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Estimating the discard survival rates of Common sole (*Solea solea*) and plaice (*Pleuronectes platessa*) in the Bristol Channel trammel net fishery and of plaice in the Bristol Channel otter trawl fishery

May 2015

Executive Summary

Discarding fish back to the sea that are caught during commercial fishing is often considered to be wasteful. On 1st January 2014, the latest reform of the EU Common Fisheries Policy (CFP) came into force and with it, under Article 15, a discard ban or landing obligation for regulated species (EU 2013). This discard ban is being phased in, and will cover all stocks of quota species in EU waters by the end of 2019. The new policy includes a number of exemptions including for '… species for which scientific evidence demonstrates high survival rates, taking into account the characteristics of the gear, of the fishing practices and of the ecosystem …'.

Research has shown that some discards survive and that in some cases, the proportion of discarded fish that survive can be substantial. The principle of the new CFP is to motivate fishers to avoid catching unwanted fish, whereby all fish are deducted from quota and fishers are obligated to land all catches of quota species. When a quota is exhausted, fishing operations are to cease. However, when avoiding unwanted catches is not possible, and the survival rate of discarded fish is shown to be high, then the return of those fish to the sea is justifiable and allowable.

There are some published discard survival data but the results are highly variable and available for only a few selected species and fisheries. Many factors, including biological attributes, environmental conditions and technical elements of the capture process, can affect the survival rate of discarded species. There is an immediate demand for scientific evidence on fishery specific discard survival rates, which consider the specific characteristics of the gear and fishing practices.

To meet this requirement, this project aimed to generate discard survival estimates for key species in Welsh fisheries. The specific objectives were to estimate discard survival rates of plaice (*Pleuronectes platessa*) and sole (*Solea solea*) in the trammel net fishery and of plaice in the otter trawl fishery, both fisheries operate off the south coast of Wales.

The structure of the project dictated the method that could be used, and this was developed within the project and in parallel with the ICES' Workshop on Methods to Estimate Discard Survival (WKMEDS). The approach selected was to assess the health and vitality of fish at the point of discarding during a representative range of conditions and combine this with survival rates of fish held in captivity, also selected from the catch with a representative range of vitality conditions, and combine these data to generate an overall weighted mean discard survival estimate.

This study demonstrated that after an observation period of 76-81h, the percentage of discarded plaice surviving normal commercial fishing practice was 49%. For Dover sole, after this period, discard survival was 21%. Model predicted final rates of discard survival were 3.6-39.1% for plaice and 18.6-20.3% for sole. Using captive observation results from a similar otter trawl fishery in a parallel study, combined with health assessment data in this study, produced inferred discard survival estimates for plaice caught by an otter trawler in the Bristol Channel of 75-88%.

All estimates, included avian predation but excluded other marine predation. Furthermore, the stressors exerted on the fish from the method applied, including temperature differences, handing, confinement, proximity with other fish, dissolved oxygen depletion, were likely to have induced some experimental mortality. Therefore, the results presented here should be interpreted as minimum estimates of discard survival, excluding marine predation.

There were many factors identified with the potential to effect survival and the relatively low number of replicates of the treatment made it difficult to identify the key influencing variables. However, some initial analysis showed that lower survival was associated with poor weather conditions. There was also an indication that higher survival was associated with monofilament nets compared with multi-monofilament nets, suggesting that changing the net design could provide a method to increase survival rates.

The survival estimates generated here are representative of the observed trips. Assumptions must be made in order to extrapolate the data to vessel and fleet level. However, this evidence is considered to provide scientifically robust estimates of discard survival and will inform fisheries managers of the appropriateness and potential to develop proposals to gain exemption from the landing obligation under the high survivability provision in European Regional Discard Plans.

Contents

Background

Discarding fish back to the sea that are caught during commercial fishing is often considered to be wasteful by fishers, conservationists and fisheries managers alike. On 1st January 2014, the latest reform of the EU Common Fisheries Policy (CFP) came into force and with it, under Article 15, a discard ban or landing obligation for regulated species (EU 2013). This discard ban is being phased in, beginning with pelagic fisheries from 1st January 2015 and will cover all stocks of quota species in EU waters (and those with a Minimum Landing Size in the Mediterranean) by the end of 2019. The final text agreed by the European Council and European Parliament includes a number of exemptions and flexibility tools. In paragraph 2(b), an exemption from the landing obligation is described for "*species for which scientific evidence demonstrates high survival rates, taking into account the characteristics of the gear, of the fishing practices and of the ecosystem*".

The discarding process can be defined by three phases: i) capture by fishing gear, ii) handling at the surface, and iii) release back to the sea. Research has shown that some discards survive the process. In some cases, the proportion of discarded fish that survive may be substantial, depending on the species, the characteristics of the vessels and other operational, biological and environmental factors. The principle of the new CFP is to motivate fishers to avoid catching unwanted fish, whereby all fish are deducted from quota and fishers are obligated to land all catches of quota species. When a quota is exhausted fishing operations are to stop. However, when avoiding unwanted catches is not possible, and the survival rate of discarded fish is high, then the return of those fish to the sea is justifiable and allowable.

The European Commission's Scientific, Technical, Economic Committee for Fisheries (STECF) concluded that selection of a value which constitutes "high" survival is subjective and likely to be species- and fishery-specific. The value will be based on "trade-offs" between the stock benefits of continued discarding and the potential removal of incentives to change exploitation pattern and how this contributes to the minimisation of waste and the elimination of discards (STECF 2014). Central to any proposal for an exemption for selected species or fisheries, is the requirement for clear, defensible, scientific evidence on discard survival rates.

Details of exemptions will be included in regionally formulated Discard Plans and Multi-Annual Plans, and these will be based on scientific studies that have been independently reviewed before the plans are assessed by the EU Commission. There are some published discard survival data but the results are highly variable and available for only few species and fisheries. Many factors, including biological attributes, environmental conditions and technical elements of the capture process, can affect the survival rate of discarded species. Article 15 notes that consideration must be given to the specific characteristics of the gear, fishing practices and of the ecosystem. Therefore, there is an immediate demand for scientific evidence on fishery specific discard survival rates.

Introduction

In March 2014, Cefas was contracted by the Welsh Government to conduct a series of meetings with the Welsh fishing industry to consider the impact of the landing obligation on the catching sector and to see what specific actions or operational studies could alleviate this. Based on these meetings, the main ‘choke species’ (those most likely to stop fishing activities) in Welsh inshore fisheries (using both static and towed gear) is anticipated to be plaice, but Dover sole and rays could also have the potential to limit fishing opportunities under the discard ban. There is a perception that certain areas of the sea bed off the coast of South Wales have a high abundance of smaller sized plaice and sole. These areas can be avoided to some degree, but in a mixed fishery of mostly quota species, where some quotas are low, the discard rates can be high despite efforts to avoid these fish. In such circumstances, even relatively low catches can risk a premature end to the fishing season.

There was considerable support from vessel operators in attendance at these meetings for a study of the survivability of unwanted fish that cannot be avoided, particularly plaice, in Welsh inshore fisheries. In recognition of this feedback from skippers, the Welsh Government agreed to fund a research study to estimate the survival of discarded fish, with a focus on plaice. This work is expected to complement other studies being undertaken in England and other Member States and the outputs are expected to guide Welsh fisheries managers on whether exemptions from the Landing Obligation should be applied for.

The original aim of this work was to obtain estimates of the survival of commercially caught and discarded plaice, Dover sole and rays. This would add to the evidence base on survival rates for these species summarised by STECF (Annex 1). It was evident early in the project that imitations in resources and time meant that we had to focus our attention on plaice and sole, these were prioritised as these had the most limited evidence base on survival whereas there is some evidence on the survival of discarded elasmobranchs. We aimed to estimate the survival rates across the full length range of the catch, under the assumption that fish at any length could be discarded and an exemption, if awarded, would not apply to fish only within a specific size range.

The original scope was to conduct experiments with both trawl caught fish and fish caught in gill nets. The experimental approach was to: i) conduct vitality assessments on board commercial vessel(s) during a representative range of conditions to quantify the reflex responses and physical damage of plaice and sole, after having been caught, handled and discarded; ii) conduct captive observations of individuals representing the various vitality levels to determine survival rates; iii) combine the vitality scores with the likelihood of survival for each vitality category to estimate a survival rate for the fishery.

The method used was that described in the report of the ICES Workshop on Methods to Estimate Discard Survival (ICES 2014). The report details the different approaches and the limitations of the conclusions that can be drawn from them (Table 1). The resources and, more critically, the time available in this project, dictated which of the approaches was used and would deliver the most robust evidence on discard survival estimates. The approach selected was to use vitality assessments on-board commercial vessels during a representative range of conditions and combining this with the captive observation of individuals with a different vitality levels to generate an overall weighted mean survival estimate. It was decided that added to this we would provide estimates of avian predation. This approach would provide an estimated discard survival rate, excluding marine predation, which is representative of the fishery.

Materials & Methods

Methodological approach

Research aimed at determining whether aquatic organisms survive, which have been caught and subsequently returned to the water, has been conducted over many decades. Although there have been reviews of the outputs from this work (Broadhurst et al. 2006, Revill et al. 2013), at the commencement of this project there had been no assessment of the scientific methods and approaches that can be used to meet this aim.

Around the same time as the start of this project, an ICES (International Council for the Exploration of the Sea) group on Methods to Estimate Discard Survival (WKMEDS) was initiated. The co-chair of ICES WKMEDS provided the scientific advice for this project. The ICES workshop was initiated to develop and describe the methods of best practice to quantify the survival of aquatic organisms caught and returned to the water. The catalyst for the creating the WKMEDS was the change in European Union fisheries policy, generating a need for guidance on how to investigate levels of discard survival, which was absent at the beginning of this project.

Therefore, during the course of this project, the methods of best practice to derive estimates of discard survival have been developing. The outputs from ICES WKMEDS have been applied to this project, moreover, the experiences from this project have been used to improve the guidance on how best to conduct discard survival assessments as reported by WKMEDS.

What is survival?

Before discussing the most appropriate methods for measuring the survival of discards it is useful to consider what we mean by "survival". The opposite of survival is death, which is a more definitive state to identify. So typically when we measure the "survival" of organisms, after they have experienced a particular treatment, we in fact quantify the number of individuals that died, based on a measurable definition of death. More precisely, we usually measure mortality rates, which is the number of individuals that die over a defined period of time. The inverse of the mortality rate is the survival rate.

Death is not normally an instantaneous process and some time will elapse between an initial exposure to a fatal stressor and the eventual cessation of life. Conversely, if observed long enough, any individual will die. Therefore, the timeframe over which observations are made will have an important influence on the estimated survival rate. There is no standard time frame for conducting a survival assessment, as it depends upon the species in question and the nature of the fatal effects, as well as the logistical limitations of the investigation. It is recommended that survival estimates should be presented with reference to the timeframe over which they were derived (e.g. "40% mortality, equating to 60% survival; 6 days observation").

What influences survival?

A fish or other animal will experience an array of different potentially injurious events, or stressors, throughout each phase of the capture process:

i) capture by the fishing gear;
ii) handling at the surface;
iii) release back to the water

In this context, an array of factors that could potentially influence discard mortality can be identified. These can be classified into three broad categories: biological (e.g. species, size, age, physical condition, occurrence of injuries), environmental (e.g. changes in: temperature, depth, light conditions) and technical (e.g. fishing method, catch size and composition, handling practices on deck, air exposure). Each stressor and the additive effects of multiple stressors will influence the survival of an individual.

How do you estimate discard survival?

There are three main approaches to conducting a discard survival assessment with the aim to estimate discard survival (ICES 2014):

(1) Vitality Assessment: where the health status of the subject to be discarded is scored relative to any array of indicators (e.g. activity, reflex responses and injuries) that can be combined to produce a vitality score. Where these scores have been correlated with a likelihood of survival they can be used as a proxy for survival likelihood;
(2) Captive Observation: where the discarded subject is observed in captivity, to determine whether it lives or dies; and
(3) Tagging and Biotelemetry: where the subject to be discarded is tagged and released, and either its behaviour/physiological status is remotely monitored (via biotelemetry) to determine its post-release fate, or survival estimates are derived from the number of returned tags.

In isolation, each method has limitations which can restrict the usefulness of the survival estimates they produce. However, when two or more of these methods are combined there is clear potential for considerable benefits. The benefits from this integrated approach include: reducing resource requirements, increasing the scope of the investigation, as well as improving the ac-curacy, precision and application of the survival estimates.

A synthesis of the approaches recommended to meet specific objectives to estimate discard survival is provided in Table 1 (ICES 2014). This table can be viewed either as means to identify a single approach to meet a specific objective or as a stepwise process, from 1 to 6. In general, the approaches taken from first to last increase in the level of resources and time required to achieve the stated goal. The outputs from each approach, range from providing estimates of the proportion of discards that appear dead or impaired at the point of discarding (referred to as "survival potential") (1), to generating a discard survival rate for a population that is representative of a fishery (6).

To conduct captive observation experiments to cover the full variability of conditions displayed by a fishery and species is practically difficult and expensive. Instead, the vitality of discarded individuals can be derived with relative ease from multiple fishing operations. In addition, estimates of survival for the different vitality levels can be derived from captive observation. The proportion of survivors at each vitality can produce a proxy estimate of survival that is representative of conditions in the fishery (excluding predation) by applying it to the vitality data. This technique also gives the relative influence on discard survival of selected variables.

The limitations and assumptions of the selected approach

1) The captive observation approach excludes predation and therefore may overestimate survival. The inclusion of estimates of avian predation in this project meant that it is only marine

predation that is not accounted for, but the levels of this are unknown. To account for marine predation requires the use of data storage or acoustic tagging techniques but these could not be delivered within the time and cost structure of this project.

2) When using captive observation, the period of observation will dictate the context of the survival estimates (e.g. 60% survival after 6 days). Ideally monitoring should continue until mortalities cease or at least slow down. However, in practice, the duration of monitoring has to be a trade-off between ideal scientific needs, the available resources (sea time, budgets and available tank time) and occurrence of confounding mortality not associated with the process of discarding. Therefore, if the observation period is too short, the survival estimates might be overestimated. Models to project forward from a survival probability curve were used to inform whether a longer observation period would have generated lower survival estimates (see Analytical methods section).
3) For survival estimates to be representative of the fishery, vitality data should be generated for fish discarded during all conditions of a fishery. However, because conditions are constantly changing, without a continuous vitality monitoring programme, the survival estimates may be representative only for the trips from which vitality data have been collected. To extrapolate the results to a fishery, it must be assumed that the combination and strength of stressors on the discarded fish are the same on all trips as those from which vitality data were collected.
4) It must be assumed that retaining fish in holding tanks does not have a recuperative effect and artificially increase survival. This was considered unlikely in this project - see below (5).
5) Holding wild animals in captivity can induce stress, which can potentially increase mortality in addition to the treatment effect. Moreover, physical damage from being held in tanks on-board a moving vessel, changes in salinity, light, pressure and temperature, and being held in close proximity with other fish, all exert stress on fish. When these stressors occur, they will likely have additive effects to the treatment stressors and reduce observed survival rates.
6) To be able to use the assessments of fish vitality as a proxy for survival when combined with captive observation results, two assumptions have to made:
    a) Scientific fieldworkers need to be able to assess the vitality of fish consistently, in time, in different conditions and between different workers. All the fieldworkers collecting data in this project underwent training in handling live fish and performing vitality assessments. One scientist oversaw all of the fieldwork.
    b) Most importantly, to be able to use vitality assessments as a proxy for survival, there must be a significant relationship between survival and vitality score. Therefore, the protocol used to generate vitality scores must deliver scores that can consistently predict survival likelihood. The results from the captive observation will determine whether assessed vitality is a good predictor of survival.

