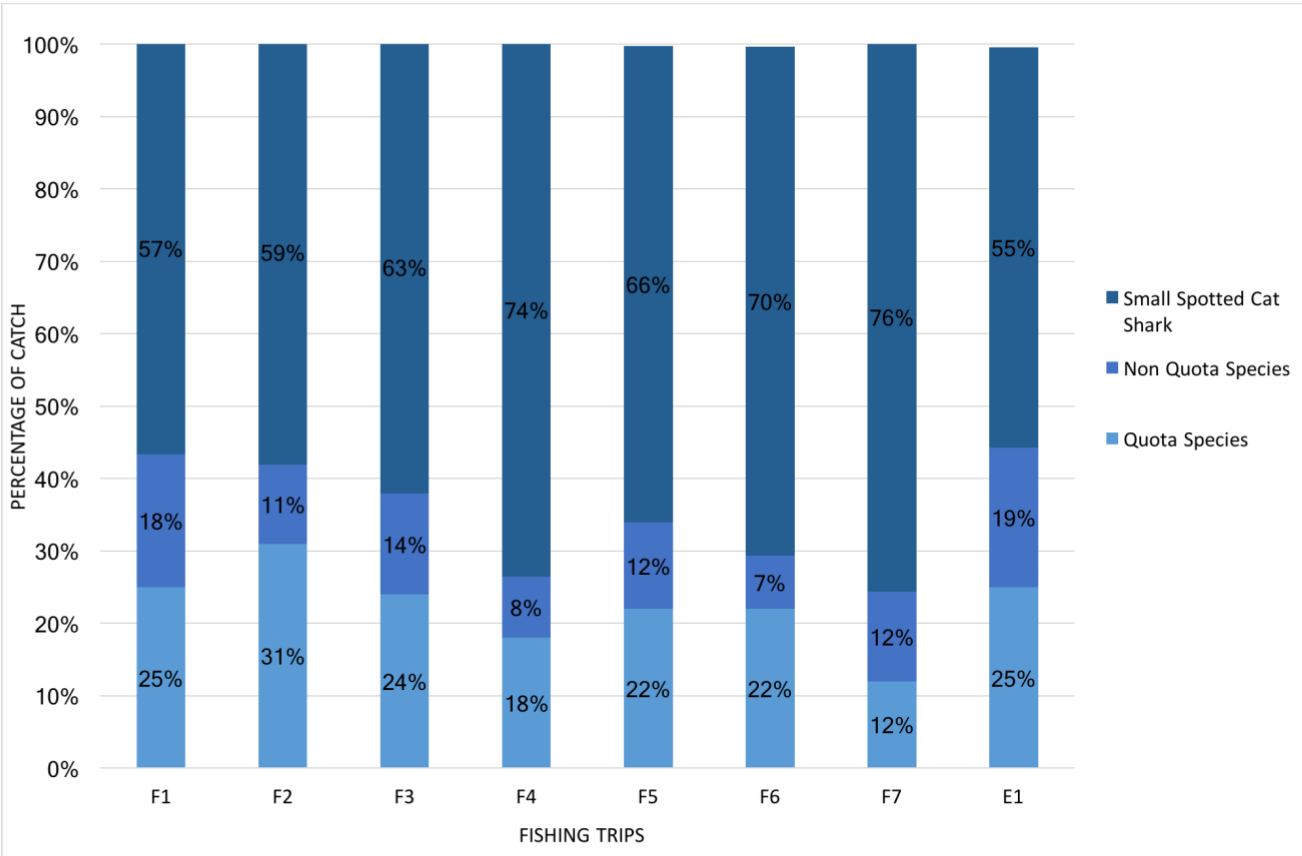


Figure 11 *Bycatch landing composition for each fishing trip, Small spotted cat shark was separated from the non-quota species because of the large quantity caught*.

A total of 3141 fish were landed as bycatch. 2137 small-spotted catshark, 212 Red Gurnard, 187 Plaice, 126 Lemon Sole, 138 Dab, and 56 rays. The two species that had the highest catch rates are both non-quota species. Plaice was the most common quota species, caught and was the third most common species caught during the 8 trips (Figure 12). A total of 56 rays were caught; 20 Cuckoo Rays, 19 Spotted Rays, and 19 Thornback rays.

3.4 Vitality Scores

Each fish landed was assessed with a scoring guide based on vigor and injury status, mentioned above in the methods. The distribution of vitality scores varied by species (Figure 12). The small spotted cat shark has largest number of individuals in vitality 1 (excellent), 2 (good), and, 3 (poor). The second largest distribution of individuals in all vitality score categories was Plaice. Red gurnard, Dab, Lemon Sole, Whiting, Haddock, and Monk fish had the most fish assessed as vitality score 4, moribund.

Although the rays only accounted for 6% of the total bycatch landings, 73% of the rays assessed were vitality score 1 and vitality score 2. Only 3 rays were assessed as vitality score 4.

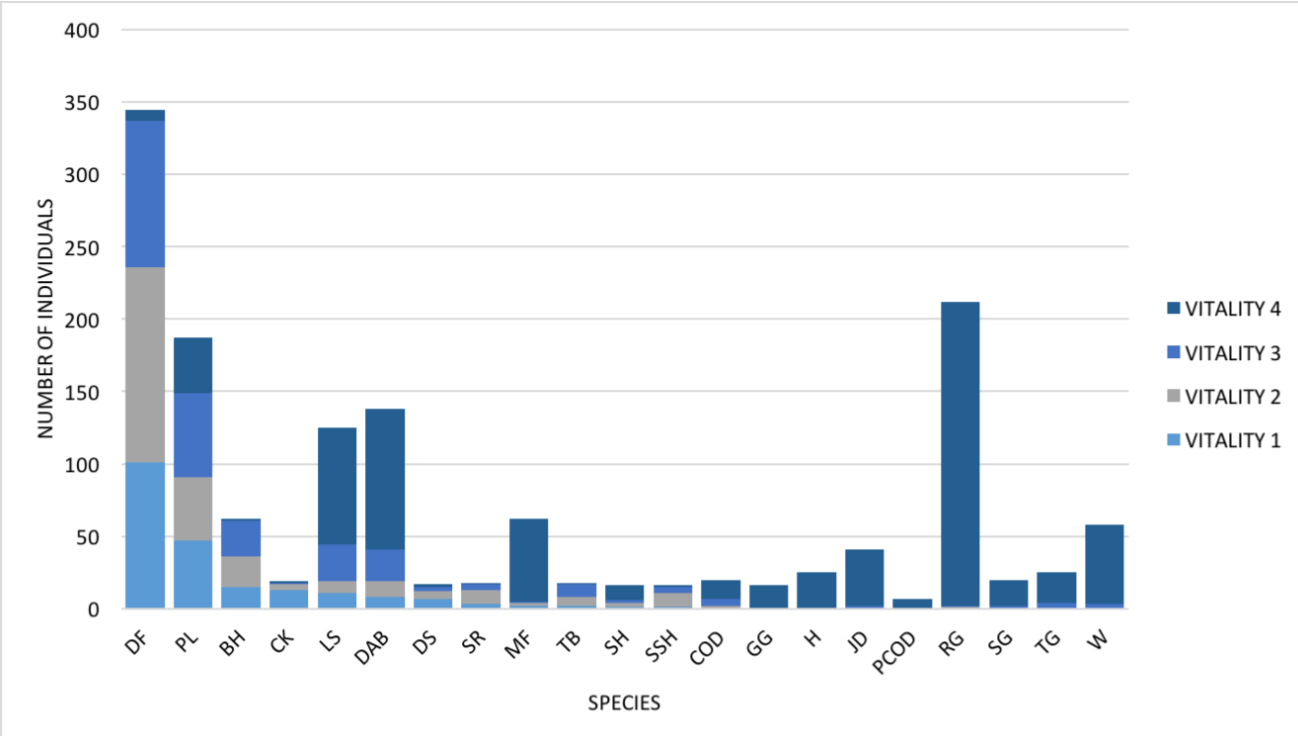


Figure 12 *Total landings composition separated in to the four vitality categories for each species assessed. TheCOD: Atlantic Cod (Gadus morhua), BH: Bull Huss (Scyliorhinus stellaris), CK: Cuckoo Ray (Leucoraja naevus), GG: Grey Gurnard (Eutrigla gurnardus), DAB: Dab (Limanda limanda), JD: John Dory (Zeus faber), DS: Dover Sole (Solea solea), RG: Red Gurnard (Aspitrigla cuculus), H: Haddock (Melanogrammus aeglefinus), SG: Streaked Gurnard (Trigloporus lastoviza), LS: Lemon Sole (Microstomus kitt), DF: Small Spotted Cat Shark (Scyliorhinus canicula), MF: Monk Fish (Lophius piscatorius), SH: Smooth Hound (Mustelus mustelus), PL: Plaice (Pleuronectes platessa), SSH: Starry Smooth Hound (Mustelus asterias), PC: Poor Cod (Trisopterus minutus), TG: Tub Gurnard (Chelidonichthys lucerna), SR: Spotted Ray (Raja montagui), TB: Thornback Ray (Raja clavata), W: Whiting (Merlangius merlangus)*

3.4.1 Plaice

Plaice had the biggest distribution of fish per vitality category, other than the small spotted cat shark. 79% of Plaice were alive when they were brought on deck. 27% of plaice were vitality score 1, 21% were vitality score 2, 30% were vitality score 3 and 21% were vitality score 4. The calculated proportion for the fishing fleet is 1.6t for the 2019 QSC season (Table 8). A total of 51% of plaice were vitality score 1 and 2, this is an estimated .8t of excellent and good fish brought on deck.

