Fisheries Innovation Scotland

FIS015 - Post-catch survivability of discarded Norway lobsters (*Nephrops norvegicus*): Further investigations within the large-scale fleet operation

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AND PREPARED BY

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Post-catch survivability of discarded Norway lobsters (*Nephrops norvegicus*): Further investigations within the large-scale fleet operation – Final project report FIS project FIS15

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Summary of activities according to project objectives as agreed in project contract

1. Working with the SIDI program data manager and SFF to analyse existing data and collect further data on (i) fishing patterns in the west coast Nephrops fleet – areas fished and locations discarded, tow durations, total catch bulk, size composition, discarding routines and quantities of Nephrops discarded, and importantly, evaluate levels of physical damage of Nephrops after trawling (damage index as in FIS15 survival trials).

SFF observers performed a series of trials using three different commercial vessels fishing in the North Minch during summer/autumn 2016 and during winter/early spring 2016/2017 (3 single-rig vessels and 3 twin-rig vessels, TR2; 10 tows for comparison in the summer and 14 in the winter). Relevant data to this project from those SFF trials has been compared with data obtained from survival trials conducted by the University of Stirling and SAMS. This data has allowed to put the survival results obtained in this project into a wider context.

2a. To conduct tank-based Nephrops post-trawl survival trials over extended periods of time (estimated at around 15 days) with Nephrops being captured using two representative fishing vessels operating in the Minches in early summer and autumn/winter. Experiments will be designed explicitly to test the effect of visible damage on animals on their post-recovery survival.

Tank-based survival trials on discarded *Nephrops* have been conducted over an extended period of recovery using a twin-rig vessel ‘Ocean Trust’ operating from Mallaig during summer/autumn 2016 and winter/early spring of 2017. A total of 24 recovery trials were performed covering both TR1 and TR2 mesh sizes. The captive observation method used to estimate survival was designed following recommendations set by ICES WKMEDS with monitoring periods of up to 13 days.

2b. At the request of FIS an additional objective was added to conduct similar studies during summer on the east coast.

Similar tank-based survival trials were conducted during summer 2017 using the twin-rig fishing vessel ‘Winaway’ operating from Pittenweem. A total of 6 recovery trials were performed using a TR2 mesh size in June 2017. Data from a trip conducted by SFF in a different vessel (comprising data from 6 tows) was also available and comparisons between both datasets have been made.

3. To conduct further behaviour observations on how post-trawl discard Nephrops with different degrees of damaged and exposed to different temperatures and length air exposure recover under natural conditions on the seabed and interact with potential predators using fixed and mobile underwater camera systems.

Behavioural observations were conducted using a remotely operated vehicle in April, November and December 2017. A total of fifteen dives were completed at water depths between 70 and 115 m observing the reactions of 23 individual discard-sized *Nephrops* released on the seabed.

1. *Based on Objectives 1-3, generate a robust estimated level of Nephrops discard survival that is representative of the investigated fisheries, with any assumptions clearly stated.*

Estimates of survival have been generated for both west coast and east coast based on the recovery trials conducted on the fishing vessels 'Ocean Trust' and 'Winaway'.

5. Taking into consideration data collected the project will evaluate which environmental and on-board factors are causative determinants for survival and will produce recommendations for best practice to minimise post-discard mortality rates.

Based on the data collected under objective 2 potential factors determining survival of post-discard *Nephrops* have been discussed and a set of recommendations for best practice to minimise post-discard mortality drawn up.

1. Executive Summary – key findings

- In the commercial *Nephrops* trawl-fishery off the Scottish west coast (Minches) mean (+ 95% confidence interval) *Nephrops* discards survival estimates were 45.7% (43.4-48.3%) in summer and 56.3% (53.5-59.4%) in winter (12 hauls for each season) and 52.7% (50.9-54.6%) across both seasons, based on data from one vessel 'Ocean Trust' using both TR2 and TR1 gear.
- In the commercial *Nephrops* trawl-fishery off the Scottish east coast (Firth of Forth) mean (+ 95% confidence interval) *Nephrops* discards survival estimates were 74.5% (71.8-77.1%) in summer (6 hauls) based on data from one vessel 'Winaway' using TR2 gear.
- These estimates were obtained using the captive observation method as recommended by ICES WKMEDS with monitoring periods of up to 13 days. The holding tanks caused negligible deaths during the monitoring period (control samples showed mortalities of 3% Ocean Trust trials and 0% Winaway trials) providing confidence in the survival estimates.
- Predation effects were not investigated so the survival estimates should be interpreted as discard survival that excludes marine predation.
- Discard survival estimates were generated from samples taken during normal commercial fishing activity. These data were supplemented with observations on discard patterns from other vessels fishing in the same areas to determine the representativeness of the survival estimates for each fishery.
- For the Scottish west coast (Minches) the environmental conditions, fishing practices and damage to discarded *Nephrops* from 'Ocean Trust' were compared seasonally with the wider fleet (3 single-rig vessels and 3 twin-rig vessels, TR2; 10 tows for comparison in the summer and 14 in the winter). In general terms, 'Ocean Trust' data were in range with the wider fleet information indicating that the discard survival estimates are representative of the wider fleet operating on the west coast.
- For the Scottish east coast (Firth of Forth) environmental conditions, fishing practices and damage on discarded *Nephrops* from 'Winaway' were compared with available data from one other vessel (6 tows). There were substantial differences in the estimates of discard rates, occurrence of injuries and immediate mortalities between the two vessels, which also fished in different locations. To apply the discard survival estimates to the whole fleet in this fishery would require assumptions that these differences do not influence overall discard survival. The survival estimates obtained in the recovery trials are likely to be most representative of smaller (<15m) vessels, such as the 'Winaway', operating in the inner Firth of Forth and less representative of larger vessels fishing further offshore.
- Samples for captive recovery observations were selected at both the start and towards the end of the catch sorting period for the winter west coast and summer east coast trials. However, samples were taken only from the start of the catch sorting process for the initial summer west coast trials. However, analysis of the relationship between sorting time and discard survival for trials where this could be compared indicated no significant relationship. However, it must be cautioned that because the catch sorting

times were longer for the west coast summer tows and air temperatures were higher, the discard survival estimates from these trials may not be representative of the whole discard fraction.

- Using a remotely operated underwater vehicle (ROV) a novel method was developed to observe the behaviour of discard-sized *Nephrops* in order to assess whether the animals are able to exhibit normal behaviour when they reach the seafloor. Deployment of the ROV to release of the animals, which required sediment stirred up by the ROV landing to clear, took on average 10 minutes.
- After this period undamaged discarded *Nephrops* appeared to exhibit normal behaviour and they began to explore their surroundings. This applied even after 3.6 h of aerial exposure (mainly winter conditions), although in these cases recovery took a few more minutes. *Nephrops* were also observed entering existing burrows and in some cases clearing partially blocked burrows when the animals were deposited on suitable ground.
- No interactions with predators were observed although the lack of predators could be site dependent or affected by the presence of the ROV.
- Discarded undamaged *Nephrops* (which comprised between 49.5-57.6% of the discard-fraction) are therefore expected to become capable of exploring their immediate surroundings within 10-15 minutes of being discarded and finding shelter in existing burrows on suitable ground.
- The project also investigated factors, such as length of tow, air temperatures etc., that might be thought to influence survival in order to formulate recommendations of best practice designed to minimise discard mortality in these fisheries.
- Based on statistically modelling the combined data from both sets of recovery trials it was concluded that lower survival was associated with the physiological condition of *Nephrops* at the point of release i.e. proportion in the poorest vigour category, with the proportion of *Nephrops* with signs of physical damage, and with higher weights of non-*Nephrops* catch.
- No other direct links were found between discard-fraction *Nephrops* survival and other factors which might be expected to impact their survival, such as air temperature, tow length or total catch weight. However, the proportion of discarded *Nephrops* in the poorest vigour category was itself significantly positively correlated with higher air temperatures.
- While the recommendations below are considered to provide the most likely measures to improve survival of discarded *Nephrops*, the absolute and relative benefits of each cannot be determined without further experimental investigation.
- Recommendations:
    - A fine seawater mist spray could be installed in the catch sorting hoppers. This should have the effect of keeping air temperatures in the hopper cooler than the surrounding air at minimal cost.
    - Closing the hatch over the sorting hopper or covering the hopper once the nets are emptied is also recommended. This should have the effect of keeping air temperatures in the hopper cooler than the surrounding air at minimal cost.

- Handling strategies that minimise damage would have a positive effect on discards survival (i.e. not walking on top of the catch and reducing the use of metal rakes to handle the catch).
- There is circumstantial evidence to suggest that a sloping floor in the hopper might help reduce damage to the catch by reducing the need to manually push or drag the catch through the hatch to the sorting table.
- This study suggests that survival might be improved by use of more selective fishing gear by reducing the proportion of non-*Nephrops* catch.
- *Nephrops* should be discarded over suitable grounds to improve their chances of finding burrows to shelter in when they reach the seafloor.

2. Project overview

2.1. Introduction

The project was funded by Fisheries Innovation Scotland in order to gather data regarding the discard survival of *Nephrops norvegicus* caught during commercial trawl fishing operations. The main driver for the project is the 'Landings Obligation' introduced as part of the reformed Common Fisheries Policy of the European Union. Under this change in rules, fishers will be required to return to port all material caught belonging to quota-managed species. Because most of this material has limited commercial value, this is likely to lead to significant increases in operating costs. However, exemptions can be granted on the grounds of high-survivability, if it can be demonstrated that a high proportion of discarded animals are likely to survive the catch and discard process. Returning such material to port would thus increase overall mortality for little additional conservation benefit.

A previous project (Albalat et al. 2015) examined survival of *Nephrops* from a trawl fishery operating in the Clyde. This fishery is however somewhat specialised as it sells *Nephrops* to the live market and thus operates relatively short trawl durations. The aims of the present project were to gather similar information from trawlers selling to the fresh and tail markets.

This report is presented in separate sections, one for each of the objectives below, which have been slightly re-ordered from the original proposal, followed by an overall concluding section. Several appendices are also included detailing some additional work which was undertaken.

1. To conduct tank-based Nephrops post-trawl survival trials over extended periods of time (estimated at around 15 days) with Nephrops being captured using two representative fishing vessels operating in the Minches in early summer and autumn/winter. Experiments will be designed explicitly to test the effect of visible damage on animals on their post-recovery survival.
2. At the request of FIS an additional objective was added to conduct similar studies during summer on the east coast.
3. Working with the SIDI program data manager and SFF to analyse existing data and collect further data on (i) fishing patterns in the west coast Nephrops fleet – areas fished and locations discarded, tow durations, total catch bulk, size composition, discarding routines and quantities of Nephrops discarded, and importantly, evaluate levels of physical damage of Nephrops after trawling (damage index as in FIS15 survival trials).
4. To conduct further behaviour observations on how post-trawl discard Nephrops with different degrees of damaged and exposed to different temperatures and length air exposure recover under natural conditions on the seabed and interact with potential predators using fixed and mobile underwater camera systems.
5. Based on 1-3, generate a robust estimated level of Nephrops discard survival that is representative of the investigated fisheries, with any assumptions clearly stated.
6. Taking into consideration data collected the project will evaluate which environmental and on-board factors are causative determinants for survival and will produce recommendations for best practice to minimise post-discard mortality rates.

3. Tank recovery trials on the west coast

Objective 1a (Objective 2a in the original proposal). To conduct tank-based Nephrops post-trawl survival trials over extended periods of time (estimated at around 15 days) with Nephrops being captured using two representative fishing vessels operating in the Minches in early summer and autumn/winter. Experiments will be designed explicitly to test the effect of visible damage on animals on their post-recovery survival.

3.1. Introduction

Initial discussions with Mallaig and North-west Fishermen's Association suggested that most vessels operating out of Mallaig would be fishing twin-rig TR1[1] or TR2 trawls. An initial meeting was then held with Marine Scotland to review their data on the *Nephrops* trawl fisheries operating on the west coast (Table 3.1). This suggested a much higher amount of landings by single-rig vessels (nearly 70% landings overall) although this did not accord with perceptions of the fleet composition from MNWFA or the Marine Scotland Senior Fishery Officer based in Stornoway[2]. These results clearly suggested that for a full coverage of survival it would be necessary to investigate all three vessel:gear combinations, namely:- twin-rig TR1 and twin-rig TR2 as well as single-rig TR2. This suggested a need to expand the originally planned work which had envisaged that there would be a single dominant gear which would be investigated on two vessels across two seasons. This full combinational coverage could not be practically achieved with the funding available, so for the present project so it was decided, after discussion with FISC, to conduct both TR1 and TR2 trials but based on a single twin-rig vessel.

Vessel monitoring system (VMS) data collected by Marine Scotland were analysed to see whether single and twin-rig vessels were fishing in similar locations. This analysis was performed in order to evaluate whether these types of vessels share fishing grounds and if survival/damage score results from the twin-rig *Nephrops* recovery trials might also be applicable to single-rig fishing (this point will be further covered in section 4). According to the data supplied by Marine Scotland (David Turnbull), in 2016 there was high VMS effort by single-rig (OT, OTB) and twin-rig (OTT) both operating in clearly overlapping fishing grounds in the South Minch. Fishing in the grounds further offshore, to the south of Barra, is predominantly twin-rig which would accord with the generally larger size of these vessels. In North Minch it would appear that that the VMS effort is higher for single-rig compared to twin rig in grounds nearer the coast (Figure 3-1).

[1] TR1 refers to trawls and demersal seines with mesh ≥100 mm. TR2 gears use nets with mesh <100 mm but ≥70 mm.

[2] According to Donald Morrison the western Isles fleet comprises 13 twin rig and 10 single rig vessels. All single rig vessels use TR2 gear and almost all voyages for twin riggers are also TR2. It is only very occasionally that they see their twin riggers using TR1 over 100mm.

Further based on discussion with the Cefas advisor (Tom Catchpole) it was considered that it would be necessary to conduct a minimum of six tows and to cover the winter and summer seasons as air temperature has previously been suggested to have an influence on post-trawl *Nephrops* survival. The total number of recovery trials undertaken was therefore 24 consisting of six TR1 and TR2 tows in winter and six TR1 and TR2 tows in summer.

Modification to Objective 2a: Evaluation of gears used in the area showed that there was a need to include both TR1 and TR2 mesh sizes. This resulted in a requirement to double the original planned sampling effort. The decision was therefore made to conduct all the trials using the twin-rig trawler, 'Ocean Trust', rather than on two vessels. Scientific, Technical and Economic Committee for Fisheries (STECF[3]) have acknowledged that given the logistical demands of conducting Nephrops recovery trials, work conducted on a single vessel is acceptable.

3.2. Materials and methods

The fishing vessel 'Ocean Trust' was chartered for the twin-rig west coast trials (Figure 3-2). This is one of the larger vessels operating out of Mallaig and carries the Maritime and Coastguard Agency Load Line certification allowing the carrying of scientific observers. The nets used were 10 m wide rock-hoppers fitted with 200 mm square mesh escape panels and either 100 mm (TR1) or 80 mm (TR2) cod-ends.

Fishing took place during daylight hours on commercially trawled *Nephrops* grounds in the Sea of Hebrides within three hours steaming of Mallaig (Figure 3-3). On each day of trial fishing two tows were completed. Prior to the first tow the temperature and salinity of the water column were recorded using a Castaway CTD (Sontek, San Diego, USA). Ocean Trust has a covered working area and at the end of each tow the catches are transferred to a flat-based hopper using the power-block (Figure 3-4). Sorting takes place on a metal rectangular cross-section channel table with a chute at the far-end down which discards and *Nephrops* waste are normally returned to the sea (Figure 3-5). The skipper and crew were asked to follow their normal working practices apart from modifying the catch sorting so that discard fraction *Nephrops* (those which would normally be rejected by the crew) and non-*Nephrops* discards (finfish, crabs etc.) were placed into baskets rather than being sent immediately over-board. During the summer/autumn trials one hundred live, discard-fraction *Nephrops* were sampled randomly from the discards basket towards the start of the catch sorting (once some specimens had accumulated in the basket) and placed in an individual compartment of a set-box. As this was being done each animal's damage, vigour and reflex were scored following the CEFAS

[3] STECF are consulted by the EU with regard to Discard Plan proposals and any new proposals from the UK are likely to go through that route (at least up till Brexit), we therefore consider their previous evaluations provide a benchmark which study results need to pass if they are to be considered by the Commission.

protocol (Table 3.2). The number of dead *Nephrops* in the discard-fraction at time=0 was also recorded whilst the set-box was being loaded.

This procedure was modified slightly for the winter/early spring trials in that an additional 50 discard-fraction *Nephrops* were sampled towards the end of the sorting period and added to the set-box. This modification was made because the project reviewers had pointed out that the recovery samples collected during the summer/autumn trials did not come from the full duration of the catch sorting and that animals exposed to air for the full duration of catch sorting might have a lower recovery potential.

The set-boxes were then placed into a 220 litre Saeplast (Dalvic, Iceland) insulated tank filled with fresh seawater on-board the Ocean Trust. The carapace lengths of a random sub-sample of *Nephrops* from the catch (taken directly from the hooper) were then measured using digital calipers. Once the total catch had been sorted by the crew the weights of the retained fresh whole *Nephrops* (these are the larger *Nephrops* caught) and retained *Nephrops* tails (smaller *Nephrops* are tailed on board with the heads/cephalothorax being discarded) were recorded based on the number of baskets filled. The weights of the discard fraction *Nephrops* and non-*Nephrops* catch were also recorded using hanging balances (Dr Meter ES-PS01 electronic balance and Silverline heavy duty model). The weight of tails was raised to a whole *Nephrops* equivalent by multiplying by three (following the MMO guideline for this conversion). The weights of the individual measured *Nephrops* in the catch sub-sample were estimated using the ICES formulae appropriate for the South Minch from Table 3 in Howard and Hall (1983):-

$$\text{Weight males} = 0.00029 * CL^{3.24} \quad \text{(g)}$$

$$\text{Weight females} = 0.00087 * CL^{2.91} \quad \text{(g)}$$

The total estimated weight of the sub-sample (based on *Nephrops* lengths) was then compared with the weighed sub-sample (based on hanging balance measurements) and generally found to be within 0.5 kg. The small differences between the two measures of sub-sample weight were due to the hanging balance being affected by the vessel movement. The estimated total weight was then used to raise the number of *Nephrops* measured in the sub-sample to the total catch weight. The *Nephrops* in the discard fraction were then expressed as a percentage of the total catch – both in terms of weight and numbers.

On return to Mallaig at around 17:00-18:00, the two set-boxes prepared each day were transferred into two, 220 l Saeplast insulated boxes containing fresh seawater to which cold-blocks were added for transporting the animals to the SAMS aquarium. During transport a Hobo temperature logger was placed in each of the Saeplast containers. On 16 of the 24 trials control *Nephrops* were also included in the boxes these being transported from and back to the aquarium. On reaching the laboratory, each set-box was transferred into an individual recovery tank and 10 control animals added to each box (Figure 3-6). The recovery tanks were located in a constant temperature room running at 5^{o}C air temperature with continuous flowing seawater running through a chiller unit. Each tank was also continuously aerated. Water temperatures in the tanks were monitored every 15 minutes using Hobo temperature loggers and the salinity was measured periodically using a Castaway CTD. Ammonia levels were checked daily using an API Saltmaster (Mars Fishcare, Chalfont, Pennsylvania, USA) test-kit. Oxygen levels were monitored using a YSI-Pro20 portable meter.

Appropriate control animals for this type of trial are difficult to source so we used *Nephrops* from the previous discard trips which had fully recovered, had no external damage and were in vigour class 1 and reflex class 0 when removed from the SAMS aquarium stock tank. These animals were used as control animals during transport and during the tank-recovery period. We opted for this type of control as creel-caught *Nephrops*, which have been used in other discard recovery studies, would be larger in size which might affect their vulnerability to the recovery-tank conditions. We acknowledge that the use of this strategy to source control animals might not represent all tested animals as control animals in this study were the most resilient and robust to stress conditions experienced.

The survival of the test and control *Nephrops* in each set-box was checked every two days. Animals in the set-boxes were not fed or disturbed other than during checks. Any dead animals were removed, their carapace lengths recorded and the animal examined for signs of external damage. After 13 days mortalities had generally stabilised (see results) so the remaining live animals were measured and scored for external damage, vigour and reflex. *Nephrops* with signs of external damage or low vigour or reflex scores were euthanized by freezing. *Nephrops* with no external damage and excellent vigour and high reflex were placed in stock tanks for use as control animals in future trials.

Survival data were analysed and modelled against available co-variates following the chapter "Survival Analysis" in Crawley (2013). Results were shown as Kaplan-Meier plots which show the mean decline in survival against time. All statistical analyses were conducted using R version 3.3.2.

The methods used in this project are consistent with recent studies on *Nephrops* post-discard survival carried out by CEFAS on fishing grounds off the North East of England (area IVb) and by the Swedish University of Agriculture Sciences in ICES area IIIa.

3.3. Results

3.3.1. Tows, catch weights and discard rates

Air temperatures during the summer/autumn trials were in the range 13.8 to 19^{o}C (Table 3.3). Water temperatures were generally warmer at the surface than at depth but the maximum difference was only around 1^{o}C (Figure 3-7). Across the summer/autumn trials bottom temperatures were between 12.3 to 14.3^{o}C. Surface salinities tended to be lower than at depth but again this difference was small. There was little variation in bottom salinity apart from the more offshore tows (trials 9 and 10) where salinity was slightly higher.

During the winter/early spring trials air temperatures were in the range 6.9 to 11.5°C (Table 3.4). The water column appeared well mixed with surface to bottom water temperature differences being less than 0.1°C (Figure 3-8). Bottom water temperatures showed little variation in winter being between 8.0 and 8.5°C. Both surface to bottom salinity differences and differences in salinity between sampling days were negligible with the average bottom salinity being 34.6 (Figure 3-8).

During the summer/autumn trials the average tow duration was 3:30 h and during the winter/early spring trials was 3:46 h.

Total catch weights were not significantly different between seasons (ANOVA, F=3.32, p=0.08) or fishing gear (F=2.691, p=0.12). The catch weights of *Nephrops* appeared higher during the summer/autumn TR1 tows (Figure 3-9) and these differences were significant (ANOVA between gears, F=5.26, p=0.03; interaction of gear with season, F=6.25, p=0.02) but not with season averaged across both gears (F=1.85, p=0.19). However, these results should not be taken as necessarily being driven by the difference in mesh size as *Nephrops* catches are influenced by the strength of the tides, and hence the dates when the trials were conducted. Weaker tidal flows tend to lead to larger catches (skipper's personal comment).

Total catch sorting times ranged from as little as 53 mins to over 4 h with some relationship between total sorting time and total catch weights (Figure 3-10). Sorting of TR1 summer/autumn catches took noticeably longer with several being in excess of 3 h. Catch sorting times were also affected by the number of crew available, which varied between two and four persons.

Discarded *Nephrops* comprised between 0.8 to 7.6% of the *Nephrops* catch weights (Table 3.5 and Table 3.6) making the average values 2.6% +/- 0.5% (mean +/- 95% conf. int.) of the weights of *Nephrops* caught. The total number of *Nephrops* discarded per tow may also be of interest - these estimates ranged from 119 to 3,054 with an average of 626 +/- 253 (mean +/- 95% conf. int.). There were no statistically significant effects of gear, season or the interaction of these two factors on the *Nephrops* discard rates by weight or numbers (ANOVA, all factors p>0.05).

3.3.2. Sizes of retained and discarded *Nephrops*

Length frequency plots of the *Nephrops* caught on each tow (Figure 3-12 to Figure 3-19) showed that the sizes of the *Nephrops* were generally similar between locations, except for trials 9 and 10 which were further offshore where the skipper had expected to encounter larger animals (Figure 3-3).

Based on ANOVA both sex, season and gear, and their interactions, had significant effects on the sizes of retained and discard fraction *Nephrops*. However, the reason why all these factors came out as significant is related to the large number of observations recorded and the effect sizes need to be considered (Table 3.7). For lengths of *Nephrops* in the total catch, sex contributed the greatest differences in mean size (males being on average 4.2 mm larger than females), followed by gear type (TR2 catches being on average 1.8 mm larger than TR 1) whilst season had the smallest effect (winter caught *Nephrops* being on average just 0.3 mm smaller than summer caught animals - Table 3.7 and Figure 3-20). The seasonal difference in length was considered to be very minor and so was ignored in subsequent analyses. Factor related length differences were much smaller for the discard fraction *Nephrops* which was expected given their smaller overall size range. There was a small difference of 1.1 mm in the mean carapace lengths of discard *Nephrops* comparing summer to winter catches.

The amount of discarding will tend to be affected by the overall size distribution of the catches in each gear (Figure 3-21). Overall length frequency distributions tended to be positively skewed (i.e. the tail of the distribution is longer to the right) and so for comparison with the Minimum Conservation Size Limits, the length distributions were better described using log-normal, as opposed to normal, curves. However, because the effects of gear and season on the mean lengths of *Nephrops* in the catches were relatively small (Table 3.7) it seems reasonable to pool all the catch length data. On this basis only about 0.8% (cdf lognormal, x=20, logmean=3.435, logsd= 0.1811) of the *Nephrops* caught were actually below the Minimum Conservation Reference Size of 20 mm CL applicable for Division VIa (Figure 3-22).

Carapace lengths of discard fraction *Nephrops* ranged from 15.6 to 35.5 mm CL with the mean being 24.3 +/- 1.98 mm CL (mean +/- 95% conf. int.) based on 2,954 observations. Ignoring the relatively small effect of season on discard *Nephrops* carapace length (Table 3.8), the overall length frequencies of the discard fraction *Nephrops* were reasonably fitted using a normal distribution (Figure 3-23). This implies that around 97% of the discarded *Nephrops* were above the minimum conservation reference size of 20 mm CL applicable in Division VIa. These results are fairly consistent with data presented in Balestri (2015) although she showed discards for Mallaig to have a slightly lower mean CL length of around 23 mm. As mentioned above the size distribution of *Nephrops* is known to vary with fishing area and this will affect the amount and sizes of the discards, in addition to any differences in sorting behaviour between crews on different vessels.

3.3.3. Discard fraction damage, vigour and reflex scores

Estimates of the percentage of discard fraction *Nephrops* alive during sorting ranged from 69% to 95.5% with the overall mean being 88% ± 2.4% (mean ± 95% conf. int., n=23[i]). There was however a marginally significant impact of season on these values (Anova F=5.171, df=1, p=0.034), but no significant impact of gear (Figure 3-24). The mean percentage of discards alive during sorting on the summer trials was thus slightly lower than during the winter trials (85.5% ± 4.3% versus 90.3% ± 2.3%, means ± 95% conf. int.).

The damage scores across all the trials recorded during catch sorting by type are shown in Table 3.9 and Table 3.10. The most common injury recorded was loss of one chelae followed by thorax or tail punctures. The mean percentage of discard fraction *Nephrops* showing no external damage when scored immediately after trawling was 60.2% ± 3.7% (mean ± 95% conf. int., n=24). However, comparing the percentages recorded as having no damage when scored on-board with the percentages recorded as having no damage when scored at the time of death or at the end of the 13 day recovery period, revealed higher levels of damage (Table *3.11* and Table *3.12*). The reason for the discrepancy between damage scoring on-board Ocean Trust and later on in the aquarium appears to be that that many of the small puncture or crush wounds were not obvious on-board and only became visible on closer examination or once melanised after a period of healing. The average percentage of discard fraction *Nephrops* across both seasons with damage when scored in the aquarium was 63.4±4.4% (mean±95% CI). The data were subsequently recoded to exclude wounds which had healed (i.e. damage end healed represents more serious injuries). On this basis 52.7±3.8% of the *Nephrops* were seriously damaged (Table 3.13).

Proportion tests indicated that there was no significant difference between sexes in the percentage of animals being scored as damaged, either when scoring was conducted on board or at a later date. The proportions of *Nephrops* showing no damage versus any damage by tow (Table 3.14 and Table 3.15) were further modelled using separate quasi-binomial glms for on-board scoring and for scoring at death or end of the recovery period. Based on these models none of the factors: season, sex, gear nor their interactions had a significant influence on damage levels at p=0.05.

There was also no statistically significant correlation between the percentage of discard fraction *Nephrops* showing at least one sign of damage (scored at the time of death or after 13 days recovery) and the total catch weights (Figure 3-25, t = -0.35, df = 22, p-value = 0.73) or catch weight of *Nephrops* (t = -0.08, df = 22, p-value = 0.93). A similar result was obtained when wounds which had healed were excluded from the damaged category scoring (Figure 3-26).

At the time of sampling the majority of discard *Nephrops* were in vigour category 3 (Table 3.16 and Table *3.17*) and reflex category 1 (Table *3.18*). This is consistent with most animals being in an exhausted state after trawl capture with noticeable reduction of abdominal muscle strength.