Table 1 - An overview of possible objectives for a survival assessment and the recommended approaches

Objective (for the selected species, variables & management unit)	**Suggested approach**	**Resource Implications**
1. To estimate discard survival potential for particular conditions	**Vitality assessment** on-board commercial vessel(s), with targeted observations of the factors that affect mortality.	**Personnel:** Trained observers & fishers **Specialist equipment:** None **Time frame:** hours to days for field trials
2. To estimate discard survival potential that is representative of the management unit	**Vitality assessments** on-board commercial vessels during representative range of conditions	**Personnel:** Trained observers & fishers **Specialist equipment:** None **Time frame:** hours to days for field trials
3. To estimate discard survival rate, excluding predation, for particular conditions	**Captive observation** of individuals under particular conditions	**Personnel:** Experienced researchers & fishers **Specialist equipment:** Containment facilities (e.g. aquaria & sea-cages) **Time frame:** days to weeks for monitoring period
4. To estimate discard survival rate, excluding predation, representative of the management unit	**Vitality assessments** on-board commercial vessel(s) during a representative range of conditions combined with **captive observation** of individuals representing the various vitality levels to generate an overall weighted-mean survival estimate	**Personnel:** Trained observers, Experienced researchers & fishers. **Specialist equipment:** Containment facilities **Time frame:** days to weeks for monitoring period
5. To estimate discard survival rate, including predation effects, for particular conditions	**Tagging/biotelemetry** on-board commercial vessel(s) under particular conditions	**Personnel:** Experienced researchers & fishers. **Specialist equipment:** Tags **Time frame:** days to months/years for monitoring
6. To estimate discard survival rate, including predation effects, representative of the management unit	Option 1: **Vitality assessment** on-board commercial vessel(s) during representative range of conditions combined with **tagging/biotelemetry** of individuals representing the various vitality levels on-board commercial vessel(s) to generate an indirect survival estimate	**Personnel:** Trained observers, Experienced researchers & fishers. **Specialist equipment:** Tags **Time frame:** days - months/years for monitoring
	Option 2: **Vitality assessment** on-board commercial vessel(s) during representative range of conditions combined with **captive observation** (to estimate short term mortality) and **tagging/biotelemetry** (to estimate conditional long-term mortality) of individuals representing the various vitality levels on-board commercial vessel(s) to generate an indirect survival estimate	**Personnel:** Trained observers, Experienced researchers & fishers. **Specialist equipment:** Tags, Containment facilities (e.g. aquaria & sea-cages) **Time frame:** days to months/years for monitoring

Specific study methods

Two studies were completed as part of this project. The first was on the survival of Dover sole and plaice in a

1) Static net study

Vessel & port of operation

The advantage of conducting field studies on board commercial fishing vessels during representative fishing operations is that the fish under study have been exposed to realistic and combined stressors associated with the capture and discarding process. The participation of vessels for this work was sought through an open tendering process in accordance with government procurement procedures. Although the invitation to tender was well publicised and a reasonable amount of time was provided for tender submission, the number of applicants was low. The selection of vessels was based on the willingness of the skippers to cooperate, the space on board and the safety of the vessel to accommodate observers and necessary equipment and the track record of fishing in the defined area. Upon evaluation of the received tenders it was concluded that a static netter, targeting Dover sole, fulfilled the required criteria for the field trials. It was clear that extra effort was required to locate a suitable trawler, but despite further publicity and lengthy negotiations we were unable to source a willing and suitable otter trawler for this work based in Wales.

Sea trials were carried out in Swansea Bay (ICES rectangle 31E6), off the coast of South Wales, using the fishing vessel Seapie (NT28), a fibre-glass hulled netter of 9.88m overall length with a 90kw engine (Figure 1). MFV Seapie operates from Swansea Marina, at the mouth of the River Tawe, with access to and from Swansea Bay through the Tawe Barrage Lock.

The fishing activity during the study was representative of normal practice. All fishing was carried out during neap tides in August and September 2014, on typical fishing grounds for this vessel at this time of year (Figure 2). Sole was the main target species. The vessel was operated by the skipper only.

At sea

Fishing activity

Sole trammel nets were shot from a net pound, hauled with a hydraulic hauler and cleared as per normal commercial fishing practice; the nets were boarded on deck and were cleared once the final anchor was retrieved and stowed. It is normal practice for the skipper to pick out/un-mesh sole and plaice as a priority, where possible, leaving other species such as Starry smoothound (*Mustelus asterias*) and Nursehound (*Scyliorhinus stellaris*) in the nets until all accessible sole and plaice have been un-meshed. This routine was adhered to throughout the trials. Sole and plaice were handed to the observer at the time that these fish would normally have been retained in a fish box or discarded back to the sea.

Occasionally, when the weather conditions were considered to be too uncomfortable or dangerous to clear the nets at sea, the nets were boarded and cleared once the vessel returned to port. In these instances fish were assessed only when the nets were cleared by the skipper at the port.

Figure 1 The static netter MFV Seapie (NT28) in Swansea port and fishing in Swansea Bay

Data collection

All sole and plaice caught were recorded by length (to the nearest cm below) and all other species were recorded as numbers of individuals. The catch composition from each tier was recorded separately, alongside the positional (lat/long; depth) and environmental information (air temperature; sea surface temperature; light level) specific to that particular tier. Light levels were measured using a Reed Instruments' ST-1301 digital light meter, placed at deck level. The specification of the fishing gear used in each individual tier was recorded (Table 2) and the times were logged when tiers were shot, hauled and the subsequent catch sorting process began and ended.

Once the sole and plaice had been un-meshed and handed to the observer, each individual was measured and scored using a predefined assessment protocol. This assessment protocol was developed using methods described in the ICES WKMEDS 2014 report and refined in the Cefas laboratory using aquarium kept (unstressed) plaice. A series of behavioural reflex tests was identified that consistently produced unimpaired responses in both free swimming and restrained fish, and could be scored rapidly in a replicable manner. Injury types specific to the fishery of interest were also defined.

Figure 2 Map of Swansea Bay & positions of gear

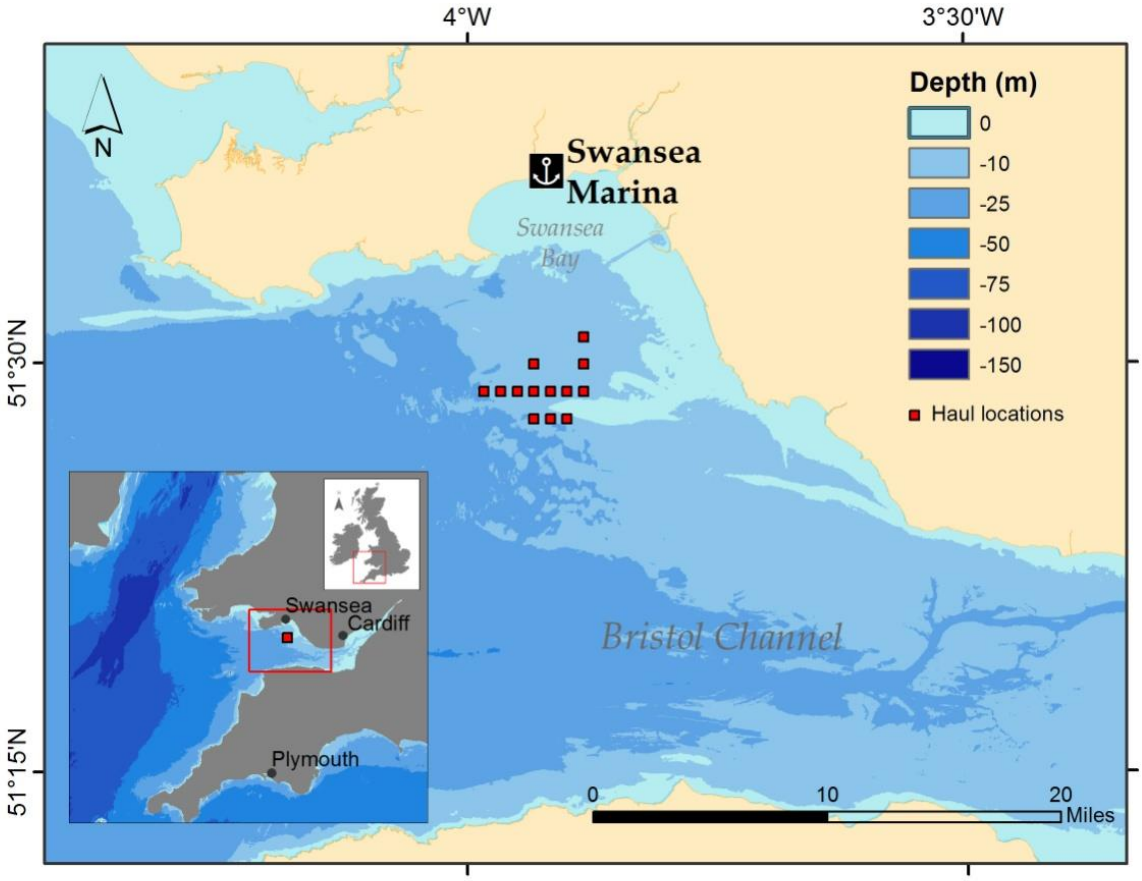


Table 2 Gear description

Gear	Length of Fleet (m)	Hanging Ratio	Twine Type Inner	Twine Type Outer	Twine Diameter Inner	Twine Diameter Outer	Mesh Size Inner (mm)	Mesh Drop Inner	Mesh Size Outer (mm)	Mesh Drop Outer
A	300	0.5	Mono	Multi Mono	0.35	8x3	114	40	610	4.5
B	300	0.5	Multi Mono	Multi Mono	1.5x4	8x3	114	30	610	2.5

Vitality was assessed using a semi-quantitative assessment of activity (SQA) and a quantitative reflex and injury scoring method. The SQA framework used was based on four ordinal vitality classes that are defined, at one extreme as characterising very lively and responsive fish (excellent) and at the other extreme unresponsive (dead) individuals (Table 3). The sole and plaice that showed no visible response (body or opercular movement) to touching, prodding or immersion in water were classified as dead and were simply measured and recorded. Sole and plaice that were assessed, using the SQA scoring, to have excellent, good or poor health states were then scored by the presence or absence of specific behavioural reflexes and injuries. Behavioural reflex tests were performed both in and out of water (Table 4). A circular observation container was filled with approximately 50 litres of sea water for the in-water reflex tests. A reflex action was scored as unimpaired (0) when it was strong or easily observed, or impaired (1) when it was not present or if there was doubt about its presence. An injury (including barotraumas) was scored as absent (0) when it was not present or there was doubt about its presence, and present (1) when clearly observed (Figures 3 to 6).

Table 3 Vigour vitality assessment category definitions

Vitality	Description
Excellent	Vigorous body movement; lively
Good	Fair body movement; responds to touching/prodding
Poor	Weak or no body movement; fish can move operculum
Dead	No body or opercular movements (no response to touching or prodding)

Figure 3 Examination of a plaice; left, splitter used to divert water to the onshore tanks for continuous water flow

Table 4 Vitality reflex and injury assessment protocol developed and applied to both species and in both fisheries. * Injury specific to Experiment 2 (otter trawl)

Fish Reflex Actions Scored as 0 (unimpaired) / 1 (impaired)	Description
Body Flex	Tested by holding the fish out of water, with both hands under the fish, and rotating to get a 'ventral bend' (head and tail move together). Any fish showing a 'ventral bend' or attempting to struggle free was scored
Operculum Closure	Tested by holding the fish out of water and lifting operculum with a blunt object (pencil) to get a 'clamp'. Any fish showing an active 'clamp' reaction was scored
Startle Touch	Tested in water by gentle grabbing of the tail of the fish to get an escape reaction. Any fish that responded to the grab with a startled escape was scored
Orientation Right	Tested in water by holding the fish upside down, just below the surface, to get a 'righting' movement. Any fish actively righting itself within 5 seconds was scored

Fish Injury Scored as 0 (absent) / 1 (present)	Description
Exophthalmia	Eyes distended outwards from the head
Corneal Gas Bubbles	Air bubbles visibly present in the eye or the membrane covering the eye
Subcutaneous Gas Bubbles	Air bubbles visibly present under skin
Bleeding	Visible bleeding from any part of the body
Abrasion	Haemorrhaging red area from abrasion
Mucus Loss	Visible area of mucus loss
Scale Loss	Visible area of scale loss
Wounding	Shallow cuts on the body
Deep Wounding	Deep cuts or gashes on the body
Fin Fraying	Fins damaged
Predatory Damage	Bite marks or area of the body eaten or lice actively present
Prolapsed Internal Organs	Intestine protruding out of the anus
Net Marks	Visible line marks caused by the net
Bruises *	Red/purple bruising visible on the body
Scratches *	Scratch marks visible on the body

The measurements and vitality assessments were carried out by the same individual throughout the experiment to eliminate potential observer effect. After the vitality assessment some of the fish were then selected for retention in on board tanks. The selection of fish for the on board tanks was based on the need to identify them throughout the experiment; only fish of differing total lengths, by species, were placed in the numbered on board tanks. In order to minimise additional captivity stress and to remove potential interspecific interactions, the stocking density of the on board tanks was set at a maximum of four individuals and the two species were kept in separate tanks throughout the experiment. The tank number was then recorded against the data for each individual fish (haul number; species; length; SQA and reflex and injury scores) to ensure that each fish stored in the on board tanks was uniquely identifiable. The temperature, salinity and dO2 concentration

(dO_2) were monitored using an Oxyguard Handy Polaris 2 dissolved oxygen meter and an Aquamarin refractometer. Fish that were not selected for the on board tanks (non-unique species/length combinations or dead fish) were either retained by the vessel for sale or discarded back to the sea after being measured and assessed for vitality.