An ordinal logistic regression was conducted to evaluate which variable had the biggest influence on the vitality score each fish was assessed as. Deck time was the only coefficient that was significant (Table 7). Therefore, deck time was the only factor that could be used as a predictor for vitality score.

Table 7 *An ordinal logistic regression of vitality scores for fish in relation to external variables; where p<0.01 indicates the coefficient has a significant effect on the vitality score.*

AIC: 264.8644				
Coefficients	**Value**	**Std. Error**	**t value**	**p value**
Deck time	0.17037	0.031	5.4909	**<0.01**
Scallop Weight	-0.0005	0.0023	-0.2302	0.8179
Tow time	0.0247	0.0196	1.263	0.20658
Depth	0.1242	0.1125	1.1049	0.26922
Total Length	-0.05165	0.0451	-1.1438	0.25272

Table 8 *Distribution of Plaice assessed during the eight fishing trips on the F.V. Benolas and an estimate of the total plaice caught for the entire fleet per vitality score.*

	Plaice Bycatch (t)	
Vitality Score	**F.V. Benolas**	**Fishing Fleet**
1	0.0137	0.4543
2	0.0105	0.3503
3	0.0149	0.4934
4	0.0107	0.3553
Total	0.0499	1.653

3.4.2 Minimum Conservation Reference Size

The minimum conservation size (MCRS) for plaice is 27cm, 63% of plaice landed were over MCRS (n=121) (Figure 13). 30% of Plaice measured over the MCRS were in vitality 1 (n=36), 19% in vitality 2 (n=23), 30% in vitality 3 (n=37), and 21% in vitality 4 (n=25). Out of the 37% of plaice caught under MCRS (n=66) (Figure 13), only a 16% of plaice were vitality 1 (n=11), 31% in vitality 2 (n=21), 31% in vitality 3 (n=21), and 20% in vitality 4 (n=13).

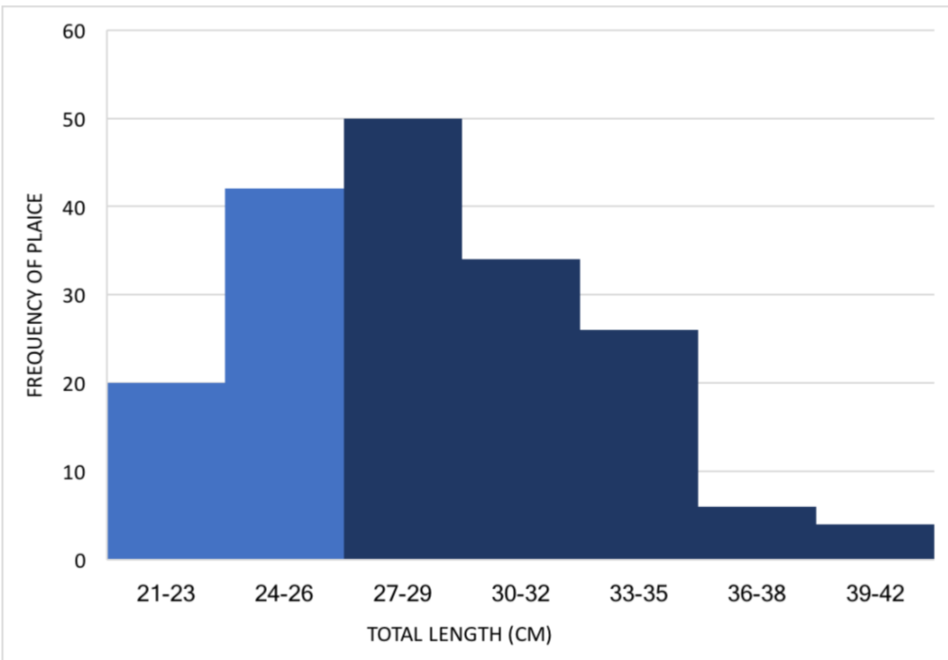


Figure 13 *Frequency of plaice per length recorded. Light blue represents fish under MCRS and dark blue represents fish over MCRS.*

3.4.3 Deck time

The total time sent on deck including, handling during vitality assessments, affected the probability of survival. During fishing trips F6, F7, and E1 the time that each individual fish was assessed was recorded. Only data from F6, F7 and E1 were used to assess the effect of deck time.

The amount of time each fish was on deck varied from 3 minutes to 40 minutes though out F6, F7, and E1. There is a clear relationship between the time on deck and vitality score. A total of 75% of plaice sorted in the first ten minutes were recorded in vitality 1 or 2, with 60% of plaice being in vitality 1. After 10 minutes the number of plaice recorded as vitality 1 decreased rapidly to 17%. After 20 minutes on deck, 90% of plaice were in vitality 3 and 4 (Figure 14).

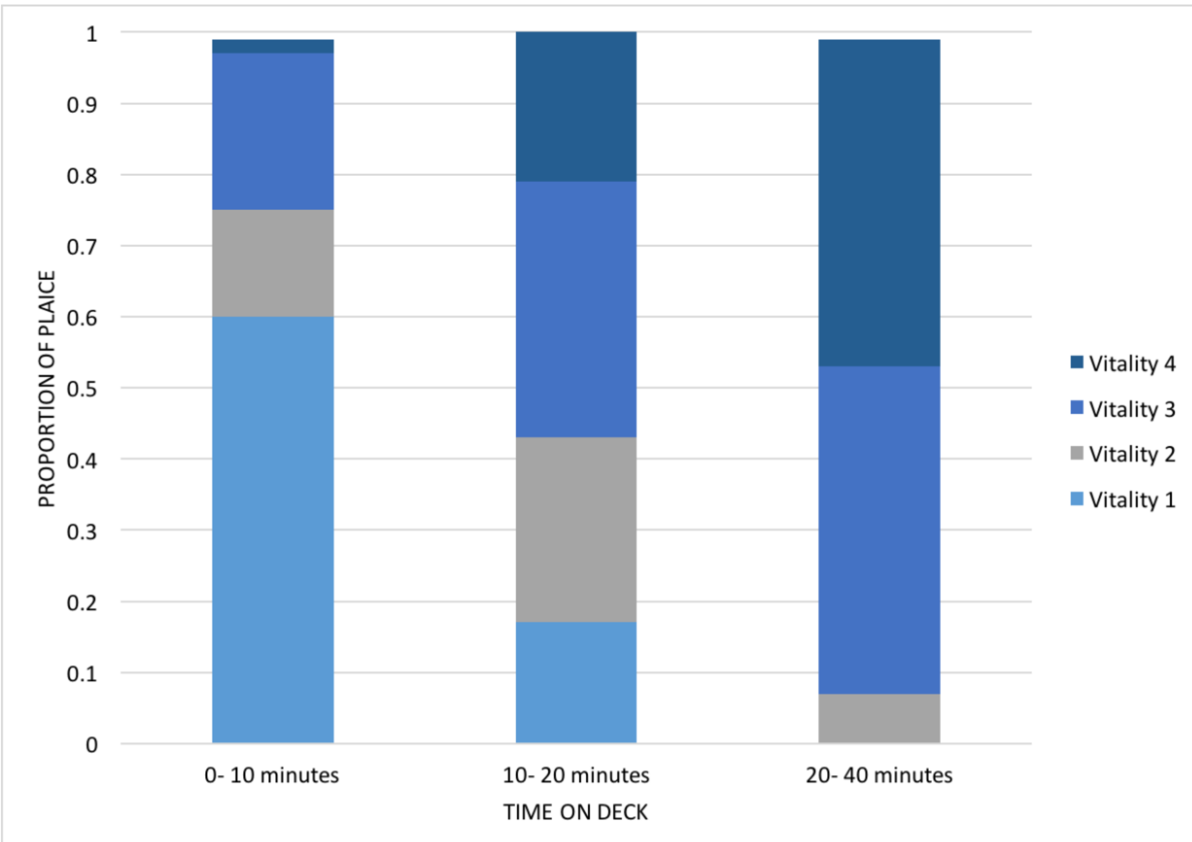


Figure 14 *Percentage of plaice in each vitality score per 10 minute interval for trips F6, F7 and E1. The 20 – 30 and 30 – 40 minute groups were combined to increase the sample size.*

A non-parametric Kruskal Wallace test was conducted to compare the median vitality scores per ranges in deck time. The was a significant difference between the median vitality scores ($\chi^2(2) = 36.65$, $p<0.01$) and deck time. Post Hoc comparisons using a pairwise comparisons test was carried out. There was a significant difference between the mean vitality score and deck times (Table 9). The median vitality score for 0-10 was a vitality 1. The median vitality score for 10-20 was vitality 2, and the median vitality score for 20-40 was vitality 4 (Figure 15).