3.3.4. Discard fraction *Nephrops* recovery

Transporting the set-boxes from Mallaig to SAMS generally took around two hours, excepting one trip where a road-traffic accident delayed arrival at the aquarium. Water temperatures during transport were within 2^{o}C of the measured bottom water column temperatures during trawling (Table 3.3 and Table 3.4). Oxygen measurements were only taken from trial 13 onwards due to availability of the monitor but levels at the end of transport to the aquarium were > 7.8 mg l^{-1} (= 83% saturation at 9^{o}C and salinity 33). Ammonia was also monitored in the on-board tank and in the transport tanks and was never above 0.1 mg l^{-1}. On trials 1 and 9 the dividers in the set-boxes became displaced during transport so that some of the *Nephrops* were trapped. These animals were removed from the set-boxes and excluded from further analysis.

Temperature in the recovery tanks was monitored every 10 minutes, salinity and ammonia daily whilst oxygen was monitored daily during the winter trials only as the equipment was not available for the summer trials. Temperatures in the recovery tanks were not as controlled as desired, in particular problems were experienced with the chillers failing to cope during summer trials 1 and 2 and the latter part of trials 5 to 8 when the temperature of the incoming seawater was elevated (Figure 3-27). However, the water temperatures in the recovery tanks did not rise above the summer bottom water temperatures as measured during the field sampling (Table 3.3). For the summer recovery trials temperatures in the recovery tanks averaged 9.4 ± 1.8°C (mean ± std. dev.) and for the winter recovery trials tank temperatures averaged 7.6 ± 0.4°C (mean ± std. dev.). Ammonia levels were usually undetectable and only ever reached a peak of 1 ppm in one tank when the water flow became temporarily reduced. Salinities were between 31 and 32. The recovery tanks were continuously aerated with individual air feeds and air-stones. An oxygen meter was not available for the summer recovery trials but was obtained for the winter trials. Measured dissolved oxygen was always above 8 mg l^{-1} in the recovery tanks for trial 13 onwards. Erikson and Baden, 1997, conducted behavioural experiments with juvenile *Nephrops* and suggested that normal behaviour was observed at oxygen around 7.7 mg l^{-1} whilst some reductions in the activity of animals were observed when oxygen was at 2.9 mg l^{-1} (oxygen converted from % saturation to equivalent mg l^{-1} at 8°C and salinity 32).

The maximum number of control animals which died during any recovery trial was 1 out of 10 and this only occurred on five out of the 15 trials to which control animals were added (controls were not available for the initial trials in each season). Thus on 2/3 of the trials containing controls, survival was 100% suggesting that recovery was not being adversely affected by the use of set-boxes for recovery or the recovery tank set-up in the SAMS aquarium.

The mortality rates of discard fraction *Nephrops* sampled from the 24 tows were monitored every two days over a total of 13 days. The majority of live discard fraction *Nephrops* were in vigour category 1 or 2 and reflex category 0 or 1 after 13 days recovery (Table *3.17* and Table *3.18*). This is consistent with the majority of animals being in a “good” state after recovery.

For the winter/early spring trials additional discard *Nephrop*s were sampled towards the end of catch sorting to check for any effect on survival of the total aerial exposure time during catch sorting (Figure 3-28). The survival curves suggest there was no statistical effect of whether N*ephrops* were sampled early or late during catch sorting and this was confirmed by survival regression (survival regression Start/End p = 0.824). However, overall sorting times during winter/early spring trials were often shorter compared with the summer tows and air temperatures in the hopper were lower (Table 3.3 and Table 3.4). In future trials it is recommended that discard *Nephrops* are sampled at both ends of the catch sorting, unless total sorting time is short, to test for any impacts of this factor on subsequent recovery.

Survival curves by trial indicated that for the summer/autumn trials the majority of mortalities occurred within the first 100 h of recovery and after that survival had largely stabilised (Figure 3-29 to Figure 3-32). However, for winter/early spring recovery trials the mortality rates were less steeply concave and there was some evidence that mortality had not completely stabilised, even after 13 days. Over all the trials survival rates after 13 days recovery estimated using the Weibull-based parametric approach ranged from as low as 31.0% to as high as 75.3% (Table *3.20*). The overall mean was 59.9% ± 1.1% (mean ± 95% conf. int.) but note that an effect of season or air temperature was identified so that separate winter and summer survival rates should be used as shown in Table *3.20*. Also note that this overall mean survival does not take account of the proportion of *Nephrops* which were dead in the discard fraction during catch sorting. This further correction is included in section 7.3 of this report.

A highly significant impact of visible damage ($p<0.001$) on subsequent survival was shown from regression of mean survival by tow against presence of visible damage, both for damage scoring immediately after trawling and for scoring undertaken at the end of the 13 day recovery period (Figure 3-33 to Figure 3-35). Although damage scoring at the end of recovery revealed a higher proportion of *Nephrops* with wounds, the impact of these differences had little effect on the overall survival, damage relationships.

Other factors which could impact survival in this study included season and gear. Applying Weibull-based survival regression against these factors suggested that the relationship between recovery and damage was influenced both by season and gear and also by the interaction of these two factors (all $p<0.05$). This means that survival rates of damaged versus survival rates of undamaged *Nephrops* was affected differently in summer and winter and, at least in one season, differently by the trawling gear. Examining the survival plots supports this conclusion because the difference between seasons is clear but comparing the survival of damaged versus undamaged *Nephrops* between gears appears different for winter trials, but similar for the summer trials. The season effect is relatively easy to explain and is most likely related to either differences in air temperature during catch sorting, or to water temperature in the recovery tanks. These issues are considered further in the next section. However, there is no obvious reason for the differential effect of trawl gear during winter alone, especially as the previous analysis did not find any significant effect on overall damage by season or gear, nor were the winter catch rates significantly different by gear (Figure 3-9).

Plotting overall recovery (damaged plus undamaged *Nephrops*) by season and gear suggested there was a stronger effect of season but a lesser effect of gear (Figure 3-36). Modelling the differences in mean responses using Weibull survival regression confirmed that whilst season was statistically significant ($z=6.91$, $p<0.001$), gear was not ($z= -1.42$, $p=0.16$).

The seasonal effect on discard recovery could reflect either differences in air temperatures during catch sorting or differences in water temperature in the recovery tanks. Considering hopper air temperatures first, both Weibull-based survival regression and linear regression modelling of the mean final survivals per tow suggested that there was a significant effect of air temperature on subsequent survival at the end of the 13 day recovery period (Weibull-survival regression Air = -0.063, $z= -6.04$, $p<0.001$). Based on the linear fit to the mean survival estimates at day 13 survival declined by 1.4% for each 1°C increase in hopper air temperature. However, caution is advised in interpreting this as a direct cause and effect because reduced survival at warmer temperatures could be driven by seasonal differences in the recovery tank water temperatures, or by a combination of hopper air temperatures and recovery tank temperatures (Figure 3-37). This latter possibility cannot be discounted because it was not possible to control winter versus summer temperatures in the recovery tanks to be exactly matched (*Table 3.19*). However, the average temperatures in the recovery tanks during summer and winter were close to the temperatures measured near the bottom of the water column in the field in each season (Table 3.3 and Table 3.4) so it seems reasonable to conclude that the seasonal effect on recovery will likely apply to animals discarded to the sea. This effect on post-discard survival is probably caused by differences in temperature, either during aerial exposure or during the subsequent recovery. The estimate of mean survival of discard fraction *Nephrops* in summer was therefore 53.8% ± 3.1% and was slightly higher in winter at 62.6% ± 3.4% (means ± 95% conf. ints, Table *3.20*).

Given that individual recovery potential is clearly impacted by damage, factors which might affect the overall level of damage in the discard fraction *Nephrops* are of interest. Mean survival per tow was therefore modelled against catch weights. Relationships against the catch weight of *Nephrops* or the total catch weight were highly significant ($p<0.001$), but these relationships were entirely driven by a single result, Trial 4 (Figure 3-38). If this result is excluded then the regressions of mean final survival per tow against catch weights become insignificant ($p=0.3$ and $p=0.11$ for *Nephrops* catch and total catches, respectively). There was therefore little convincing evidence from these trials that catch weight affects the overall levels of damage (Figure 3-25) or the eventual recovery rates of discard fraction *Nephrops* although an effect might become apparent if the data had contained a larger number of exceptionally heavy hauls.

3.4. Discussion

The results for both the west coast and east coast recovery trials are compared and discussed further in in Section 7.

[i] The number of discard *Nephrops* classified as alive during selection was not recorded for the first tow.

Table 3.1: Official *Nephrops* landings over last five years for the Scottish west coast.

Landings by weight							
Area	Year	Single-rig trawls TR2 (tonnes)	Selective trawls TR1 (tonnes)	Twin-rig trawls TR1 (tonnes)	Total trawl (tonnes)	Creel (tonnes)	Total (incl creel) (tonnes)
North Minch	2011	1,866	17	243	2,126	571	2,697
	2012	2,536	12	427	2,975	565	3,540
	2013	2,034	480	322	2,836	575	3,411
	2014	1,754	586	423	2,763	490	3,253
	2015	1,578	720	280	2,578	417	2,995
	All	9,768	1,815	1,695	13,278	2,618	15,896
South Minch	2011	2,234	11	642	2,887	783	3,670
	2012	2,335	32	824	3,191	773	3,964
	2013	1,712	543	778	3,033	729	3,762
	2014	1,341	422	726	2,489	637	3,126
	2015	1,387	508	786	2,681	658	3,339
	All	9,009	1,516	3,756	14,281	3,580	17,861
Both areas	All	18,777	3,331	5,451	27,559	6,198	33,757
Landings by area by percentage weight, excluding creel caught							
North Minch	All	73.6	13.7	12.8			
South Minch	All	63.1	10.6	26.3			
Both areas	All	68.1	12.1	19.8			

Table 3.2: Codes for scoring *Nephrops* vigour, reflex and damage

Criterion	Code	Description
	Vigour	
Excellent	1	Vigorous body movement; all limbs moving and tail moves or is held flexed
Good	2	Vigorous body movement; all limbs moving but no movement of tail; tail hangs limp
Poor	3	Limited or no body movement but movement of maxillipeds
Moribund	4	Only slight movement (in response to gentle prodding)
Dead	5	No response/movement to physical stimuli
	Reflex	
Abdominal turgor	0	Abdomen extends horizontally or tail-flips, limbs moving
Limb motion	1	Limbs moving
Maxilliped motion	2	Maxillipeds moving
Moribund	3	Only very slight movement of limbs or maxillipeds when stimulated
	Damage	
Chelae	D1	Either claw missing or damaged
	D2	Both claws missing or damaged
Rostrum	DR	Rostrum damaged
Thorax	THC	A crush injury on the thorax
	THP	A puncture injury on the thorax
	THCH/THPH	A healed thorax injury
Tail	TAC	A crush injury on the tail
	TAP	A puncture injury on the tail
	TACH/TAPH	A healed tail injury
Eye	EYE	Damage to one or both eyes
Leg	LEG	One or more walking legs missing or damaged

Table 3.3: Tow details for Ocean Trust summer/autumn 2016 *Nephrops* recovery experiments, all times shown are UTC. Latitudes and longitudes are the approximate mid-points of the tows.

Date (dd/mm/yy)	Trial	Cod-end (mm)	Shoot (hh:mm)	Haul (hh:mm)	Lat (dec º)	Lon (dec º)	Shoot depth (m)	Haul depth (m)	Speed (kts)	Air temp (ºC)	Tow (h)	Sort time (h)	Bottom temp (ºC)	Bottom sal	Temp transport to aquarium (ºC)
15/07/16	1	100	03:28	07:00	56.806	-6.045	79	73	2.5	14.3	3.53	2.98	12.3	34.0	12.7
15/07/16	2	100	07:35	10:20	56.790	-6.157	104	90	2.5	15.0	2.75	3.22	12.3	34.0	12.4
29/07/16	3	100	05:15	08:30	56.798	-6.154	93	106	2.6	13.8	3.25	3.52	13.3	34.1	13.3
29/07/16	4	100	09:25	12:30	56.810	-6.243	93	150	2.5	15.0	3.08	4.47	13.3	34.1	13.3
18/08/16	5	100	04:48	08:55	57.120	-6.333	106	88	2.8	19.0	4.12	2.25	12.7	34.2	14.5
18/08/16	6	100	09:36	13:25	57.119	-6.329	95	148	2.7	19.0	3.82	3.32	12.7	34.2	14.5
19/08/16	7	80	04:33	07:53	56.811	-6.090	60	75	2.5	17.0	3.33	2.40	13.0	34.2	13.3
19/08/16	8	80	08:46	12:16	56.895	-6.087	119	73	2.4	16.5	3.50	1.03	13.0	34.2	13.3
16/09/16	9	80	06:10	10:04	56.977	-6.616	88	95	2.6	15.2	3.90	2.23	14.1	34.9	15.1
16/09/16	10	80	10:30	14:35	56.979	-6.586	97	90	2.7	15.6	4.08	0.88	14.1	34.9	15.1
17/09/16	11	80	05:37	09:05	57.140	-6.307	128	144	2.7	16.4	3.47	2.58	14.3	34.3	13.7
17/09/16	12	80	10:12	13:28	57.104	-6.232	100	100	2.5	14.2	3.27	0.88	14.3	34.3	13.7

Table 3.4: Tow details for Ocean Trust winter/early spring *Nephrops* recovery experiments, all times shown are UTC. Latitudes and longitudes are the approximate mid-points of the tows.

Date (dd/mm/yy)	Trial	Cod-end (mm)	Shoot (hh:mm)	Haul (hh:mm)	Lat (dec º)	Lon (dec º)	Shoot depth (m)	Haul depth (m)	Speed (kts)	Air temp (ºC)	Tow (h)	Sort time (h)	Bottom temp (ºC)	Bottom sal	Temp transport to aquarium (ºC)
15/02/2017	13	100	07:50	12:00	56.958	-6.151	86	110	2.5	11.5	4.17	1.75	8.5	34.7	8.5
15/02/2017	14	100	12:50	16:45	57.005	-6.055	101	128	2.7	10.1	3.92	1.45	8.5	34.7	8.5
16/02/2017	15	100	07:20	11:08	57.051	-6.211	104	117	2.8	10.2	3.80	1.62	8.5	34.7	8.8
16/02/2017	16	100	11:30	15:35	57.064	-6.124	90	88	2.5	9.6	4.08	1.65	8.5	34.7	8.8
17/02/2017	17	100	06:46	10:45	56.932	-6.250	104	121	2.4	10.4	3.98	2.23	8.4	34.5	9.0
17/02/2017	18	100	11:15	14:49	56.901	-6.246	104	128	2.5	10.1	3.57	2.08	8.4	34.5	9.0
06/03/2017	19	80	07:45	11:40	56.940	-6.258	115	118	2.4	10.4	3.92	2.08	8.3	34.6	7.9
06/03/2017	20	80	12:15	16:15	56.936	-6.225	126	127	2.7	10.5	4.00	1.25	8.3	34.6	7.9
07/03/2017	21	80	08:20	11:25	56.791	-6.166	100	130	2.5	8.2	3.08	2.12	8.0	34.5	9.1
07/03/2017	22	80	12:00	15:20	56.790	-6.160	55	62	2.5	6.9	3.33	1.25	8.0	34.5	9.1
08/03/2017	23	80	07:10	10:45	56.896	-6.096	55	51	2.6	7.5	3.58	1.72	8.2	34.6	8.5
08/03/2017	24	80	11:15	15:00	56.898	-6.092	49	51	2.0	7.5	3.75	1.33	8.2	34.6	8.5

Table 3.5: Catch weights and numbers Ocean Trust summer/autumn 2016 trials

Trial	Retained *Nephrops* live (kg)	Retained *Nephrops* tails (kg)	Retained *Nephrops* tails raised to live (kg)	*Nephrops* discarded (kg)	Total *Nephrops* caught (kg)	Non-target discards (fish etc.) (kg)	Total catch (*Nephrops* plus non-target discards) (kg)	Estimated number *Nephrops* caught	Estimated number *Nephrops* discarded	Discarded *Nephrops* by total weight of *Nephrop*s caught (%)	Discarded *Nephrops* by total number *Nephrops* caught (%)	Discard fraction alive during sorting (%)
1	57.0	38.0	114.0	6.4	177.4	30.0	207.4	6,654	602	3.6	8.6	NA
2	57.0	44.0	132.0	4.4	193.4	60.0	253.4	7,962	503	2.3	5.8	69
3	57.0	102.0	306.0	7.0	370.0	82.0	452.0	21,777	730	1.9	3.0	85
4	114.0	127.0	381.0	7.0	502.0	100.0	602.0	25,120	775	1.4	2.8	88
5	63.5	76.0	228.0	12.2	303.7	44.8	348.5	13,294	1,541	4.0	10.9	85
6	57.0	76.0	228.0	23.9	308.9	38.0	346.9	14,970	2,935	7.7	18.3	86
7	48.0	38.0	114.0	6.3	168.3	64.2	232.5	7,757	604	3.8	7.1	83
8	44.4	25.4	76.2	3.7	124.3	45.4	169.7	5,629	360	3.0	5.9	89
9	127.0	25.4	76.2	1.7	204.9	141.4	346.3	5,870	159	0.8	2.6	84
10	76.0	13.0	39.0	1.3	116.3	130.2	246.5	3,485	119	1.1	3.3	89
11	57.0	45.0	135.0	3.2	195.2	124.1	319.3	9,541	391	1.7	3.9	88
12	44.0	19.0	57.0	2.3	103.3	66.2	169.5	4716	284	2.2	5.7	94

Table 3.6: Catch weights and numbers Ocean Trust winter/early spring 2017 trials

Trial	Retained *Nephrops* live (kg)	Retained *Nephrops* tails (kg)	Retained *Nephrops* tails raised to live (kg)	*Nephrops* discarded (kg)	Total *Nephrops* caught (kg)	Non-*Nephrops* catch (fish etc.) (kg)	Total catch (*Nephrops* plus non-*Nephrops* discards) (kg)	Estimated number *Nephrops* caught	Estimated number *Nephrops* discarded	Discarded *Nephrops* by weight of total *Nephrops* catch (%)	Discarded *Nephrops* by number of total *Nephrops* catch (%)	Discard fraction alive during sorting (%)
13	70.0	25.0	75.0	1.5	147.8	42.5	190.3	6,537	188	1.9	1.5	96
14	63.5	19.0	57.0	1.6	123.5	53.5	177.0	6,174	211	2.5	1.7	96
15	44.5	19.0	57.0	2.3	105.2	84.5	189.7	5,239	420	3.5	1.9	93
16	76.0	25.0	75.0	3.8	156.1	48.3	204.4	7,837	621	3.3	2.5	89
17	133.0	38.0	114.0	4.0	252.2	54.5	306.7	13,138	685	2.1	1.7	85
18	152.0	51.0	153.0	4.8	310.9	61.8	372.7	14,846	827	1.9	1.6	83
19	127.0	44.5	133.5	3.5	265.4	53.0	318.4	8,956	563	1.8	1.5	89
20	76.0	25.4	76.2	2.0	155.4	41.0	196.4	6,202	420	2.0	1.6	91
21	127.0	38.0	114.0	5.0	247.3	46.3	293.6	9,427	836	2.5	2.1	91
22	76.0	32.0	96.0	3.5	177.7	26.0	203.7	7,736	401	3.2	2.8	91
23	89.0	25.0	75.0	2.0	167.3	44.8	212.1	7,194	374	2.0	1.6	89
24	63.5	19.0	57.0	1.8	123.7	28.7	152.4	5,184	353	2.6	2.1	91

Table 3.7: Summary statistics for retained *Nephrops* carapace lengths by sex, season and gear type

Sex	Gear code	Season	Obs	Mean CL (mm)	Difference CL (mm)	sd	se	95% Conf. int.
Female	TR1	Summer	733	29.8		5.1	0.2	0.4
Female	TR1	Winter	357	26.5		3.5	0.2	0.4
Female	TR2	Summer	443	30.3		5.2	0.2	0.5
Female	TR2	Winter	256	27.8		3.9	0.2	0.5
Male	TR1	Summer	660	32.3		5.8	0.2	0.4
Male	TR1	Winter	842	32.1		5.6	0.2	0.4
Male	TR2	Summer	699	34.1		5.3	0.2	0.4
Male	TR2	Winter	858	33.8		6.2	0.2	0.4
Total F	Both	Both	1,789	28.9		4.9	0.1	0.2
Total M	Both	Both	3,059	33.1	+ 4.2	5.8	0.1	0.2
Both	Total TR1	Both	2,592	30.7		5.6	0.1	0.2
Both	Total TR2	Both	2,256	32.5	+ 1.8	5.9	0.1	0.2
Both	Both	Total Summer	2,535	31.7		5.6	0.1	0.2
Both	Both	Total Winter	2,313	31.4	- 0.3	6.0	0.1	0.2

Table 3.8: Summary statistics for discard fraction *Nephrops* carapace lengths by sex, season and gear type

Sex	TR code	Season	Obs	Mean CL (mm)	Difference CL (mm)	sd	Se	95% Conf. int.
Female	1	Summer	376	24.8		2.2	0.1	0.2
Female	1	Winter	465	23.7		2.4	0.1	0.2
Female	2	Summer	327	25.0		2.4	0.1	0.3
Female	2	Winter	445	23.9		2.3	0.1	0.2
Male	1	Summer	199	24.6		2.3	0.2	0.3
Male	1	Winter	434	24.1		2.3	0.1	0.2
Male	2	Summer	271	25.4		2.3	0.1	0.3
Male	2	Winter	437	23.7		2.4	0.1	0.2
Total F	Both	Both	1,613	24.3		2.4	0.1	0.1
Total M	Both	Both	1,341	24.3	0.0	2.4	0.1	0.1
Both	Total 1	Both	1,474	24.2		2.3	0.1	0.1
Both	Total 2	Both	1,480	24.4	+ 0.2	2.4	0.1	0.1
Both	Both	Total Summer	1173	25.0		2.3	0.1	0.1
Both	Both	Total Winter	1781	23.9	- 1.1	2.3	0.1	0.1

Table 3.9: Percentage occurrence of different external injuries during catch sorting in discard fraction *Nephrops* during summer/autumn tows – males and females combined, Obs = 1,196.

Damage	0	D1	D2	TAP	DR	TAC	THP	D1, DR	THC	D1, TAC
Count	716	313	44	24	23	17	16	11	6	4
Percent	59.8	26.1	3.7	2.0	1.9	1.4	1.3	0.9	0.5	0.3

Damage	D1, THP	D1, LEG	D1, TAP	D1, THC	D2, TAC	D2, TAC	D1, DR	EYE	CLAW	D1, DR
Count	3	2	2	2	2	2	1	2	1	1
Percent	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.1

Damage	D1, TAP	D2, DR	DR, LEG	D2, TAP	D2, DR	D2, TAP	LEG	THC, DR	THP, DR
Count	1	1	1	1	1	1	1	1	1
Percent	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table 3.10: Percentage occurrence of different external injuries during catch sorting in discard fraction *Nephrops* during winter/early spring tows – males and females combined, Obs = 1781.

Damage	0	D1	THP	TAC	TAP	D2	DR	D1, THP	THC	D1, TAC	D1, DR	CLAW	D1, TAP
Count	1079	275	76	68	43	36	35	26	17	14	10	9	8
Percent	60.6	15.4	4.3	3.8	2.4	2.0	2.0	1.5	1.0	0.8	0.6	0.5	0.5
Damage	D1, THC	D2, TAP	LEG	THP, TAC	D2, THP	TAIL	THP, TAP	D1, THP, TAC	D2, TAC	D1, LEG	D1, THP, TAP	D1, THP, THC	TAC, CLAW
Count	7	7	6	6	4	4	4	3	3	2	2	2	2
Percent	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Damage	TAC, TAP	THC, CLAW	THC, TAC	THP, DR	THP, THC	D1, DR, THC	D1, DR, THP	D1, TAC, THP	D1, TAIL	D1, TAP, CLAW	D1, TAP, TAC	D1, THC, TAC	D1, THP, LEG
Count	2	2	2	2	2	1	1	1	1	1	1	1	1
Percent	0.1	0.1	0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Damage	D2, DR, LEG	D2, TAIL	D2, TAP, DR	D2, TAP, TAC	D2, THC	DR, CLAW	DR, LEG	THP, TAIL	EYE	TAIL, CLAW	THC, DR	THC, TAP	THP, TAC, DR
Count	1	1	1	1	1	1	1	1	1	1	1	1	1
Percent	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table 3.11: Percentage occurrence of different external injuries for Ocean Trust summer/autumn tows discard-fraction *Nephrops* at end of recovery period - males and females combined, Obs = 1,167

Damage	0	D1	TAPH	D2	TAP	D1, TAPH	TAC	THP	DR	THPH	LEG	D1, LEG
Count	468	264	80	74	40	25	22	22	20	20	16	12
Percent	40.0	22.6	6.9	6.3	3.4	2.1	1.9	1.9	1.7	1.7	1.4	1.0
Damage	D1, TAP	D1, THPH	D1, DR	D1, TAC	D2, TAPH	THC	D1, THP	D2, LEG	TACH	D1, THC	D2, EYE	D2, TAC
Count	12	10	8	8	8	5	4	4	4	3	3	3
Percent	1.0	0.9	0.7	0.7	0.7	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Damage	D2, TAP	D1, TACH	D2, DR	D2, DR, TAPH	DR, LEG	LEGH	TAP, LEG	TAPH, LEG	D1, DRH, TAILH	D1, THCH	D1, THCH, TAPH	D2, DRH
Count	3	2	2	2	2	2	2	2	1	1	1	1
Percent	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	<0.1	<0.1	<0.1	<0.1
Damage	D2, TACH	D2, THP	D2, THPH	THCH	TAIL	TAPH, DR	TAPH, THCH	TAPH, THPH	THCH	THCH, TAPH	THP, DR	THPH, TAPH
Count	1	1	1	1	1	1	1	1	1	1	1	1
Percent	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table 3.12: Percentage occurrence of different external injuries for Ocean Trust winter/early spring tows discard-fraction *Nephrops* at end of recovery period - males and females combined, Obs = 1,780

Damage	0	D1	THP	TAP	TAPH	THPH	TAC	D2	DR	D1, THP	D1, TAP	D1, THPH
Count	582	188	112	105	93	88	74	38	36	35	24	21
Percent	32.7	10.6	6.3	5.9	5.2	4.9	4.2	2.1	2.0	2.0	1.4	1.2
Damage	THPH,TAPH	D1,TAPH	THC	CLAW	D1,TAC	LEG	D2, TAPH	D1,DR	D1,THC	D1, LEG	D2, TAP	THP, TAC
Count	21	20	20	19	17	17	12	11	10	7	7	7
Percent	1.2	1.1	1.1	1.1	1.0	1.0	0.7	0.6	0.6	0.4	0.4	0.4
Damage	THPH, LEG	D1, THPH, TAPH	D1, THP, TAC	TACH	TAPH, LEG	THCH	D2, THP	TAPH, CLAW	TAPH, TACH	THP, DR	THP, TAPH	THP, THC
Count	7	6	5	5	5	5	5	4	4	4	4	4
Percent	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2
Damage	THPH, TAP	D1, TACH	D1, TAPH, DR	D1, THCH	D2, DR	D2, TAC	D2, TACH	D2, THPH	TAC,TAP	TACH, CLAW	TAIL	TAPH, EYE
Count	4	3	3	3	3	3	3	3	3	3	3	3
Percent	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Damage	THP, CLAW	THPH, CLAW	THPH, DR	THPH, TACH	D1, CLAW	D1, DR, THP	D1, TAC, TAPH	D1, TAPH, LEG	D1, TAPH, TACH	D1, THP, TAP	D1, THP, THC	D2, DR, LEG
Count	3	3	3	3	2	2	2	2	2	2	2	2
Percent	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table 3.12: Percentage occurrence of different external injuries for Ocean Trust winter/early spring tows discard-fraction *Nephrops* at end of recovery period - males and females combined, Obs = 1,780

Damage	D2, DR, TAPH	EYE	TAC, DR	TAC, TAPH, CLAW	TAPH, TAC	TAPH, TAIL	TAPH, TAP	THC, DR	THC, TAC	THC, TAP	THPH, TAC	THPH, TAPH, CLAW
Count	2	2	2	2	2	2	2	2	2	2	2	2
Percent	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Damage	THPH, TAPH, LEG	THP, DR	D1, DR, TACH	D1, DR, TAPH	D1, DR, THC	D1, DR, THP, TAP	D1, DR, THPH	D1, TAC, THP	D1, TAP, TAC	D1, TAPH, THCH	D1, THC, TAC	D1, THCH, DR
Count	2	1	1	1	1	1	1	1	1	1	1	1
Percent	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Damage	D1, THCH, TAPH	D1, THP, LEG	D1, THP, THPH	D1, THPH, CLAW	D1, THPH, DR	D1, THPH, EYE	D1, THPH ,TACH	D1, THPH, THP	D1, THPH, THP, TAIL	D2, TAIL	D2, TAP, DR	D2, TAP, TAC
Count	1	1	1	1	1	1	1	1	1	1	1	1
Percent	0.06	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Damage	D2, TAPH, TAP	D2, THC	D2, THCH, TAIL	D2, THP, TAP	D2, THPH, TACH	D2, THPH, TAPH	DR, CLAW	DR,LEG	DR,THPH	MOUTLED	TAC,LEG	TAC,TAPH
Count	1	1	1	1	1	1	1	1	1	1	1	1
Percent	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Damage	THPH, THCH, TACH	TAC, THP	TACH, LEG, CLAW	TACH, TAPH	TAP, DR	TAP, THPH	TAPH, CLAW, LEG	TAPH, DR	TAPH, TACH, THPH	TAPH, THCH	TAPH, THPH	THC, CLAW
Count	1	1	1	1	1	1	1	1	1	1	1	1
Percent	<0.1	<0.1	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