Figure 4 Examples of some injuries sustained by plaice; above, net marks; below abrasion

Figure 5 Example of fin fraying in plaice (above) and conducting the reflex assessments in assessment container (below)

Figure 6 Example of body flex in plaice (above) and sole (below)

On board tanks

A vertical stack of six numbered grey polypropylene holding tanks was positioned on board the deck of the vessel, roughly amidships on the port side, and secured to the vessel's superstructure (Figure 7). A constant supply of sea water was supplied to this stack, in a flow to waste circuit, from the vessel's deck wash system. Sea water was pumped through the seacock valve in the hull of the vessel by a Jabsco electric-clutch pump, and supplied to deck level using a reinforced PVC hose. This deck wash hose was then connected to a ball valve on deck that was used to split the water supply to feed the stack of tanks (Figure 7). The flow of sea water to the tanks was adjusted using the ball valve to maintain a constant flow rate of 2-4l/min. Changes in engine revs during the fishing activity changed the water flow rate, so regular adjustments and monitoring were necessary. The sea water supply entered the stack through an inlet pipe in the top tank. The water then flowed through the vertical stack by gravity-fed drainage, through interconnecting overflow pipes and exited the stack through an overflow pipe in the bottom tank (Figure 7). This flow-through of fresh sea water was initiated on the steam to the fishing grounds, after the vessel was clear of the brackish water surrounding the mouth of the river and with sufficient time for the circulation of fresh sea water to all six tanks, prior to hauling the fishing gear.

Avian predation

To evidence avian predation of discarded fish, individuals of known species, size and vitality scores were released back to the sea, in a manner consistent with normal discarding during commercial fishing on this vessel. These fish were then tracked visually by two observers and the presence or absence of sea birds and the subsequent fate of the fish were recorded.

Transit from sea to shore

The vessel returned to port with the selected fish in the on board tanks. The pump supplying the stack of tanks with sea water was turned off when the vessel reached an appropriate distance from the port entrance to avoid subjecting the fish to substantial changes in salinity. The outflow of the River Tawe meant that water salinity reduced when approaching Swansea port. This distance, and position, was determined by taking repeated measurements of salinity and identifying the minimum distance from the port at which the sea surface salinity was no less than on the fishing grounds. The same distance, and position, was used throughout the trials and the pump was turned off at this point; the fish remained in their tanks until the vessel was in port. Immediately prior to turning off the pump, the observation container that was used previously for the reflex tests was filled with seawater in preparation for the transportation of fish to the shore tanks.

The vessel entered Swansea Marina through the Tawe Barrage Lock. The time taken to pass through the lock gates varied daily and was highly dependent on the number and behaviour of other lock users. The amount of time that the fish were held in the on board tanks with no water flow varied accordingly.

As quickly as possible after docking in port the fish in the six numbered on board tanks were transferred to six identically numbered buckets (38L purple Tubtrugs® flexible) for transportation to the shore tanks (Figure 8). Each numbered bucket contained a clear polythene bag that was partially filled with sea water from the observation container before the fish (along with some of the water from the on board tank) were carefully poured into the bag to minimise handling. The total volume of water in each bucket when containing the fish was 16 litres. The six numbered buckets were then transported by vehicle a distance of 2.5 miles to the shore tanks. In the absence of temperature control apparatus, the water in the buckets was susceptible to the heat inside the vehicle.

Figure 7 On-board tank system

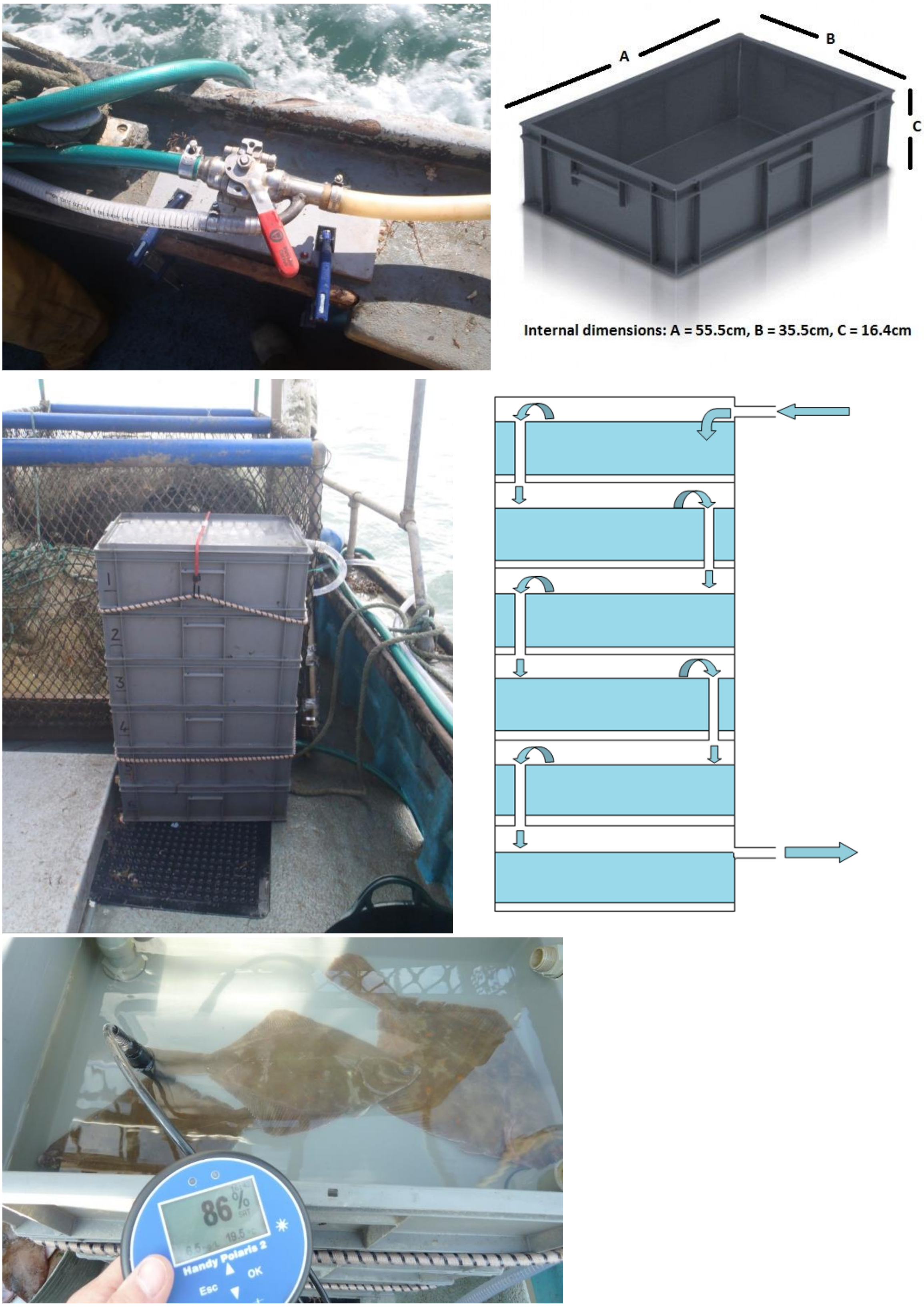


Figure 8 Tubs and process to transport fish from on-board tanks to onshore tanks.

On shore

A purpose built shore unit containing twelve separate holding tanks was used for the shore based captive observations (Figure 9). Following build completion, the shore based tank unit was tested in a control situation at the Cefas laboratory in Lowestoft. The tanks were supplied with sea water in a flow to waste circuit, pumped from the underground sea water tanks that typically feed the laboratory aquarium. Aquarium acclimatised plaice were assessed for activity, reflex and injury, prior to their introduction to four of the individual holding tanks in the shore unit. Stocking densities of 3, 4, 5 and 6 plaice were observed. Water temperature and salinity were consistent with the typical aquarium levels. The plaice were checked for vitality, using a gentle tail grab, at 24hr intervals for a period of 72hrs. The dissolved oxygen concentration of the water was also checked. At the end of the observation period, the plaice were assessed again for vitality, reflex and injury, before being returned to the aquarium facility.

For the purposes of this experiment, the shore based was installed at Swansea University's Centre for Sustainable Aquatic Research facility and was supplied with sea water, originating from Swansea Bay. The sea water was pumped from Swansea Bay via sub-sand filters and was then treated with ozone to remove incoming pathogens, passed through carbon filters to remove residual ozone, and into a re-circulating automated water treatment system made up of a mechanical sand filter, protein skimmer, biological filter, UV lamps, temperature control, pH dosing and oxygen control. A supply of water from this re-circulating system was plumbed into our twelve tank shore unit. The flow of water to each of the twelve separate holding tanks was independent and could be individually controlled using integral flow meters; the flow rate was set and monitored at a constant rate of 2l/min. A thin layer of aquarium silica sand was placed on the bottom of each holding tank to provide a familiar substratum for the fish and minimise captive stress.

On arrival at the shore based unit, the six numbered buckets containing fish were topped up with sea water taken from the pumped supply feeding the shore holding tanks; this process was carried out in an attempt to acclimatise the fish prior to their placement in the shore holding tanks and to stabilise any differences in the temperature, salinity and dO2 concentration of the holding water. After a 5-10 min acclimatisation period the fish in the numbered buckets were transferred to the numbered shore holding tanks by hand and the tank number was recorded; sole and plaice were stored in separate holding tanks. At the point of transfer any fish that had died in transit were declared dead, measured, identified, recorded and removed from the experiment.

A series of captive observations was then performed for a period of 72 hours, in agreement with The Home Office. At 12-hourly intervals (from the point at which the fish arrived at the shore holding tanks) the survival of the fish in the holding tanks was determined using a gentle tail grab. Fish that responded to the tail grab by undulation of their fins were declared alive and fish that produced no response movement were lifted to the surface and their health status was investigated further. Fish that showed no visible response (body or opercular movement) to touching, prodding or immersion in water were classified as dead. At the point of these 12-hourly inspections any fish that were assessed to be dead were removed from the tank, measured, identified and recorded. After a captive observation period of 72 hours all fish were individually removed from the holding tanks, measured, identified and their vitality was assessed and recorded using the SQA and reflex and injury scoring systems. The experiment for these fish was then terminated and they were disposed of.

The process described in 2, 3 and 4 above was carried out for 12 consecutive fishing days over the period 18th August to 6th of September 2014.

Figure 9 The onshore captive observation tanks

2) Otter trawler study

Vessel and port of operation

As a result of being unable to find a willing and suitable trawler based in Wales, the decision was taken to approach the English North Devon trawler fleet and a vessel was selected for this work. Further sea trials were carried out in Bideford Bay (ICES rectangle 31E5), off the coast of North Devon, using the vessel Ann Louise (BD22), a fibre-glass hulled trawler of 9.95m overall length with a 148kw engine (photos). Ann Louise operates from the port of Bideford, on the estuary of the River Torridge.

The fishing activity during this study was representative of normal commercial practice and was considered to be comparable to that of the South Wales trawler fleet, with the exception that this vessel towed two trawls in a twin-rig arrangement as opposed to the single trawl typically operated by the Swansea vessels. All fishing was carried out during March 2015, on typical fishing grounds for this vessel at this time of year. Rays were the main target species.

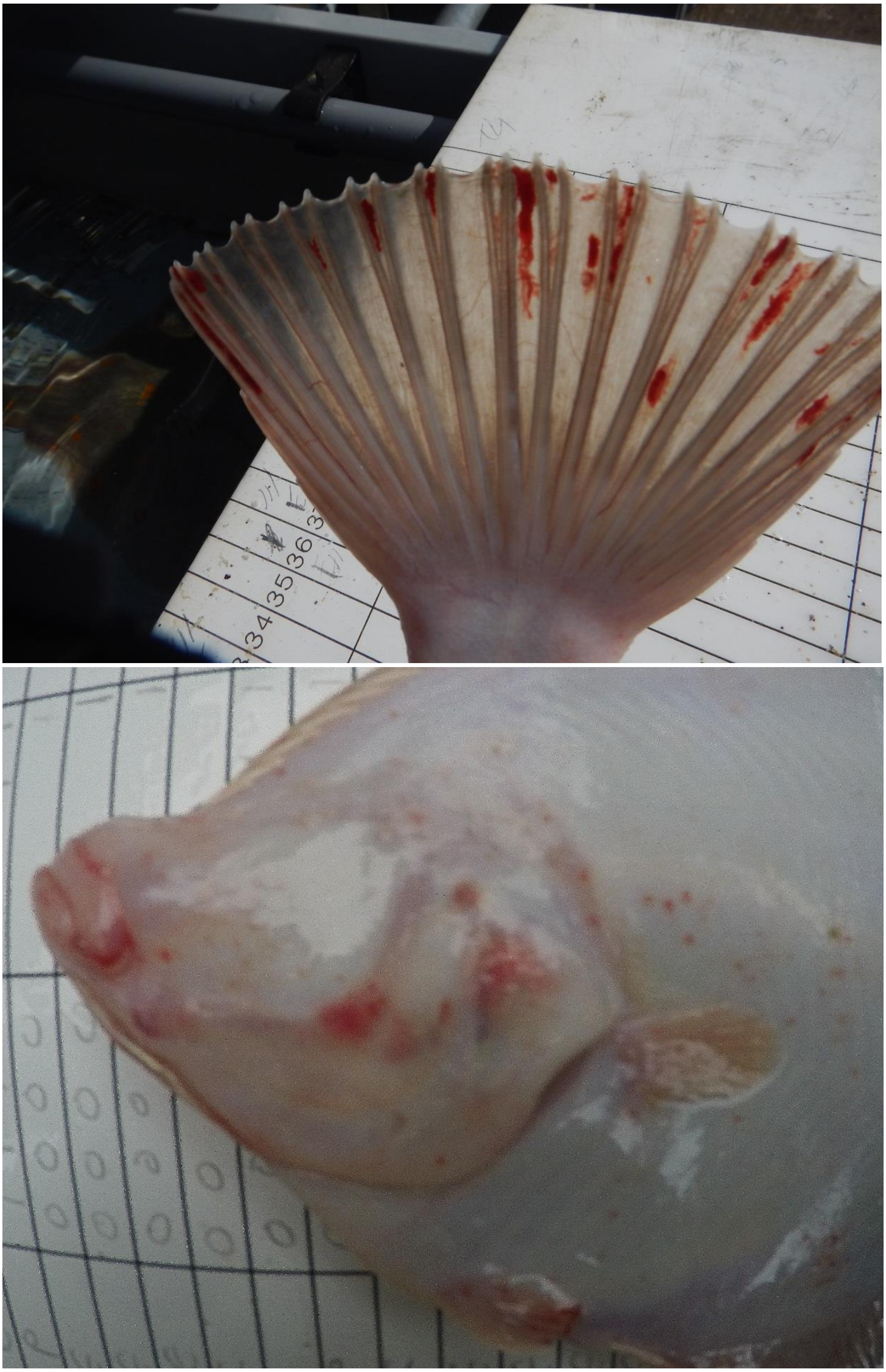
Fishing activity and data collection

The trawl gear was deployed, towed, and hauled as per normal commercial fishing practice. The cod ends were emptied into the aft pounds and the nets were fully re-deployed prior to catch sorting. The crew sorted the catch by hand, as they normally would, and any small, unwanted, rays present in the catch were thrown back to the sea immediately. The unwanted plaice and other unwanted species were left in the pound and, at the point of normal discarding, were collected from the deck by the observer and placed into a 5-stone fish basket. A circular container was then filled with approximately 50 litres of sea water, using the vessel's deck wash system, and the basket containing the plaice was submerged into it. A second circular container (38L Tubtrugs flexible) was filled with seawater, using the vessel's deck wash system, and was used for the in-water reflex tests.