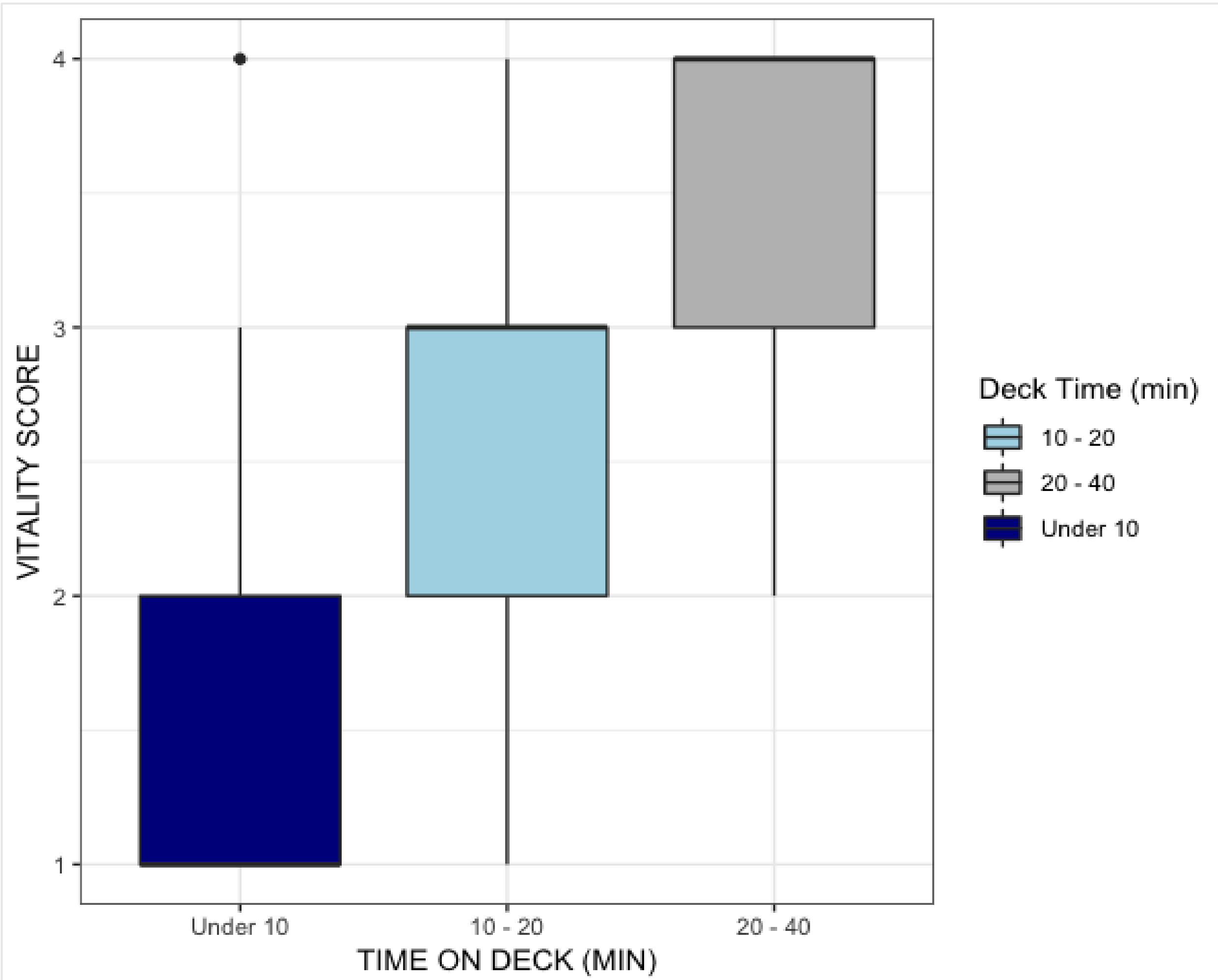


***Figure 15** Box plot of the vitality scores recorded per 10 minute interval from zero to 40 minutes recorded from trips F6, F7 and E1. 20 – 30 and 30 – 40 minute groups were combined to increase the sample size.*

Table 9 *Paired comparisons of vitality scores for fish between the intervals of deck time using a Wilcoxon pairwise comparison test; where p<0.05 indicates the time on deck per fish within these two vitalities differ significantly.*

Deck Time (min)	p values
0-10 and 10-20	**<0.01**
0-10 and 20-40	**<0.01**
10-20 and 20-40	**<0.01**

3.5 Injury/ Reflex Assessment

The most common injuries observed for all species were 'Other Injuries' (Figure 16). Less than 10% of fish suffered from stomach reversion or eye bulging injuries. The most common injuries within the 'Other Injuries' category, were abrasions, fin fraying and bleeding. The total catch suffered from greater than 53% reflex impairment in all reflex response categories. Fin dive, Head Grab, Evasion and Righting were impaired in >75% of fish.

The most common injury observed in plaice was also 'other injuries, however 67% of plaice assessed suffered from 'Other Injuries' in comparison to 47% in the total catch (Figure 16). The most common injuries observed in plaice were Fin fraying, abrasions, and scale loss. The absence of respiration was only observed in 29% of plaice. The other reflex categories ranged from 52% to 64% impairment.

Although 'other injuries' were found in 67% of plaice these injuries were not as severe in relation to impaired reflex responses in plaice. In comparison to the total catch, plaice suffered from more injuries over all, but reflex responses were not impaired as much as other species (Figure 16).

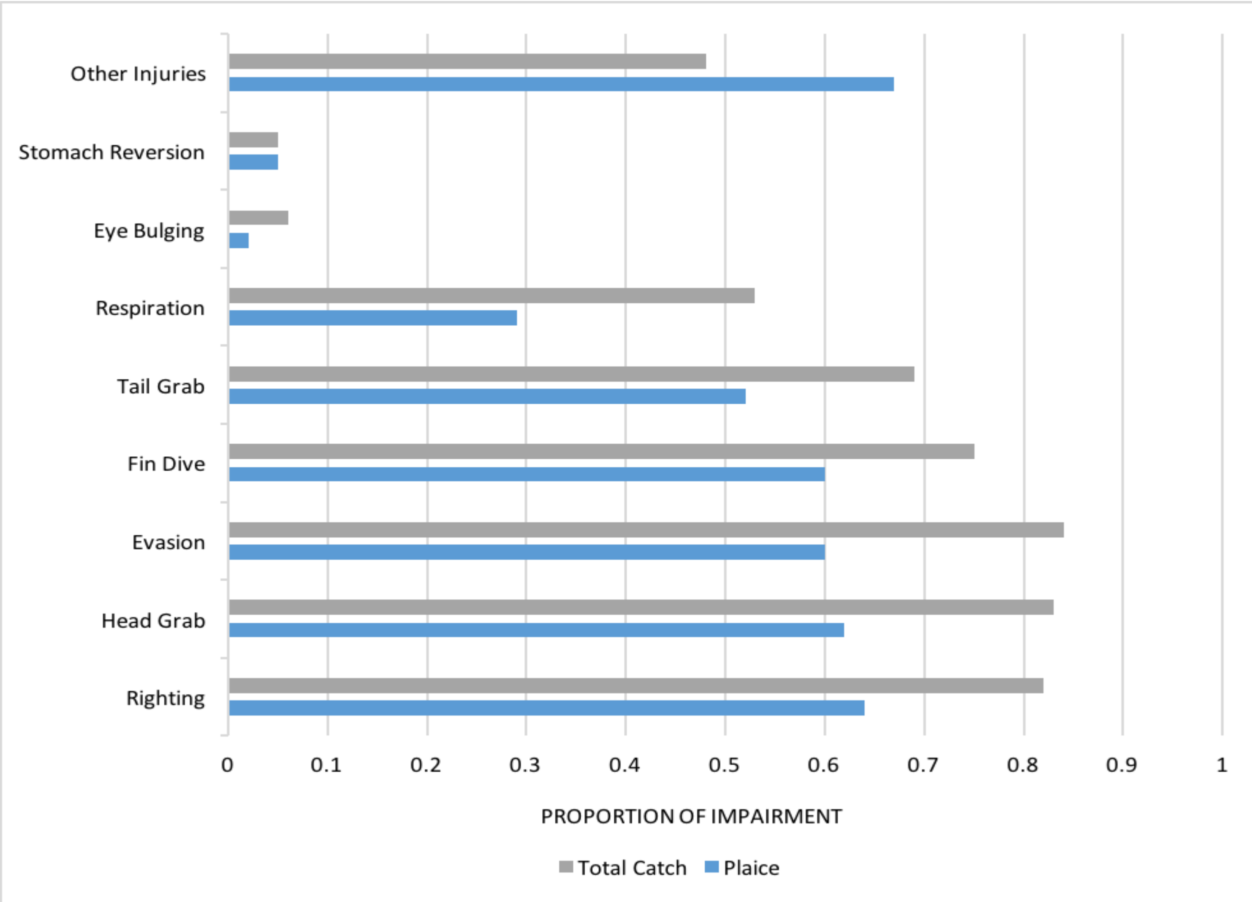


Figure 16 *The proportion of reflexes impaired and injury presence in plaice and the total catch.*