Damage	THC, TAPH	THC, THP	THC, THP, CLAW	THCH, LEG	THP, DR, CLAW	THP, TAC, DR	THP, TAC, EYE	THP, TAP, LEG	THP, TAPH, EYE	THP, THPH	THPH, DR, CLAW	THPH, TACH, TAPH
Count	1	1	1	1	1	1	1	1	1	1	1	1
Percent	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Damage	THPH, TAIL	THPH, THCH
Count	1	1
Percent	<0.1	<0.1

Table 3.13: Percentages of Ocean Trust discard fraction *Nephrops* with physical damage

Trial	Season	Gear	Damaged scored on-board (%)	Damaged scored at time of death or recovery (%)	Damaged scored at time of death or recovery excluding healed injuries (%)
1	Summer	TR1	36.4	47.9	38.4
2	Summer	TR1	33.0	52.0	41.0
3	Summer	TR1	41.0	62.0	55.0
4	Summer	TR1	33.3	61.0	53.0
5	Summer	TR1	43.4	66.7	55.6
6	Summer	TR1	27.0	51.0	43.0
7	Summer	TR2	44.0	72.0	60.0
8	Summer	TR2	40.0	53.5	46.5
9	Summer	TR2	50.0	64.0	54.0
10	Summer	TR2	46.0	59.2	51.0
11	Summer	TR2	46.0	67.3	59.2
12	Summer	TR2	42.0	59.0	50.0
Mean ± 95% CI	Summer	Both	40.2±4.2	59.6±4.7	50.5±4.5
13	Winter	TR1	31.3	49.0	43.6
14	Winter	TR1	25.3	49.0	36.7
15	Winter	TR1	41.3	68.0	50.7
16	Winter	TR1	39.3	69.3	52.7
17	Winter	TR1	42.7	78.0	60.7
18	Winter	TR1	35.6	78.0	56.7
19	Winter	TR2	66.7	90.0	76.7
20	Winter	TR2	52.7	72.0	59.3
21	Winter	TR2	37.4	59.2	43.5
22	Winter	TR2	32.7	66.7	57.3
23	Winter	TR2	35.3	68.4	64.2
24	Winter	TR2	32.2	60.0	55.3
Mean ± 95% CI	Winter	Both	39.3±7.0	67.2±7.6	54.8±6.7
Mean ± 95% CI	Both	Both	39.8±3.7	63.4±4.4	52.7±3.8

Table 3.14: Percentage occurrence of overall external damage immediately after trawling in Ocean Trust discard fraction *Nephrops* by sex and season

Season	Summer/autumn			Winter/early spring			Overall		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
Undamaged	295 61.2%	421 58.9	716 59.8%	555 63.7%	524 57.6%	1,079 60.6%	850 62.8%	945 58.1%	1,795 60.3%
Damaged	187 38.8%	293 41.1%	480 40.1%	316 36.3%	386 42.4%	702 39.4%	503 37.2%	679 41.8%	1,182 39.7%
Total	482	714	1,196	871	910	1,781	1,353	1,624	2,977

Table 3.15: Percentage occurrence of overall external damage in Ocean Trust discard fraction *Nephrops* at end of recovery period by sex and season

Season	Summer/autumn			Winter/early spring			Overall		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
Undamaged	186 39.5%	282 40.5%	468 40.1%	309 35.5%	273 30.0%	582 32.6%	495 36.9%	555 34.6%	1,050 35.6%
Damaged	285 60.5%	414 59.5%	699 59.9%	562 64.5%	636 70.0%	1,198 67.3%	847 63.1%	1,050 65.4%	1,897 64.4%
Total	471	696	1,167	871	909	1,780	1,342	1,605	2,947

Table 3.16: Percentage occurrence of Ocean Trust discard fraction *Nephrops* vigour scores immediately after trawling

Trial	Season	Gear	Percentage in vigour category			
			1	2	3	4
1	Summer	TR1	1.0	22.4	48.0	28.6
2		TR1	0.0	9.0	48.0	43.0
3		TR1	3.0	19.0	54.0	24.0
4		TR1	1.0	15.2	47.5	36.4
5		TR1	0.0	13.3	44.9	41.8
6		TR1	4.0	15.0	60.0	21.0
7		TR2	0.0	11.0	61.0	28.0
8		TR2	2.0	9.0	60.0	29.0
9		TR2	Missing data due to box dividers moving in transit			
10		TR2	3.0	19.0	56.0	22.0
11		TR2	6.0	12.0	58.0	24.0
12		TR2	2.0	14.0	58.0	26.0
Mean ± 95% CI	Summer	Both	2.0±1.3	14.4±2.9	54.1±4.0	29.4±4.1
13	Winter	TR1	0.7	18.1	73.8	7.4
14		TR1	0.0	1.3	95.3	3.4
15		TR1	6.0	36.9	47.0	10.1
16		TR1	6.7	26.2	45.0	22.1
17		TR1	8.0	22.7	51.3	18.0
18		TR1	2.7	24.0	54.0	19.3
19		TR2	10.0	44.0	29.3	16.7
20		TR2	4.7	48.0	30.0	17.3
21		TR2	4.1	30.6	54.4	10.9
22		TR2	2.0	36.7	47.3	14.0
23		TR2	3.7	14.0	66.9	15.4
24		TR2	1.3	7.4	72.5	18.8
Mean ±	Winter	Both	4.2±2.0	25.8±9.1	55.6±12.0	14.5±3.5
95% CI	Both	Both	3.2±1.2	20.4±5.2	54.9±6.1	21.6±4.3

Table 3.17: Percentage occurrence of vigour over all trials for Ocean Trust discard fraction *Nephrops* comparing scores immediately after trawling and post-recovery

Vigour score after trawl	1	2	3	4	Total
Males + Females					
Count	96	619	1579	579	2875
Percent	3.3	21.5	55.0	20.2	
Males					
Count	47	303	717	240	421
Percent	3.6	23.2	54.9	18.4	
Females					
Count	49	316	862	339	656
Percent	3.1	20.2	55.0	21.6	
Vigour score after recovery	1	2	3	4	Total
Males + Females					
Count	1280	423	93	8	1804
Percent	71.0	23.4	5.2	0.4	
Males					
Count	611	187	36	3	837
Percent	73.0	22.3	4.3	0.4	
Females	669	236	57	5	382
Count	69.2	24.4	5.9	0.5	
Percent					

Table 3.18: Percentage occurrence of reflex scores immediately after trawling and post-recovery for Ocean Trust discard fraction *Nephrops*.

Reflex score after trawl	0	1	2	3	Total
Males + Females					
Count	767	1431	619	55	2872
Percent	26.7	49.8	21.6	1.9	
Males					
Count	380	640	264	22	436
Percent	29.1	49.0	20.2	1.7	
Females					
Count	387	791	355	33	1566
Percent	24.7	50.5	22.7	2.1	

Reflex score after recovery	0	1	2	3	Total
Males + Females					
Count	1648	142	13	1	1804
Percent	91.4	7.9	0.7	0.1	
Males					
Count	779	50	8	0	837
Percent	93.1	6.0	1.0		
Females					
Count	869	92	5	1	967
Percent	89.9	9.5	0.5		

Table 3.19: Summary statistics for the continuous temperature records in the recovery tanks in the SAMS aquarium.

Trials	Mean temperature (ºC)	Std. dev. (ºC)
Trials 1 to 2	9.2	1.69
Trials 13 to 18	7.2	0.34
Trials 19 to 24	7.8	0.26
Trials 3 to 4	8.7	0.30
Trials 5 to 8	11.0	2.17
Trials 9 to 12	8.5	0.86
Summer trials	9.4	1.75
Winter trials	7.6	0.42

Table 3.20: Weibull-based final survival estimates at day 13 of recovery by trial number and by season for Ocean Trust discard-fraction *Nephrops*.

Trial	Season	Gear code	Mean survival	Std error	95% LCI	95% UCI
1	Summer	TR1	0.753	0.050	0.661	0.859
2	Summer	TR1	0.500	0.050	0.411	0.608
3	Summer	TR1	0.490	0.050	0.401	0.598
4	Summer	TR1	0.310	0.046	0.231	0.415
5	Summer	TR1	0.455	0.050	0.366	0.564
6	Summer	TR1	0.660	0.047	0.573	0.760
7	Summer	TR2	0.610	0.049	0.522	0.713
8	Summer	TR2	0.707	0.046	0.623	0.803
9	Summer	TR2	0.560	0.050	0.471	0.666
10	Summer	TR2	0.663	0.048	0.576	0.764
11	Summer	TR2	0.469	0.050	0.380	0.579
12	Summer	TR2	0.410	0.049	0.324	0.519
	Total summer	Both	0.538	0.015	0.510	0.569
13	Winter	TR1	0.664	0.039	0.593	0.745
14	Winter	TR1	0.718	0.037	0.649	0.794
15	Winter	TR1	0.707	0.037	0.637	0.783
16	Winter	TR1	0.720	0.037	0.652	0.796
17	Winter	TR1	0.660	0.039	0.588	0.740
18	Winter	TR1	0.753	0.035	0.687	0.826
19	Winter	TR2	0.467	0.041	0.393	0.554
20	Winter	TR2	0.567	0.041	0.493	0.652
21	Winter	TR2	0.701	0.038	0.630	0.779
22	Winter	TR2	0.720	0.037	0.652	0.796
23	Winter	TR2	0.610	0.042	0.534	0.698
24	Winter	TR2	0.651	0.039	0.579	0.732
	Total winter	Both	0.626	0.017	0.594	0.660
	Both	Both	0.599	0.0107	0.578	0.620

Figure 3-1: Map of VMS effort of single-rig and twin-rig trawl fisheries on the inshore west coast of Scotland. Figure created by Scottish Government 2016 (Dr David Turnbull).

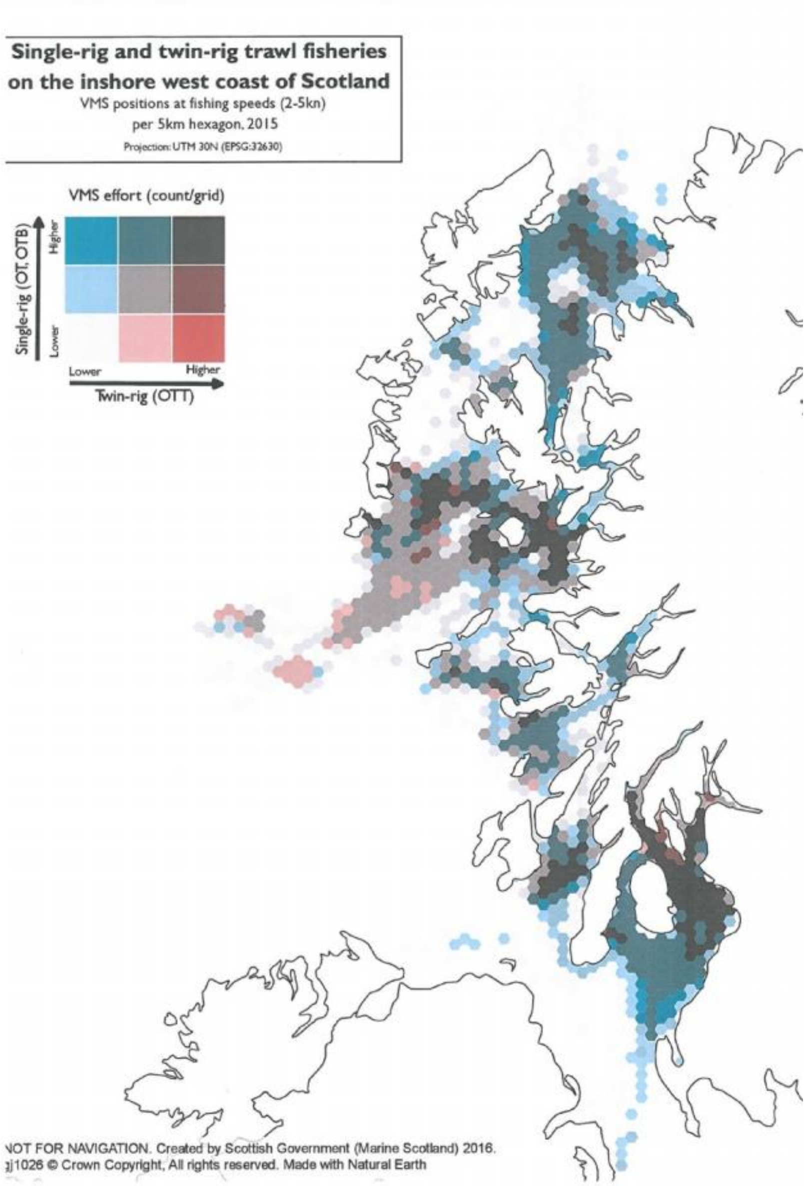


Figure 3-2: The twin-rigger 'Ocean Trust' which is based in Mallaig.

Figure 3-3: Ocean Trust west Scotland recovery trial trawl locations.

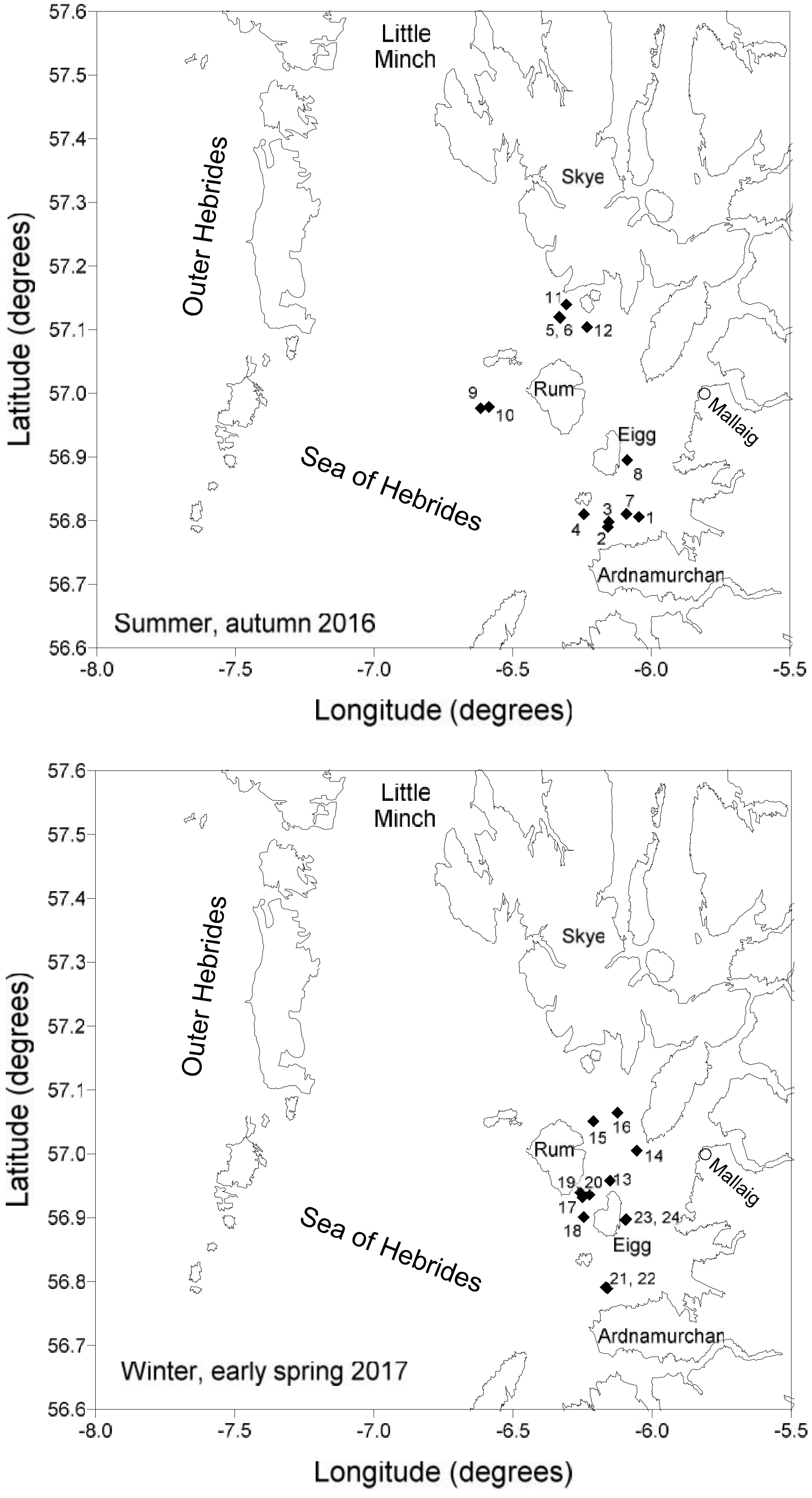


Figure 3-4: Catches in the hopper on Ocean Trust.

Figure 3-5: Sorting catch on Ocean Trust – Sept 2016.

Figure 3-6: The recovery tanks in the SAMS aquarium.

Figure 3-7: Water column temperature and salinity profiles at the start of each day of sampling for Ocean Trust summer/autumn 2016 trials.

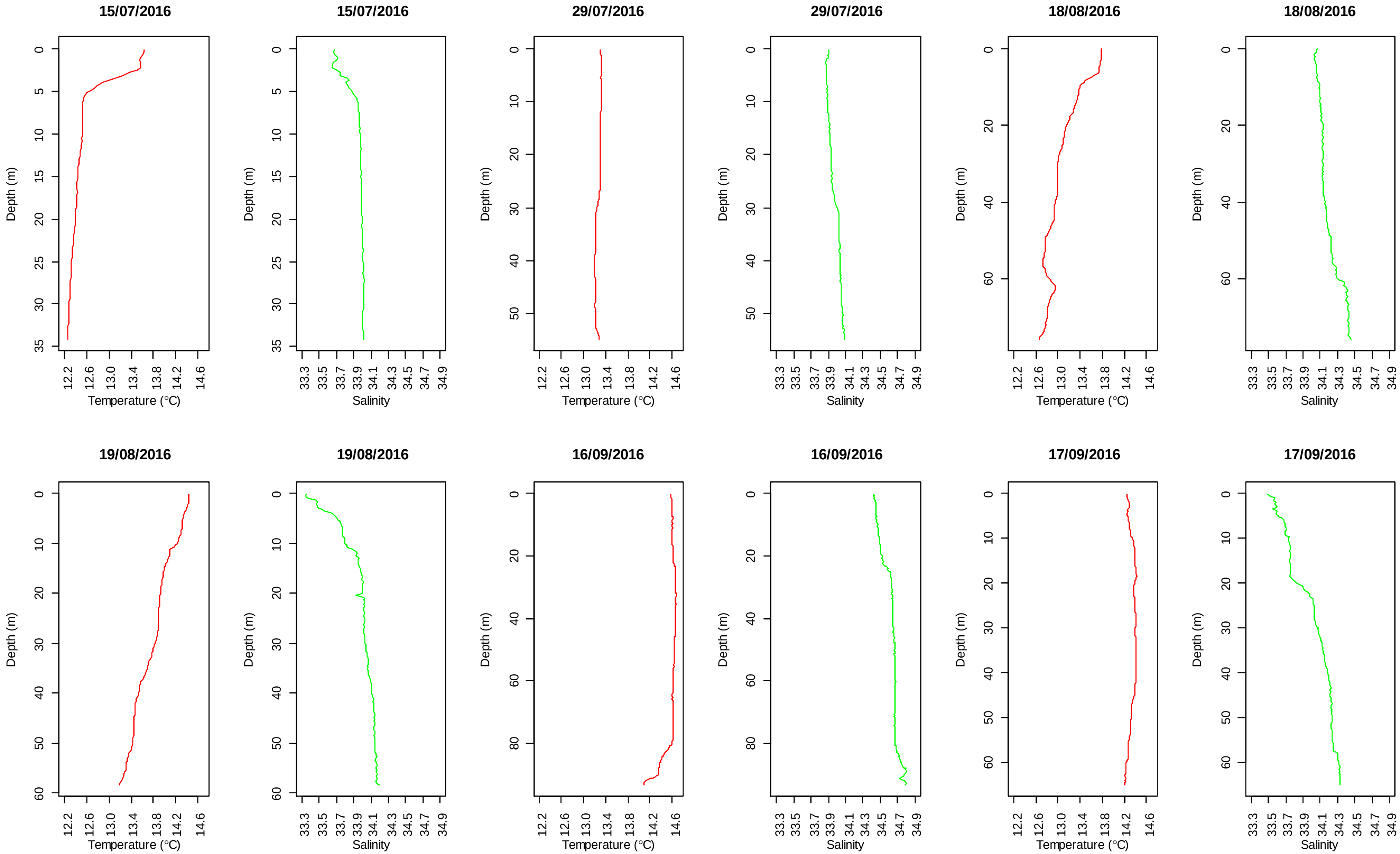


Figure 3-8: Water column temperature and salinity profiles at the start of each day of sampling for Ocean Trust winter/early spring 2017 trials.

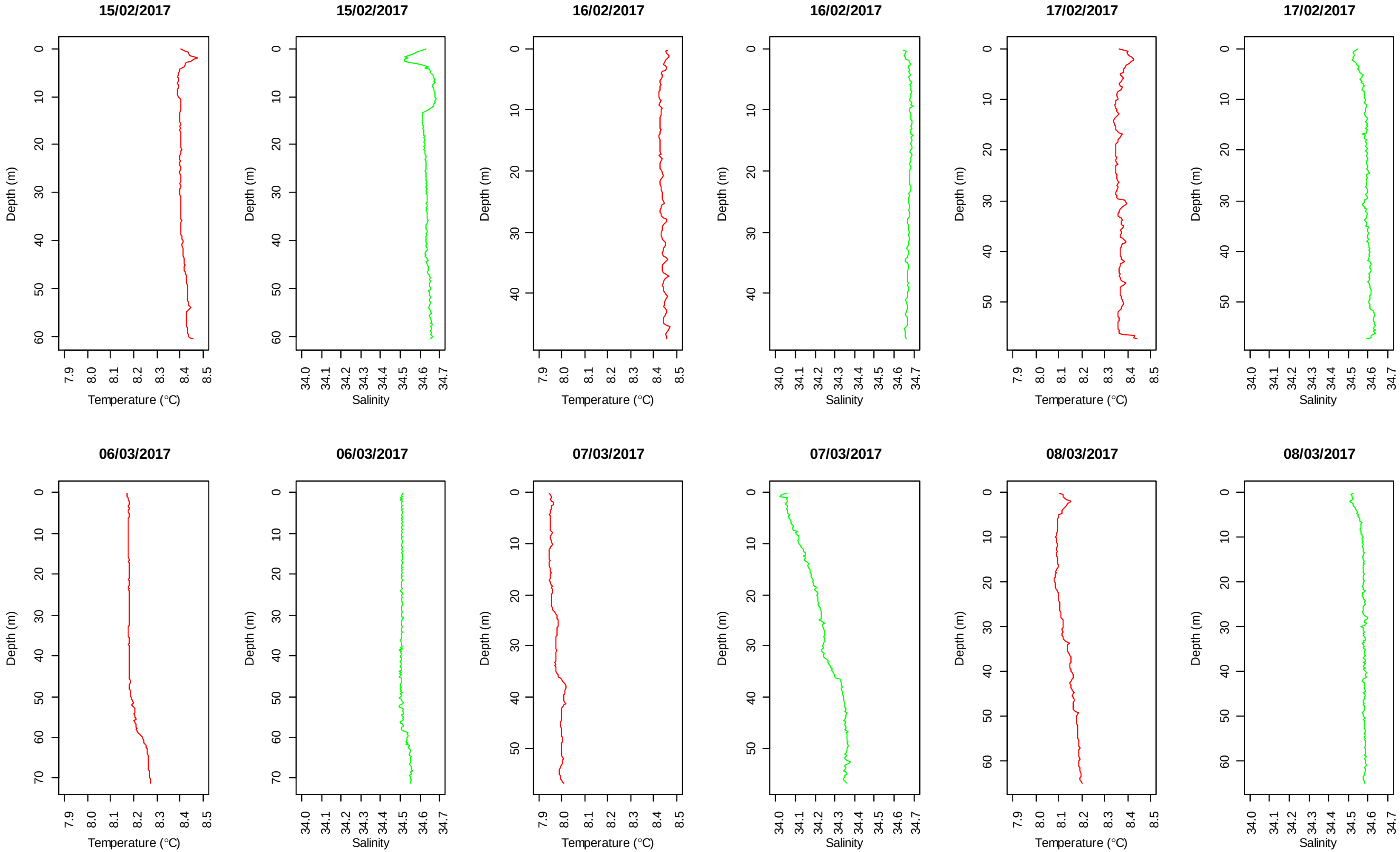


Figure 3-9: Catch weights by gear and season: left panel is the total catch weight (Nephrops plus non-target catch); right panel is total catch of Nephrops. Box coding refers to the TR gear code plus the trial season.

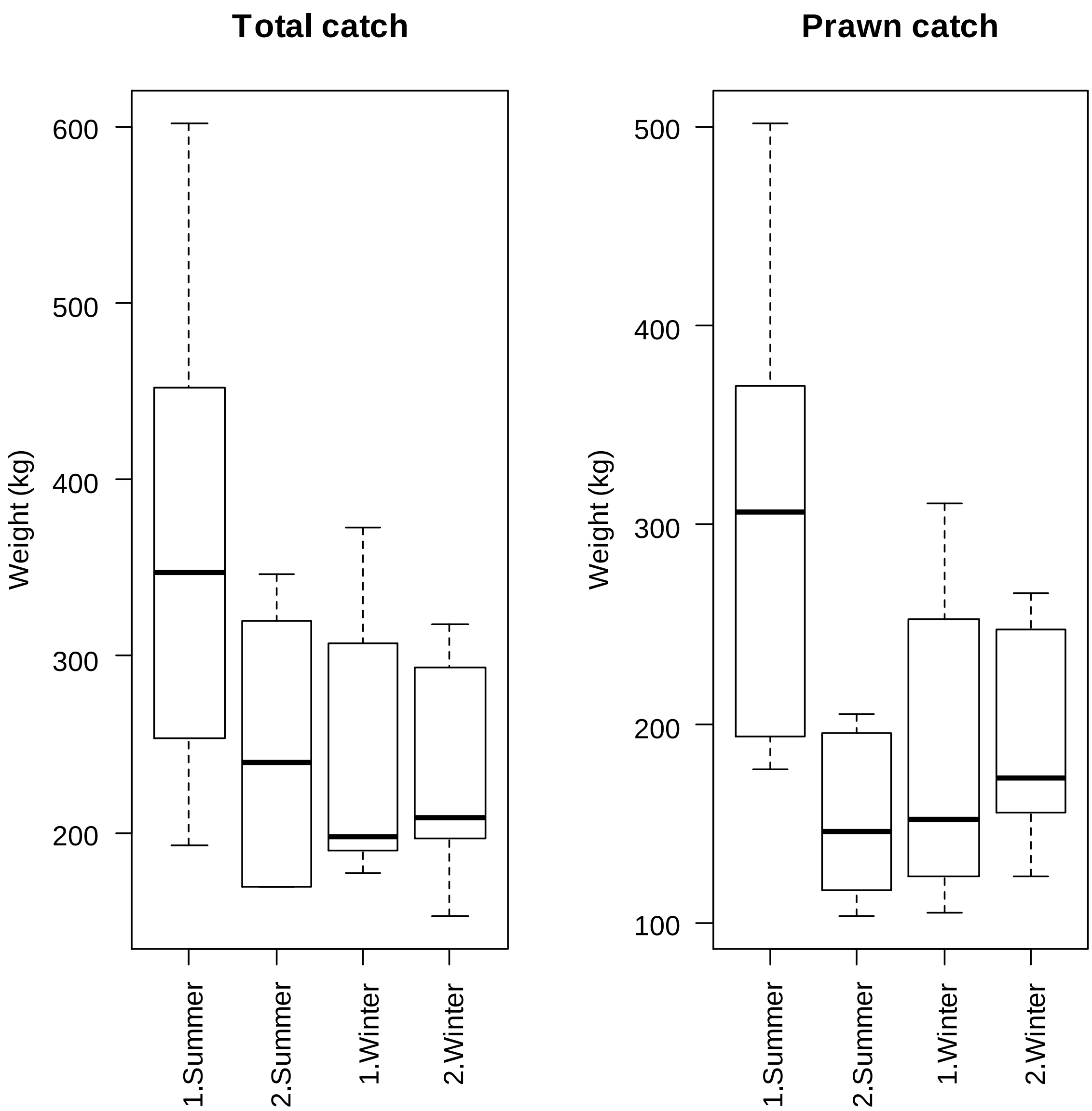


Figure 3-10: Relationship between total catch weight of Nephrops (excluding non-target organisms) and catch sorting time for Ocean Trust recovery trials. Numbers indicate the trial as shown in Table 3.3 and Table 3.4. Symbols indicate the season and net mesh type.