Each plaice was measured and recorded by length (to the nearest cm below), then assessed for vitality using the identical scoring protocol from study 1, with the addition of two gear-specific injury types (reflex table). The measurements and vitality assessments were carried out by the same individual throughout the experiment and that of study 1, to eliminate potential observer effect. After the vitality assessment the fish were then thrown back to the sea. Avian predation observations were made for a proportion of the plaice caught and discarded.

Figure 10 The otter trawler MFV Ann Louise (BD22) in Bideford port and fishing the in Bristol Channel

Figure 11 Example of bleeding injury (above) and bruising (below) seen on plaice from otter trawler only



Analytical methods

As with the fieldwork methods, at the commencement of the project there were no accepted analytical methods to apply to survival assessments. The statistical methods have been developed from previous studies and within the work of the ICES WKMEDS.

Summary data from each study

Descriptive and summary data are presented, including the period of study, the number of fishing days, the mean length of fish assessed for vitality, the mean length of fish under captive observation and the length of observation time. The proportion of fish in the total catch at each vitality from the vigour assessment and details of the reflex and injury assessment are presented. The summary table also summarises the results from the captive observation trials and the survival estimates derived from the different stages of the analysis for study 1.

Survival methods

The captive observation data provide the length of time that each fish was observed for following capture and the state of the fish (dead or alive) when the final observation for that fish was made. This type of data is called longitudinal data and is analysed using survival methods. These methods provide estimates of the survivor function, *S(t)*, the probability of surviving for longer than time *t*.

Survival methods account for a common propriety of survival data known as censoring. The data for fish that were still alive at their final observation time are referred to as right censored. Here, we know that a fish survived until at least that observation time but not how long it would have survived if the observation period was extended.

Kaplan-Meier plots

The Kaplan-Meier (K-M) estimator generates the survivor function against time. K-M estimates with 95% confidence intervals were calculated for each category of fish vitality, using the R function *survfit*. Confidence intervals were computed on the log-log scale as in Venables and Ripley (2002, pg 357).

The K-M method has the advantage of making few assumptions about the data, although it cannot be used to predict outside the observed experimental period. K-M estimates can also be variable towards the end of the experimental period when few fish remain observed. Therefore, a “plus-group” time was defined and times greater than these assigned to the plus-group time when calculating the K-M estimates. In this case the time was 73.03 hours.

For each case study, the survivor curves from each vitality category (Excellent, Good, Poor) were then compared using the log-rank test (R function *survdiff*). First, an overall comparison of all curves then comparisons between each pair of vitality categories.

Survival models

For discard survivability studies, a plausible description of the results is that the proportion of fish surviving will gradually decrease and then flatten off with a proportion of fish surviving the capture, handling and release process. To model this process and predict the long-term survival probability requires an extension of standard survival analysis models as these assume that the discard-related mortality must extend until survival is zero. The extended models required are referred to as mixture cure models or mixture-distribution models.

Two such models were fitted to the case study results: (1) a semi-parametric proportional hazards mixture cure model (PHMC) as implemented in R package *smcure* (Cai et al. 2012); (2) a parametric mixture distribution model (Benoit et al. 2012), fitted by maximizing the likelihood function for the model within the R optimization function *optim*. Fitting more than one model, using different implementations, is valuable to provide evidence on the sensitivity of the estimates to the model properties.

Model (1) fits a common baseline survivor curve across all SQA categories (fish quality), based on the observed pattern of mortalities, and then scales the risk to reflect the survival within each SQA category. Model (2) assumes that the survival pattern can be modelled by the Weibull statistical distribution, this is a relatively flexible distribution that can represent a range of survival functions commonly encountered in ecological data. Here, we fitted Model (2) to each SQA category separately to remove any assumption of similarities in their survivor curves.

The estimate of survival probability from each model was extracted to apply to the vitality data.

Applying survival rates to vitality data

For each species, the survival rate for each of the categories in the vigour assessment (Excellent, Good, Poor, Moribund) were applied to the proportion of fish assessed with that category from all sampled catches. Data were raised where appropriate to give the proportions at each vitality category pooled across all sampled trips.

Summing across the proportions of catch at each vitality, multiplied by the survival rate for that category gave an overall estimated survival rate of the observed trips. Three survival rates are presented, one in the context of the captive observation period, the other two using the predicted final survival rates for each of the vitality categories from the extension models.

Identifying factors that influence survival

Potential links between the vigour assessment in the sampled catch and variables related to each fishing haul were examined for plaice from the trammel net fishery. This study was selected as a range of variables covering the sea conditions, environmental variables, catch processing and catch composition were available to analyse within the time constraints of the project. Vigour assessment in the sampled catch was used as the response (rather than survival at the end of on-shore observation), as links between vigour assessment and survival had been observed, using the sampled catch provided a greater sample size and allowed the focus to be on factors related to the hauls. The number and proportion of fish in each vigour assessment category was calculated for each haul, and then linked to the haul data using a unique combination of haul date and haul number. As a visual analysis, the vigour category proportions were plotted against each potential influencing variable. Where appropriate, smooth curves (loess smoother with span of 0.75) were added to the plots to aid interpretation.

To assess each variable’s ability to describe patterns in vigour category proportions, multinomial statistical models were fitted to the counts in each category using function *multinom* in R package MASS (Venables et al. 2002). A separate model was fitted for each potential influencing variable, with categorical variables as factors and continuous variables as linear terms within each vigour category. A model’s fit was measured using the likelihood ratio statistic from comparing the model to a null model which had the same vitality category probabilities for every haul.

The effect of reflex impairment and injury on survival

A Generalized Linear Model (GLM) with the binomial family and a logit link was used to examine which injuries and reflexes had a significant impact on proportion of dead (D) and alive (A) fish. For both species in study 1 we fit a binomial GLM to the reflexes and injuries, separately. The models were estimated using the software R 3.1.0.

Results

Overview of results

Data from both fishery studies are summarised in Table 6.

Study 1 – Trammel net, plaice and sole

In total, 44 hauls of commercial sole trammel nets were made during two neap tides between 18th August and 6th September 2014 (Table 5). The nets were deployed on the sea bed at depths ranging from 14m to 30m (mean 21m), for soak durations of between 19hr 20min and 28hr 52min (av. 23hr 52min). Once the nets had been hauled, the time taken for the catch to be sorted, and hence the maximum amount of time fish were exposed to the air, ranged from 20min to 2hr 34min.

The catch composition was dominated by starry smooth hound (1055), with sole (455) and plaice (409) featuring as the next most abundant species. All sole and plaice caught were recorded and the length distribution is shown in Figure 13. The mean lengths of sole and plaice caught in 4 ½ inch (inner mesh) trammel nets were 35.8cm and 29.8cm respectively; plaice caught in nets designed to catch marketable sized sole were notably smaller than the sole.

A total of 409 plaice and 455 sole were caught and assessed for vitality. In total, 83 plaice and 189 sole were assessed as being dead/moribund at the point that they were unmeshed from the nets. The remaining fish were scored as either Excellent, Good, or Poor (Figure 13), and a proportion of fish at each of these vitality scores was selected (by length) for the on-board observation tanks).

The 107 plaice and 96 sole retained for captive observation had a length profile comparable to the total catch (Table 6, Figure 13). The Kaplan-Meier plots (Figure 15) show clear separation between the vitality (vigour) categories, with the amount of survival in the expected order – the best survival with Excellent vitality. This finding is supported by the results of the log-rank tests comparing the survivor curves. Overall, there are statistically significant differences in survivor curves between vitality categories for both species between Excellent fish and Good and Poor fish. These results demonstrate that the vitality assessment effectively distinguished the chances of survival of Excellent fish from the other vitality categories.

Fish were held in captivity for 76-81 hrs; survival probability for plaice was 72.7% for Excellent fish, 36.4% and 42.1% for Good and Poor. When weighted to the proportion of fish in each vitality category in the total catch, the estimated survival in the observation period was 49.3% (37.1-59.8%) (Table 8). Two models were used to forecast forward from the KM survival plots; when combined across all hauls, because the a small number of fish died at the end of the observation (Figure 15); the forecast survival estimate varied between 3.6-39.1% owing to the different sensitivities of the model (Table 9).

For sole, the survival probability was 50.0% for Excellent fish, 0.0% and 6.3% for Good and Poor. When weighted to the proportion of fish in each vitality category in the total catch, the estimated survival in the observation period was 20.6% (14.8-27.9%) (Table 8). Two models were used to forecast forward from the KM survival plots; when combined across all hauls, because the rate of mortality of sole had not reached asymptote (Figure 15); the forecast survival estimate was lower at 18.6-20.3% (Table 9).

Simulated discarding of 32 fish was conducted to observe evidence of avian predation; 28 fish were observed to actively swim away (Table 8). The remaining four fish were scored to be in Poor or Moribund (Dead) condition and sank, unmoving, out of view. There were some seabirds present in the area, but only one sea bird was observed to show interest in one discarded plaice, but it made no attempt to pick the fish up. Therefore, there was no evidence of avian predation observed.

Ad hoc measurements of sea-surface temperature, air temperature, salinity and dO2are given in Annex 3. Salinity at sea was 35ppt, whilst in the onshore tanks it was maintained at 30ppt; the air temperature varied between 15.7 deg. C and 19.9 deg. C; and dO2 fell to 85% in the onshore tanks but was often at 100%, and down to 44% in the tubs when fish were moved from the vessels to the on-shore tanks.

Figure 12 Enmeshed sole in trammel net were moved to the side during the hauling process during normal sorting

Table 5 Details of hauls, including soak time, sea conditions, and sorting times

Haul date	Tide (m)	Gear Type	Haul	Haul time	Haul depth (m)	Soak time (h:m)	ICES rectangle	Wind force	Wind direction	Swell Height (feet)	Light level (lux)	Air temp. (°C)	Sea surface temp. (°C)	Total sorting time (h:m)
18/08/2014	10.9	B	1	10:58	21	24:58	31E6	4 to 5	NW	3 to 4		17		01:04
		B	2	12:26	23	25:56	31E6	5	NW	3 to 4		17		00:32
		B	3	13:36	25	26:36	31E6	4 to 5	NW	3 to 4		17		00:48
		A	4	15:16	23	27:46	32E6	3 to 4	NW	3		17		01:46
		A	5	15:33	21	27:33	32E6	3 to 4	NW	3		17		02:34
19/08/2014	10.5	B	6	10:11	22	19:23	31E6	3	NW	2		16		00:28
		B	7	11:17	21	22:58	31E6	3	NW	2 to 3		16		00:40
		B	8	12:30	21	23:05	31E6	3	NW	2 to 3		16		00:26
20/08/2014	10	B	9	13:10	21	24:48	31E6	2	NW	1 to 1.5		20		00:36
		B	10	14:27	22	27:22	31E6	2	NW	1 to 1.5		20		00:46
21/08/2014	9.9	A	11	09:44	18	24:19	31E6	3 to 4	NW	2 to 2.5		16		00:45
		A	12	10:55	18	25:20	31E6	3 to 4	NW	2		16		00:38
		B	13	12:22	22	22:27	31E6	4 to 5	NW	2 to 3		16		00:35
		B	14	13:53	18	22:04	31E6	4 to 5	NW	3		16		01:59
22/08/2014	10.3	A	15	09:45	18	21:35	31E6	3	NW	1		17.2	17.8	00:42
		B	16	11:14	19	21:49	31E6	3 to 4	NW	1 to 2		17.2	17.8	00:34
		B	17	12:26	18	22:46	31E6	3	NW	1 to 2		17.2	17.8	00:31
23/08/2014	10.9	B	18	11:25	17	26:00	31E6	3	NW	1		16.6	17.7	00:41
		A	19	12:29	17	26:29	31E6	3 to 4	NW	2		16.6	17.7	00:33
		B	20	13:33	19	24:38	31E6	3 to 4	NW	1 to 2		16.6	17.7	01:46
01/09/2014	11.3	A	21	09:30	29	23:30	31E6	5	NW	1.5	49000	18.5	18	01:10
		B	22	11:22	24	25:07	31E6	3	W	0.5	49000	18.5	18	00:43
		A	23	12:43	21	26:12	31E6	3 to 4	W	0.5	49000	18.5	18	00:55

Haul date	Tide (m)	Gear Type	Haul	Haul time	Haul depth (m)	Soak time (h:m)	ICES rectangle	Wind force	Wind direction	Swell Height (feet)	Light level (lux)	Air temp. (°C)	Sea surface temp. (°C)	Total sorting time (h:m)
		B	24	14:20	16	27:35	31E6	3 to 4	W	0.2	49000	18.5	18	01:00
		B	25	15:40	14	28:40	31E6	2 to 3	S	0.3	49000	18.5	18	00:20
02/09/2014	10.9	A	26	09:30	29	22:15	31E6	2	SE	0.3	71500	17.7	18.1	01:05
		B	27	11:30	24	23:00	31E6	3	SE	0.3	71500	17.7	18.1	00:40
		A	28	12:45	24	22:30	31E6	2	E	0.3	71500	17.7	18.1	00:40
		B	29	13:50	21	22:05	31E6	2	W	0.3	71500	17.7	18.1	01:00
03/09/2014	10.4	A	30	09:43	27	22:28	31E6	2	W	0.3	46600	20	18.8	01:02
		B	31	11:24	23	22:54	31E6	2	W	0.3	46600	20	18.8	00:50
		A	32	12:48	23	22:48	31E6	2	W	0.3	46600	20	18.8	00:52
		B	33	14:18	22	23:03	31E6	2	W	0.3	46600	20	18.8	00:42
04/09/2014	10.3	A	34	13:52	30	26:45	31E6	3	NW	1 to 2				00:56
		B	35	15:57	20	27:25	32E6	3	NW	1 to 2				00:53
		A	36	17:50	20	27:40	31E6	3	NW	1 to 2				00:42
05/09/2014	10.2	A	37	09:58	25	21:28	31E6	0	V	0				00:54
		B	38	11:31	20	20:01	31E6	0	V	0				00:36
		B	39	12:40	20	19:20	31E6	0	V	0				00:43
		A	40	14:06	23	20:26	31E6	0	V	0				00:47
06/09/2014	10.7	A	41	09:23	20	22:03	31E6	1	SE	0.5	63300	20.3	18.8	00:45
		B	42	10:40	18	22:10	31E6	1	SE	0.5	63300	20.3	18.8	00:34
		B	43	11:40	18	21:40	31E6	1	SE	0.5	63300	20.3	18.8	00:34
		A	44	12:54	20	21:34	31E6	1	SE	0.5	63300	20.3	18.8	00:53