The reflex and injury scores were combined to create a Reflex and Injury impairment score (RI score). The relationship between RI score and the he vitality scores were examined for plaice. A non-parametric Kruskal Wallace test was conducted to compare median RI scores and vitality scores. There was a significant difference in median RI scores per vitality score (χ^2 (3) =1290.1, p<0.01). Post Hoc comparisons using a pairwise comparisons test were carried out. There was a significant difference between median RI score and vitality score (Table 10). The median RI score for vitality score 1 was 0.08, the median RI score for vitality score 2 was 0.23, the mean RI score for vitality score 3 was 0.61 and the median RI score for vitality score 4 was 1 (Figure 17).

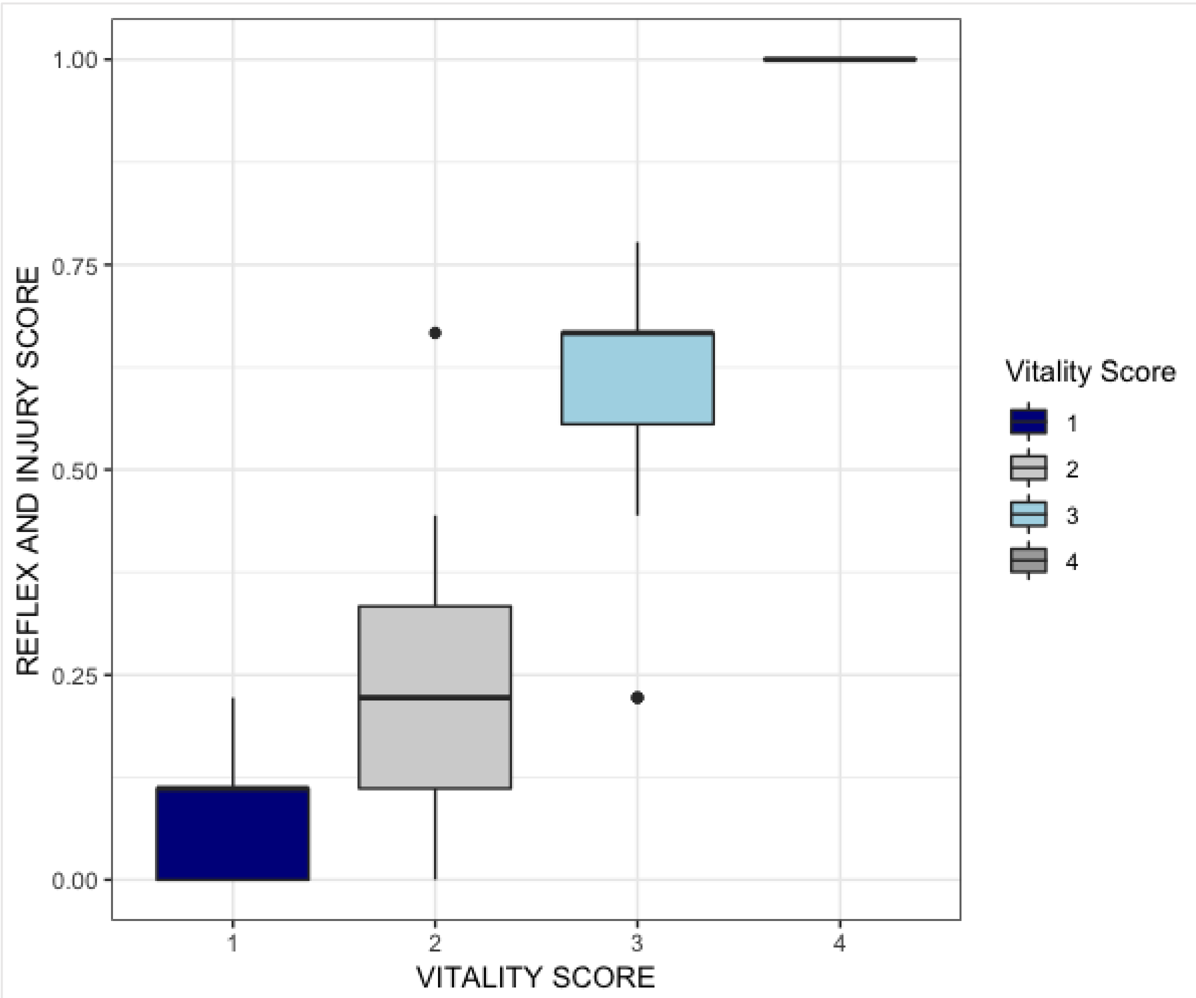


Figure 17 *Box plot of the combined Reflex and Injury Score recorded compared to the Vitality Score recorded for each plaice assessed.*

Table 10 *Paired comparisons of RI Scores for fish between the vitality scores using a Wilcoxon pairwise comparison test; where p<0.05 indicates the mean RI Score of fish within these two vitalities differ significantly.*

Vitality Scores	p values
1 and 2	**<0.01**
1 and 3	**<0.01**
1 and 4	**<0.01**
2 and 3	**<0.01**
3 and 4	**<0.01**

3.6 Survivability

A total of 44 plaice were retained for captive observation from two of the fishing trips. The length distribution was comparable to the total catch of plaice assessed during the study (20cm- 41.5cm; mean length 28.3 cm). Fish were observed in captivity for 192h. Plaice survival reached asymptote at 144 hours when 4 plaice or 11% had survived the capture, transport, and captivity process. Fish survival rates retained from both fishing trips were combined to make a total onshore survival rate. After 196 hours of observation, 4 plaice or 11% of the observed fish were still alive.

Using the K-M curve, vitality scores 1, 2, and 3 were found to be significantly different ($\chi^2 = 19$, Df=2, $p<0.01$) (Table 9). The 4 fish that survived were all assessed as vitality 1. The fish in vitality 2 reached 0% survival at 120hrs and vitality 3 reached 0% at 48hrs (Figure 18). The highest mortality rates were observed in the first 48 hours of captive observation. Vitality 1 had a mortality rate of 45%, vitality score 2 had a mortality rate of 71% and vitality 3 had 94% mortality. Plaice in vitality score 1 have the highest potential for surviving after discard.

The fishing trips that plaice were retained for captive observation were F6 and E1. We originally compared the relationship between the normal fishing practice survival rates and experimental survival rates, however no significance differences were found between the two trips. The survival rates were combined to increase the sample size for each vitality score group.