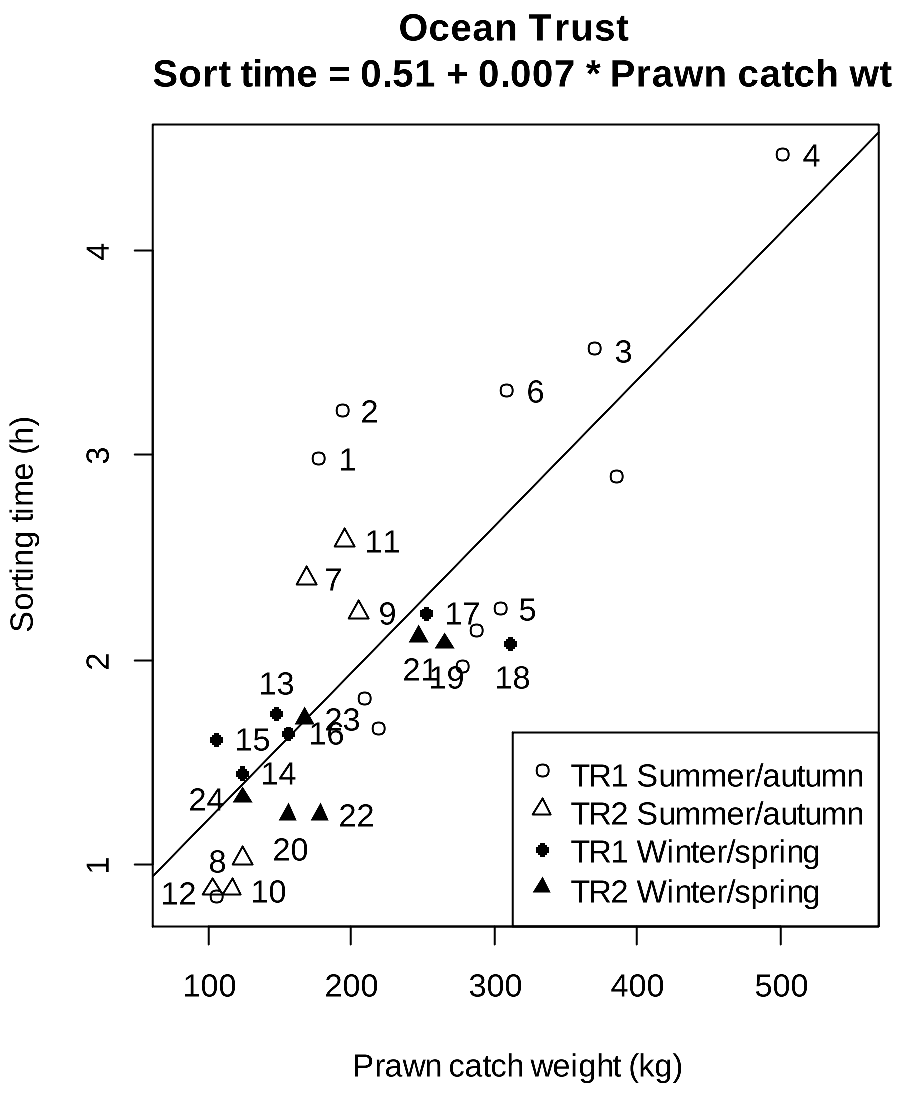


Figure 3-11: Percentage of catch comprising discard-fraction Nephrops by gear and season: left panel is expressed as the percentage of the total catch weight (Nephrops plus non-target catch); right panel is expressed as the percentage of the total catch of Nephrops. Box coding refers to the TR gear code plus the trial season.

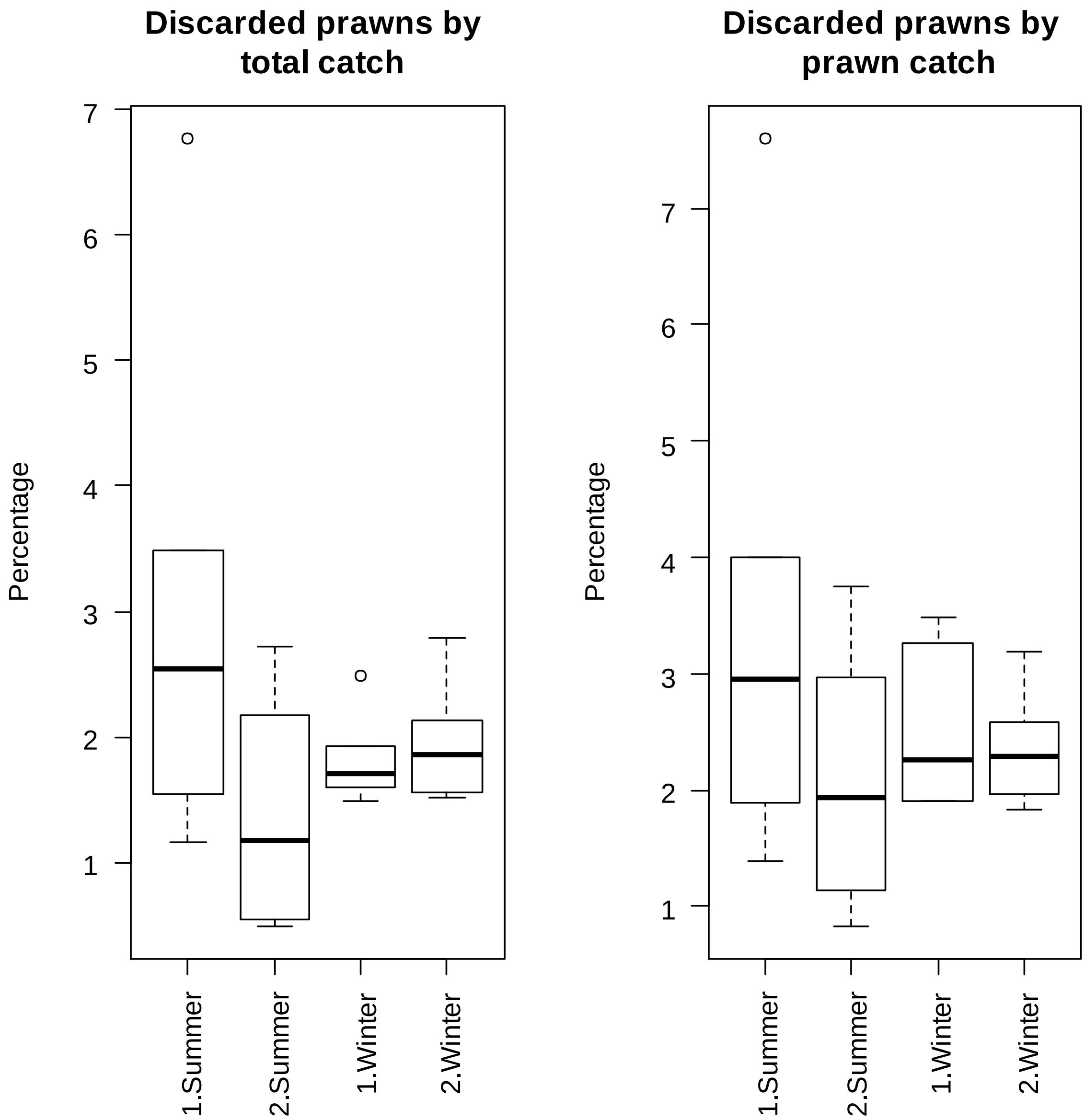


Figure 3-12: Length frequencies for sub-sampled Nephrops from total catch and the discard fraction, Ocean Trust summer/autumn 2016 - trials 1 through 3 (gear TR 1).

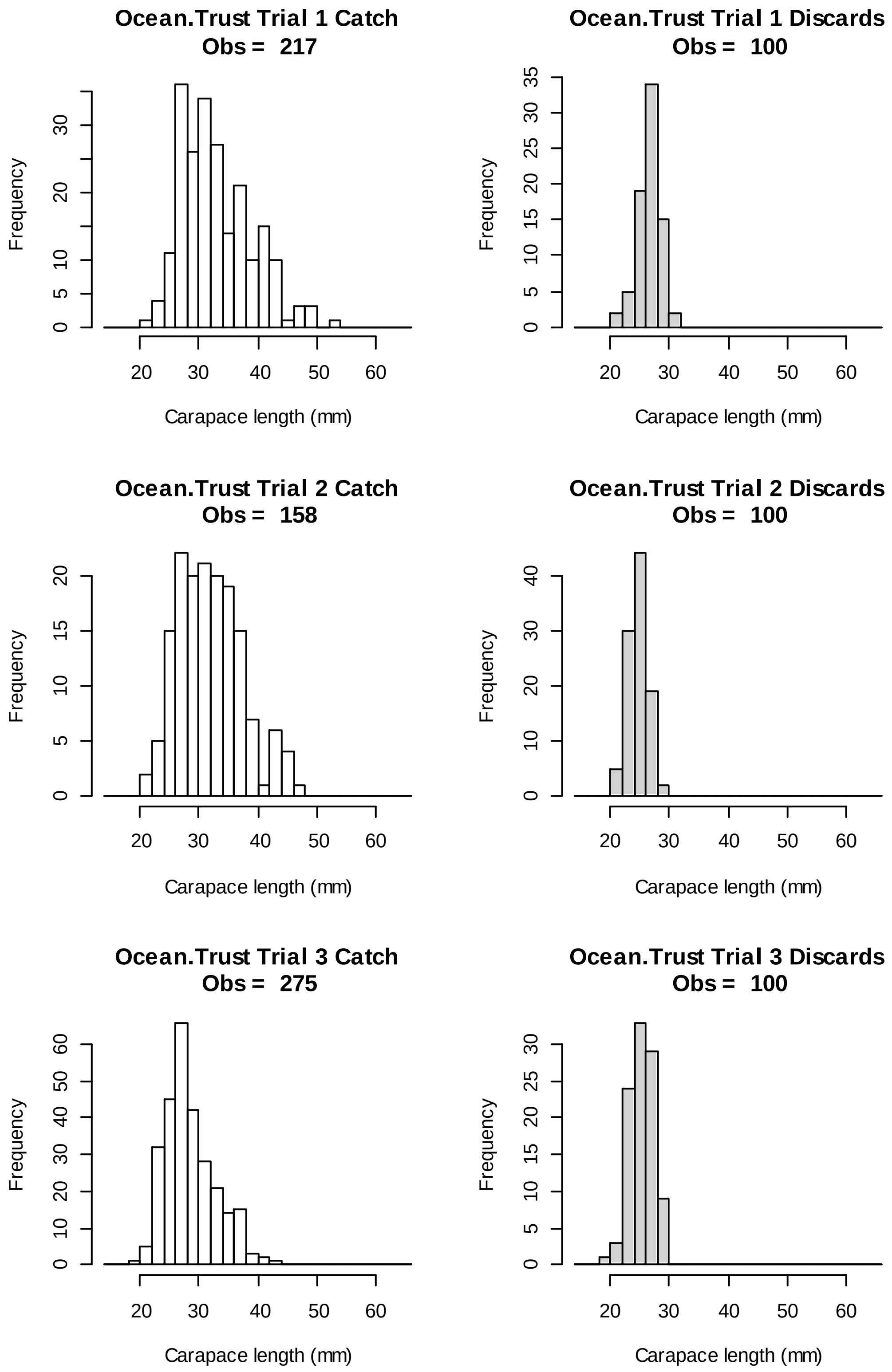


Figure 3-13: Length frequencies for sub-sampled Nephrops from total catch and the discard fraction, Ocean Trust summer/autumn 2016 - trials 4 through 6 (gear TR1).

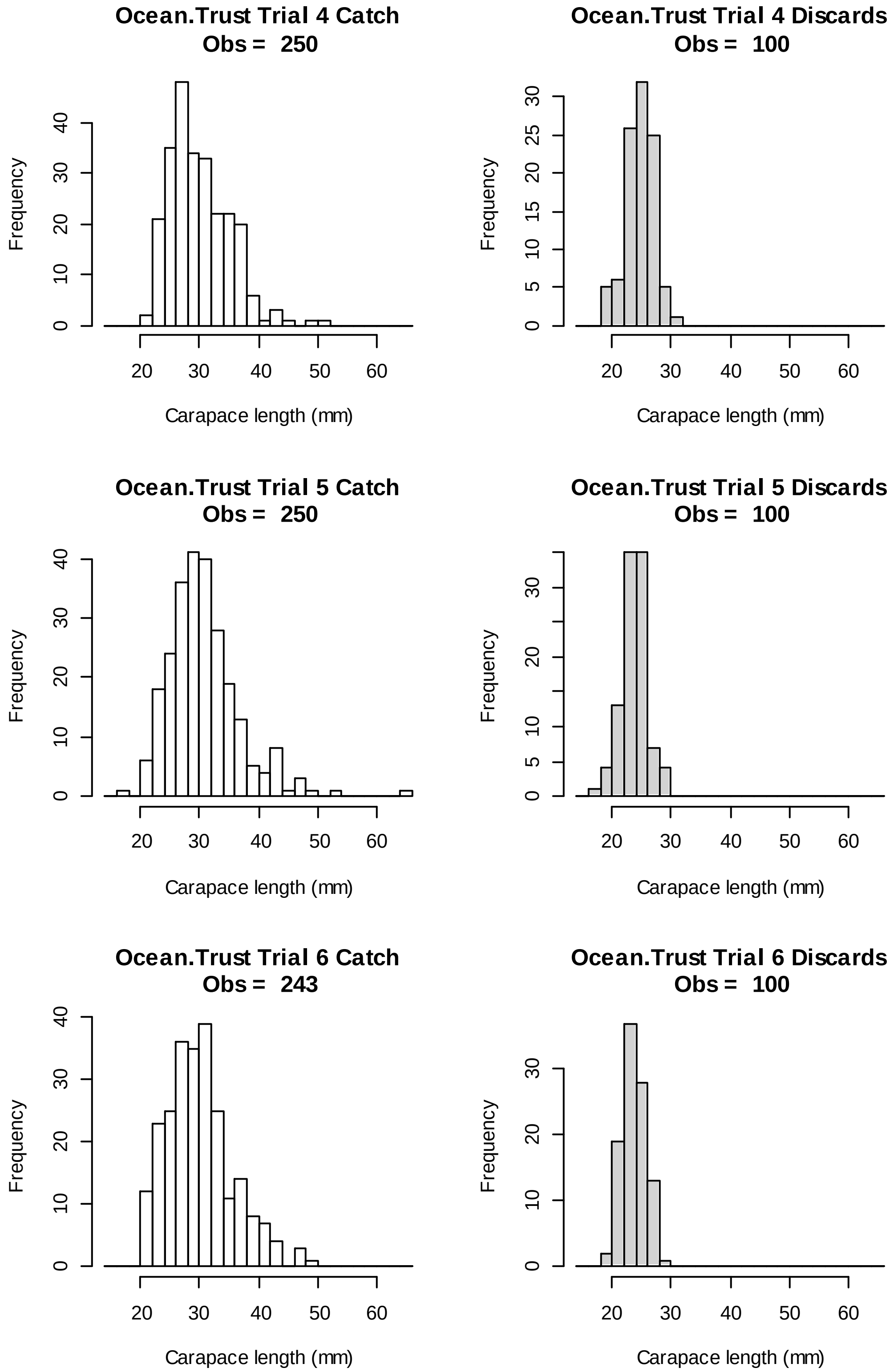


Figure 3-14: Length frequencies for sub-sampled Nephrops from total catch and the discard fraction, Ocean Trust summer/autumn 2016 - trials 7 through 9 (gear TR2).

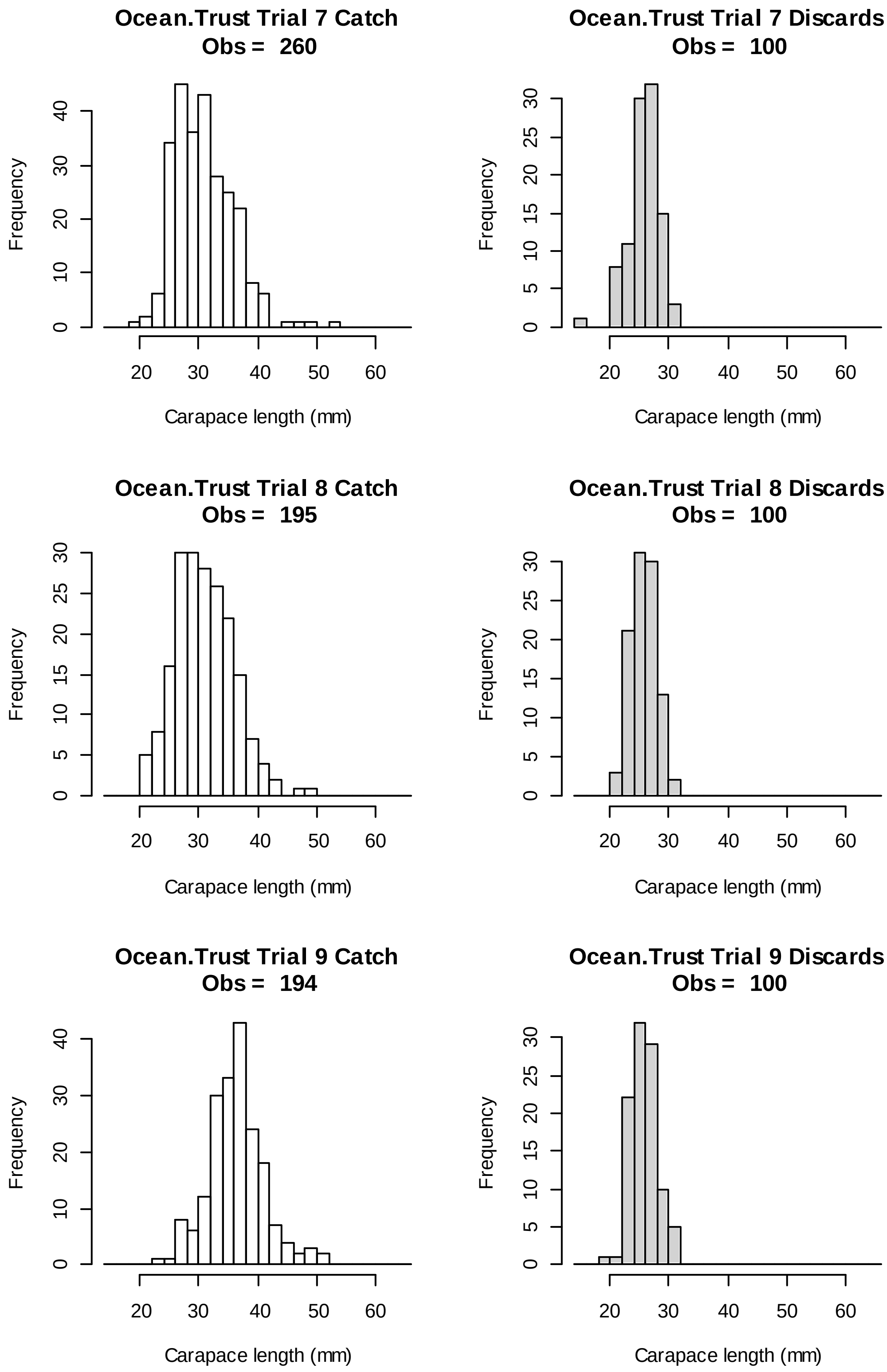


Figure 3-15: Length frequencies for sub-sampled Nephrops from total catch and the discard fraction, Ocean Trust summer/autumn 2016 - trials 10 through 12 (gear TR2).

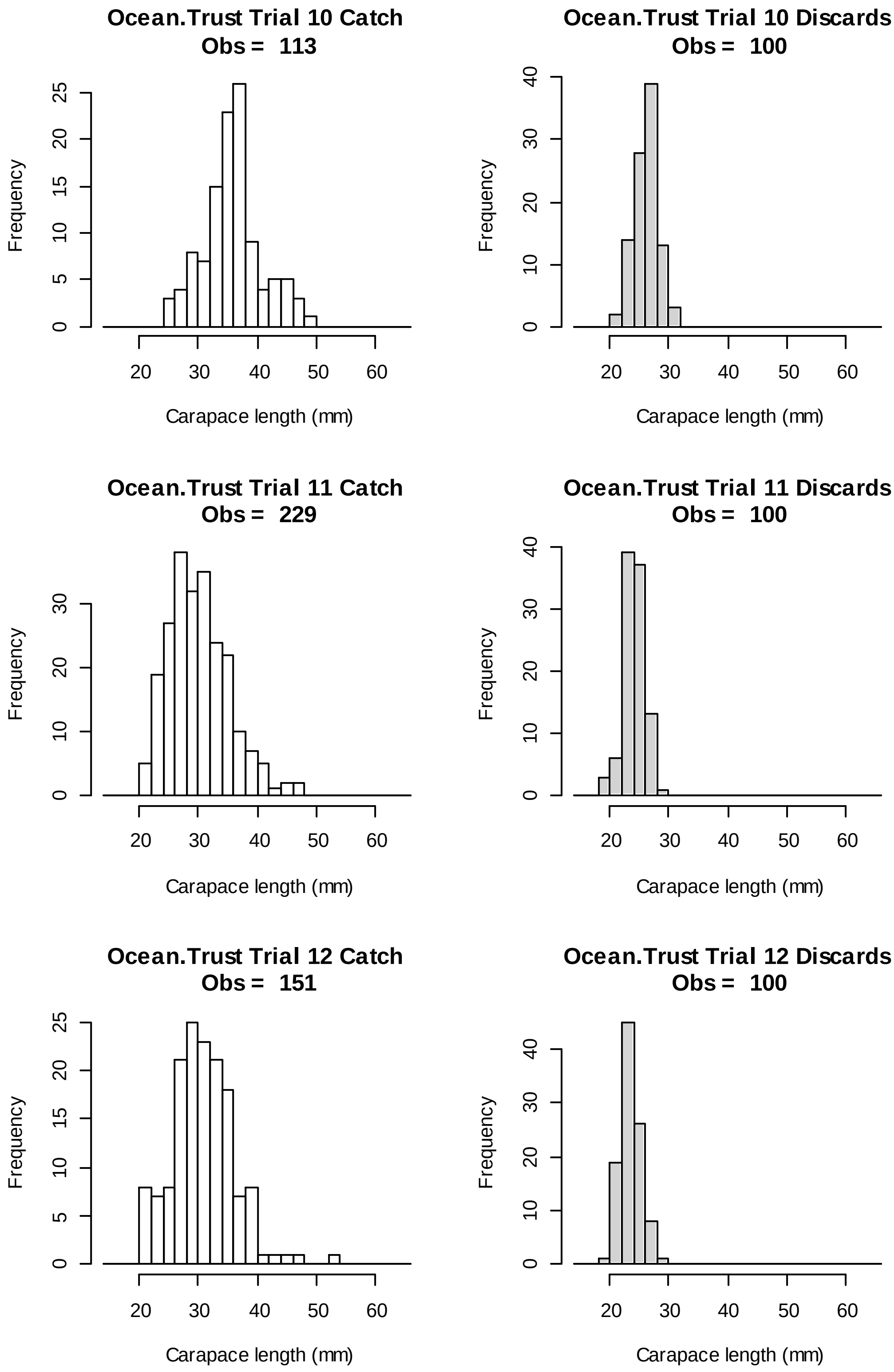


Figure 3-16: Length frequencies for sub-sampled Nephrops from total catch and the discard fraction, Ocean Trust winter/early spring 2017 - trials 13 through 15 (gear TR1).

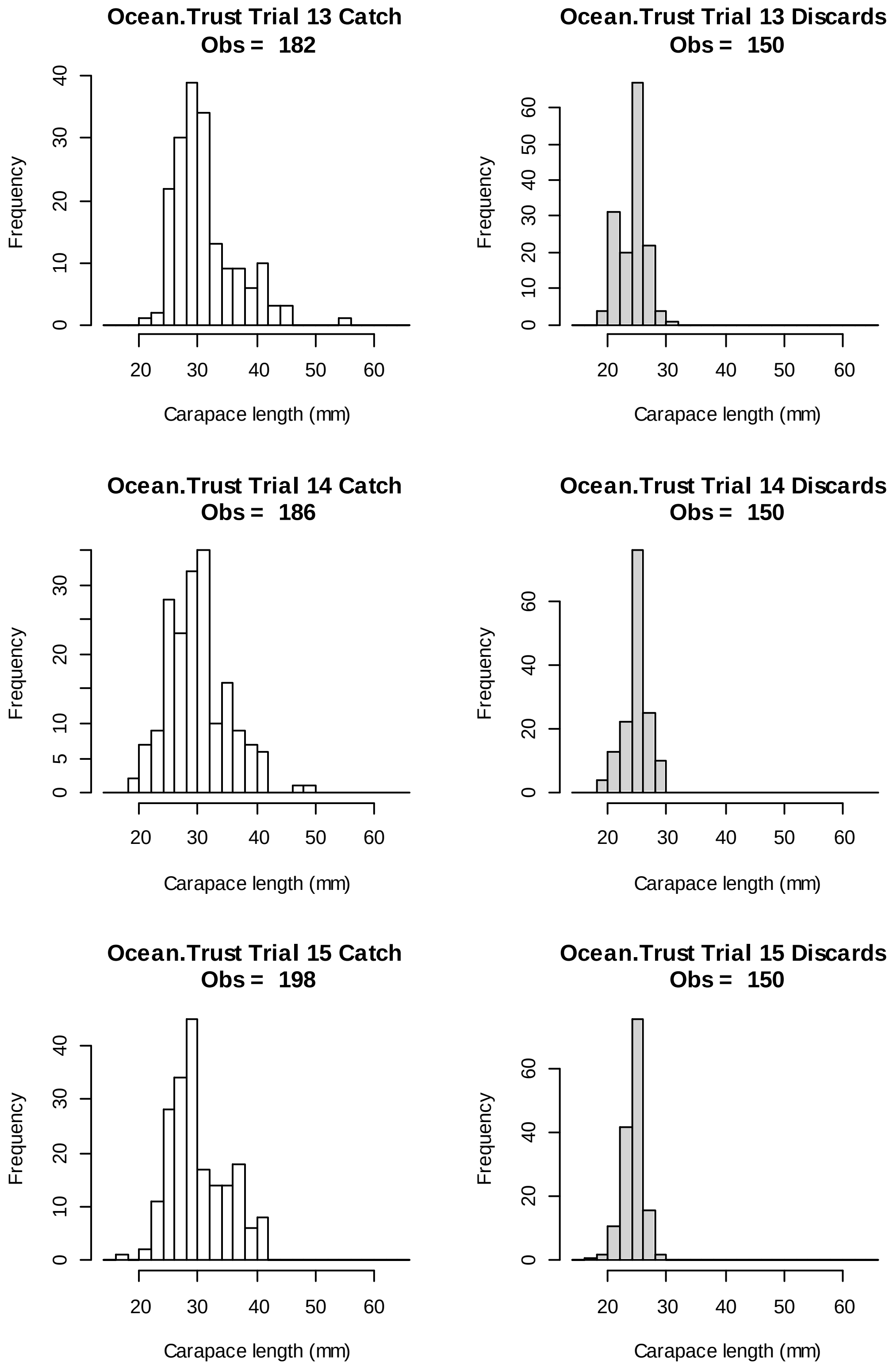


Figure 3-17: Length frequencies for sub-sampled Nephrops from total catch and the discard fraction, Ocean Trust winter/early spring 2017 - trials 16 through 18 (gear TR1).