Table 6 Data summary

Area	Study 1 Bristol Channel ICES VIIf	Study 1 Bristol Channel ICES VIIf	Study 2 Bristol, Channel ICES VIIf
Gear	Trammel net	Trammel net	Twin otter trawl
Mesh size: inner; outer	114mm; 610mm	114mm; 610mm	85mm
Target	Dover sole	Dover sole	Mixed demersal
Study period	18 Aug - 6 Sept	18 Aug – 6 Sept	10 Mar – 16 Mar
Fishing days	12	12	3
Hauls	44	44	10
Species	Plaice	Sole	Plaice
Mean length plaice catch cm	29.8	35.8	23.5
Vitality assessed from catch n	409	455	572
% plaice catch assessed as excellent	53	39	57
% plaice catch assessed as good	10	10	13
% plaice catch assessed as poor	16	15	20
%plaice catch assessed as dead/moribund	20	46	10
Captive observation sample number	107	96	-
Captive observation method	Onshore	Onshore	-
Mean length observed cm	30.2	36.8	-
Observation period	76-81h	76-81	-
% survival of plaice catch assessed as excellent	72.7	50.0	-
% survival of plaice catch assessed as good	36.4	0.0	-
% survival of plaice catch assessed as poor	42.1	6.3	-
% survival in observation period for plaice catch	49.3 (37.1-59.8)	20.6 (14.8-27.9)	-
Modelled % survival with no time constraint for total plaice catch	3.6-39.1	18.6-20.3	-

Figure 13 Study 1 Length frequencies of plaice and sole in trammel net catches and held for observation

Figure 14 Study 1 Semi-quantitative vigour vitality score for plaice and sole trammel net catches

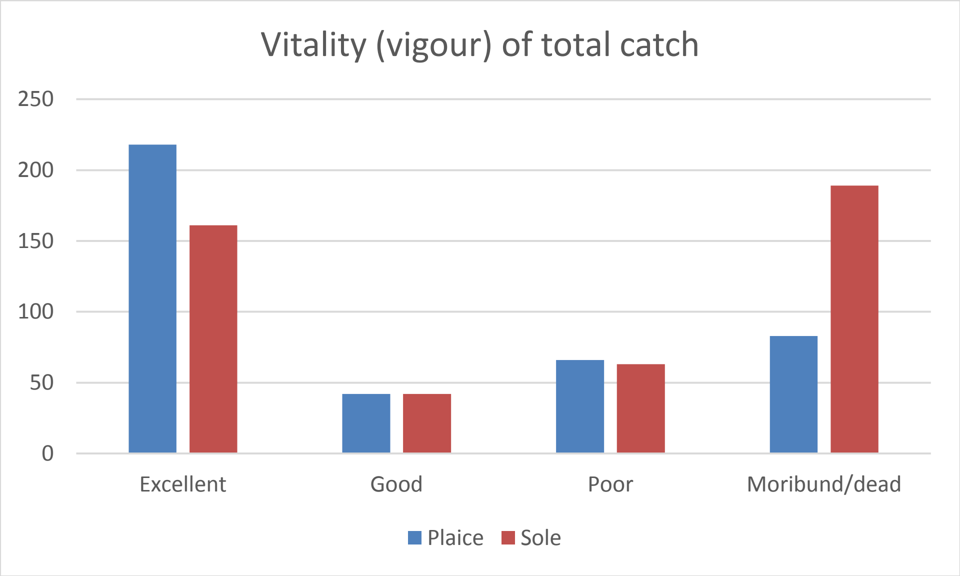
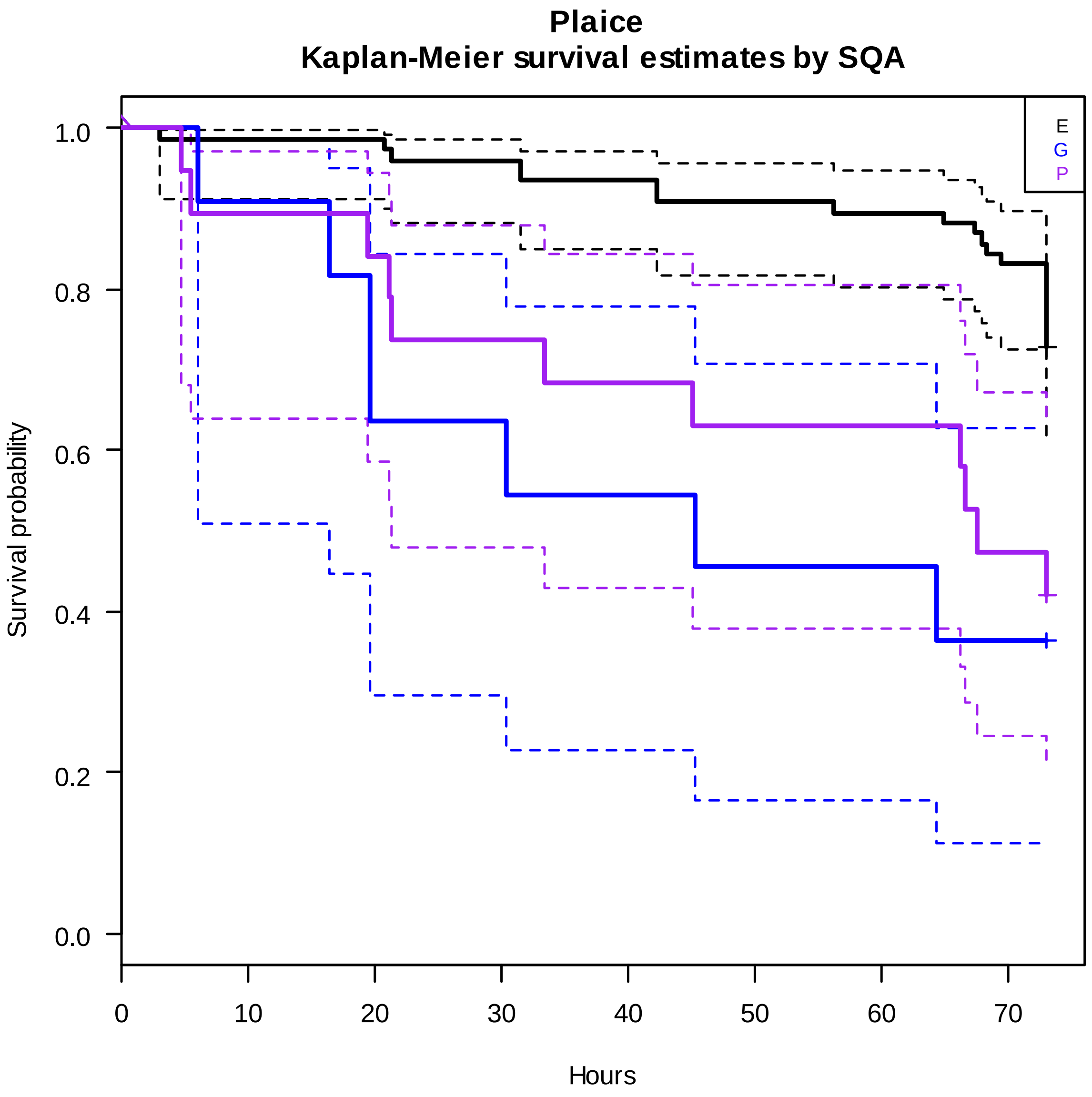


Table 7 Study 1 Avian predation observations

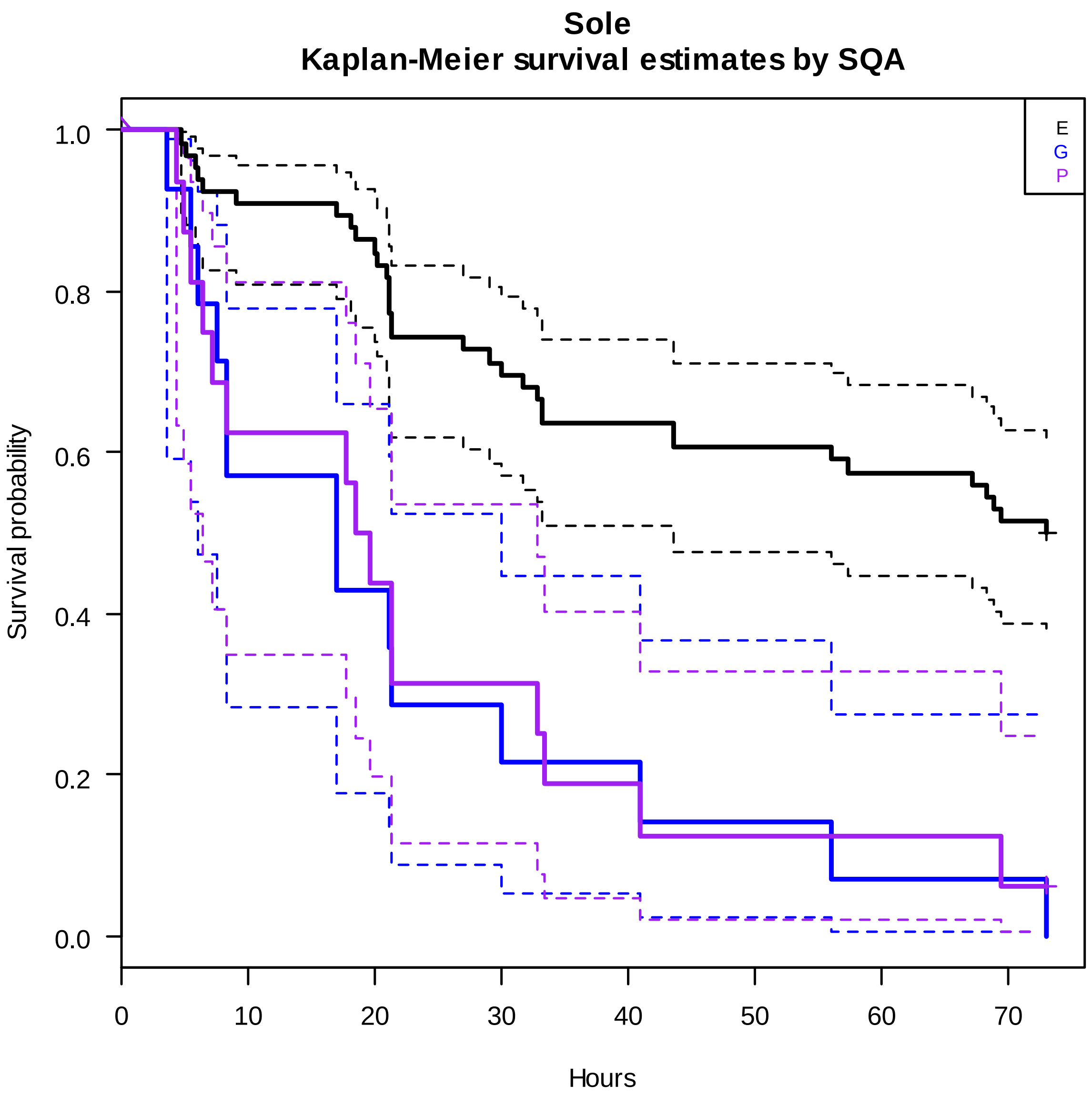
	Excellent	Good	Poor	Moribund/dead	Total
Mean Fish Length (cm)	25.3	25.6	25.3	27.0	
Swam Clear	23	5	0	0	28
Bird(s) Interested	0	1	0	0	1
Birds fighting or competing	0	0	0	0	0
Picked up but rejected	0	0	0	0	0
Eaten	0	0	0	0	0
Lost sight of fish	0	0	3	1	4

Figure 15 Study 1 Kaplan-Meier estimates of survival probability

The Kaplan-Meier plots show clear separation between the vitality (vigour) categories, with the level of survival in the expect order – i.e. best survival with Excellent vitality and survival decreasing with vitality. This finding is supported by the results of the log-rank tests comparing the survivor curves. Overall, there are statistically significant differences in survivor curves between vitality categories for plaice and sole between pairs of categories except for Good and Poor. These results demonstrate that the vitality assessment distinguished the chances of survival of fish assessed as Excellent compared with other categories.



Bristol Channel gill net fishery - Plaice		
Comparison	**Chisq**	**p**
E , G	12.8	<0.001
E , P	10.2	0.001
G , P	0.3	0.564



Bristol Channel gill net fishery - Sole		
Comparison	**Chisq**	**p**
E , G	24.6	<0.001
E , P	19.7	<0.001
G , P	0.1	0.722

Table 8 Study 1 Survival of captive fish during observation time period and modelled for extended period

The table gives the overall percentage survival of the captive fish; the survival probability within the observation period with upper and lower 95% CIs from the K-M analysis and also the predicted percentage survival based on a modelled asymptote in the survival curve from the two extension models. Extension model 1 (ph) gives the output from a semi-parametric proportional hazards mixture cure model (PHMC) (Cai, Zou et al. 2012); Extension model 2 (Wei) gives the outputs from a parametric mixture distribution model (Benoit, Hurlbut et al. 2012).

Captive observation results							
Species	SQA	Percentage survival of captive fish	Survival probability (KM) as percentage	lower 95%	upper 95%	Extension model 1 (ph)	Extension model 2 (Wei)
Plaice	Excellent	72.7	72.7	61.3	81.3	56.6	0.0
	Good	36.4	36.4	11.2	62.7	36.0	34.6
	Poor	42.1	42.1	20.4	62.5	32.5	0.0
Sole	Excellent	50.0	50.0	37.5	61.3	49.2	45.1
	Good	0.0	0.0	0.0	0.0	0.0	0.0
	Poor	6.3	6.3	0.4	24.7	6.3	5.5

Table 9 Study 1 Estimated discard survival for all plaice and sole on observed trips using vitality as a proxy

The table presents the weighted mean survival proportions of the total catch from the captive observation estimates (Table 7) and the catch vitality profiles

	SQA	Proportion at vitality in total catch	Survival probability as percentage in obs. period	Survival probability as percentage in obs. period Lower 95%	Survival probability as percentage in obs. period Upper 95%	Survival with no time constraint model 1	Survival with no time constraint model 2
Plaice	Excellent	0.53	38.8	32.7	43.3	30.2	0.0
	Good	0.10	3.7	1.1	6.4	3.7	3.6
	Poor	0.16	6.8	3.3	10.1	5.2	0.0
	Moribund/dead*	0.20	0.0	0.0	0.0	0.0	0.0
Survival rate %			**49.3**	**37.1**	**59.8**	**39.1**	**3.6**
Sole	Excellent	0.39	19.7	14.7	24.1	19.3	17.8
	Good	0.10	0.0	0.0	0.0	0.0	0.0
	Poor	0.15	1.0	0.1	3.8	1.0	0.9
	Moribund/dead*	0.46	0.0	0.0	0.0	0.0	0.0
Survival rate %			**20.6**	**14.8**	**27.9**	**20.3**	**18.6**

*Moribund/dead individuals not assessed for survival in captive observation experiment; assumed 0% survival of fish assessed as moribund/dead in catch

Study 2 – Otter trawl, plaice

In total, 10 hauls of a commercial otter trawl were made during three days in March 2015. The tows were conducted in depths ranging from 19m to 34m (mean 26m), for durations of between 2hr 45min and 4hr 45min (mean 3hr 52min). After hauling, the time taken for the catch to be sorted, and the maximum amount of time fish were exposed to the air, ranged from 15min to 30min (mean 23min).