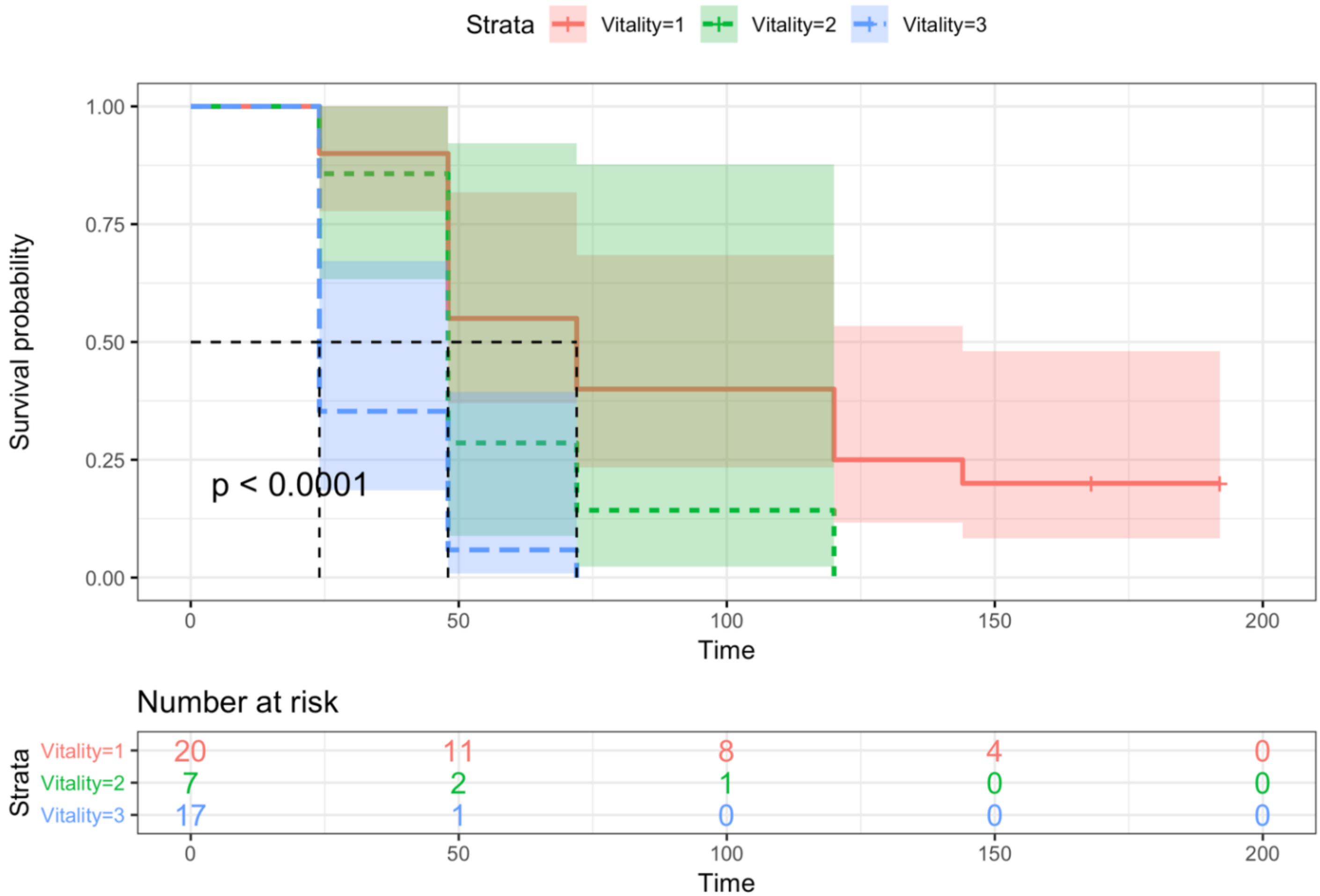


Figure 18 *Kaplan-Meier estimates of survival are shown as solid lines and 95% pointwise confidence intervals as dashed lines. The small crosses at the end and along the lines mark times when one or more surviving fish stopped being observed. The x-axis represents the time when the fish was first assessed to the time of death or at the end of observation. The umber at risk are the individual fish still alive at that time (hrs).*

Table 11 *Paired comparisons of survival curves for fish between the vitality scores using a log-rank test; where p<0.05 indicates the survival probability of fish with these two vitalities differ significantly.*

Vitality Score	p Value
1 & 2	0.114
1& 3	**<0.01**
2 &3	**0.035**

4. Discussion

Bycatch assessment studies in the queen scallop fishery have been undertaken around every three years, previously in 2017, 2014, 2012, and 2009. In this study the proportion of bycatch relative to the total quantity of catch of all fishing trips was 5%. Although information on the percentage of bycatch in proportion to the catch in 2017 isn't available, Boyle and Thompson (2012) found that the bycatch accounted for 6.8% of the total catch and the 2014 Bangor University Fisheries and conservation report found that the bycatch accounted for 7.1% of the total catch (Bloor et al., 2014).

Southworth (n.d.) assessed bycatch in three out if the five fishing grounds, not including East Douglas. Southworth (n.d.) found the most common species caught in Chickens, Targets and Ramsey were similar to this study. The most common non quota species were the small spotted cat shark (*Scyliorhinus stellaris)*, grey gurnard (*Trisopterus cuculus*) and red gurnard (*Aspitrigla minutus)*; and quota species were plaice (*Plueronectes platessa*), dab (*Limanda limanda)* and lemon sole (*Microstomus kitt*). Other quota species we caught were cod (*Gadus morhua)*, haddock (Melanogrammus aeglefinus), whiting (*Merlangius merlangus)* and dover sole (*Solea* solea). Although these fish were caught in a relatively low quantity in this study, Southworth (n.d.) conducted their study at Chickens, Targets and Ramsey and caught a greater quantity of haddock. Bloor et al. (2015) caught higher quantities of dab, cod, plaice and lemon sole. The area that is fished is a major factor influencing the fish species and quantities caught. Although the Isle of Man territorial sea isn't a vast area, each fishing ground has unique characteristics that influence the fish species that are most abundant. This study only surveyed in East Douglas, as a result limiting the assessment to one area. The Isle of Man territorial sea is a habitat for many juvenile fish, supporting stocks early in their life cycle. The rocky shore is home to many juvenile gadoid fish, like cod, whiting, poor cod (*Trisopterus minutus)*, pollock (*Pollacius pollachius*), and saithe (*Pollachius virens*), and the sandy and muddy shores are often habitats for juvenile plaice, and a nursery ground for dover sole and dab. If bycatch rates for these species increase in future years, the implications could be severe. Even though there hasn't been a commercial fishery in the Isle of Man territorial sea specifically for fish species since 1990, when stocks became unviable for the whitefish fishery, there are implications for other fisheries around the Irish sea that are supported by the nursery and juvenile grounds in the Isle of Man (Hanley et al., 2013).

In the bycatch assessment conducted in this study only a few species of fish, when brought on deck and assessed, were alive. The small spotted cat shark, plaice, bull huss *(Scyliorhinus stellaris*) and Cuckoo Ray *(Leucoraja naevus)* were the only species with a range of vitality scores. Plaice and cuckoo rays were the only quota species that showed evidence of surviving after discard based on the on-deck condition. All other species caught were assessed as dead or very few alive. Many fish are very susceptible to experiencing severe trauma when caught in trawls. There are several factors that can influence the condition the fish are landed in. Certain taxa are more susceptible to specific types of injures and are more likely to face mortality because of their biology and physiology. Barotrauma is trauma from the pressure change, often resulting in a ruptured gas bladder, stomach reversion, a prolapsed cloaca, and bulging eyes (Broadhurst et al., 2006; Benoit et al., 2013). These injuries significantly increase the chance of mortality (Benoit et al., 2013). Crushing injuries in the trawl can result in scale loss, abrasions, and wounding. These injuries may not always result in mortality on deck, but can lead to a higher susceptibility to disease and infection, therefore, a higher probability for delayed mortality (Suuronen et al., 1996a, 1996b). All of these injuries can have an impact on the condition of the fish, however, the physiological response to stress fish experience when immersed in a hypoxic environment in the trawl can be severe enough to result in mortality (Methling et al., 2017). Due to the combination of both injuries endured and stress, it's no surprise there was such a high quantity of species recorded as dead on deck. The few species that were alive were the small spotted cat shark, plaice, bull huss, and the cuckoo ray. In comparison to more active fish species, Sedentary fish species have different hormonal responses to stress (Benoit et al., 2013). Although three of these species are elasmobranchs and plaice is a flat fish, they live similar sedentary lifestyles. Some sedentary fish species are capable of metabolic depression and activating an anaerobic metabolism to have a greater tolerance of hypoxic environments (Benoit et al., 2013). Flatfish in particular, typically have lower aerobic capacities. They have the ability to retain lactate in their muscle rather than releasing it into their circulation for further metabolism (Turner et al., 1983). These physiological traits in sedentary species would increase the likelihood of survival when caught, brought on deck, and discarded.

Out of all the species assessed the only quota species viable for a survivability study would be cuckoo rays and plaice. Only 19 cuckoo rays were caught and assessed, however, only one ray was recorded as dead. There is currently an exemption for cuckoo rays in the Irish Sea, although the exemption will expire in future years. The cuckoo ray is a species that has a high likelihood receive another discard exemption if this small sample is a representative of the entire species.

Plaice were the most common quota species caught in this study and had the most individuals in vitality groups 1, 2 and 3. Only 20% of plaice assessed were dead when brought on board. The most common injuries in plaice were fin fraying, abrasions and scale loss. In comparison to all other species, where the most common injuries were abrasions, fin fraying and bleeding. Eskelund, et al. (2019) assessed plaice in nephrops fisheries and recorded similar common injuries: the most common being scale loss and fin fraying. Catchpole, et al. (2015) also found similar injury results in otter trawl trials. Interestingly, plaice, overall, endured more injuries than any other species however this did not seem to effect the impairment of reflexes. The total fish species assessed had less injuries, but over 75% of fish suffered from impaired fin dive, head grab, evasion and righting.