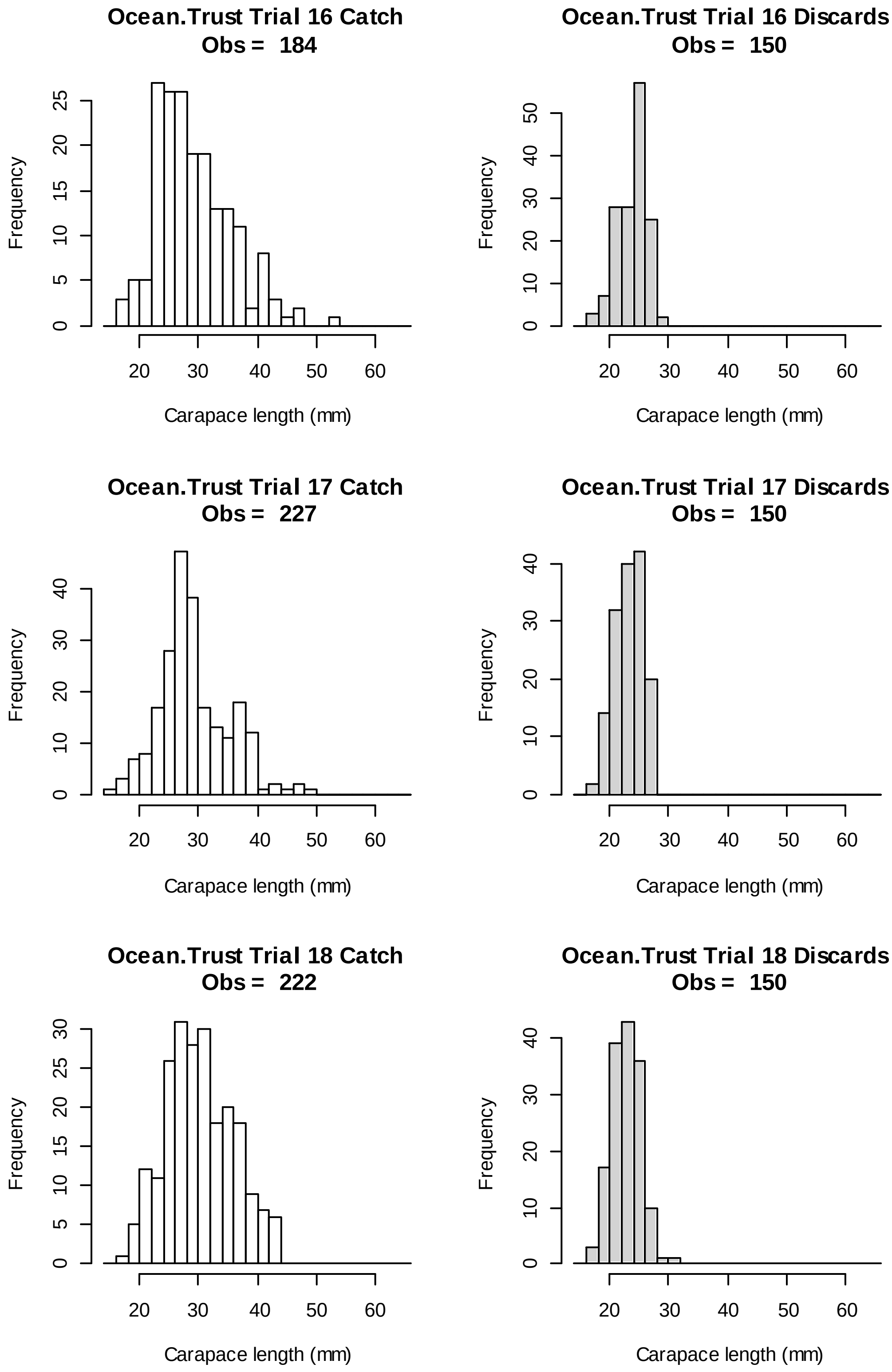


Figure 3-18: Length frequencies for sub-sampled Nephrops from total catch and the discard fraction, Ocean Trust winter/early spring 2017 - trials 19 through 21 (gear TR2).

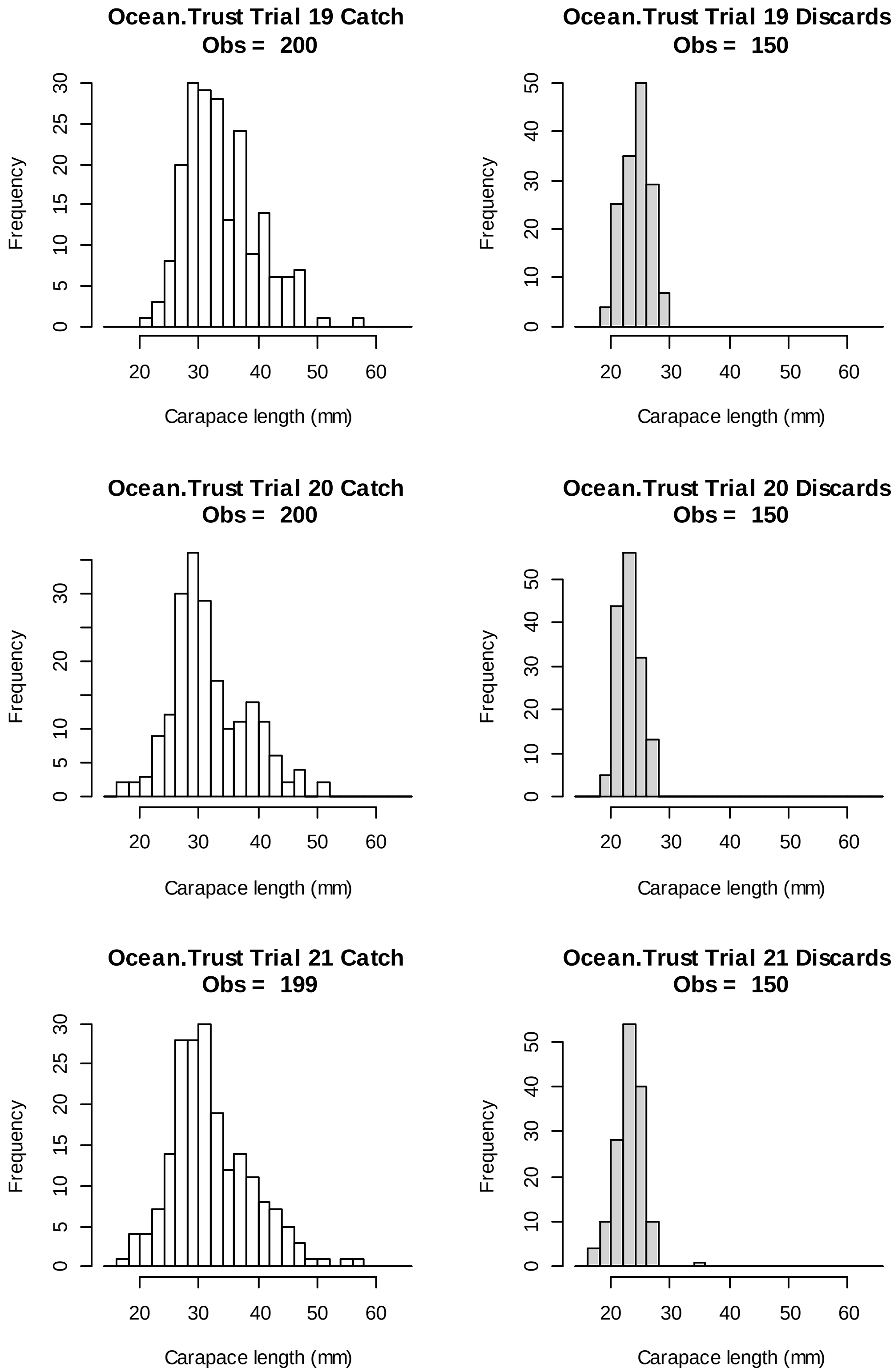


Figure 3-19: Length frequencies for sub-sampled Nephrops from total catch and the discard fraction, Ocean Trust winter/early spring 2017 - trials 22 through 24 (gear TR2).

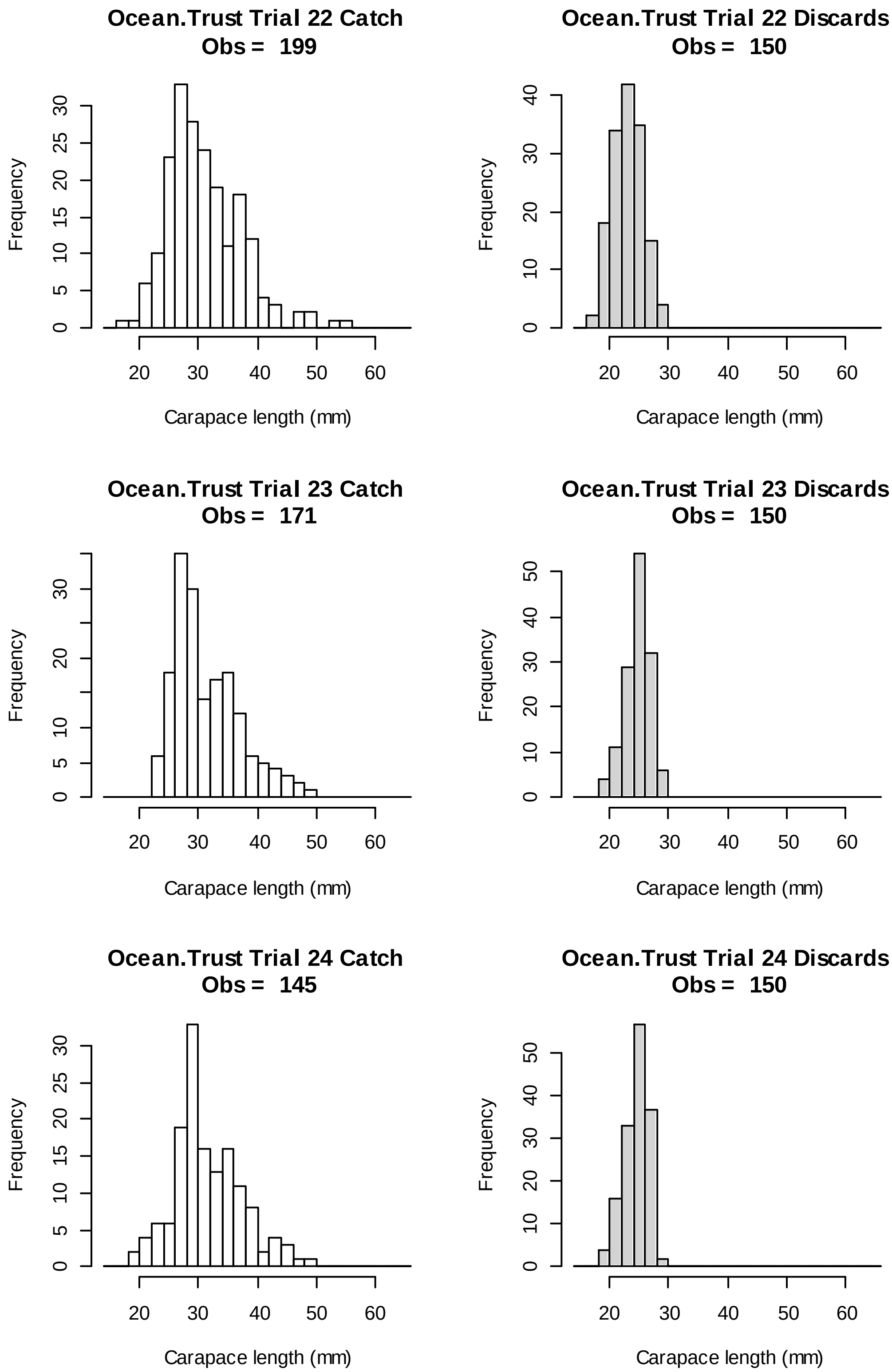


Figure 3-20: Boxplots of the carapace lengths of the total catch (left panel) and Nephrops discard fraction (right panel) by season and gear type (TR1 or TR2).

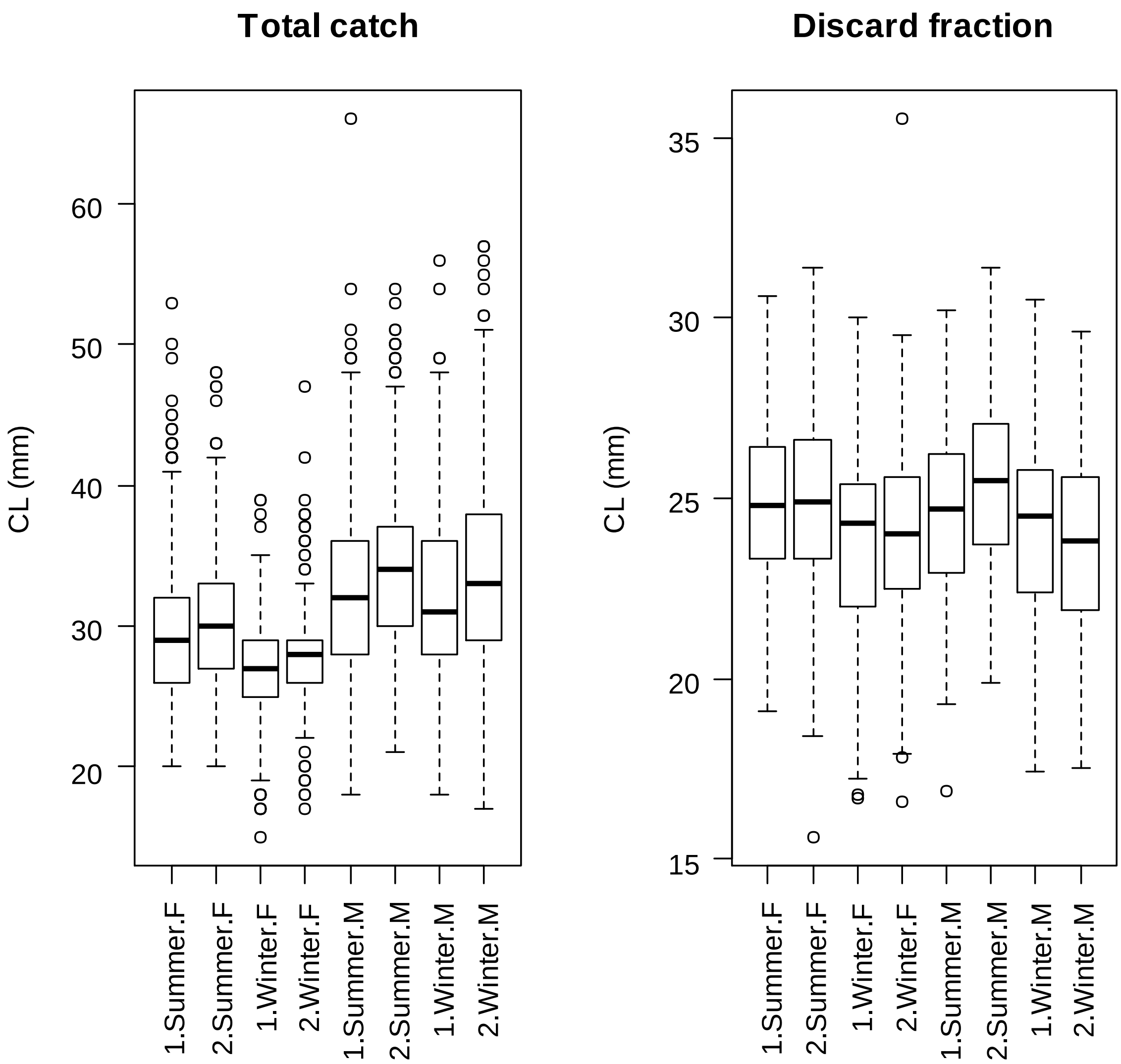


Figure 3-21: Length frequency for measured Nephrops in catch sub-samples across all Ocean Trust trials split by season and gear – Solid curves are log-normal fits to the length frequency data while the current Minimum Conservation Size limit for ICES Division VIa is indicated by the dashed vertical line (20 mm CL).

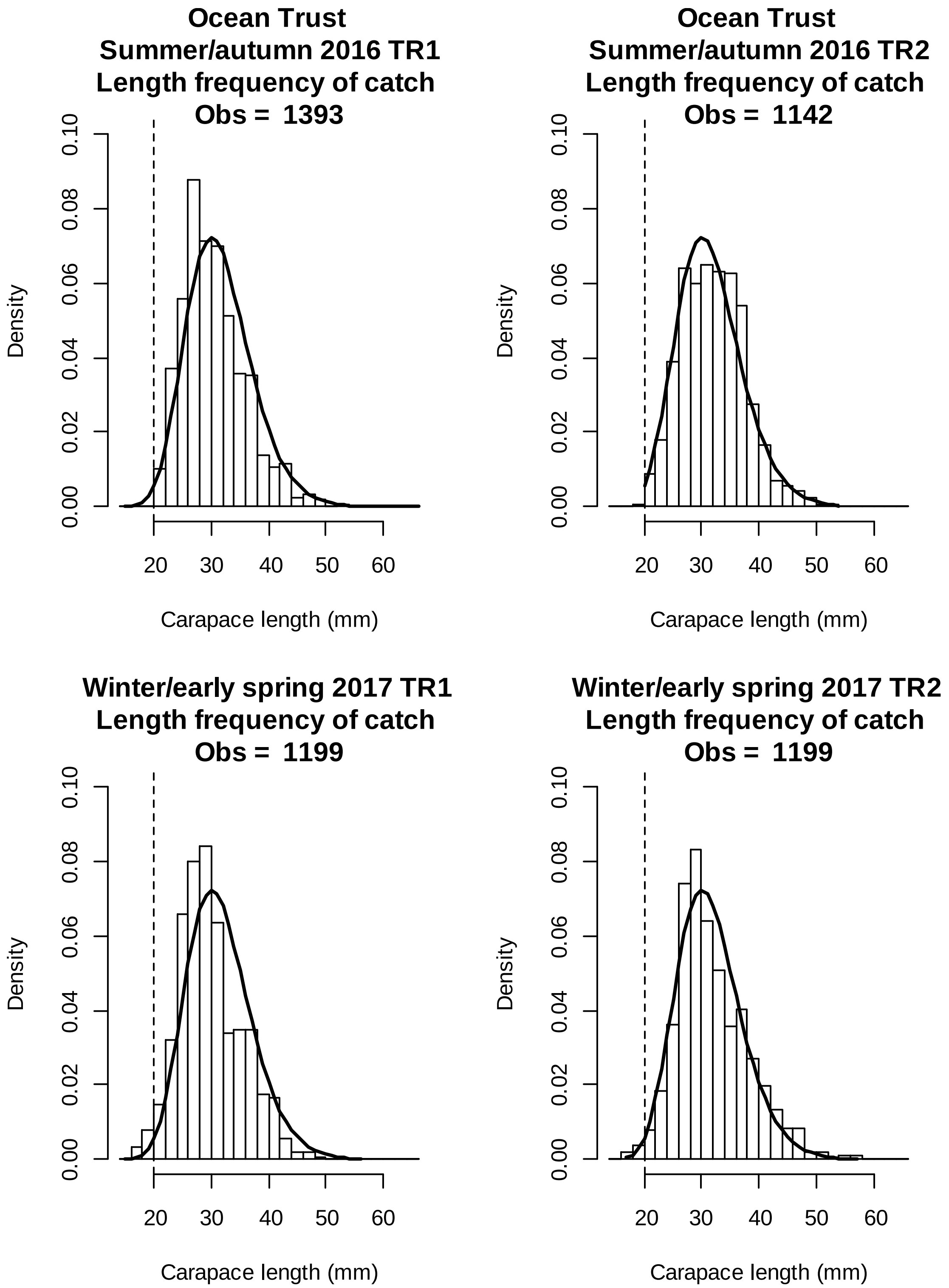


Figure 3-22: Length frequency for measured Nephrops in catch sub-samples across all Ocean Trust - Solid curve is a log-normal fit to the length frequency data while the current Minimum Conservation Size limit for ICES Division VIa is indicated by the dashed vertical line (20 mm CL).

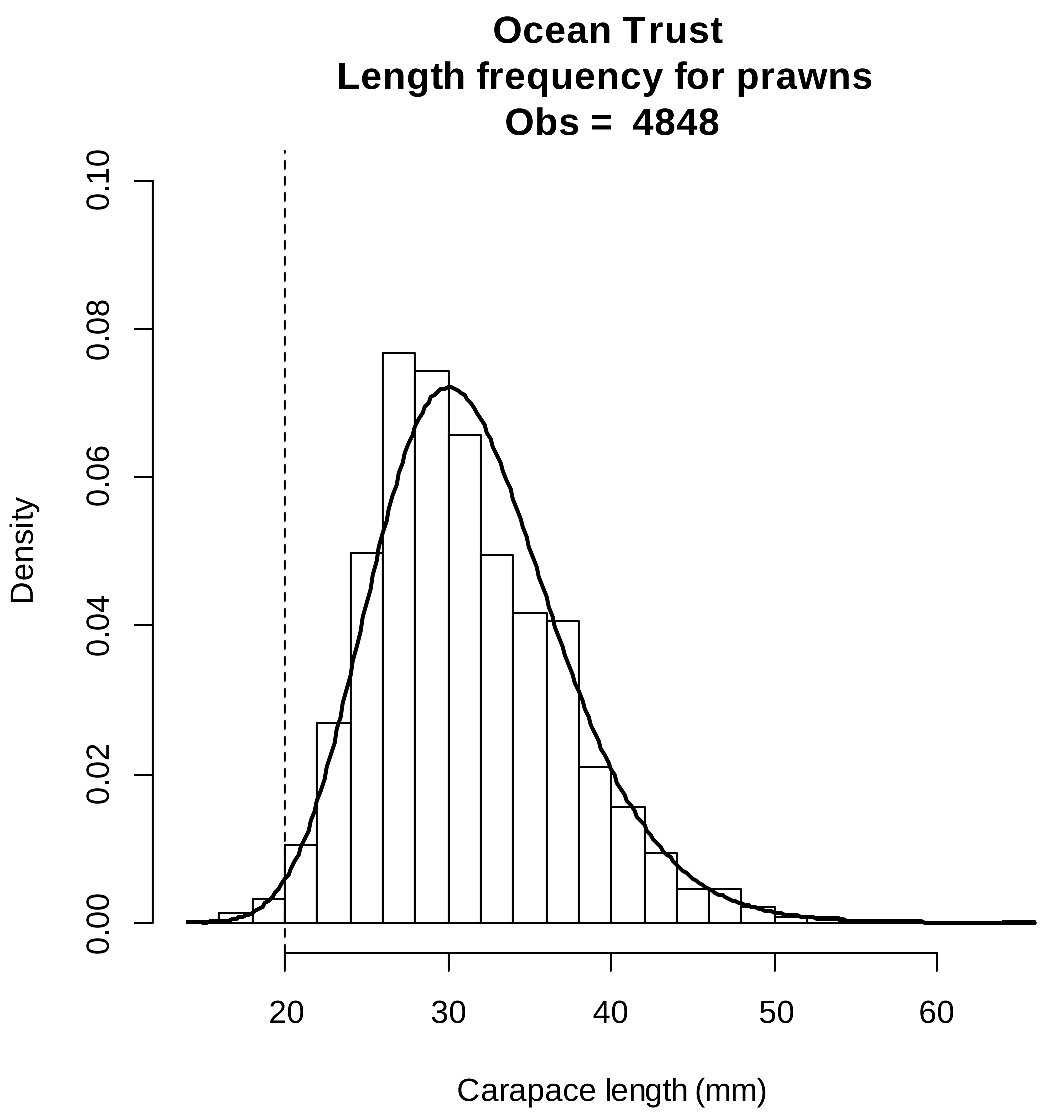


Figure 3-23: Length frequency for discard fraction Nephrops across all Ocean Trust trials – Solid curve is a normal fit to the length frequency data while the current Minimum Conservation Size limit for ICES Division VIa is indicated by the dashed vertical line (20 mm CL).

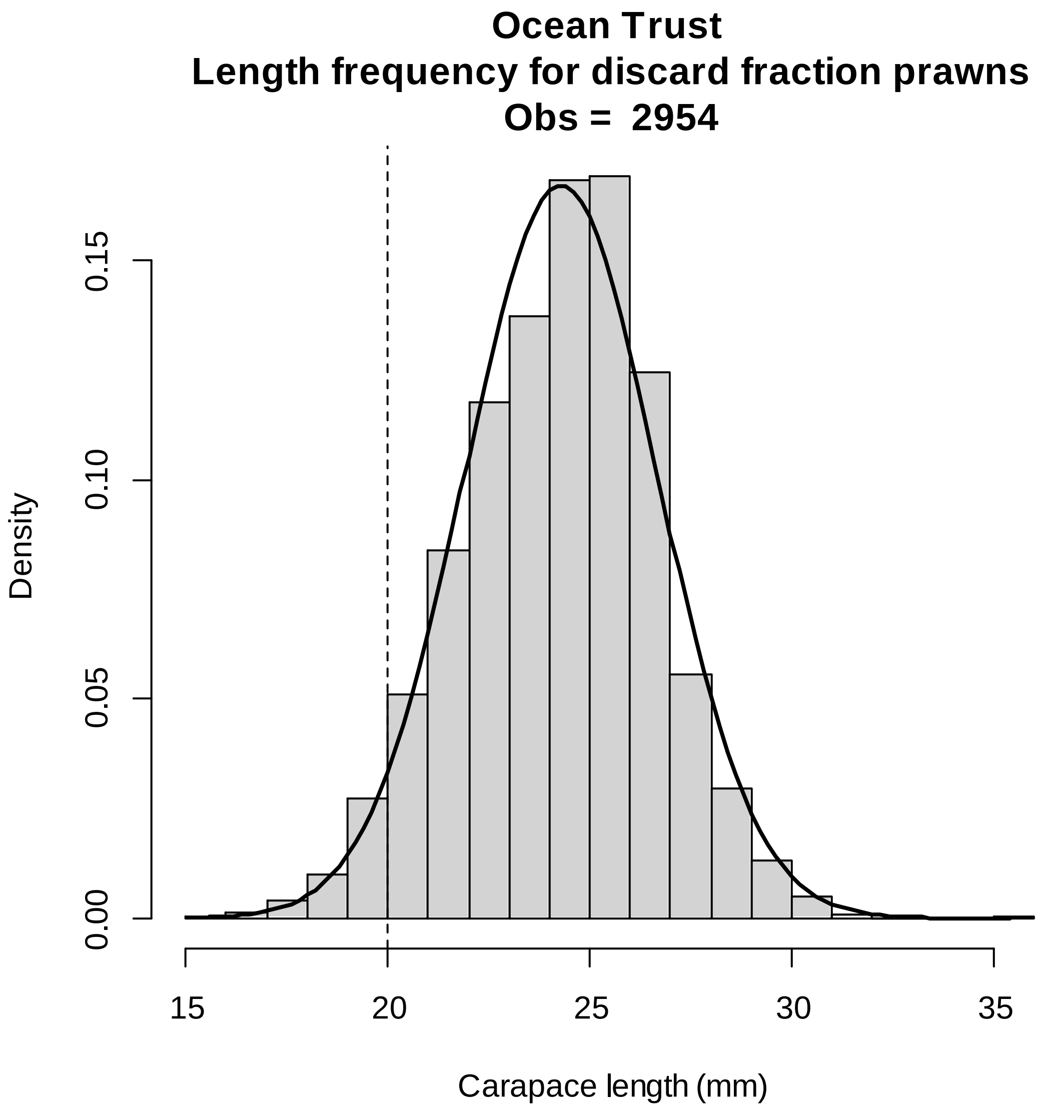


Figure 3-24: Percentage of discard fraction Nephrops alive during catch sorting. Gear and season by gear interactions were not statistically significant and so are not shown.

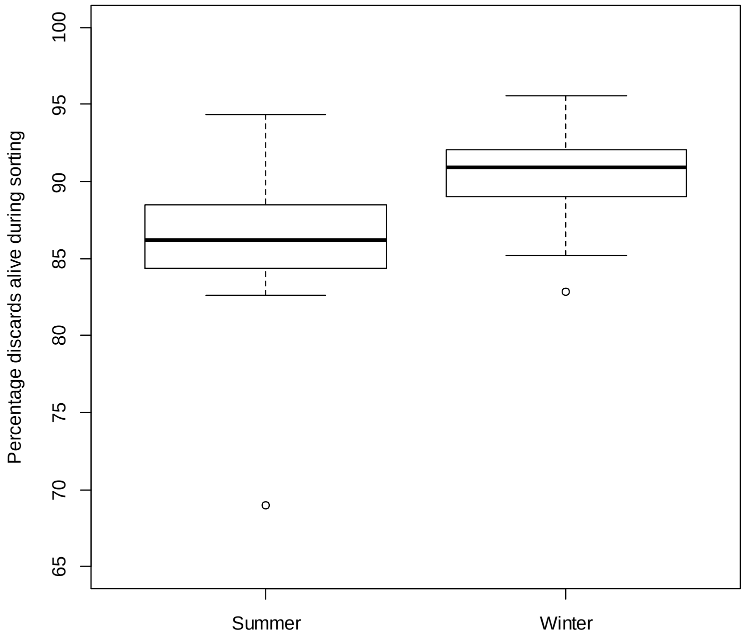


Figure 3-25: Relationship between the percentage of damaged discard fraction Nephrops evaluated at the time of death or at the end of 13 days recovery, versus the catch weight per tow: left panel; total catch (Nephrops plus finfish) and right panel; Nephrops.