The catch composition was dominated by Lesser Spotted Dogfish, rays and plaice. All unwanted plaice caught were recorded by length (to the nearest cm below; Figure 16). Only a few plaice, 3% of the total number, were retained by the vessel; the mean length of the unwanted plaice was 23.6 cm.

Of the 572 plaice assessed, 18 (3%) were categorised as dead at the point that they would be discarded. The majority of plaice (57%) were assessed as being in Excellent condition with the remaining scored as either Good or Poor (Figure 17).

Simulated discarding of 70 plaice was conducted to observe evidence of avian predation. 39 fish were observed to actively swim away (Table 11), most of which were assessed as Excellent or Good. The observers lost sight of the remaining 31 fish which were assessed as mostly Moribund (Dead). Therefore, no evidence of avian predation was observed.

Figure 16 Study 2 Length frequency of plaice caught by a Bristol Channel otter trawler

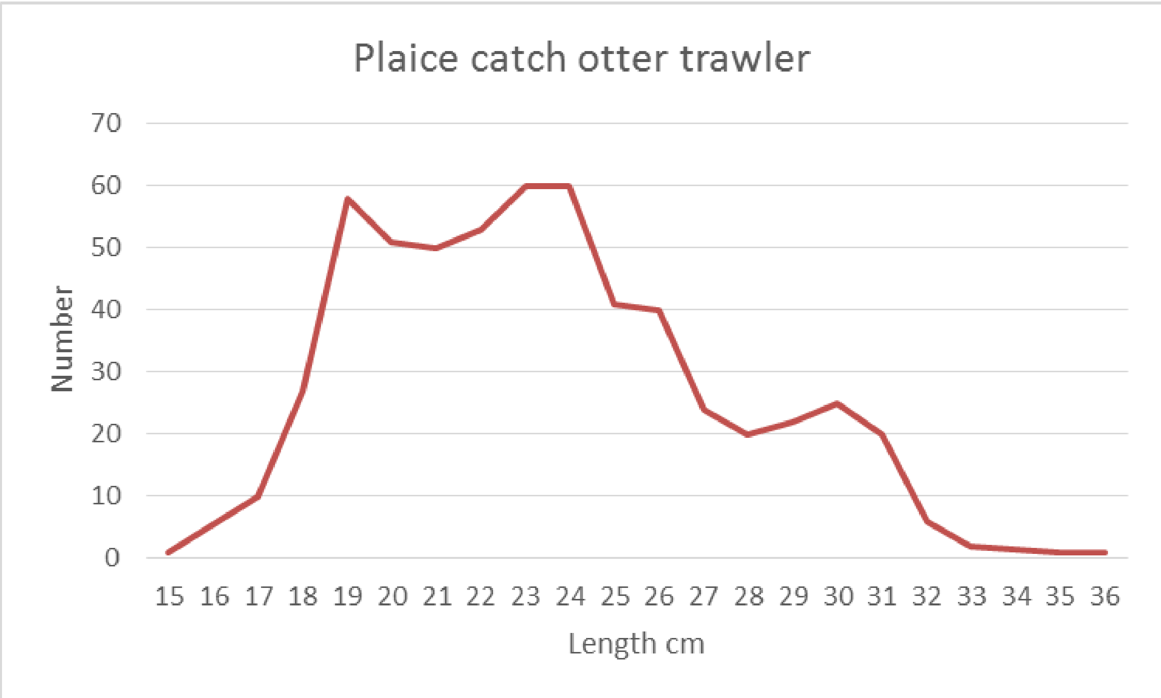


Figure 17 Study 2 semi-quantitative vigour vitality score for plaice catches in a Bristol Channel otter trawler

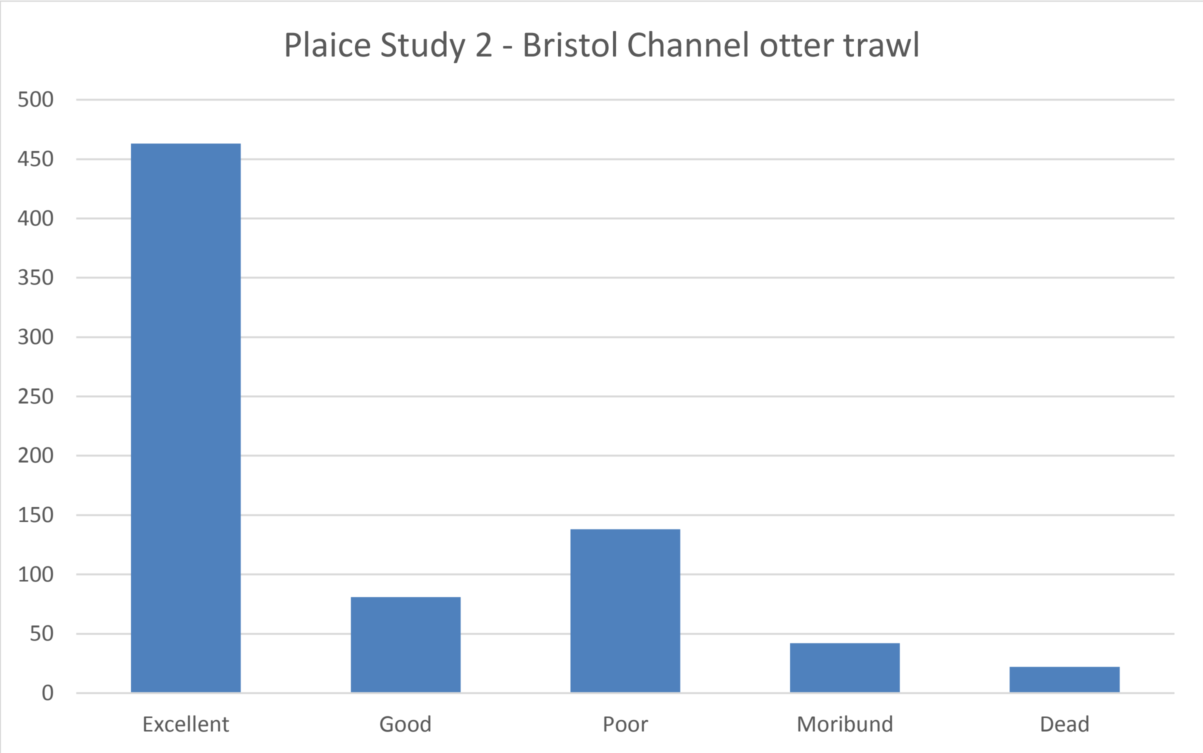


Table 10 Study 2 Avian predation observations

	Excellent	Good	Poor	Moribund/dead	Total
Mean Fish Length (cm)	22.4	23.6	23.9	23.0	
Swam Clear	16	13	0	10	39
Bird(s) Interested	0	0	0	0	0
Birds fighting or competing	0	0	0	0	0
Picked up but rejected	0	0	0	0	0
Eaten	0	0	0	0	0
Lost sight of fish	1	4	8	18	31

Table 11 Study 2 inferring discard survival for plaice on observed trips on-board a Bristol Channel otter trawler using vitality as a proxy

Study 2 results			Captive observation data from comparable otter trawl fishery in ICES VIIe*					Inferred discard survival %				
Vitality	Number (raised)	Percentage	Survival probability (KM) as percentage	lower 95%	upper 95%	Extension model 1 (ph)	Extension model 2 (Wei)	Survival probability as percentage in obs. period	Survival probability as percentage in obs. period Lower 95%	Survival probability as percentage in obs. period Upper 95%	Survival with no time constraint model 1	Survival with no time constraint model 2
Excellent	324 (463)	81%	90.2	82	94.8	84.6	90.2	73	66	77	68	73
Good	73 (81)	14%	70.4	59.7	78.8	40.6	71.3	10	8	11	6	10
Poor	117 (138)	24%	28.7	18.8	39.5	2.3	18.3	7	5	10	1	4
Moribund	40 (42)	7%	5	0.9	14.8	4.7	4.6	0	0	1	0	0
Dead	18 (22)	4%	0	0	0	0	0	0	0	0	0	0
Total	572 (746)	100						**90**	**79**	**99**	**75**	**88**

* Other survival studies were conducted in separate contract at the same time as this project. Data from these studies were generated using the same methodology by Cefas in Defra funded project MF1234 (Catchpole, unpubl. 2015, Tom Catchpole, Peter Randall, Robert Forster, Sam Smith, Stuart Hetherington, Victoria Bendall, Frank Armstrong. Estimating the discard survival rates of selected commercial fish species (plaice - Pleuronectes platessa) in four English fisheries (MF1234/C6160), May 2015, Cefas report)

Factors influencing discard survival

The effect of impaired reflexes

The binomial GLM model in case study1, the trammel net fishery, showed that plaice with impaired orientation had significant higher mortality that the unimpaired plaice. The orientation impairment was the only reflex that showed significant association with the proportion of dead: alive fish. For sole, no impaired reflexes showed significance in affecting the proportion of dead and alive fish (Table 12). In the case study 2, the otter trawl fishery, only plaice was assessed for vitality, no captive experiment was conducted. Therefore, it was not possible to make any analysis on the effect of impairments on the mortality of plaice, around one third of fish displayed impairment in all reflex tests. Summary of vitality scores are presented in Table 13.

Table 12 – Summary data for case study 1 – Trammel net fishery, with the number of fish dead and alive in the experiment, when impaired and unimpaired for each vitality reflex, percentage (%) of dead fish impaired, percentage (%) of alive fish impaired, *p* value from binomial GLM. Number of impaired/ unimpaired and proportion of impaired plaice and sole in the total catch.

Species	Reflex name	Reflex response	Experiement					Population	
			Alive	Dead	% of dead fish impaired	% of alive fish impaired	p-value	Number	Proportion impaired
Plaice	Body flex	unimpaired	64	34	13%	6%	0.973	253	12%
		impaired	4	5				34	
	Operculum	unimpaired	66	38	3%	3%	0.277	271	6%
		impaired	2	1				16	
	Startle touch	unimpaired	67	35	10%	1%	0.293	262	9%
		impaired	1	4				25	
	Orientation	unimpaired	63	27	31%	7%	0.012*	235	18%
		impaired	5	12				52	
Sole	Body flex	unimpaired	33	58	6%	3%	0.994	214	12%
		impaired	1	4				29	
	Operculum	unimpaired	33	59	5%	3%	0.992	217	11%
		impaired	1	3				26	
	Startle touch	unimpaired	33	54	13%	3%	0.993	194	20%
		impaired	1	8				49	
	Orientation	unimpaired	33	52	16%	3%	0.993	193	21%
		impaired	1	10				50	

Table 13 – Summary data for case study 2 – otter trawl fishery, with the number of impaired/unimpaired fish and proportion impaired in the population.

Species	Reflex name	Reflex response	Number	Proportion impaired
Plaice	Body flex	unimpaired	402	30%
		impaired	170	
	Operculum	unimpaired	434	24%
		impaired	138	
	Startle touch	unimpaired	389	32%
		impaired	183	
	Orientation	unimpaired	386	33%
		impaired	186	

The effect of injuries

In the trammel net case study, for plaice and sole net marks were observed in 70% and 79% of fish, respectively, and was the most prevalent injury. Abrasion and scale loss were also frequently seen, in both species but were more common in sole (Table 14). The same analyses with the binomial GLM was applied to the injuries observed for each species in the trammel net case study. The GLM results for plaice showed the injuries that had the most significant association on the proportion of dead fish were internal organs exposure ($p < 0.01$) fin fraying and abrasion ($p = 0.05$)(Table 14). On the other hand, the injuries that caused significantly higher proportion of dead sole were net marks and abrasion.

Table 14 - Summary data for case study 1 with the number of fish dead and alive in the experiment, when injured and not injured for each injury, percentage (%) of dead fish injured, percentage (%) of alive fish injured, *p* value from binomial GLM. Number of injured/not injured and proportion of impaired plaice in the total catch.

Species	Injury	Response	Experiement					Population	
			Alive	Dead	% of dead fish injured	% alive fish injured	*p*-value	Number	Proportion injured
Plaice	Net marks	not injured	28	9	77%	59%	0.744	87	70%
		injured	40	30				200	
	Internal organs exp	not injured	63	29	26%	7%	0.022*	257	10%
		injured	5	10				30	
	Fin fraying	not injured	62	26	33%	9%	0.056·	236	18%
		injured	6	13				51	
	Wounding	not injured	68	36	8%	0%	0.993	277	3%
		injured	0	3				10	
	Scale loss	not injured	52	30	23%	24%	0.461	214	25%
		injured	16	9				73	
	Abrasion	not injured	53	21	46%	22%	0.051·	183	36%
		injured	15	18				104	
	Exophthalmia	not injured	68	36		0%	0.993	283	1%
		injured	0	3	8%			4	
	Bleeding	not injured	64	37		6%	0.932	275	4%
		injured	4	2	5%			12	
	Mucus loss	not injured	68	37		0%	0.994	284	1%
		injured	0	2	5%			2	
Sole	Net marks	not injured	16	8	87%	53%	0.005*	50	79%
		injured	18	54				193	
	Internal organs exp	not injured	32	55	11%	6%	0.29	218	10%
		injured	2	7				25	
	Fin fraying	not injured	30	42	32%	12%	0.289	197	19%
		injured	4	20				46	
	Wounding	not injured	32	55	11%	6%	0.537	214	12%
		injured	2	7				29	
	Scale loss	not injured	16	17	73%	53%	0.563	100	59%
		injured	18	45				143	
	Abrasion	not injured	17	13	79%	50%	0.048*	70	71%
		injured	17	49				173	
	Exophthalmia	not injured	34	61		0%	0.994	242	0%
		injured	0	1	2%			1	
	Bleeding	not injured	32	52		6%	0.375	213	13%
		injured	2	10	16%			33	
	Mucus loss	not injured	34	61		0%	0.994	241	1%
		injured	0	1	2%			2	

In the otter trawl case study, scale loss was observed in 70% of fish, and was the most prevalent injury, followed by bruising (41%) and bleeding (34%) (Table 15).

Table 15 – Summary data for case study 2 – otter trawl fishery, with the number of injured/not injured fish and proportion injured fish in the population.