The three stages of the fishing process that have an effect on the likelihood of survival are being caught in the trawl, bringing the fish on deck and discarding the fish. The injuries listed above will arise from the time spent in the trawling net. However, when the fish were brought on deck there were many variables that were thought to effect the vitality of fish. In this study, tow length, catch weight, the total length of the fish and time on deck were measured. As the time on deck increases, so does the time that the plaice are exposed to air. Several studies show correlations between air exposure and discard mortality (Humborstad et al., 2009 ; Benoit et al., 2013; Methling et al., 2017; Eskelund et al., 2019). In this study, when fish were assessed between 0 to 10 minutes, 10 to 20 minutes and 20 to 40 minutes there was a significant difference between the median vitality scores for each range as well as a positive correlation between the time on deck and vitality scores. Angus and Macdonald (2017) reported similar numbers from zero to 10 minutes with greater than 90% of plaice in vitality groups 1 and 2. As time on deck increased, numbers declined rapidly in vitality scores 1 and 2 and increased in vitality scores 3 and 4. Angus and Macdonald (2017) also found that plaice assessed up to 90 minutes have a potential of being in vitality score 1 and 2. Several studies have found that plaice have the ability to tolerate the capture process and survive if time on deck is minimized (Catchpole et al., 2015; Morfin et al., 2017; Eskelund et al., 2019;).

The overall short-term discard survival of this trial was estimated at 11%. This survival estimate is on the lower end of survival rates in previously examined discard survival proportions from otter and beam trawls (Depestele et al., 2014; Morfin et al., 2017; Eskelund et al., 2019). The survival curve in this study reached asymptote at 144 hours, suggesting that the observation period of 192 hours was a sufficient amount of time to observe short term discard mortality. Although, a longer observation period could be useful to account for delayed mortality from disease, infection or starvation.

In comparison to Milner, et al. (1993), Morfin, et al. (2017) and Oliver, et al. (2018) this study had a very low discard survival rate. Milner, et al. (1993) estimated 63% to 93%, Morfin, et al. (2017) and Oliver et al. (2018) estimated 45% and 43%, respectively, in July. These studies were all conducted in fisheries that target fish species, which could explain the higher survival estimates. Eskelund, et al. (2019) conducted their study in a nephrops targeted fishery, estimating a lower survival rate at 15%. There has not been another plaice study conducted in a scallop fishery to compare these survival rates, however a nephrops fishery would have the most similar stressors in comparison to a fishery that targets predominantly fish species. The sharp edges and hard exoskeleton can be comparable to queen scallops. Oliver, at al. (2018) excluded any catches that contained nephrops because of the negative impact they have on the condition of fish in the catch. Although catch weight was not shown as a significant factor in predicting vitality score in this study, it can be assumed that the crushing weight and hard and sharp queen scallop shells do play a part in the condition the fish are in when brought on deck.

This study was conducted in July and August, although air and sea floor temperature was not a factor measured in this study, there are implications that the extreme temperature change from sea floor to ambient temperature on deck had an effect on the vitality scores recorded. The average air temperature for July and August is 18 ° C and the average sea surface temperature is 14 ° C. Several studies compared survival rates in winter and survival rates in summer (e.g. Morfin et al., 2017; Kraak et al., 2018). When survival studies were conducted in summer when sea surface temperature and air temperature are at their highest, lower survival rates were found (Morfin et al., 2017; Oliver et al., 2018). Kraak, at al. (2018) found a strong correlation between air temperature and plaice mortality, as the vitality score increased from 1 to 4, the mortality increased as well. There is reason to assume that the mortality and low survival rates were influenced by the change in air temperature with prolonged time on deck. Further investigation is required to examine the extent of the influence of temperature in the Irish Sea.

During the assessment of bycatch, the injuries and reflexes were recorded, as well as an overall vitality score which incorporated injury and vigor. When comparing the vitality scores and median combined reflex and injury score (RI score). There was a significant difference between each median RI score and the vitality score. Although they were measured separately, incorporating an injury and reflex assessment to select an appropriate vitality score provides the vitality scoring method with measurable variables, rather than being strictly subjective. Morfin et al. (2017) and Catchpole et al. (2015) used only a vitality index to assess fish and Eskelund et al. (2019) only used RI scoring. Although these still have interesting results, combining the two methods creates a less subjective method with variables that can be repeated by more than one person.

4.1 Limitations

From the very beginning of this study many issues arose, from onboard procedures to the tanks onshore, this study proved to be very logistically challenging. A control experiment was not conducted because of the time constraints, however, it is necessary to assume that onboard and onshore conditions did not affect the survival rate of the plaice.

Onboard the F.V. Benolas, a 13 m vessel, space was limited. Originally, four 100L insulated fish tubs were to be used to retain plaice throughout the day during each fishing trip. In reality, as we were conducting this study during normal commercial fishing practice, as scallops were landed and stored on deck there was not enough space for storing the fish and the landed bags. As a contingency plan, plaice were stored in a 200L bongo and in two 70L flexi tubs. These conditions were not optimal. Although plaice are a hardy species, the conditions on deck most likely added unmeasurable stress to each fish, therefore effecting their overall survival rate.

Transportation from the port to the tanks in peel was likely another added stressor. The DEFA inland fisheries department loaned their tank and truck. The tank was filled in the harbor before the boat docked at the port. The water in the tank was the same temperature as the sea surface temperature, but with increased air temperature and sea surface temperature this could have effected and added extra stress to the plaice.

The holding tank setup at Isle of Man Seafood (ISF) in Peel, supplied by the Manx Fishing Producers was not ready for fish until mid-July. The system to monitor water conditions failed, and was not able to be utilized by this point. The room temperature and water conditions were monitored by the Isle of Man Sea Food (ISF). The tank used a recirculating sea water system with cascade flow, a protein skimmer and bio filter monitored by the ISF. Due to this it was not possible to change water conditions during the experiment. The top three layers of the tanks were used for plaice survival observations, however, the ISFC used the bottom layer of the tank to keep lobster (*Homarus gammarus*). The tank system was a closed recirculating system, the effects of the lobsters is unknown, but it was assumed that they added extra stress to the plaice in the captive observation experiment. All of the challenges that were faced throughout the project had an impact on the overall survival rate, therefore it is safe to assume that the rate presented in this study is the worst case scenario for discard survival rates of plaice in the Isle of Man queen scallop fishery. Further investigation is required to alleviate these confounding factors.

5. Conclusion

This research aimed to quantify discard survival rate of plaice (*Plueronectes platessa)* and the factors that influence the survival rate of plaice onboard a commercial queen scallop vessel. Based on the onboard vitality assessment and reflex and injury assessment we found that 47.8% of plaice that are brought onboard in a commercial trawler are in excellent/good condition. Although the captive observation experiment resulted in an extremely low survival rate of 11%, many interesting results were found. Deck time had the biggest influence on the vitality score, therefore on discard survival rate. When fish were assessed within 10 minutes, 75% of fish were in excellent/good condition. During all fishing trips except E1, normal fishing practice procedure was followed. Before sorting the catch, the crew redeployed the net leaving the fish on deck exposed to the elements (air exposure) for a minimum of 10 minutes. To potentially increase the survival rate for future studies and for exemption purposes sorting the fish within 10 minutes is critical.

Altering fishing practice is an issue that needs to be addressed, although it seems easy enough to sort the catch then redeploy the net; fishermen potentially lose valuable time that they could be fishing. At the moment, the amount of plaice that has been caught this season is not anywhere near the quota that the Manx Fishing Producers own. However, this year is unique because East Douglas was the only fishing ground used. Other common fishing grounds fished in previous years could have a higher density of plaice. Unfortunately, the quota for queen scallops is at an all-time low since 1993, as a result fishing intensity has decreased fishermen this season were reaching weekly quota in one day of fishing sometimes two. As a result, of a decrease in fishing intensity, the possibility of reaching the quota for plaice is unlikely in the near future. Interestingly, 63% of plaice landed were over minimum conservation size. With slight changes to fishing practice onboard, the landed plaice could be sold for human consumption, creating another source of additional income for fisherman.

Based on the findings of this study, in order to apply for an exemption in the future further investigations are necessary. These results should be treated as preliminary findings. For future studies onboard, rather than working alongside fisherman, a purely scientific survey aboard a commercial vessel should be arranged in order to have sufficient space for assessment and optimal storage of the plaice. When transporting the plaice, limiting the amount of times they are transferred from tank to tank would reduce the stress plaice endured. To ensure accurate discard survival estimates, the onshore tanks must have appropriate means to monitor tank conditions and alter tank conditions when they are not optimal to keep stress to a minimum and give the plaice the best chance at survival.