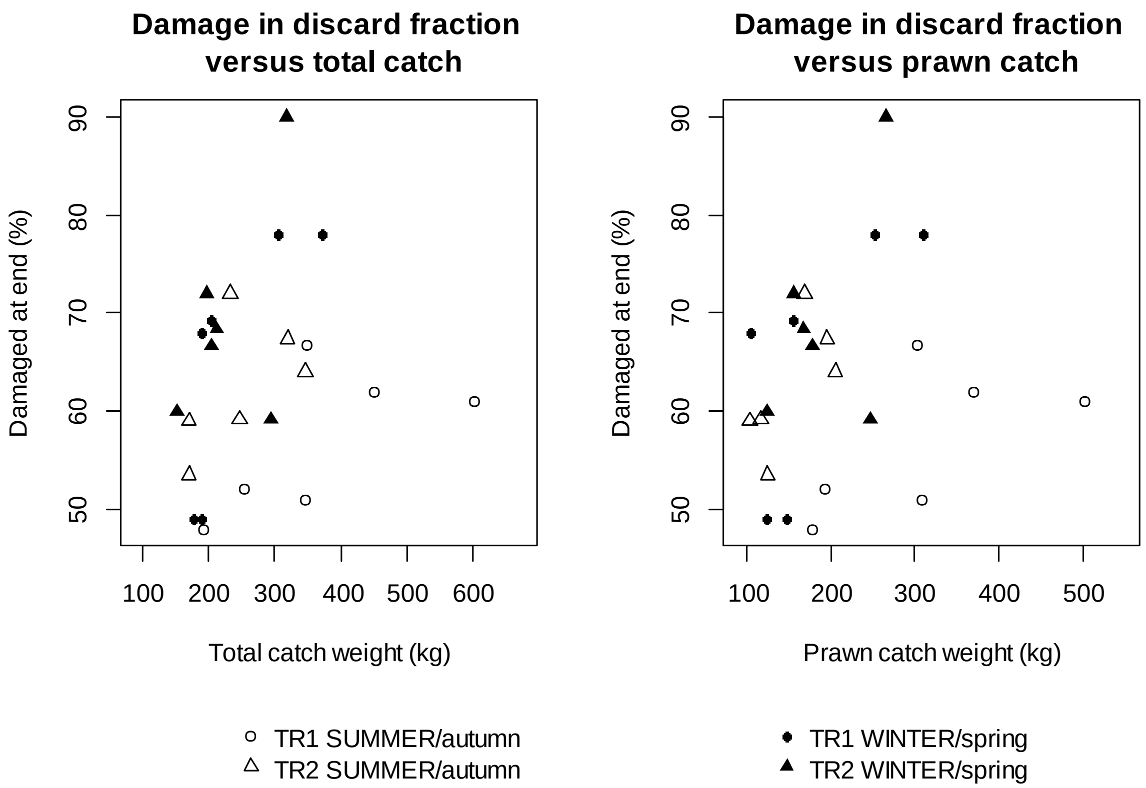


Figure 3-26: Relationship between the percentage of damaged discard fraction Nephrops evaluated at the time of death or at the end of 13 days recovery when healed wounds were excluded, versus the catch weight per tow: left panel; total catch (Nephrops plus finfish) and right panel; Nephrops.

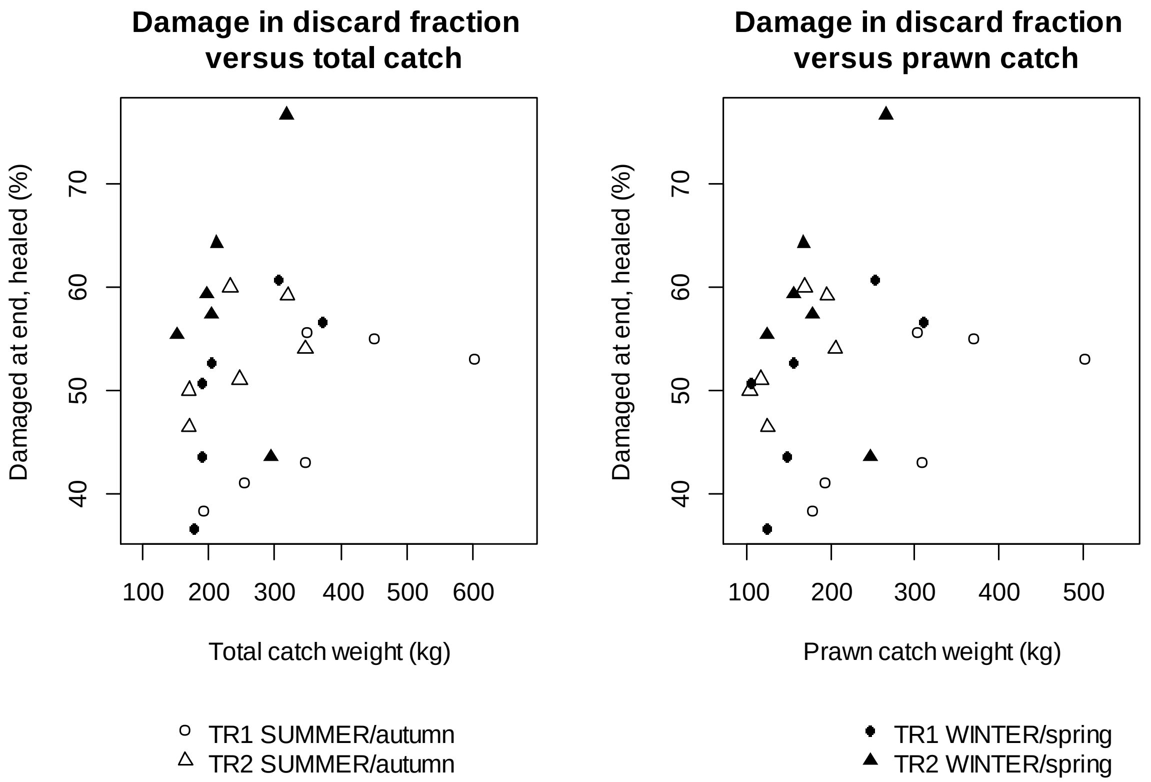


Figure 3-27: Continuous temperature records in the recovery tanks in SAMS aquarium.

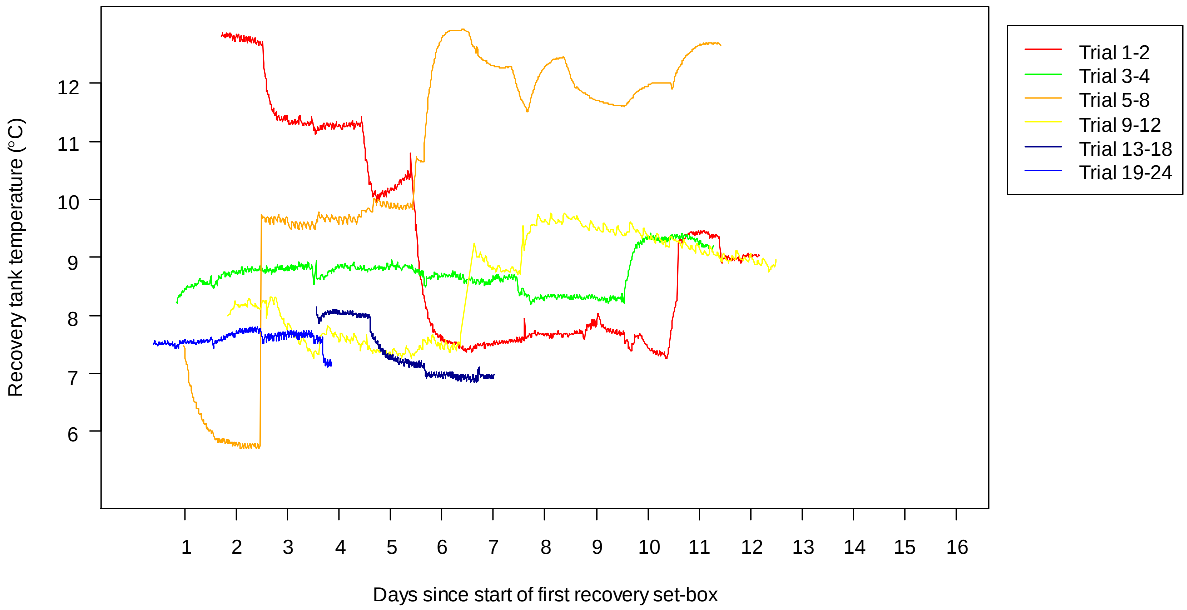


Figure 3-28: Kaplan-Meier plots for recovery of Ocean Trust discard fraction Nephrops against observation time partitioned by whether the discard Nephrops were sampled towards start or end of the catch sorting time. Dashed lines indicate the 95% confidence intervals for the group survival.

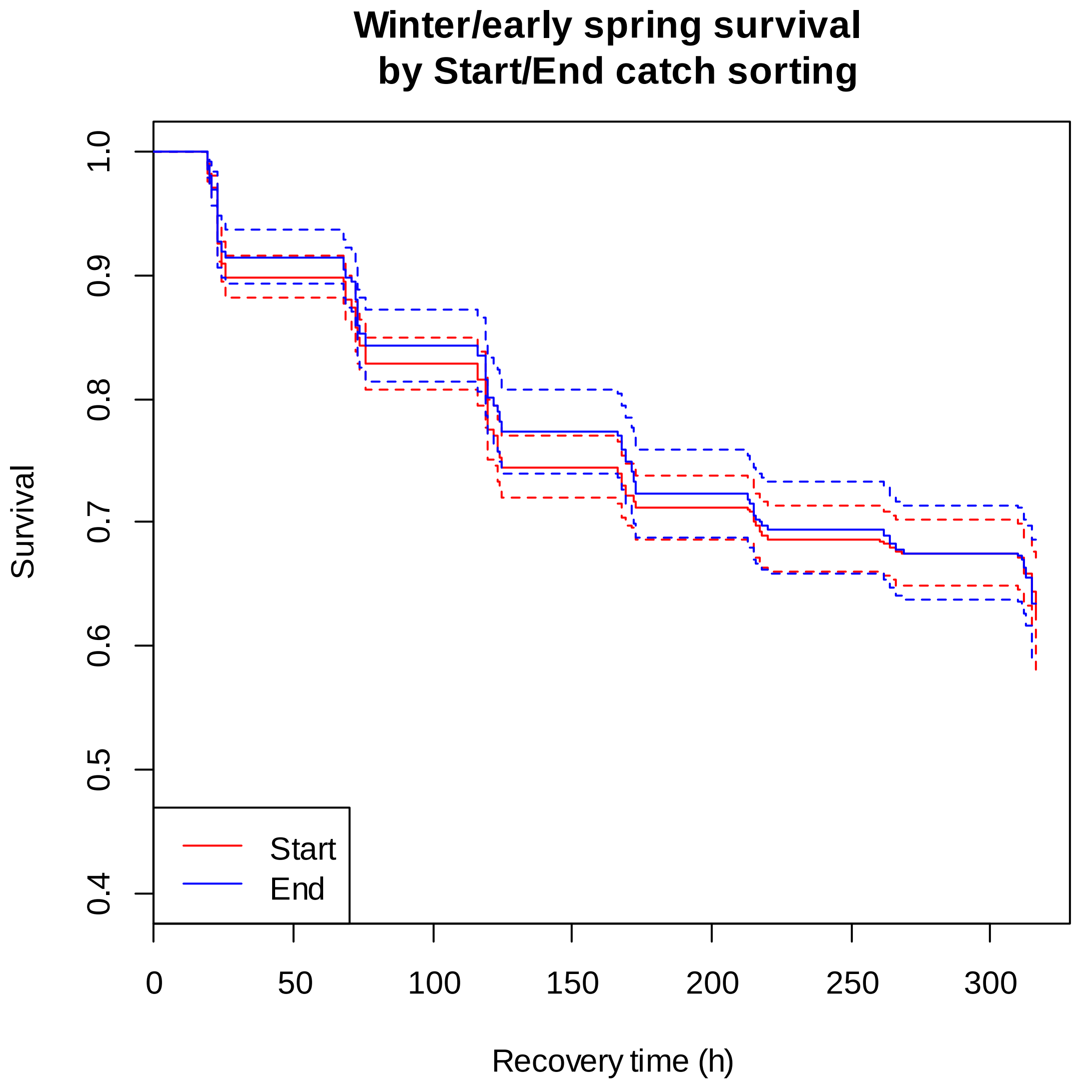


Figure 3-29: Kaplan-Meier plots for Nephrops survival from Ocean Trust tows during the 13 day recovery period – Summer/autumn TR1 trials. Dashed lines indicate the 95% confidence intervals for the group survival; vertical ticks indicate the time of the observations

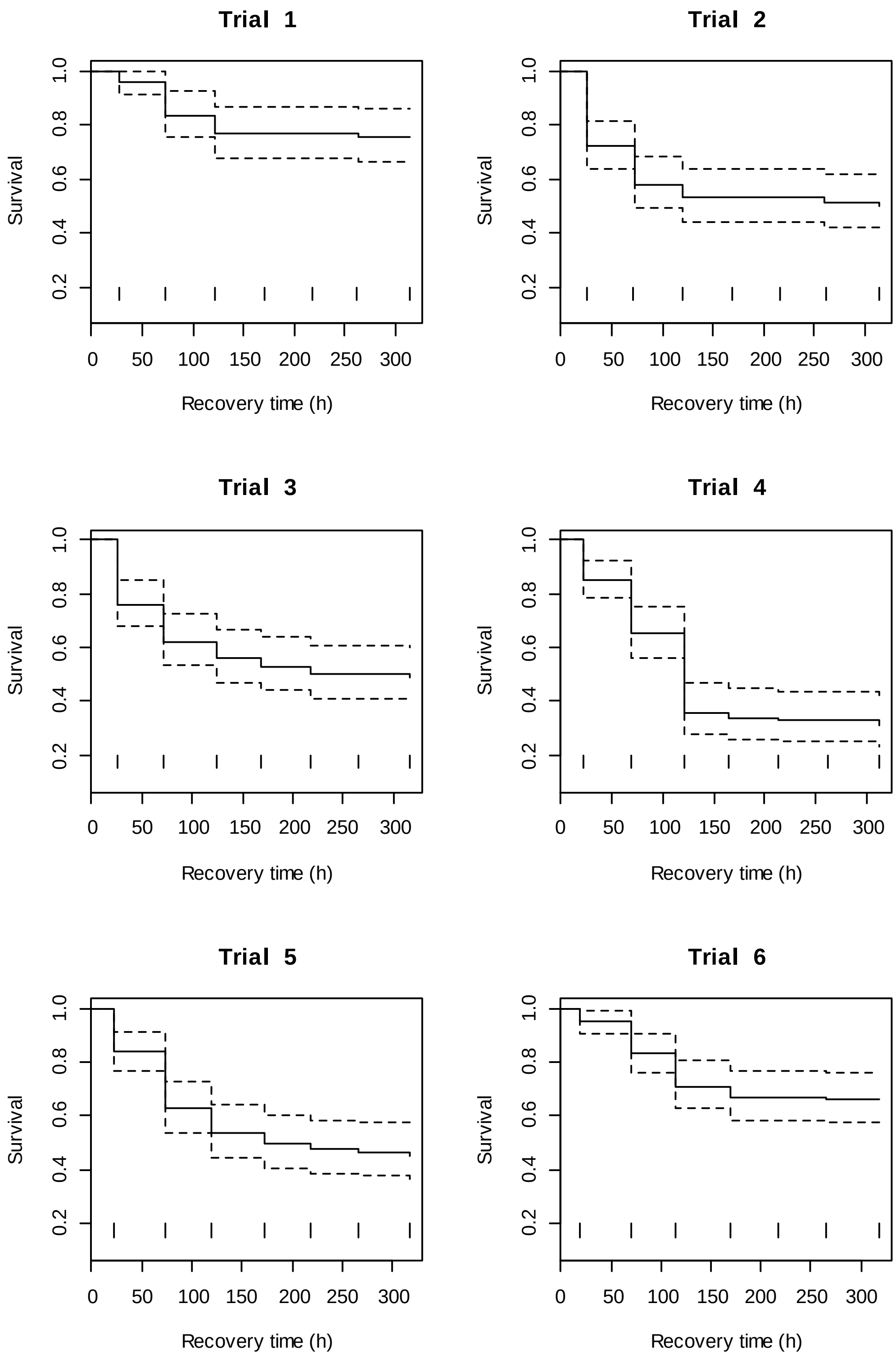


Figure 3-30: Kaplan-Meier plots for Nephrops survival from Ocean Trust tows during the 13 day recovery period – Summer/autumn TR2 trials. Dashed lines indicate the 95% confidence intervals for the group survival; vertical ticks indicate the time of the observations.

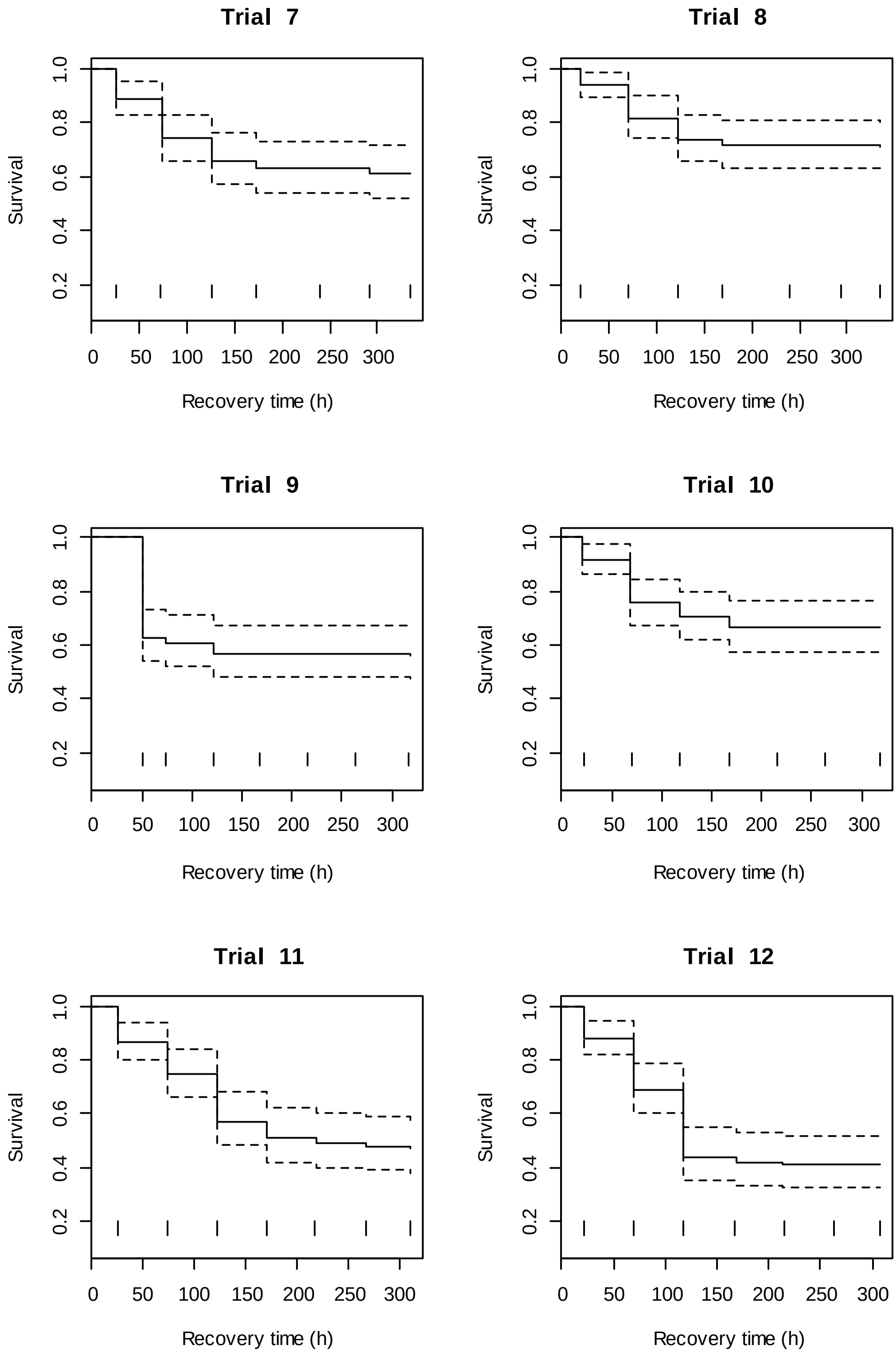


Figure 3-31: Kaplan-Meier plots for Nephrops survival from Ocean Trust tows during the 13 day recovery period – Winter/spring TR1 trials. Dashed lines indicate the 95% confidence intervals for the group survival; vertical ticks indicate the time of the observations.

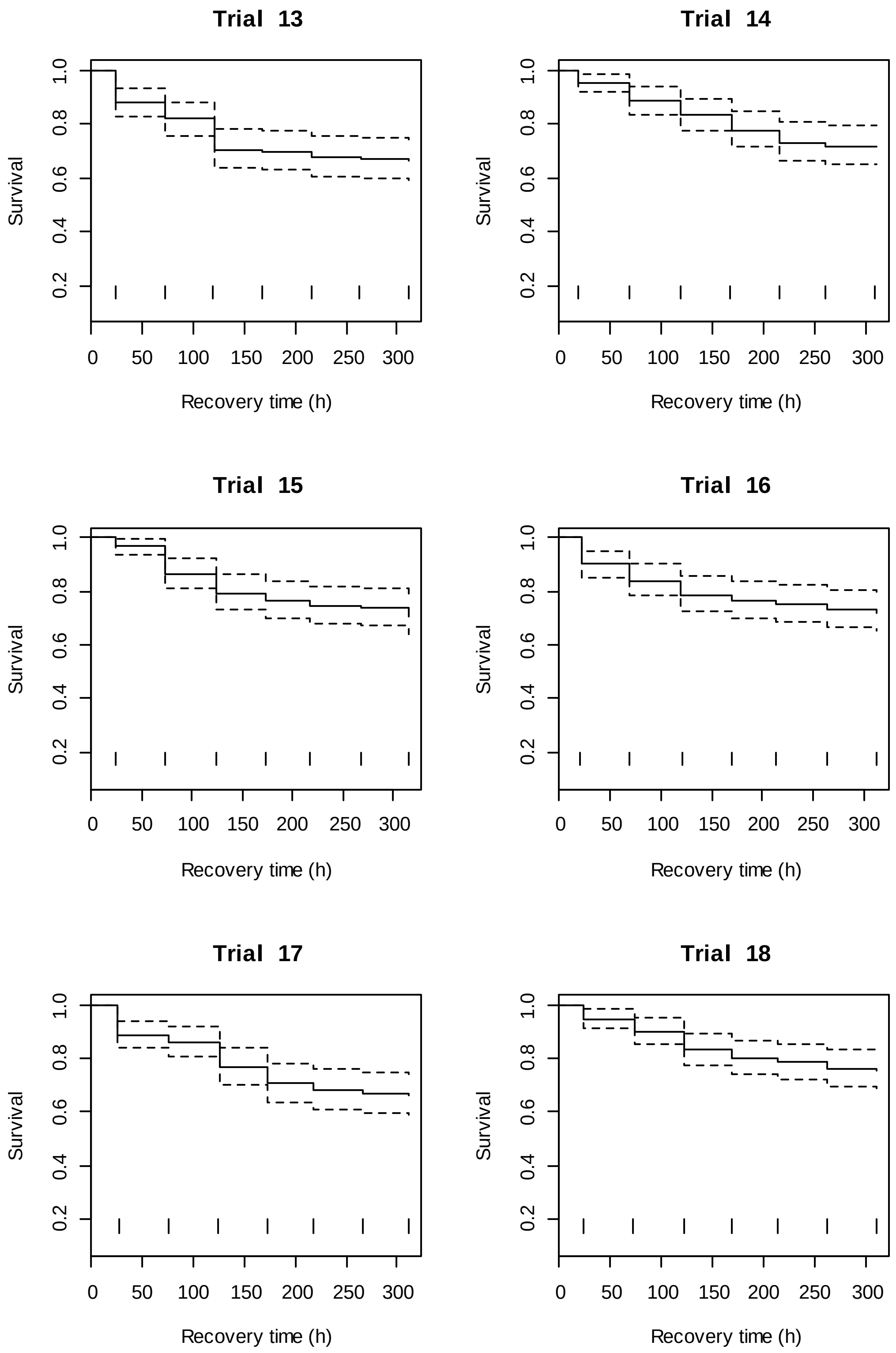


Figure 3-32: Kaplan-Meier plots for Nephrops survival from Ocean Trust tows during the 13 day recovery period – Winter/spring TR2 trials. Dashed lines indicate the 95% confidence intervals for the group survival; vertical ticks indicate the time of the observations.

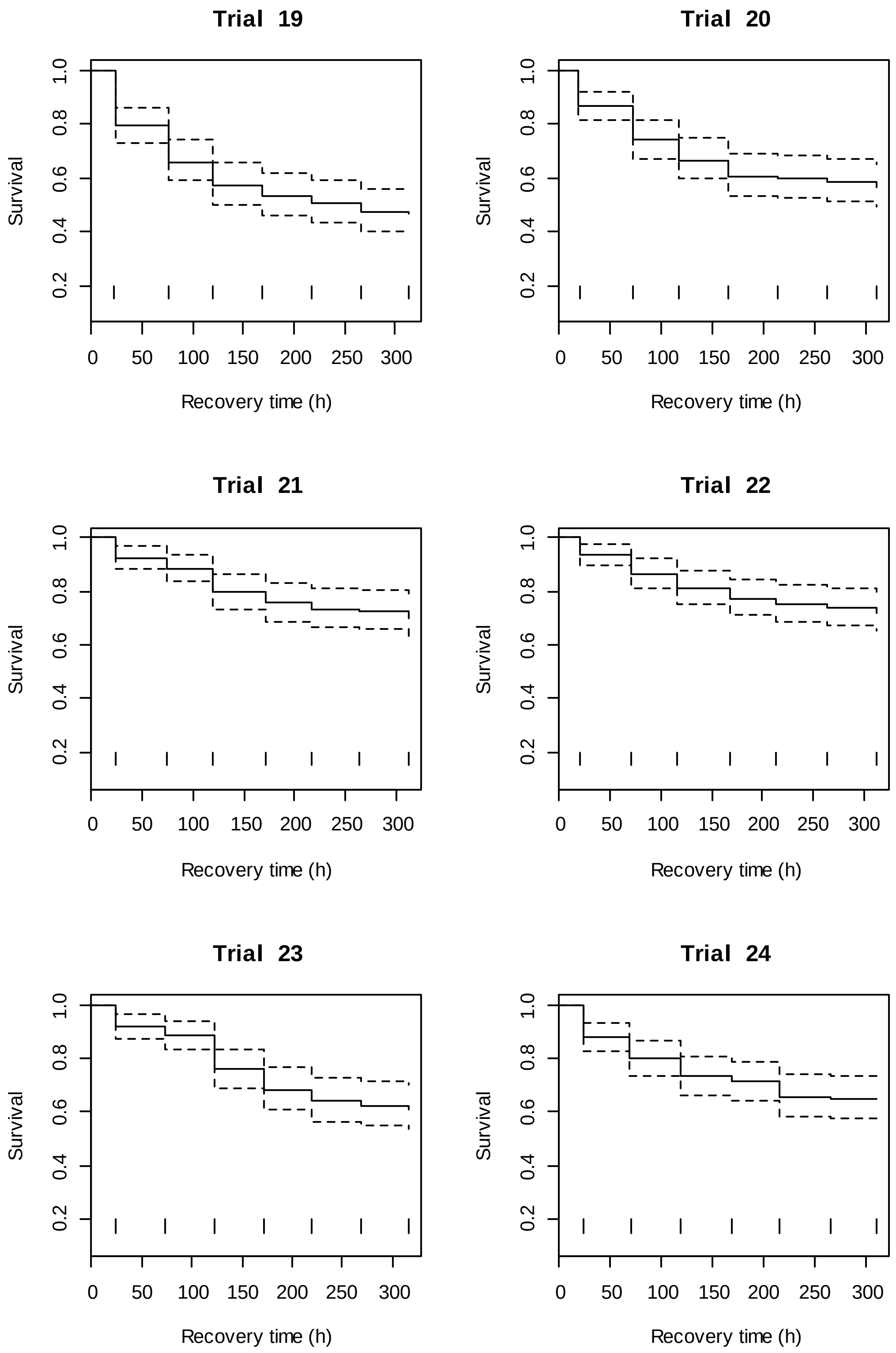


Figure 3-33: Ocean Trust discard fraction survival estimates plus 95% confidence intervals (dashed lines) versus visible damage to the Nephrops when damage was scored on-board - partitioned by season and gear.