Species	Injury	Response	Population	
			Number	Proportion injured
Plaice	Net marks	not injured	561	2%
		injured	11	
	Internal organs exp	not injured	567	1%
		injured	5	
	Fin fraying	not injured	550	4%
		injured	22	
	Wounding	not injured	538	6%
		injured	34	
	Scale loss	not injured	173	70%
		injured	399	
	Abrasion	not injured	496	13%
		injured	76	
	Bleeding	not injured	375	34%
		injured	197	
	Mucus loss	not injured	446	22%
		injured	126	
	Bruising	not injured	335	41%
		injured	237	
	Scratches	not injured	462	19%
		injured	110	

Factors influencing survival

Annex 5 summarizes the fit of multinomial models to the counts by vigour assessment category (vigour), using each variable singly. This analysis was conducted for plaice only. In terms of the criteria $p<0.05$, 13 of the 19 variables considered to improve the description of the vigour categories by haul compared to using the same proportions for all hauls. However, care in interpretation is required as many of the variables are linked and analysis of large numbers of variables can generate a proportion of spurious results.

The model results show some effects interest that can be observed with a visual analysis. The wind strength, seas-state and swell height were all associated with vigour category as the proportion of Excellent plaice was higher for hauls undertaken in calm weather conditions (Table 16 and Figure 18). There was also an indication that the two different gear types were associated with different vitality category with more Excellent fish caught in Mono-filament nets than in the Multi Mono-filament nets (Table 16).

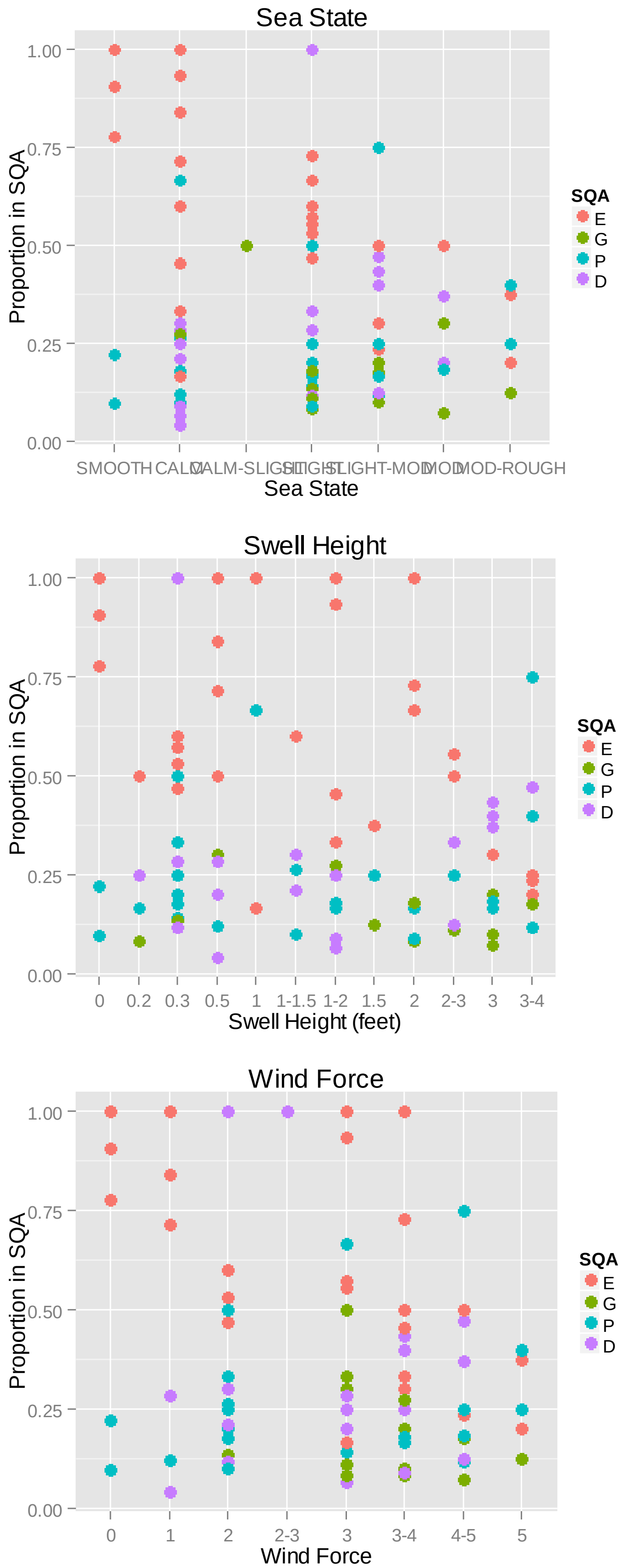


Figure 18 The proportion of fish in each vigour assessment category for each haul vs sea state, swell height and wind force; to provide visual analysis.

Table 16 Vitality (vigour) associated with wind force, seas state, swell height and gear type; defined as end of hauling to end of sort time.

Wind Force	Predicted proportions in Vigour category			
	E	**G**	**P**	**D**
0	0.89	0.00	0.11	0.00
1	0.85	0.00	0.07	0.08
2	0.44	0.16	0.21	0.19
2-3	0.00	0.00	0.00	1.00
3	0.57	0.13	0.11	0.18
3-4	0.48	0.11	0.15	0.25
4-5	0.34	0.11	0.21	0.34
5	0.28	0.06	0.33	0.33

Swell Height (ft)	Predicted proportions in Vigour category			
	E	**G**	**P**	**D**
0	0.89	0.00	0.11	0.00
0.2	0.50	0.08	0.17	0.25
0.3	0.48	0.13	0.20	0.19
0.5	0.80	0.05	0.05	0.09
1	0.38	0.12	0.50	0.00
1-1.5	0.38	0.17	0.21	0.24
1-2	0.54	0.13	0.13	0.20
1.5	0.37	0.13	0.25	0.25
2	0.74	0.11	0.11	0.04
2-3	0.53	0.16	0.11	0.21
3	0.34	0.10	0.16	0.40
3-4	0.23	0.10	0.29	0.39

Sea State	Predicted proportions in Vigour category			
	E	**G**	**P**	**D**
SMOOTH	0.89	0.00	0.11	0.00
CALM	0.60	0.10	0.15	0.16
CALM-SLIGHT	0.50	0.50	0.00	0.00
SLIGHT	0.55	0.12	0.16	0.17
SLIGHT-MOD	0.31	0.12	0.19	0.37
MOD	0.41	0.14	0.14	0.32
MOD-ROUGH	0.28	0.06	0.33	0.33

Gear	Predicted proportions in Vigour category			
	E	**G**	**P**	**D**
A	0.62	0.07	0.12	0.18
B	0.47	0.13	0.19	0.22

Discussion

The project delivered its aim to generate discard survival estimates for selected species for (Welsh) commercial fisheries operating in the Bristol Channel. The structure of the project dictated the method that could be used, and this was developed within the project and in parallel with the ICES Workshop on Methods to Estimate Discard Survival (WKMEDS). Therefore, this project has provided a testing ground for the methods and concepts developed from that ICES group and observations from the project have fed back to improve the guidance on how best to conduct these experiments. The approach selected was to use vitality assessments during a representative range of conditions and combining this with the captive observation of individuals with different vitality levels to generate an overall weighted mean discard survival estimate.

It is recognised in the literature that not all discards die. Although there is considerable variation in estimates of discard survival within and between studies, research has shown that in some circumstances the proportion of discarded fish that survive can be substantial. Studies that have looked at flatfish species, including plaice and sole, show variable results, with survival rates presented in the range of ~40-80%, although zero survival was observed in some experiments (STECF 14-19). These results studies differed in the fishery, operational characteristics and method, making it difficult to compare between studies. Moreover, the results often report only a component of discard mortality, either by not including predation or by presenting estimates that do not account for the full time period over which discarded fish may die.

For many European fisheries-species combinations (particularly regulated species) there are no discard survival estimates available. A recent literature review of studies on discard survival rates for STECF (Revill, 2012) showed there are few experiments for passive gears, and no reported discard survival data for plaice and sole in European gill and trammel net fisheries. Here we present the first estimated discard survival of plaice and sole caught in gill nets. This study demonstrated that after an observation period of 76-81h, the percentage of discarded plaice surviving after normal commercial fishing practice was 49.3% (37.1-59.8%). For Dover sole, after this period, discard survival was 20.6% (14.8-27.9%). This lower survival reflected that 46% of caught sole were assessed as dead/moribund at the point of discarding and only fish assessed as being vigorous at the point of discarding survived. Although, the observation period was necessarily limited, an attempt was made to forecast a final survival estimate that would take account of all discard mortality, based on changes in the discard mortality rate over the observation period. Two models were applied, providing discard survival estimates of 3.6-39.1% for plaice and 18.6-20.3% for sole. The difference in the plaice modelled estimates was driven by the death of a few individuals at the end of the observation period, demonstrating the sensitivity of the model to these data.

In the otter trawl fishery, only plaice was investigated. For this fishery only vitality, reflex and injury data were generated. To generate an estimate of survival for this fishery required the application of survival rates from another source. Using the same method, during the same period, survival estimates by vitality category were generated from an otter trawler working in a neighbouring ICES sub division. The estimate generated inferred that survival was the same for each vitality as was observed in a closely related otter trawl fishery. This assumed that the stresses endured by the fish in one fishery were the same as those of the other and that health vitality assessments were consistent across both studies. The vessel was smaller, the fishing gear lighter, depths shallower and towing times shorter, suggesting that the survival rates are not likely to be lower than inferred. The estimated survival for otter trawl caught plaice, accounting for these assumptions, is 75-88% survival.

There are a number of factors that are known to affect the survival of discarded fish and these can be classified into three broad categories: technical (e.g. fishing method, catch size and composition, handling practices on deck), environmental (e.g. changes in temperature, depth, light conditions) and biological (e.g. species, size age, physical condition, occurrence of injuries) (Davis, 2002; Broadhurst, Suuronen et al. 2006).

All fishing methods induce stress and cause a degree of injury to captured fish (e.g. internal and external wounding, crushing and scale loss) (Davis and Ryer, 2003). Fish that are captured in trammel nets may be 'gilled' by the meshes of the inner wall, or they may be 'bagged' by pushing the inner wall through the larger meshes of the outer wall to create a pocket. In this experiment it was observed that the two species of flatfish studied meshed differently to one another. The majority of sole were 'gilled' by the inner wall of the net. As a product of their body shape, the viscera of the sole were visibly compressed by the twine (often multiple meshes) and the net marking injuries observed reflected this. The majority of plaice were observed to be 'bagged' by the outer wall. The forward movement of plaice through a trammel net causes inner meshes to be picked up (possibly on the spine behind the anus) and carried through the outer wall to create a pocket or 'bag' from within which they are unable to escape. Once captured, the fish remained 'gilled' or 'bagged' in the net until the tier of nets was hauled and cleared. Generally speaking, the longer fish are exposed to the fishing gear, the more severe the stress, leading to exhaustion and increased physical damage. For the fishing operations in this study, captured fish remained in the net for a maximum of between 19hr 20min and 28hr 52min.

Other species were caught in the nets and may have contributed to the stress or injuries if they were closely meshed, particularly the substantial catches of large elasmobranchs recorded in this study. The hauling process involved the nets being mechanically raised from the sea bed to the surface, involving a change in depth (14-30m to surface), hence pressure, and a change in sea temperature. As the nets are hauled, the headrope and the footrope are brought together and may twist, so the fish may suffer from compression injuries, especially as the nets are hauled over the rollers of the net hauler.

From the moment the fish came out of the water, they were subjected to stressors associated with air exposure. The nets were placed in a pile on the deck until the hauling process was complete and catch sorting began, although, as part of normal commercial practice, care was taken to prevent the sole and plaice from being crushed by placing these fish to the edge of the pile (Figure 10). Exposure to air is an integral part of fish capture and is directly related to the sorting and handling times on deck. On this vessel, sorting times varied from a few seconds, for fish that were un-meshed immediately, to more than 2hrs, when poor weather led to catch sorting being delayed until the vessel was in port. The process of un-meshing the individual fish also varied from a few seconds to several minutes, depending on how the fish were meshed. Due to their body shape and the way that they 'gilled' in the inner meshes, the removal of sole from the net involved gripping the head and pulling the fish through the meshes, further compressing the gut and potentially injuring the head. The 'bagged' plaice were generally removed from the net by prising the meshes back over the head, as the diamond/wedge body shape and the size of the plaice prevented them from being pulled through the meshes. It was therefore observed that removing the fish from the net would have induced substantial stress on the fish.

Previous studies have shown that air exposure is one of the greatest contributors to discard mortality rates (Davis 2002, Broadhurst, Suuronen et al. 2006) and that reducing handling time and exposure to air could be a useful measure to increase discard survival (Benoit *et al.*, 2010; Davis and Ryer, 2003). Effects of air exposure on deck may be exacerbated by simultaneous exposure to direct sunlight and increased temperatures, which can lead to rapid dehydration. Fish may already have suffered skin injuries and scale loss as a result of the capture process; the exposure to air (wind) and sunlight will have synergistic effects. This study was conducted during the commercial sole fishery in summer, at a time when air temperatures on deck ranged from 16°C to 20°C and conditions were generally bright and sunny, with up to 21kts of wind and sea surface temperature was 18°C. Temperature has been identified as an important factor effecting survival assessments, with high temperatures, of the water and air associated with lower rates of survival.

As conditions in the fishery change (e.g. seasons, areas fished), so can the resulting discard mortality rates (Benoit *et al.*, 2011). In our opinion, the presence of observers on board the vessel did not influence the catch handling process and the conditions experience by the fish in our study were consistent with the types of condition present in the fishery at this time. The vessel used in case study 1 was operated by one experienced crew member and the process of boarding the nets and un-meshing the fish was consistent with normal routine. The only difference was that at the point of normal discarding, the fish were handed to the observers for assessment. Due to the number of trips and timing of the study it was not possible to investigate different sorting practices that might reduce air exposure or investigate the potential effect of different water temperatures. However, there were some indications of factors that did influence survival, namely the weather conditions and the fishing gear construction material. Survival was observed to be lower during poor weather (quantified as wind force, swell height and sea state and when using multi-monofilament nets compared with monofilament nets. Multi-monofilament netting is a cross between multifilament netting and monofilament netting and is composed of several strands of monofilament twine loosely twisted together. There is an indication that this design of netting, may induce more stress on the fish compared with monofilament leading to lower survival rates. Therefore, different netting construction designs offer one potential mean to increase the survival rates.

This study generated discard survival estimates based on captive observation and vitality assessments as a proxy. We found no evidence of avian predation, but without the time or the resources within this project to conduct tagging experiments, the levels of marine predation remain unknown. Discarded fish may be susceptible to increased predation risk due to impaired swimming abilities (e.g. loss of orientation, reduced swimming speed) as a result of injuries or post-traumatic behaviour. Davis and Ryer (2003) found that behavioural impairment, in the fish species studied, lasted at least 2hrs with fish recovering with 24hrs, and that behavioural impairment was correlated to the magnitude of the stress. Increased risk of infection, as a result of scale loss or skin injuries, may also eventually induce mortality in the medium to long term.