References

Acoura Marine. (2016). MSC Sustainable Fisheries Certification Surveillance Visit- Report for the Isle of Man Queen Scallop Trawl Fishery.

Alverson, D., Freeberg, M., Murawski, S., & Pope, J. (1996). A global assessment of fisheries bycatch and discards, 339, 233. FAO.

Angus, C., & Macdonald, P. (2017). Identifying potential candidates species in the Shetland demersal fishery for a discard ban survival exemption.

Benoît, H. P., Hurlbut, T., & Chassé, J. (2010). Assessing the factors influencing discard mortality of demersal fishes using a semi-quantitative indicator of survival potential. Fisheries Research, 106(3), 436-447. Retrieved September 9, 2019, from 10.1016/j.fishres.2010.09.018

Benoît, H. P., Plante, S., Kroiz, M., & Hurlbut, T. (2013). A comparative analysis of marine fish species susceptibilities to discard mortality: effects of environmental factors, individual traits, and phylogeny, 70(1), 99-113. Retrieved September 9, 2019, from 10.1093/icesjms/fss132

Bloor, I., Dignan, S., Murray, L., & Kaiser, M. (2015). Bycatch Survey- Isle of Man Queen Scallop Otter Trawl Fishery Summer 2014. Bangor University.

Bloor, I., & Kaiser, M. J. (2016). The Isle of Man Aequipecten opercularis fishery stock assessment 2016. Fisheries Conservation Report No. 66, Bangor University, 1-36.

Boyle, K. and Thompson, S. (2012). Bycatch Survey- Isle of Man Queen Scallop Otter Trawl Fishery Summer 2012. Bangor University Fisheries and Conservation Report No. 19. 67pp.

Broadhurst, M. K., Suuronen, P., & Hulme, A. (n.d.). Estimating collateral mortality from towed fishing gear, 7(3), 180-218.

Cashion, T., Al-Abdulrazzak, D., Belhabib, D., Derrick, B., Divovich, E., Moutopoulos, D., Noel, S., Palomares, M. L., Teh, L., & Zeller, D. (2018, January 1). A Global Fishing Gear Dataset For Integration Into The Sea Around Us Global Fisheries Databases. Fisheries Centre Research Report.

Catchpole, T., Randall, P., Forster, R., Smith, S., Ribiero Santos, A., Armstrong, F., Hetherington, S., Bendall, V., & Maxwell, D. (2015). Estimating the discard survival rates of selected commercial fish species (plaice - Pleuronectes platessa) in four English fisheries, (Cefas Report).

Davis, M. W. (2002). Key principles for understanding fish bycatch discard mortality. Can. J. Fish. Aquat. Sci., 59(11), 1834-1843. Retrieved May 8, 2019, from 10.1139/f02-139

Depestele, J., Desender, M., Benoît, H. P., Polet, H., & Vincx, M. (2014). Short-term survival of discarded target fish and non-target invertebrate species in the “eurocutter” beam trawl fishery of the southern North Sea. Fisheries Research, 154, 82-92.

Eskelund, M., Methling, C., Vilhelm Skov, P., & Madsen, N. (2019). Survival of discarded plaice (Pleuronectes platessa) from Norway lobster (Nephrops norvegicus) otter-trawl fishery. J Appl Ichthyol, 35(3), 645-654. Retrieved September 9, 2019, from 10.1111/jai.13888

FAO. (2018). The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals.

Feathers, M. G., & Knable, A. E. (1983). Effects of Depressurization Upon Largemouth Bass. North American Journal of Fisheries Management, 3(1), 86-90. Retrieved May 8, 2019, from 10.1577/1548-8659(1983)32.0.co;2

Fox, C. J., McCloghrie, P., & Nash, R. D. (2009). Potential transport of plaice eggs and larvae between two apparently self-contained populations in the Irish Sea. Estuarine, Coastal and Shelf Science, 81(3), 381-389. Retrieved May 8, 2019, from 10.1016/j.ecss.2008.10.024

Hall, M. A., Alverson, D. L., & Metuzals, K. I. (2019). By-catch: Problems and Solutions. Marine Pollution Bulletin.

Hanely, L., Gell, F., Kennington, K., Stone, E., Rowan, E., McEvoy, P., & Brew, M. (2013). Manx Marine Environmental Assessment. Isle of Man Marine Plan. Isle of Marine Government.

ICES. (2016). Report of the Workshop on Methods for Estimating Discard Survival 5 (WKMEDS 5),23-27 May 2016, Lorient, France. ICES CM 2016/ACOM:56. 51.

Juhl, R., & Drummond, S. (1977). Shrimp by-catch investigation in the United States of America, 213-220. FAO.

Kraak, S. B. M., Velasco, A., Fröse, U., & Krumme, U. (2019). Prediction of delayed mortality using vitality scores and reflexes, as well as catch, processing, and post-release conditions: evidence from discarded flatfish in the Western Baltic trawl fishery, 76(1), 330-341.

Maclean, J. (1972). An analysis of the catch by trawlers in Moreton Bay (Qld.) during the 1966-67 prawning season, (98), 35-42.

Methling, C., Skov, P. V., & Madsen, N. (2017). Reflex impairment, physiological stress, and discard mortality of European plaice Pleuronectes platessa in an otter trawl fishery, 74(6), 1660-1671.

Milner, R., Whiting, C., & Howlett, G. (1993). Estimation of dis-card mortality of plaice from small otter trawlers using tagging and cage survival studies. ICES. Council Meeting Papers, ICES CM 1993/G:24.

Morfin, M., Kopp, D., Benoit, H., Mehault, S., Randall, P., Foster, R., & Catchpole, T. (2017, January 1). Survival of European plaice discarded from coastal otter trawl fisheries in the English Channel. ScienceDirect .

Morfin, M., Kopp, D., Benoît, H. P., & Méhault, S. (2019). Comparative assessment of two proxies of fish discard survival. Ecological Indicators, 98, 310-316. Retrieved September 9, 2019, from 10.1016/j.ecolind.2018.10.060

Morfin, M., Méhault, S., Benoît, H. P., & Kopp, D. (2017). Narrowing down the number of species requiring detailed study as candidates for the EU Common Fisheries Policy discard ban. Marine Policy, 77, 23-29. Retrieved May 8, 2019, from 10.1016/j.marpol.2016.12.003

Murray, L. (2013). The Isle of Man Aequipecten opercularis fishery stock assessment 2013.

Official Journal of the European Union. (2013). (EU Regulation No. 1380/2013 Article 26. EU.

Oliver, M., McHugh, M., Murphy, S., Browne, D., & Cosgrove, R. (2018). Plaice survivability in the Irish otter trawl fishery. BIM.

Rihan, D. (2018). Research for PECH Comittee- Landing Obligation and Choke Species in Multispecies and Mixed Fisheries- The North Western Waters, European Parliament, Policy for Structural and Cohesion Policies, Brussels.

Saila, S. (1983). Importance and assessment of discards in commercial fisheries, 1-62. FAO.

Seafish. (n.d.). The Landing Obligation Made Simple. Retrieved May 8, 2019, from https://www.seafish.org/media/Publications/Landing_Obligation.pdf

Seidel, W. (1975). A shrimp separator trawl for the southeast fisheries, (4), 94-99. Proc. Gulf Caribb. Fish. Inst.

Silva, J., Ellis, J., & Ayers, R. (2013). Length-weight relationships of marine fish collected from around the British Isles, 150, 109. CEFAS.

Southworth, L. (n.d.). Trialling innovative disruptive technology to reduce bycatch in the Isle of Man queen scallop (Aequipecten opercularis) trawl fishery. Retrieved May 8, 2019, from

Stiles, M. L., Stockbridge, J., Lande, M., & Hirshfield, M. F. (2010). Impacts of Bottom Trawling on Fisheries, Tourism, and the Marine Environment. Oceana.

Suuronen, P., Erickson, D. L., & Orrensalo, A. (1996a). Mortality of herring escaping from pelagic trawl codends. Fisheries Research, 25(3-4), 305-321. Retrieved September 9, 2019, from 10.1016/0165-7836(95)00446-7

Suuronen, P., Lehtonen, E., Tschernij, V., & Larsson, P. (1996b). Skin injury and Mortality of Baltic Cod escaping from trawl codends equipped with exit windows. Archive Fishery and Marine Research, 44, 165-178.

Szostek, C. L., Murray, L. G., Bell, E., Lambert, G., & Kaiser, M. J. (2016, November 10). Regional variation in bycatches associated with king scallop (PectenmaximusL.) dredge fisheries. Science Direct.