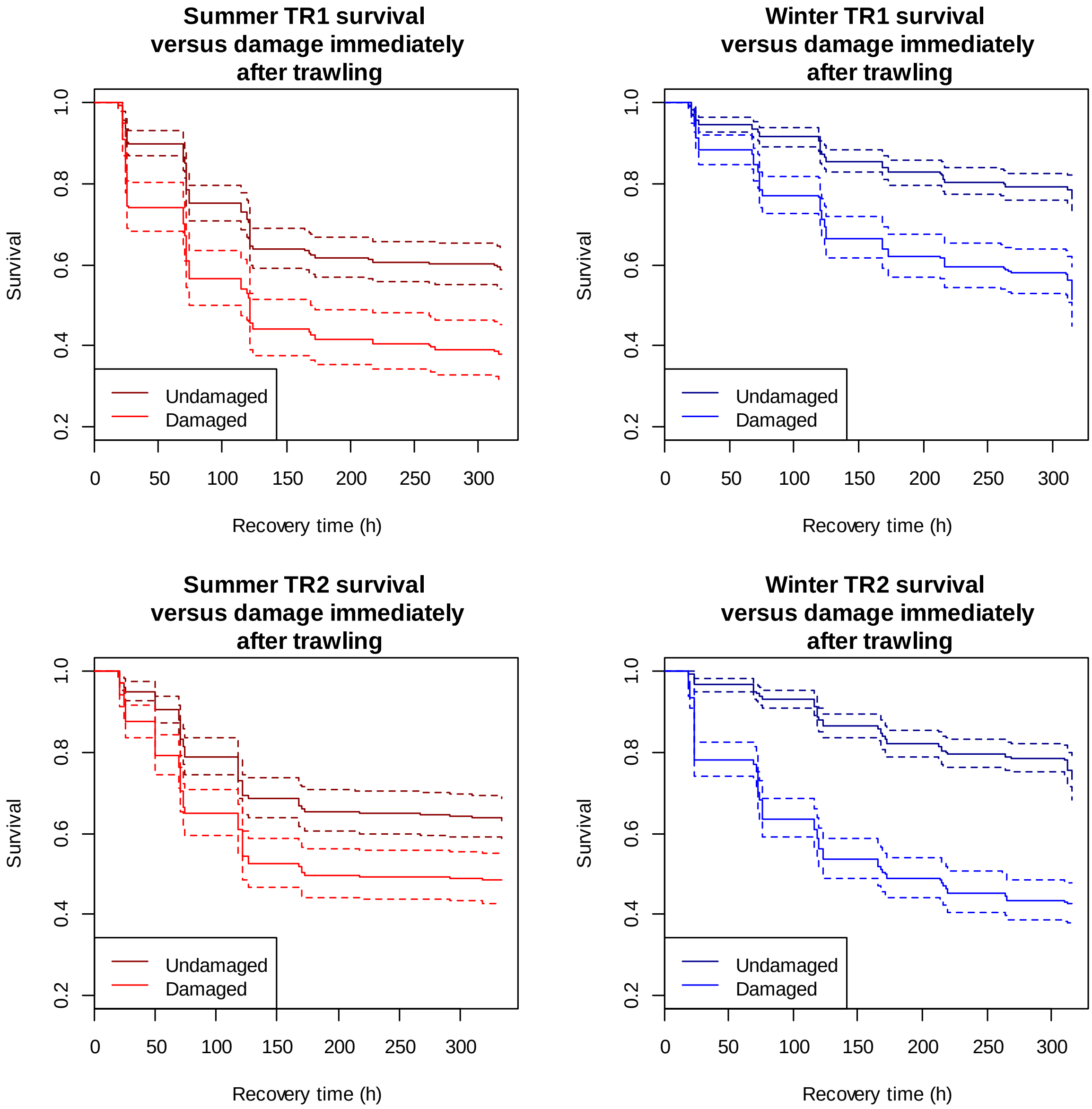


Figure 3-34: Ocean Trust discard fraction survival estimates plus 95% confidence intervals (dashed lines) versus visible damage to the Nephrops when damage was scored at time of death or end of recovery period - partitioned by season and gear.

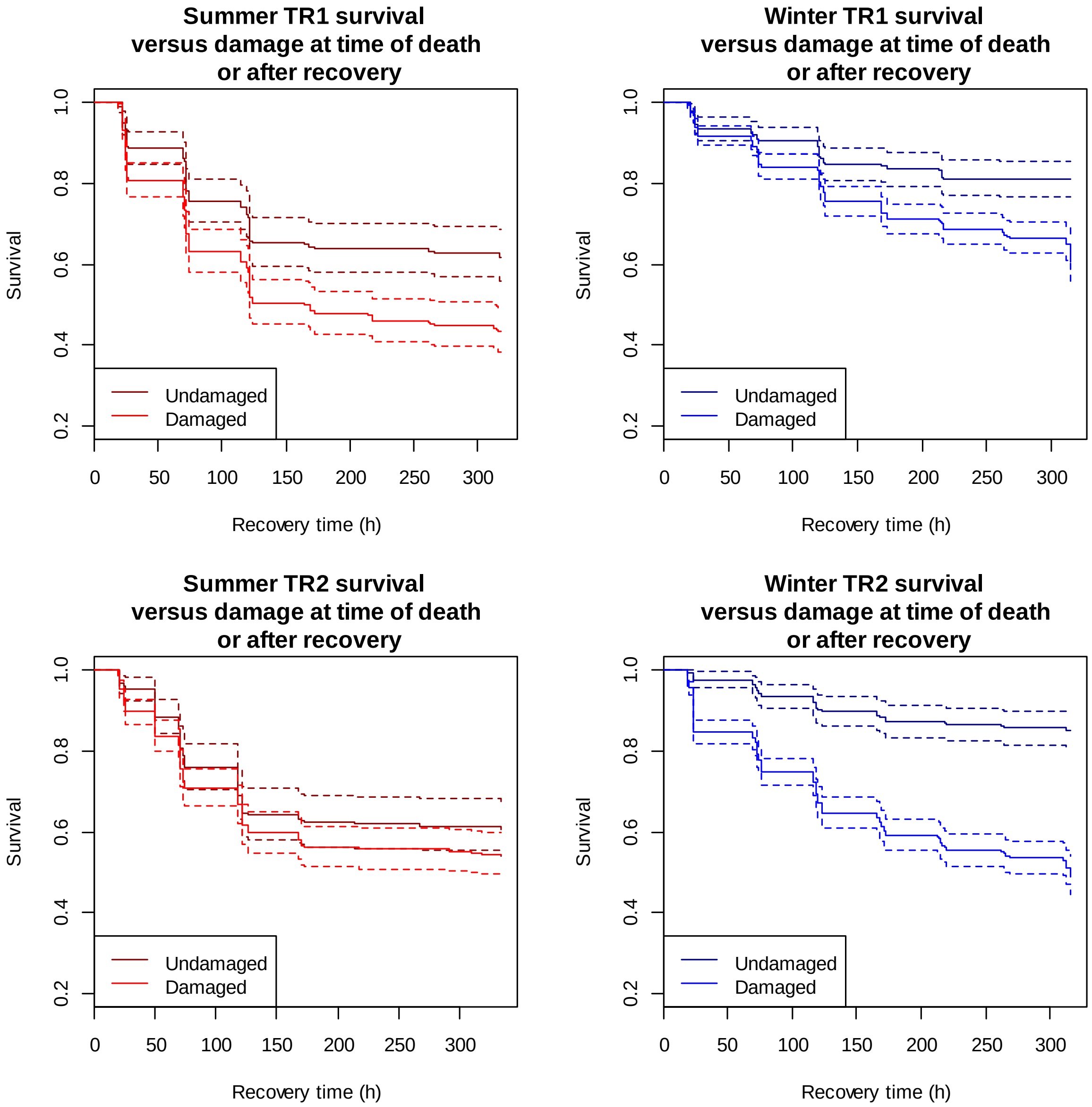


Figure 3-35: Ocean Trust discard fraction survival estimates plus 95% confidence intervals (dashed lines) versus visible damage to the Nephrops, but recoding healed wounds as no-damage, when damage was scored at time of death or end of recovery period - partitioned by season and gear.

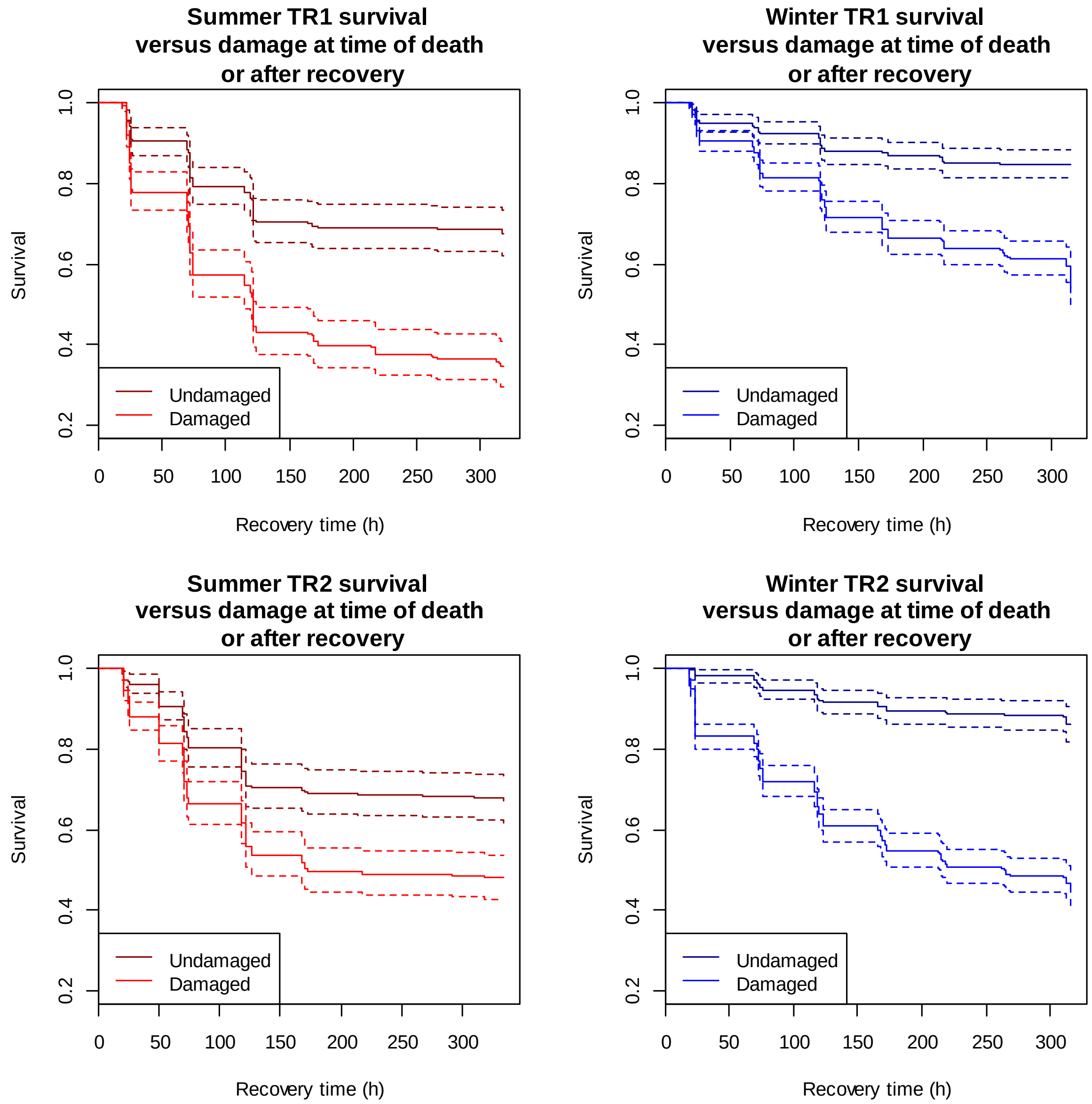


Figure 3-36: Kaplan-Meier plots for Nephrops survival during the 13 day recovery period – all trials partitioned by gear or season. Dashed lines indicate the 95% confidence intervals for the group survival.

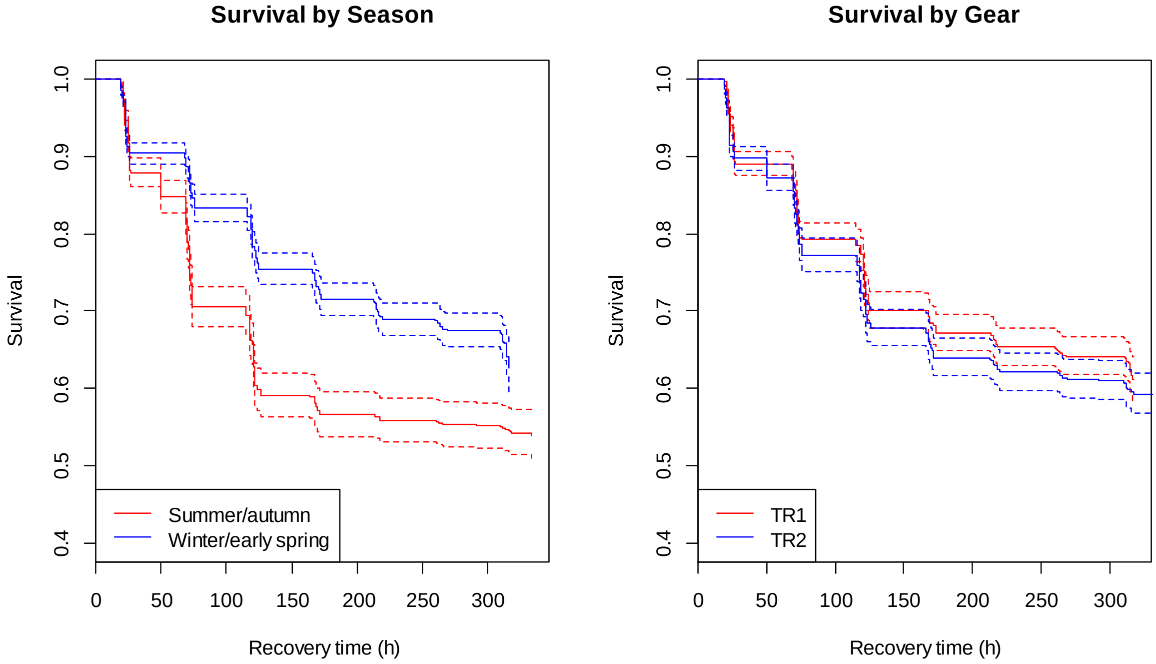


Figure 3-37: Final mean survival estimates for each trial ± 95% confidence intervals (light grey vertical bars) versus the air temperature as measured in the hopper during the catch sorting. Note that this effect could be artefactual and might as easily arise due to differences in the temperatures of the water in the recovery tanks between the summer and winter trials.

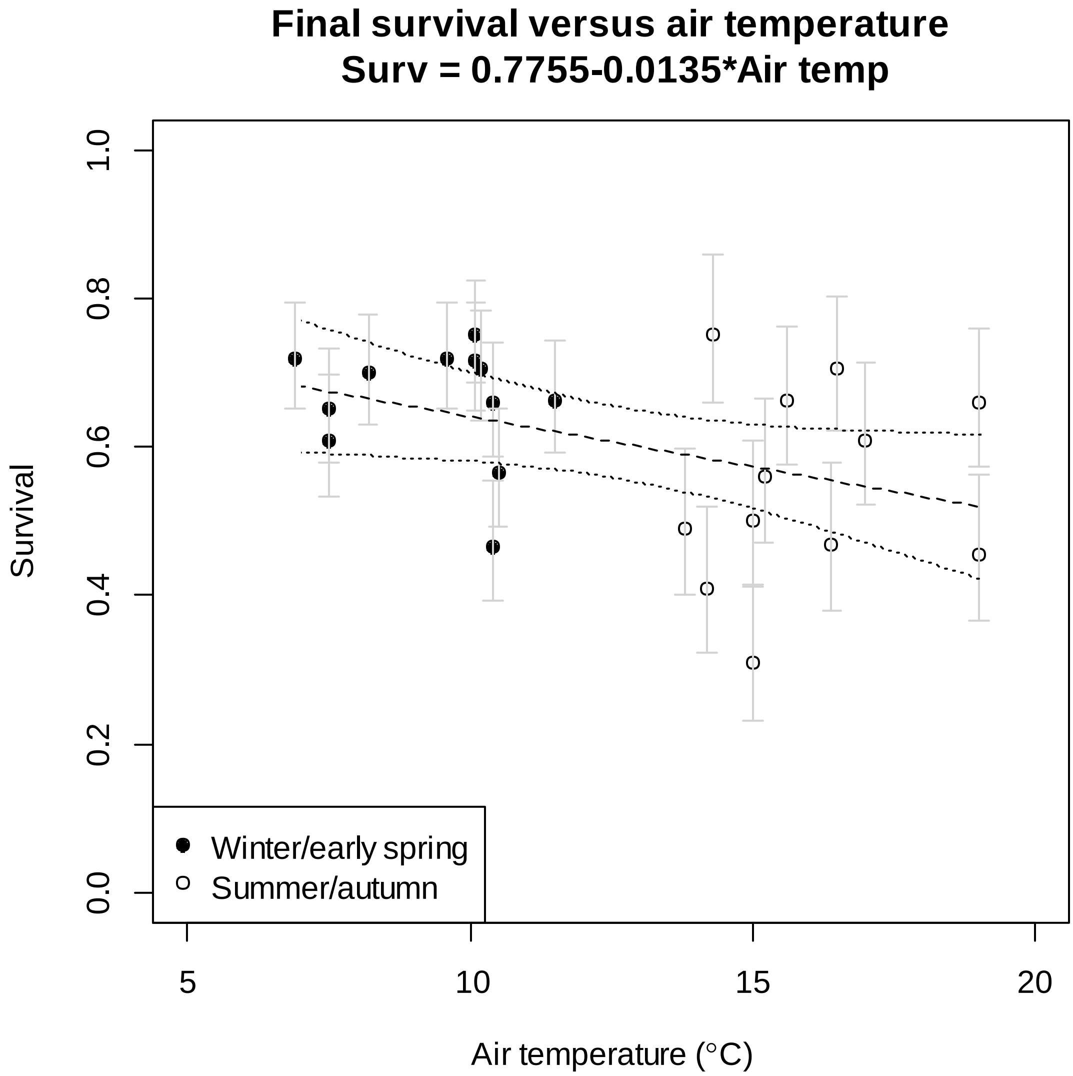
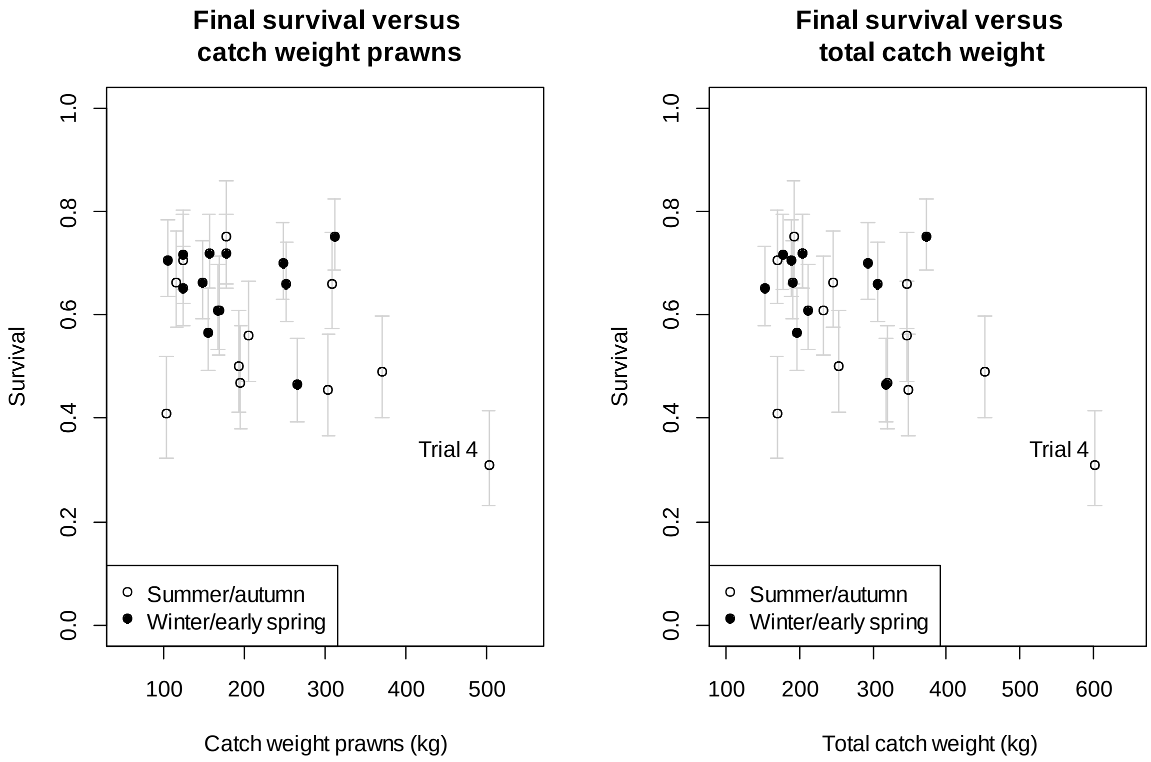


Figure 3-38: Final mean survival estimates for each trial ± 95% confidence intervals (light grey vertical bars) versus the catch weight of Nephrops (left panel) and total catch weight (right panel) in the tow. Trial 4 result is labelled because of its high leverage on the overall relationship between recovery and catch weights (see text for explanation).



4. Tank recovery trials on the east coast

Objective 1b (Objective 2b in the original proposal). At the request of FIS an additional objective was added to conduct similar tank recovery studies during summer on the east coast.

4.1. Introduction

Initial discussions with Eleni Balestri (Scottish Industry Discards Data Co-ordinator) suggested that most vessels operating out of the Firth of Forth would be fishing twin-rig TR2 trawls. An initial meeting was then held with Marine Scotland to review their data on the *Nephrops* trawl fisheries operating on the east coast (Table 4.1). These data indicate that nearly 85% of trawl *Nephrops* landings are by single-rig TR2 vessels.

Discussions with a local skipper confirmed that most boats operating in the Forth are using TR2 gears although he felt that most vessels were engaged in twin-rigging which conflicts with the official landings data (Table 4.1). Examination of vessels in Pittenweem harbour indicated most were twin-rigged but with a higher proportion of smaller vessels compared to the west coast. As with the official west coast landings data (Table 3.1) there appears to be a problem with correct allocation of landings between single and twin-rig gear types. The present project only included sufficient funding to conduct a limited number of east coast trials so it has not been possible to examine any summer:winter differences. The total number of recovery trials undertaken was therefore six TR2 summer tows using a twin-rig vessel operating out of Pittenweem.

4.2. Materials and methods

The fishing vessel 'Winaway' was chartered for the twin-rig east coast trials (Figure 4-1). This is a smaller vessel compared to 'Ocean Trust'. The nets used were 6 m wide fitted with 200 mm square mesh escape panels and 80 mm (TR2) cod-ends.

Fishing took place during night-time on commercially trawled *Nephrops* grounds in the Firth of Forth (Figure 4-2). Night fishing during summer in this area seems to be the normal pattern as all vessels were observed departing at similar times from the harbour. The first tow is made around dusk with one or more further tows being made until dawn. On each day of trial fishing two tows were sampled for discards recovery. Prior to the first tow the temperature and salinity of the water column were recorded using a Castaway CTD (Sontek, San Diego, USA). Winaway has a covered working area and at the end of each tow the catches are transferred to a hopper which has a sloping base (Figure 4-3). Sorting takes place on a flat metal table with a chute at the far-end down which discards and *Nephrops* waste are normally returned to the sea (Figure 4-4). The skipper and crew were asked to follow their normal working practices apart from modifying the catch sorting so that discard fraction *Nephrops* (those which would normally be rejected by the crew) and non-*Nephrops* discards (finfish, crabs etc.) were placed into baskets rather than being sent immediately over-board. During trials one hundred live, discard-fraction *Nephrops* were sampled from the start of the catch sorting and placed in an individual compartment of a set-box. As this was being done each animal's damage, vigour and reflex were scored following the CEFAS protocol (Table 3.2). Except for the last tow, where catch sorting was completed quickly, an additional 50 discard-fraction *Nephrops* were sampled towards the end of the sorting period and added to the set-box. The number of dead *Nephrops* in the discard-fraction whilst the set-box was being loaded was also recorded. Winaway has previously targeted the live-*Nephrops* market and is equipped with flowing seawater holding tanks which were used to store the set-boxes containing the discard fraction *Nephrops* until return to port the following morning.

The carapace lengths of a random sub-sample of *Nephrops* from the catch (taken directly from the hooper) were then measured using digital calipers. Once the total catch had been sorted by the crew the weights of the retained fresh whole *Nephrops* (these are the larger *Nephrops* caught) and retained *Nephrops* tails (smaller *Nephrops* are tailed on board the heads being discarded) were recorded based on the number of baskets filled. The weights of the discard fraction *Nephrops* and non-*Nephrops* catch were also recorded using hanging balances (Dr Meter ES-PS01 electronic balance and Silverline heavy duty model). The weight of tails was raised to a whole *Nephrops* equivalent by multiplying by three (following the MMO guideline for this conversion). The weights of the individual measured *Nephrops* in the catch sub-sample were estimated using the Marine Scotland Science formulae appropriate for the Firth of Forth from Table 3 of Howard and Hall (1983):-

$$\text{Weight males} = 0.00028 * CL^{3.24} \quad \text{(g)}$$

$$\text{Weight females} = 0.00084 * CL^{2.91} \quad \text{(g)}$$

The total estimated weight of the sub-sample (based on *Nephrops* lengths) was then compared with the weighed sub-sample (based on hanging balance measurements) and generally found to be within 0.5 kg. The small differences between the two measures of sub-sample weight were due to the hanging balance being affected by the vessel movement. The estimated total weight was then used to raise the number of *Nephrops* measured in the sub-sample to the total catch weight. The *Nephrops* in the discard fraction were then expressed as a percentage of the total catch – both in terms of weight and numbers.

Water flow to the on-board holding tanks was switched off once outside Pittenweem harbour to avoid exposing the animals to pollutants, such as oil and diesel, which might be in the water in the inner harbour. On return to Pittenweem at around 08:00 the following morning, the two set-boxes prepared each day were transferred into two, 220 l Saeplast insulated boxes containing fresh seawater to which cold-blocks were added for transporting the animals to the SAMS aquarium. During transport a Hobo temperature logger was placed in each of the Saeplast containers. For the east coast trips it was not possible to include control animals in the transport phase because the outward journey (Oban to Pittenweem) was made the night before the test animals were landed so that control animals would have had to be held in the Saeplast tanks for an excessively long time. Each Saeplast box was aerated using a small portable pump powered from the vehicle's 12V supply. On reaching the laboratory, each set-box was transferred into an individual recovery tank and 10 control animals added to each box (same aquarium setup as used in the west coast recovery trials, Figure 3-6). The recovery tanks were located in a constant temperature room running at 5°C air temperature with continuous flowing seawater running through a chiller unit. Each tank was also continuously aerated. Hobo temperature loggers were installed in the recovery tanks to monitor the water temperatures but unfortunately the loggers failed to record data correctly, possibly due to low batteries. Water temperatures and salinities in the recovery tanks were also measured daily using a Castaway CTD and these values are reported. Ammonia levels were checked daily using an API Saltmaster (Mars Fishcare, Chalfont, Pennsylvania, USA) test-kit and oxygen levels also recorded using a YSI-Pro20 portable oxygen meter).

Appropriate control animals for this type of trial are difficult to source so we used *Nephrops* from previous discard trips which had fully recovered, had no external damage and were in vigour class 1 and reflex class 0 when removed from the SAMS aquarium stock tank. We opted for this type of control as creel-caught *Nephrops*, which have been used in other discard recovery studies, would be larger in size which might affect their vulnerability to the recovery-tank conditions.

The survival of the test and control *Nephrops* in each set-box was checked every two days. Any dead animals were removed, their carapace lengths recorded and the animal examined for signs of external damage. After 13 days mortalities had generally stabilised (see results) so the remaining live animals were measured and scored for external damage, vigour and reflex. *Nephrops* with signs of external damage or low vigour or reflex scores were euthanized by freezing. *Nephrops* with no external damage and excellent vigour and high reflex were placed in stock tanks for use as control animals in future trials.

Survival data were analysed and modelled against available co-variates following the chapter "Survival Analysis" in Crawley (2013). Results were shown as Kaplan-Meier plots which show the mean decline in survival against time. All statistical analyses were conducted using R version 3.3.2.

The methods used in this project are consistent with recent studies on *Nephrops* post-discard survival carried out by CEFAS on fishing grounds off the North East of England (area IVb) and by the Swedish University of Agriculture Sciences in ICES area IIIa.

4.3. Results

4.3.1. Tows, catch weights and discard rates

Air temperatures during the east coast summer trials were in the range 11.0 to 14.2°C (Table 4.2). Water temperatures were warmer at the surface than at depth with the maximum difference being 3°C. Noticeable warming of the surface waters had occurred between the first and second set of trials a week later. For all trials the bottom temperatures were between 9.6 to 10.1°C and salinity at depth was up to 1 salinity unit higher than at the surface (Figure 4-5).

The average tow duration during the summer east coast trials was 3:28 h but there was quite a large range from as little as 1:32 h to 5:10 h.

Total catch weights averaged 271 kg with a range from 110 to 397 kg. Total catch sorting times ranged from as little as 51 mins to nearly 3 h and there was a statistically significant ($p<0.001$) linear relationship between total sorting time and total catch weights (Figure 4-6).

Discarded *Nephrops* comprised between 3.8 to 9.0% of the *Nephrops* catch weights (Table 4.3) making the average value 6.7 +/- 1.6% (mean +/- 95% conf. int.) of the weights of *Nephrops* caught. The total number of *Nephrops* discarded per tow may also be of interest - these estimates ranged from 727 to 2,680 with an average of 763 +/- 610 (mean +/- 95% conf. int.). Effects of mesh size and season could not be tested because trials were only conducted in summer using 80 mm TR2 nets.

4.3.2. Sizes of retained and discarded *Nephrops*

Length frequency plots of the *Nephrops* caught on each tow (Figure 4-7 and Figure 4-8) showed that the sizes of the *Nephrops* were generally similar between tow locations as would be expected given the relatively small area over which tows were spread (Figure 4-2). Bimodal distributions were apparent in most of the size frequency plots for the overall catch sub-samples. This bi-modality was also apparent for males when these data were separated by sex, but not for females (Figure 4-9). The presence of smaller males in the samples resulted in the average size for males in the catch (30.6 mm) being slightly lower than for females (31.9 mm) although note that the mean is not a good measure of central tendency for bimodal distributions (t-test=3.8, df=821, p=<0.001).