Captive observation studies that exclude predation and do not account for delayed mortality resulting from injuries or infection, are likely to represent over estimates of actual discard survival under commercial fishing conditions. Conversely, unless suitable experimental controls are employed, stresses associated with handling during transfer and the holding of fish in captivity can induce mortality and could lead to under estimates of discard survival (Benoit et al. 2010, Depestele et al. 2014) Portz *et al.*, 2006). Ideally, the mortality associated with captive conditions would be estimated using control fish that had not been subjected to the capture and handling processes but held in identical conditions to the treatment fish.

The control experiments at the laboratory with the on-shore holding tanks demonstrated zero mortality and unimpaired behavioural reflexes in the control fish, indicating that the design of the system did not induce mortality or negatively affect vitality. The treatment fish were held in a different location, however, the tanks were supplied with a constant supply of temperature and salinity regulated seawater. It was not logistically feasible to conduct control experiments on-board the vessel and during the transit from the vessel to the shore unit. The captive fish will have undergone a number of stresses additional to the capture and discard process. It can, therefore, not be fully determined whether it was the treatment or the method that was responsible for the observed mortality of fish in the holding tanks. Physical damage caused by being held in tanks on board a moving vessel, changes in light, salinity, temperature, water quality and being held in close proximity with other fish, all exert stress. Where these stressors are occurring, they will likely have additive effects to the treatment stressors already encountered and reduce the observed survival rates. The on-board tanks were filled with fish from the bottom up, therefore, any increasing mortality rates through the stack of tanks would indicate an experimental effect of the time spent in the tanks, the position in the stack of the fish or to different qualities of the seawater. The potential for an on-board tank effect was explored by ranking the proportion of deaths in each tank and conducting a Spearmen's rank correlation test. The absence of any significant difference between tanks (Spearman's Rank Correlation, 0.2, -0.4 for Excellent plaice and sole; number of survivors were insufficient for other categories) indicates that the on-board tanks had limited effect on survival.

The port of operation in this study presented logistical challenges for locating the onshore tanks. The cessation of water flow to the on-board tanks as the vessel approached the port, and the time taken to pass through the lock and in transit to the onshore tanks, led to reduced dO2 and increased water temperatures. While healthy individuals may be able to tolerate worsening conditions, these additional stressors may have increased mortality of the already stressed captive fish. Portz *et al.* (2006) stated that water quality is one of the most important contributors to fish health and stress level, and that short term exposure to poor water quality can result in permanent damage or mortality if physical or chemical variables combine to reach lethal levels.

Experiments conducted by Davis and Ryer (2003) showed increased stress and mortality in fish that were sequentially subjected to increased seawater temperature and air exposure, following a simulated trawl process. The treatment fish in our experiment were subjected to water temperature up to 19.9°C, increased from a sea-surface temperature of around 18°and a reduction in dO2 down to 44% during the transit phase. The dO2 concentration of water decreases with increasing temperature, and in these experiments would have decreased further as a result of increased metabolic activity and oxygen consumption of stressed fish. We did make attempts to aerate the water in the transportation containers with battery operated air stone pumps, but it was believed that the noise and vibrations generated by the pumps in the close confinement of the vehicle may have added to the stress levels and been counterproductive.

The potential stressors on the captive fish associated with the methodology in this study, are likely to have resulted in experimental induced mortality and therefore underestimated survival. The stressors of temperature, salinity and dO2 are factors known to increase mortality in fish. Specifically these stressors included:

- Handling fish to conduct the vitality assessments, length measurements and to put fish into the on-board tanks
- Captivity in the on-board tanks (movement caused by vessel movement; proximity with other fish; serial flow of water from top to bottom tank)
- Stopping water flow to on-board tanks on approach to port until docked (reducing dO2)
- Transfer of fish into tubs (handling of fish)
- Carrying tubs off the vessel and transporting, by van, to onshore holding tanks (increased temperature, reduced dO2, movement)
- Handling the fish to transfer into onshore tanks
- Adjusting to salinity and temperature change in the onshore tanks
- Monitoring fatalities using tail grab

To be able to use the assessments of fish vitality as a proxy for survival when combined with captive observation results, two conditions were required. Firstly, scientific fieldworkers had to be able to assess the vitality of fish consistently, in time and in different conditions. Secondly, to be able to use vitality assessments as a proxy for survival, there must be a significant relationship between survival and vitality score. The first condition was considered to have been met in the trammel net study, by having only one fieldworker making all the health assessments. The second condition was also considered to have been met in the trammel net study because it could be demonstrated that there were statistically significant differences in survivor curves between vitality categories for plaice and sole between pairs of categories except for Good and Poor, which had low levels of survival. These results demonstrated that the vitality assessment effectively distinguished the chances of survival, and therefore could be used as a proxy for survival.

For survival estimates to be representative of the fishery, vitality data should be generated for fish discarded during all conditions of a fishery. However, because conditions are constantly changing, without a continuous vitality monitoring programme, the survival estimates may be representative only for the trips from which vitality data have been collected. To extrapolate the results from this study to the fishery, it must be assumed that the combination and strength of stressors on the discarded fish are the same on all trips as those from which vitality data were collected. It can be stated that the trips from which these data were generated were conducted under normal representative commercial fishing conditions.

Conducting survival studies on small commercial vessels in remote ports is technically and logistically challenging. The vessels are restricted in deck space and can hold only small numbers of fish in suitable tanks, and these must be transferred to shore when fishing for less than one day; this meant that the use of controls had to be limited and there were unavoidable additional stressors exerted on the fish. The survival estimates should, therefore, be interpreted as minimum discard survival estimates that do not account for experimental induced mortality, that exclude marine predation but do include avian predation. Here we present the first estimates from a static net fishery in Europe of plaice and sole discard survival rates. The observed survival estimates was 49.3% for plaice and 20.6% for sole after 77-81hrs; and modelled estimates produced survival rates of 3.6-39.1% for plaice and 18.6-20.3% for sole. Using captive observation results from a similar neighbouring otter trawl fishery, produced inferred discard survival estimates for plaice caught by an otter trawler in the Bristol Channel of 75-88%.

Conclusions

The project achieved its aim to generate discard survival estimates for selected species in fisheries operating off the Welsh coast in the Bristol Channel. Better health condition of plaice was significantly associated with higher survival, validating the integrated method of combining the assessed vitality of fish from the catch with the survival probability associated with those vitalities. The project generated both experimental estimates within a defined observation period, and modelled results to account for predicted mortalities beyond the observation period.

This study demonstrated that after an observation period of 76-81h, the percentage of discarded plaice surviving after normal commercial fishing practice was 49.3% (37.1-59.8%). For Dover sole, after this period, discard survival was 20.6% (14.8-27.9%). Modelling the predicted final rates beyond the observation gave discard survival estimates of 3.6-39.1% for plaice and 18.6-20.3% for sole. Using captive observation results from a similar otter trawl fishery in a parallel study combined with health assessment, produced inferred discard survival estimates for plaice caught by an otter trawler in the Bristol Channel of 75-88%.

All estimates excluded marine predation, but include avian predation, of which none was observed. Furthermore, the stressors exerted on the fish from the method, including temperature differences, handling, confinement, close proximity to other fish and dissolved oxygen depletion, were likely to have induced some experimental mortality. Therefore, the results presented here should be interpreted as minimum estimates of discard survival, excluding marine predation.

There were many factors with the potential to effect survival and the relatively low number of replicates of the treatment making it difficult to identify the key influencing variables. However, some initial analysis of the factors that influence survival showed that lower survival was associated with poor weather conditions, and the netting construction type was also a possible factor. There was an indication that higher survival was associated with monofilament nets compared with multi-monofilament nets, suggesting that changing the net design could provide a mechanism to increase survival rates.

The survival estimates generated here are representative of the observed trips. Assumptions must be made to extrapolate the data to vessel and fleet levels. However, this evidence is considered to provide scientifically robust estimates of discard survival and will inform fisheries managers of the appropriateness and potential to develop proposals to gain exemption from the European landing obligation under the high survivability provision.

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References

[redacted] (2010). "Assessing the factors influencing discard mortality of demersal fishes using a semi-quantitative indicator of survival potential." Fisheries Research **106**(3): 436-447.

[redacted] (2012). "Estimating fishery-scale rates of discard mortality using conditional reasoning." Fisheries Research **125**: 318-330.

[redacted] (2006). "Estimating collateral mortality from towed fishing gear." Fish and Fisheries **7**(3): 180-218.

[redacted] (2012). "Smcure: An R-package for estimating semiparametric mixture cure models. ." Computer methods and programs in biomedicine, **108**: 1255-1260.

[redacted] (2002). "Key principles for understanding fish bycatch discard mortality." Canadian Journal of Fisheries and Aquatic Sciences **59**(11): 1834-1843.

[redacted], and [redacted] (2003). "Understanding Fish Bycatch Discard And Escapee Mortality." AFSC Quarterly Report.

[redacted] and [redacted] (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.

EU (2013). Regulation 1380/2013 on the Common Fisheries Policy (basic regulation), published in the Official Journal 28 December 2013.

ICES (2014). Report of the Workshop on Methods for Estimating Discard Survival (WKMEDS), 17–21 February 2014, ICES HQ, Copenhagen, Denmark. ICES CM 2014/ACOM:51. 114 pp. [redacted]

[redacted] and [redacted] (2006). "Stress-associated impacts of short-term holding on fishes." Reviews in Fish Biology and Fisheries **16**(2): 125-170.

[redacted] (2012). "Survival of discarded fish. A rapid review of studies on discard survival rates." DG MARE A2. Request For Services Commitment No. S12.615631

[redacted] and [redacted] (2013). "Mortality of adult plaice, Pleuronectes platessa and sole, Solea solea discarded from English Channel beam trawlers." Fisheries Research **147**: 320-326.

STECF (2014). Scientific, Technical and Economic Committee for Fisheries (STECF) – Landing Obligation in EU Fisheries - part II (STECF-14-01). 2014. Publications Office of the European Union, Luxembourg, EUR 26551 EN, JRC 88869, 67 pp.

Venables, W. N. and B. D. Ripley (2002). Modern Applied Statistics with S, 4th edn. Springer, New York, 495pp.

Annexes

Annex 1 STECF EWG 14-11 Table of survival estimates

Relevant species for which discard survival estimates are available, the gear and location of the study, the literature reference, the time period of observation from the point of discarding and the minimum and maximum levels of survival observed in the study.

Species	Common name	Gear	Location	Reference	Observation period	Min of discard survival lower limit	Max of discard survival rate higher limit
Pleuronectes platessa	Plaice	Beam trawl	English Channel	Revill et al. (2013)	3 days	37.3	79.6
Pleuronectes platessa	Plaice	Beam trawl ("eurocutter")	Belgium	Depestele et al. (2014)	77h	48	69
Pleuronectes platessa	Plaice	Otter trawl	Germany	Kelle (1976)	7 days	12	70
Pleuronectes platessa	Plaice	Otter trawl	North Sea	Berghalm et al. (1992)	5 days	0	100
Pleuronectes platessa	Plaice	Otter trawl	The Netherlands	van Beek et al. (1990)	3.5 days	0	48
Pleuronectes platessa	Plaice	Pulse beam trawl	North Sea	van Marlen et al. (2013)	71h; 133-158h; 157h	0	80
Pleuronectes platessa	Plaice	Pulse beam trawl	North Sea	van Marlen et al. (2005)192h		12	59
Solea solea	Sole	Otter trawl	North Sea	Berghalm et al. (1992)	5 days	71	100
Solea solea	Sole	Beam trawl	English Channel	Revill et al. (2013)	3 days	53.1	76.4
Solea solea	Sole	Beam trawl ("eurocutter")	Belgium	Depestele et al. (2014)	91h	14	29
Solea solea	Sole	Demersal trawl	Germany	Kelle (1976)	7 days	33	59
Solea solea	Sole	Demersal trawl	North Sea	Berghalm et al. (1992)	5 days	71	100
Solea solea	Sole	Demersal trawl	The Netherlands	van Beek et al. (1990)	3.5 days	4	37
Solea solea	Sole	Pulse beam trawl	North Sea	van Marlen et al. (2013)	36h; 72h; 133-158h; 204h	27	70
Solea solea	Sole	Pulse beam trawl	North Sea	van Marlen et al. (2005)	192h	17	54
Elasmobranch	Rays and skates	Otter trawl	U.K	Enever et al. (2009)	3 days	55	55
Elasmobranch	Rays and skates	Beam trawl	U.K	Revill et al. (2005)	2.5 days	92	100
Elasmobranch	Rays and skates	Fish trawl	Spain	Rodriguez-Cabello et al. (2005)	1 hour	78	78
Elasmobranch	Rays and skates	Gillnet	U.S.A	Hueter et al. (2006)	Tagging	60	69
Elasmobranch	Rays and skates	Hook and line	U.S.A	Gurshin and Szedlmayer (2004)	6 hours	90	90
Elasmobranch	Rays and skates	Otter trawl	U.K	Enever et al. (2010)	2 days	55	67
Elasmobranch	Rays and skates	Otter trawl	U.S.A	Mandelman and Farrington (2006)	3 days	80	100
Elasmobranch	Rays and skates	Squid trawl	Falkland Islands	Laptikhovsky (2004)	3 hours	0	71

Annex 2 *Ad hoc* physical environmental measurements

Observation date	Time	Tank	Water temp.	Flow rate	D. Oxygen (%)	Salinity (ppt)
22/08/2014	16:50	4	16.8	2	90	30
22/08/2014	16:50	8	15.9	2	90	30
22/08/2014	16:50	2	15.9	2	90	30
23/08/2014	12:15	ONBOARD	17.7	2	93	35
23/08/2014	15:35	bucket		0	44	
23/08/2014	17:55	10	16.5	2	88	30
24/08/2014	08:45	6	15.7	2	89	30
24/08/2014	18:30	3	16.8	2	96	30
24/08/2014	18:30	9	16.4	2	98	30
24/08/2014	18:30	1	16.1	2	96	30
25/08/2014	07:30	5	16.2	2	98	30
25/08/2014	07:30	7	15.8	2	102	30
25/08/2014	07:30	10	15.7	2	102	30
25/08/2014	20:00	5	16.6	2	96	30
25/08/2014	20:00	9	16.3	2	93	30
01/09/2014	19:00	7	16.7	2	104	30
02/09/2014	13:30	ONBOARD 1	18.1	2	98	35
02/09/2014	13:30	ONBOARD 5	18.1	2	89	35
02/09/2014	16:40	ONBOARD	19.5	0	86	35
02/09/2014	19:00	2	16.5	2	107	30
03/09/2014	19:00	11	16.8	2	95	31
05/09/2014	19:00	9	17.2	2	94	30
06/09/2014	19:00	bucket	19.9	0	51	30
07/09/2014	19:00	1	16.7	2	85	30
08/09/2014	19:00	5	16.8	2	90	30