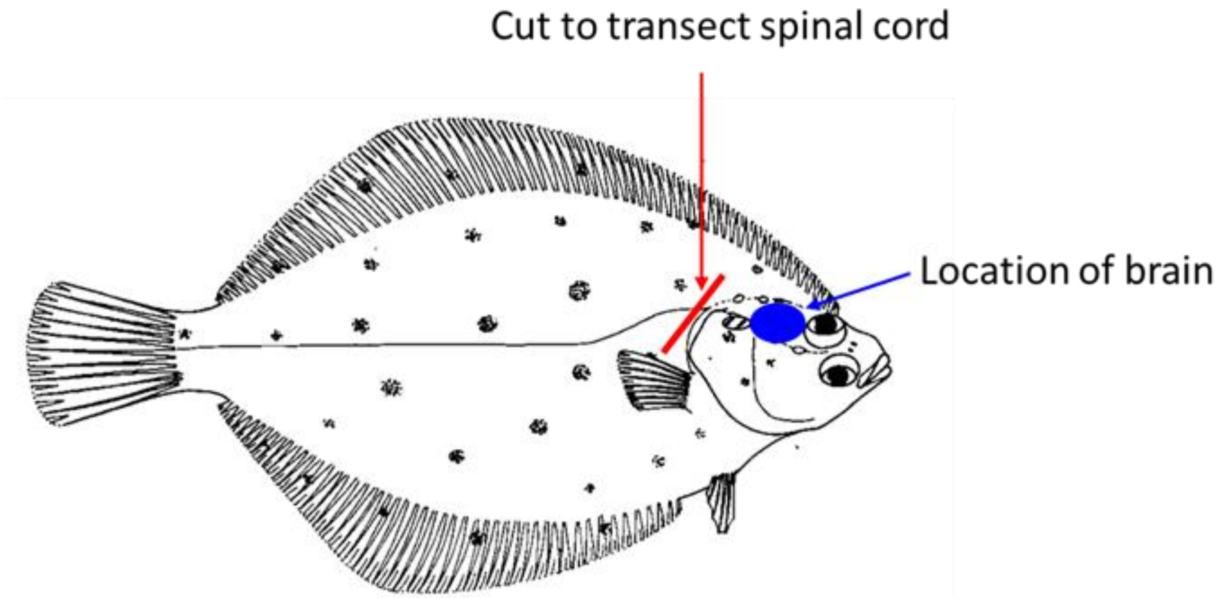
Turner, J., Wood, C., & Hobe, H. (1983). Physiological consequences of severe exercise in the inactive benthic flathead sole (Hippoglossoides elassodon): a comparison with the active pelagic rainbow trout (Salmo gairdneri). Journal of Experimental Biology, 104, 269-288.

Van Beek, F., Van Leeuwen, P., & Rijnsdorp, A. (1990). On the survival of plaice and sole discards in the otter-trawl and beam-trawl fisheries in the North Sea. Netherlands Journal of Sea Research, 26(1), 151-160.

Wassenberg, T., & Hill, B. (1989). The effect of trawling and subsequent handling on the survival rates of the by-catch of prawn trawlers in Moreton Bay, Australia. Fisheries Research, 7(1-2), 99-110.

Wassenberg, T., & Hill, B. (1993). Selection of the appropriate duration of experiments to measure the survival of animals discarded from trawlers. Fisheries Research, 17(3-4), 343-352.

Appendix A



Appendix A *Diagram of the regions to transect spinal cord and destroy the brain.*

1. Overdose
2-Phenoxyethanol – add 0.6 mL per liter of seawater. Immerse fish until gill ventilation has stopped and then leave the fish for 5 minutes. Follow by physical destruction of the brain. [If necessary, increase the amount of anesthetic added to the sea water, as it is important that the fish lose consciousness and cease gill ventilation quickly]

2. Destruction of the brain
Remove fish from the bucket/tank and use a knife to transect the spinal cord and then destroy the brain as indicated on the following figure.

Appendix B

ONBOARD DATA SHEET

Date: **Vessel:** **Site:** **Tow:** **Measurer:** **Recorder:**

Species:																													
Fish No.																													
Total Length:																													
Vitatity Score:																													
RAMP:																													
Evasion	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Fin Dive	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Tail Grab	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Head Grab	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Righting	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Respiration	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Spiracle Closure (Ray)	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Startle Touch (Ray)	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Body Flex (Ray)	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Injury:																													
BE: Bulging eyes	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
BE: Corneal gas bubbles	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
BE: Subcutaneous gas bubbles	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
SR: Prolapsed cloaca	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
OI: Fin fraying	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
OI: Wounding	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
OI: Deep wounding	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
OI: Bleeding	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
OI: Mucus loss	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
OI: Scale loss	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
OI: Abrasion	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
OI: Predation by 'lice' or another, crab or seal	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
SR: Internal organs exposed	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Keep/Discard																													
Tank number:																													

General Comments:

Appendix B *The data sheet used for vitality, injury, and reflex response. BE: Bulging Eye, SR: Stomach Reversion, and OI: Other Injuries*

Appendix C

Survivability of Plaice Project: Tow Data

Isle of Man Government
PRIFYSGOL BANGOR UNIVERSITY

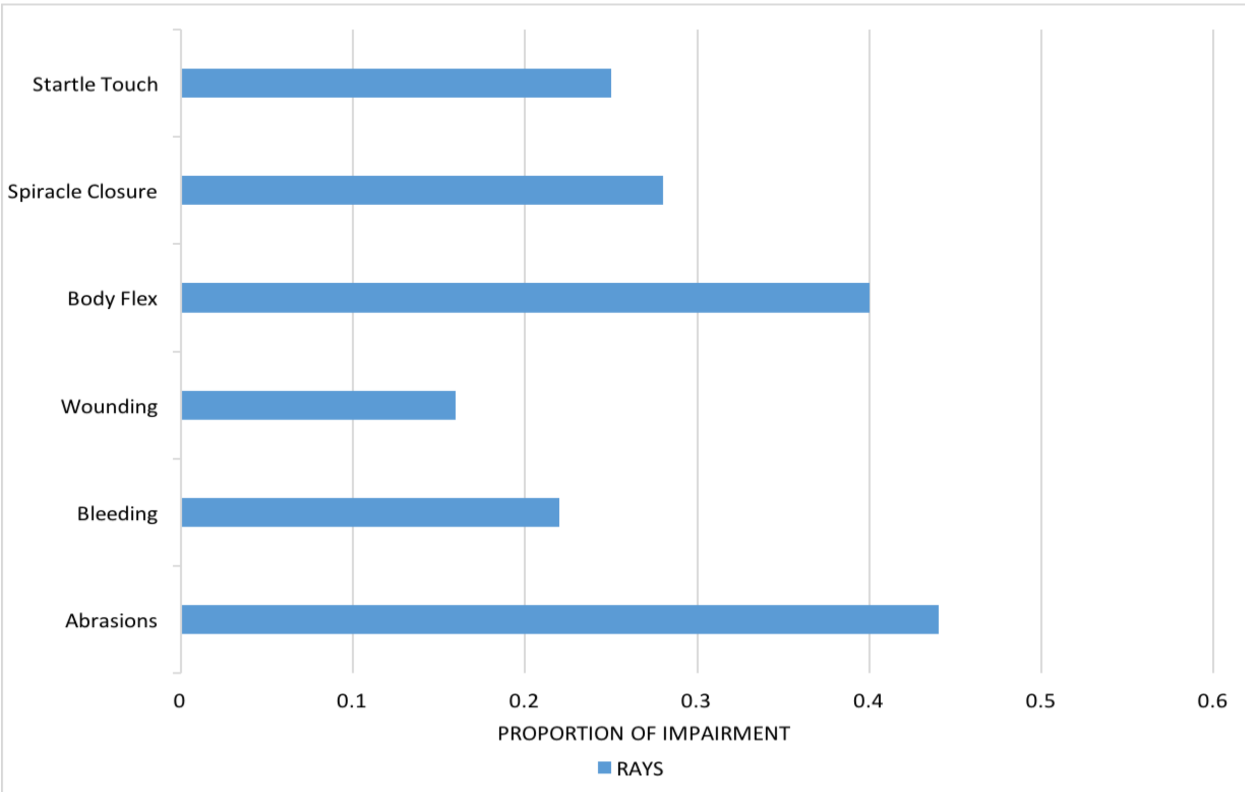
Vessel: **Skipper:** **Date:**

		Start			End			Live bag weight		
Tow	**Area**	**Time**	**Latitude**	**Longitude**	**Time**	**Latitude**	**Longitude**	**Depth (m)**	**Speed (knots)**	**Catch in bags***
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										

Data Entry Date:

Appendix C *The tow data sheet used during the survey.*

Appendix D



Appendix D *Reflex impairment and Injury proportions for rays caught during the project*.