The amount of discarding will tend to be affected by the overall size distribution of the catches. The bi-modality evident when the size distributions were separated by sex was not seen when the sexes were merged. For the overall Winaway catch samples the length frequency distribution was positively skewed (i.e. the tail of the distribution is longer to the right) and so for comparison with the Minimum Conservation Size Limits, the overall length distribution was better described using a log-normal, as opposed to normal, curve (Figure 4-10). On this basis about 12% (cdf lognormal, x=20, logmean=3.432, logsd= 0.182) of the *Nephrops* caught were below the Minimum Conservation Reference Size of 25 mm CL applicable for ICES Division IVa.

Carapace lengths of discard fraction *Nephrops* ranged in from 20.0 to 33.7 mm CL with the mean being 26.0 +/- 1.9 mm CL (mean +/- 95% conf. int.) based on 842 observations. The overall length frequency of the discard fraction *Nephrops* was reasonably fitted using a normal distribution (Figure 4-11). This implies that around 71% of the discarded *Nephrops* were above the minimum conservation reference size of 25 mm CL applicable in ICES Division IVa. These results on the lengths of discarded *Nephrops* are consistent with data presented in Balestri (2015) for the Firth of Forth.

4.3.3. Discard fraction damage, vigour and reflex scores

Estimates of the percentage of discard fraction *Nephrops* alive during sorting ranged from 91.5% to 97.4% with the overall mean being 95.2% ± 2.4% (mean ± 95% conf. int., n=6). It was not possible to test for any effect of season or gear because the Winaway trials were only undertaken during summer using TR2 gear.

The damage scores across all the trials recorded during catch sorting are shown in Table 4.4. The mean percentage of discard fraction *Nephrops* with no external damage immediately after trawling was 64.7% ± 3.0% (mean ± 95% conf. int., n=6). The most common injuries were loss of one chelae followed by tail or thorax punctures. However, comparing the percentages recorded as having no damage when scored on-board (Table 4.4) with the percentages recorded as having no damage when scored at the time of death or at the end of the 13 day recovery period revealed higher levels of damage (Table 4.5). Between 30-46% were completely undamaged giving an overall mean of 39.2 ± 6.2% (mean ± 95% conf. int., n=6). The reason for the discrepancy between damage scoring on-board Winaway and in the aquarium appears to be that that many of the small puncture or crush wounds were not obvious on-board and only became visible on closer examination, or once melanised after a period of healing. The average percentage of discard fraction *Nephrops* with damage when scored in the aquarium was 60.8 ± 6.2 (mean ± 95% CI). The data were subsequently recoded to exclude wounds which had healed i.e. “damage-end-healed” represents more serious injuries. On this basis 42.4 ± 4.4% of the *Nephrops* were seriously damaged (Table 4.6).

Proportion tests indicated that there was no significant difference between sexes in the percentage of animals being scored as un-damaged, either when scoring was conducted on board or at a later date (Table 4.7). The proportions of *Nephrops* showing no damage versus any damage by tow were further modelled using separate binomial glms for on-board scoring and for scoring damage at death or end of the recovery period. Based on these models sex did not have a significant influence on damage levels at p=0.05.

There was a statistically significant correlation between the percentage of discard fraction *Nephrops* showing at least one sign of damage (scored at the time of death or after 13 days recovery) and the total catch weights (t = 3.6, df = 4, p-value = 0.02), or catch weight of *Nephrops* (t = 3.4, df = 4, p-value = 0.03). However, it should be noted that these significant relationships are based on a limited number of tows (n=6) and that tow 25 appeared to conform less with the linear relationship (Figure 4-12). Furthermore when healed wounds were excluded the relationship was weakened (Figure 4-13), although the correlation was still just significant (t = 2.8024, df = 4, p-value = 0.048).

The percentage of animals in vigour categories 1 and 2 immediately after trawling was quite variable (Table 4.9) and there was no obvious link with factors such as tow length or catch weights. At the time of sampling the majority of discard fraction *Nephrops* were in vigour category 3 (Table 4.10) and reflex category 0 (Table 4.10). This is consistent with most animals being in a moderately exhausted state after trawl capture but not to the extent that abdominal strength was completely lost.

4.3.4. Discard fraction *Nephrops* recovery

Transporting the set-boxes from Pitenweem to SAMS generally took around 3½ hours. Water temperatures during transport were within 2^{o}C of the measured bottom water column temperatures during trawling except for tows 29 and 30 where transport temperatures were close to the surface temperatures (Table 4.2). Oxygen levels at the end of transport to the aquarium were between 6.0 and 6.7 mg l^{-1} (=70% saturation at 10^{o}C and salinity 33). Ammonia was also monitored in the transport tanks and tended to be elevated to around 1 mg l^{-1} on arrival at the SAMS aquarium.

Temperatures in the recovery tanks could only be recorded daily due to a failure of the Hobo temperature loggers. Water temperatures in the recovery tanks were in the range 10.1 to 10.9^{o}C (i.e. within 1.3^{o}C of the recorded bottom water temperatures from the trawl tows). Ammonia levels were usually undetectable and only ever reached a peak of 0.5 ppm in one tank when the water flow became temporarily reduced. Salinities were between 31.7 and 33. The recovery tanks were continuously aerated with individual air feeds and air-stones. Measured dissolved oxygen levels in the recovery tanks were in the range 5.5-7.2 mg l^{-1} (i.e. DO was never < 60% saturation). These oxygen levels were therefore well above the value of around 40% saturation considered to be moderate hypoxia for *Nephrops* (Baden et al. 1990).

None of the control animals died during the recovery trials suggesting that recovery was not being adversely affected by the use of set-boxes for recovery or the recovery tank set-up in the SAMS aquarium. However, fourteen of the test *Nephrops* died during recovery as a result of moulting in the tubesets. These animals were excluded from further analysis because it is unclear whether they would, or would not have survived in the wild.

The mortality rates of discard fraction *Nephrops* sampled from the six tows were monitored every two days over a total of 13 days. The mortality rates of discard fraction *Nephrops* sampled from the 24 tows were monitored every two days over a total of 13 days. The majority of live discard fraction *Nephrops* were in vigour category 1 or 2 and reflex category 0 or 1 after 13 days recovery (Table 4.9 and Table 4.10). This is consistent with the majority of animals being in a “good” state after recovery.

For tows 25-29 additional discard *Nephrops* were sampled towards the end of catch sorting to check for any effect on recovery of the total aerial exposure time during catch sorting. For the last tow the overall catch was low (Table 4.3) and discard sampling covered the time taken for catch sorting to be completed. The survival curves (Figure 4.14) suggest there was no statistically significant effect of whether *Nephrops* were sampled early or late during catch sorting although the recovery of later sampled animals was slightly lower (survival regression Start/End $p = 0.298$). Subsequent analyses therefore ignored whether individual animals had been sampled at the start of end of the catch sorting.

Survival curves by trial indicated that the majority of mortalities occurred within the first 120 h of recovery and after that survival had largely stabilised (Figure 4-15). Over all trials the *Nephrops* survival rates after 13 days recovery estimated using the Weibull-based parametric approach ranged from 73.3% to as high as 96.03% (Table 4.11). The overall mean was 78.4% ± 1.4% (mean ± 95% conf. int.). Also note that this overall mean survival does not take account of the proportion of *Nephrops* which were dead in the discard fraction during catch sorting. This further correction is included in Section 6 of this report.

Regressing mean survival by tow against whether *Nephrops* had visible damage or were undamaged suggested a highly significant impact of visible injuries ($p<0.001$), both for damage scoring immediately after trawling and for scoring undertaken at the end of the 13 day recovery period (Figure 4-16). Although damage scoring at the end of recovery revealed a higher proportion of *Nephrops* with wounds, the impact of these differences on the percentage of *Nephrops* showing damage had little effect on the overall survival, damage relationships. When healed wounds were discounted the impact of remaining injuries on recovery potential was even stronger. The effect of seasonality or gear on this relationship could not be examined because trials were only conducted in the summer and using TR2 gear.

The exposure of *Nephrops* to increased air temperatures has been linked to decreased survival in some studies (Rihan et al. 2016). For the Winaway trials the range of air temperatures was only 2^{o}C. Furthermore, fishing took place at night when air temperatures will be lower than during the day. Both Weibull-based survival regression and linear regression modelling of the mean final survivals per tow suggested that there was no significant effect of air temperature on subsequent survival at the end of the 13 day recovery period ($p>0.05$).

Given that individual recovery potential is clearly impacted by damage, factors which might affect the overall level of damage in the discard fraction *Nephrops* are of interest. Mean survival per tow was therefore modelled against catch weights using both Weibull-based regression and linear regression of the final mean survival per tow. Although there was some visual indication that mean survival of discarded *Nephrops* might be related to catch weights (Figure 4.17) the relationships were not statistically significant ($p>0.05$). There was therefore little convincing evidence that catch weight affects the eventual recovery rates of discard fraction *Nephrops* in these trials although it must be cautioned that such an effect might become statistically significant if data from a greater number of tows were available.

4.4. Discussion

The results for both the west coast and east coast recovery trials are compared and discussed further in Section 7.

Table 4.1: Official Nephrops landings over last five years for the Scottish east coast (Firth of Forth functional unit).

Landings by weight							
Area	Year	Single-rig trawls TR2 (tonnes)	Selective trawls TR1 (tonnes)	Twin-rig trawls TR1 (tonnes)	Total trawl (tonnes)	Creel (tonnes)	Total (incl creel) (tonnes)
	2011	1,670	6	119	1,795	89	1,884
	2012	1,765	17	179	1,961	126	2,087
	2013	1,173	24	236	1,433	58	1,491
	2014	1,796	33	517	2,346	14	2,360
	2015	1,463	104	214	1,781	43	1,824
	All	7,867	184	1,265	9,316	330	9,646
Landings by percentage weight, excluding creel							
	All	84.4	2.0	13.6	100.0		9,316

Table 4.2: Tow details for Winaway summer 2017 Nephrops recovery experiments, all times shown are UTC. Latitudes and longitudes are the approximate mid-points of the tows.

Date (dd/mm/yy)	Trial	Cod-end (mm)	Shoot (hh:mm)	Haul (hh:mm)	Lat (dec º)	Lon (dec º)	Shoot depth (m)	Haul depth (m)	Speed (kts)	Air temp (ºC)	Tow (h)	Sort time (h)	Bottom temp (ºC)	Bottom sal.	Temp transport to aquarium (ºC)
13/06/2017	25	80	18:46	22:35	56.160	-2.804	47	33	2.7	14.6	3.82	2.15	10.1	33.9	10.3
14/06/2017	26	80	22:54	04:05	56.156	-2.835	33	45	2.7	15.1	5.18	1.82	10.1	33.9	10.3
20/06/2017	27	80	19:56	23:44	56.124	-2.928	45	29	2.3	15.2	3.80	2.90	9.9	34.2	11.3
21/06/2017	28	80	00:01	03:33	56.125	-2.929	30	44	2.6	13.3	3.53	1.67	9.9	34.2	11.0
21/06/2017	29	80	19:40	22:38	56.101	-2.969	44	24	2.6	15.8	2.97	1.97	9.6	34.3	13.0
22/06/2017	30	80	01:57	03:29	56.125	-2.941	24	31	2.2	16.3	1.53	0.85	9.6	34.3	13.0

Table 4.3: Catch weights and numbers Winaway summer 2017 trials.

Trial	Retained *Nephrops* live (kg)	Retained *Nephrops* tails (kg)	Retained *Nephrops* tails raised to live (kg)	*Nephrops* discarded (kg)	Total *Nephrops* caught (kg)	Non-target discards (fish etc.) (kg)	Total catch (*Nephrops* plus non-target discards) (kg)	Estimated number *Nephrops* caught	Estimated number *Nephrops* discarded	Discarded *Nephrops* by total weight of *Nephrops* caught (%)	Discarded *Nephrops* by total number *Nephrops* caught (%)	Discard fraction alive during sorting (%)
25	64.0	70.0	210.0	13.5	287.5	40.9	328.4	13,666	1,233	4.7	9.0	97
26	48.0	51.0	153.0	8.0	209.0	66.7	275.7	9,653	727	3.9	7.5	97
27	88.0	89.0	267.0	29.6	384.6	12.4	397.0	19,410	2,680	7.7	13.8	91
28	53.0	51.0	153.0	13.7	219.7	9.1	228.8	9,837	1,133	6.3	11.5	97
29	64.0	63.5	190.5	23.2	277.7	7.8	285.5	12,526	2,060	8.4	16.4	94
30	24.0	24.0	72.0	9.4	105.4	4.3	109.7	5,034	857	9.0	17.0	95

Table 4.4: Percentage occurrence of different external injuries during catch sorting in Winaway discard fraction Nephrops during summer tows – males and females combined, Obs = 848.

Damage	0	D1	TAP	THP	DR	D1, TAP	D2	D1, THP	TAC	CLAW
Count	547	128	50	34	21	12	12	8	6	5
Percent	64.4	15.1	5.9	4.0	2.5	1.4	1.4	0.9	0.7	0.6

Damage	D1, DR	EYE	THC	D1, LEG	D1, TAC	D1, THC	D2, TAP	CLAW, TAP	D1, DR, THP	D1, TAP, LEG
Count	5	4	3	2	2	2	2	1	1	1
Percent	0.6	0.5	0.4	0.3	0.3	0.3	0.3	0.1	0.1	0.1

Damage	D1, THP, TAP	DR, THP	TAP, DR
Count	1	1	1
Percent	0.1	0.1	0.1

Table 4.5: Percentage occurrence of different external injuries for Winaway summer tow discard-fraction Nephrops at end of recovery period - males and females combined, Obs = 850.

Damage	0	D1	TAPH	TAP	THPH	THP	D1, TAPH	D1, TAP	DR	MOULTED	TAC	THPH, TAPH
Count	330	99	91	36	36	33	29	15	15	14	11	10
Percent	38.8	11.7	10.7	4.2	4.2	3.9	3.4	1.8	1.8	1.7	1.3	1.2
Damage	D2	D1, THP	CLAW	TACH	TAPH, TACH	D1, THPH	EYE	LEG	THC	D1, LEG	TAPH, CLAW	TAPH, LEG
Count	9	8	7	7	6	5	5	5	5	4	4	4
Percent	1.1	0.9	0.8	0.8	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5
Damage	D1, DR	D1, TAC	THP, TAPH	CLAW, TAPH	D1, DR, TAPH	D1, DR, THPH	D1, THC	D1, THCH	D1, THPH, TAPH	D2, THPH	THCH	THPH, TACH
Count	3	3	3	2	2	2	2	2	2	2	2	2
Percent	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Damage	D1, CLAW	D1, DR, CLAW	D1, DR, TAC	D1, DR, THP	D1, EYE	D1, TACH	D1, THP, TAP	D1, THPH, TAC	D2, LEG	D2, TAP	D2, THP, TAP	DR, TAC
Count	1	1	1	1	1	1	1	1	1	1	1	1
Percent	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Damage	DR, TAP, EYE	DR, TAPH	TACH, TAPH	TAP, LEG	TAP, TACH	TAP, THPH	TAPH, DR, EYE	TAPH, EYE	TAPH, TAC	TAPH, THCH	TAPH, THP	THC, THPH, TAPH, LEG
Count	1	1	1	1	1	1	1	1	1	1	1	1
Percent	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Damage	THPH, CLAW	THPH, DR	THPH, TAPH, TAC	THPH, TAPH, TACH	THPH, THP, DR							
Count	1	1	1	1	1							
Percent	0.1	0.1	0.1	0.1	0.1							

Table 4.6: Percentage occurrence of external injuries for Winaway discard-fraction Nephrops by tow.

Trial	Season	Gear code	Damaged scored on-board (%)	Damaged scored at time of death or recovery (%)	Damaged scored at time of death or recovery excluding healed injuries (%)
25	Summer	TR2	36.7	56.0	40.9
26	Summer	TR2	36.7	61.3	46.3
27	Summer	TR2	33.6	70.0	45.6
28	Summer	TR2	34.7	58.7	41.6
29	Summer	TR2	39.3	64.7	44.7
30	Summer	TR2	31.0	54.0	35.0
Mean ± 95% CI	Summer	TR2	35.3±3.0	60.8±6.2	42.4±4.4

Table 4.7: Percentage occurrence of overall external damage in Winaway discard fraction Nephrops summer tows by sex when scored on-board or at end of recovery period.

Damage	On-board scoring			In aquarium scoring		
	Male	Female	Total	Male	Female	Total
Undamaged	222 66.9%	325 63.0%	547 64.4%	137 41.1%	193 37.4%	330 38.9%
Damaged	110 33.1%	191 37.0%	302 35.6%	196 58.9	323 62.6%	520 61.2%
Total	332	516	848	333	516	850

Table 4.8: Percentage occurrence of Winaway discard fraction Nephrops vigour scores immediately after trawling.

Trial	Season	Gear code	Percentage in vigour category			
			1	2	3	4
25	Summer	TR2	14.7	28.7	48.0	8.7
26		TR2	9.3	33.3	49.3	8.0
27		TR2	7.3	11.3	56.7	24.7
28		TR2	4.0	11.3	61.3	23.3
29		TR2	0.7	7.3	74.7	17.3
30		TR2	2.0	8.0	69.0	21.0
Mean ± 95% CI	Summer	TR2	6.3±5.5	16.7±11.9	60.0±11.2	17.2±7.6

Table 4.9: Percentage occurrence of vigour over all trials for Winaway discard fraction Nephrops comparing scores immediately after trawling and post-recovery.

Vigour score after trawl	1	2	3	4	Total
Males + Females					
Count	56	148	504	144	850
Percent	6.6	172	59.3	16.9	
Males					
Count	28	72	179	54	333
Percent	8.4	21.6	53.8	16.2	
Females					
Count	28	74	325	89	516
Percent	5.4	14.3	63.0	17.2	
Vigour score after recovery	**1**	**2**	**3**	**4**	**Total**
Males + Females					
Count	567	87	9	5	668
Percent	84.5	13.0	1.3	0.7	
Males					
Count	229	32	6	2	269
Percent	85.1	11.9	2.2	0.7	
Females					
Count	338	55	3	3	399
Percent	84.7	13.8	0.7	0.8	

Table 4.10: Percentage occurrence of reflex scores immediately after trawling and post-recovery for Winaway discard fraction Nephrops.

Reflex score after trawl	0	1	2	3	Total
Males + Females					
Count	429	278	142	0	849
Percent	50.5	32.7	16.7		
Males					
Count	185	94	53	0	332
Percent	55.7	28.3	16.0		
Females					
Count	244	184	88	0	516
Percent	47.3	35.7	17.1		
Reflex score after recovery	**0**	**1**	**2**	**3**	**Total**
Males + Females					
Count	578	80	10	0	668
Percent	86.5	12.0	1.5		
Males					
Count	231	32	6	0	269
Percent	85.9	11.9	2.2		
Females					
Count	347	48	4	0	117
Percent	87.0	12.0	1.0		

Table 4.11: Weibull-based final survival estimates at day 13 of recovery by trial number and by season for Winaway discard-fraction Nephrops.

Trial	Season	Gear code	Mean survival	Std error	95% LCI	95% UCI
25	Summer	TR2	0.787	0.033	0.724	0.855
26	Summer	TR2	0.747	0.036	0.680	0.820
27	Summer	TR2	0.760	0.035	0.695	0.832
28	Summer	TR2	0.733	0.036	0.666	0.808
29	Summer	TR2	0.833	0.030	0.776	0.895
30	Summer	TR2	0.900	0.030	0.843	0.961
	Total summer	TR2	0.784	0.014	0.756	0.812

Figure 4-1: The twin-rigger 'Winaway' KY279 which is based in Pittenween harbour (photo C Fox).

Figure 4-2: 'Winaway' east Scotland recovery trial trawl locations.

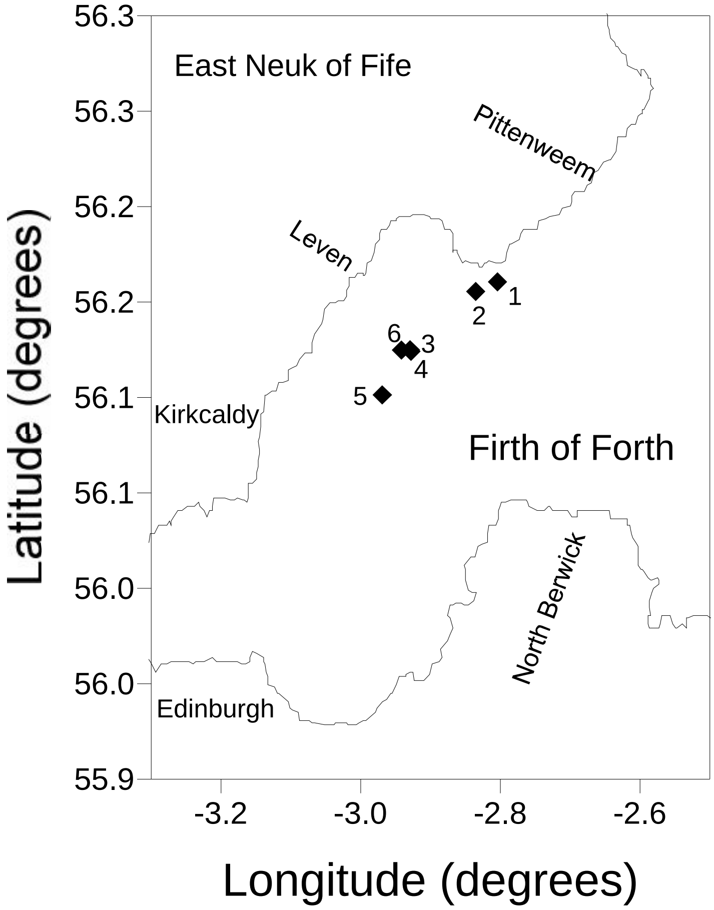


Figure 4-3: Catches in the hopper on Winaway.

Figure 4-4: Sorting table showing the access to the hopper (left panel) and sorting the catch on Winaway (right panel) – Jun 2017.

Figure 4-5: Water column temperature and salinity profiles at the start of each day of sampling for Winaway summer 2017 trials.

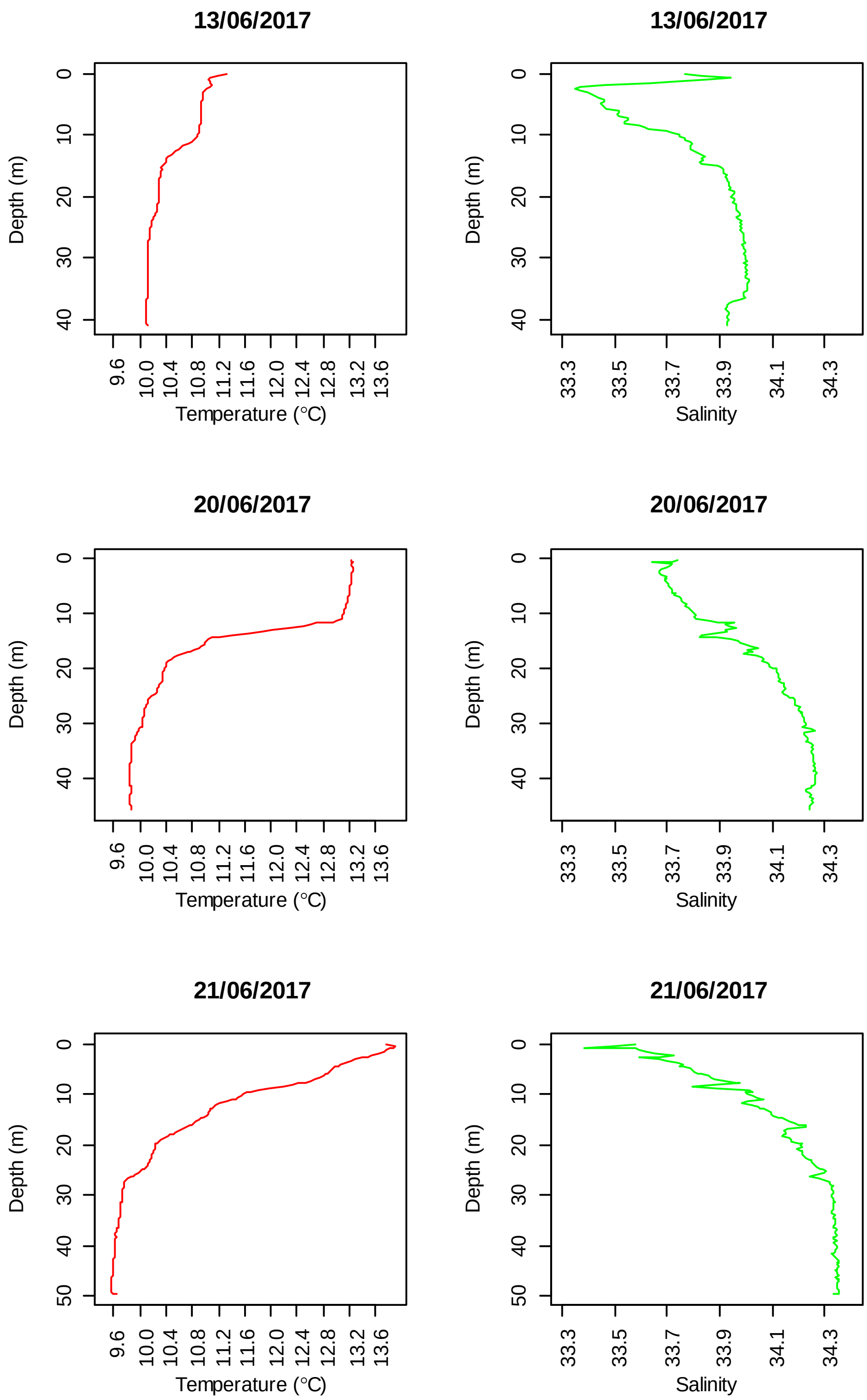


Figure 4-6: Relationship between total catch weight of Nephrops (excluding non-target organisms) and catch sorting time for Winaway recovery trials. Numbers indicate the trial as shown in Table 4.2.

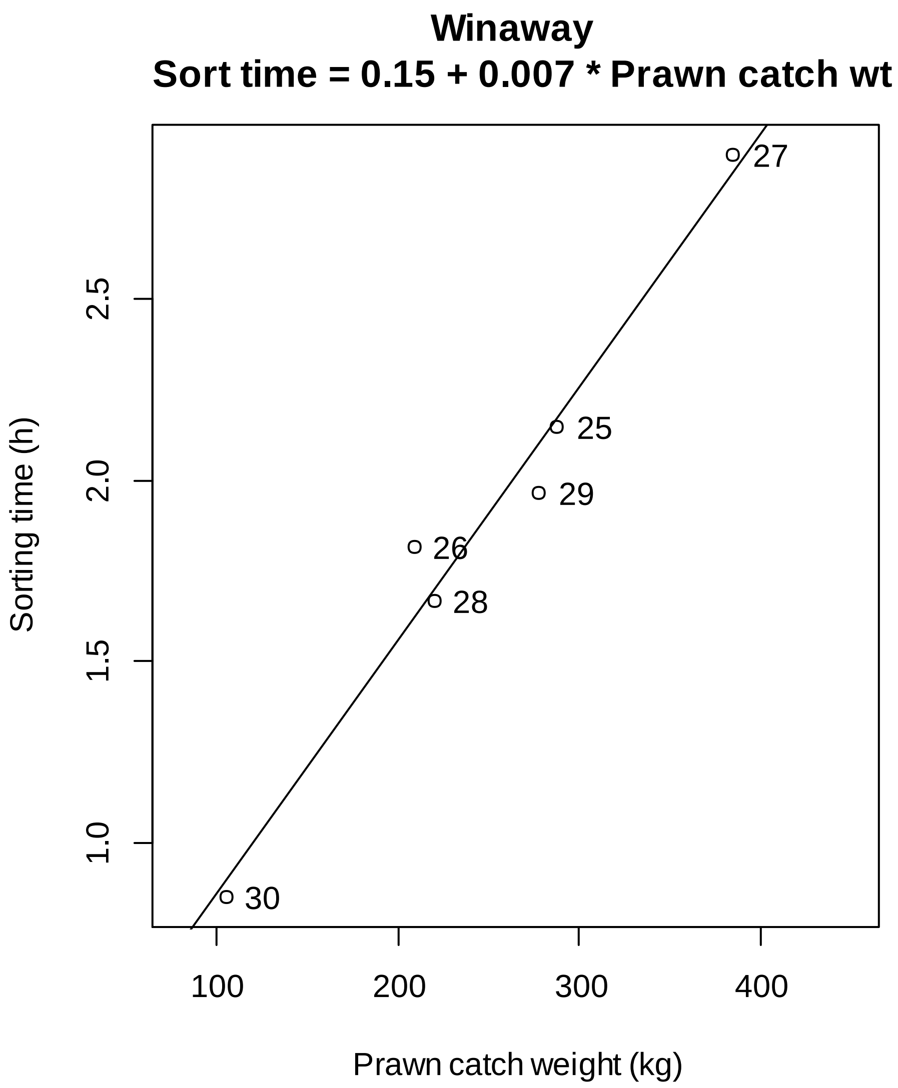


Figure 4-7: Length frequencies for sub-sampled Nephrops from total catch and the discard fraction, Winaway summer 2017 - trials 1 through 3 (gear TR 2).

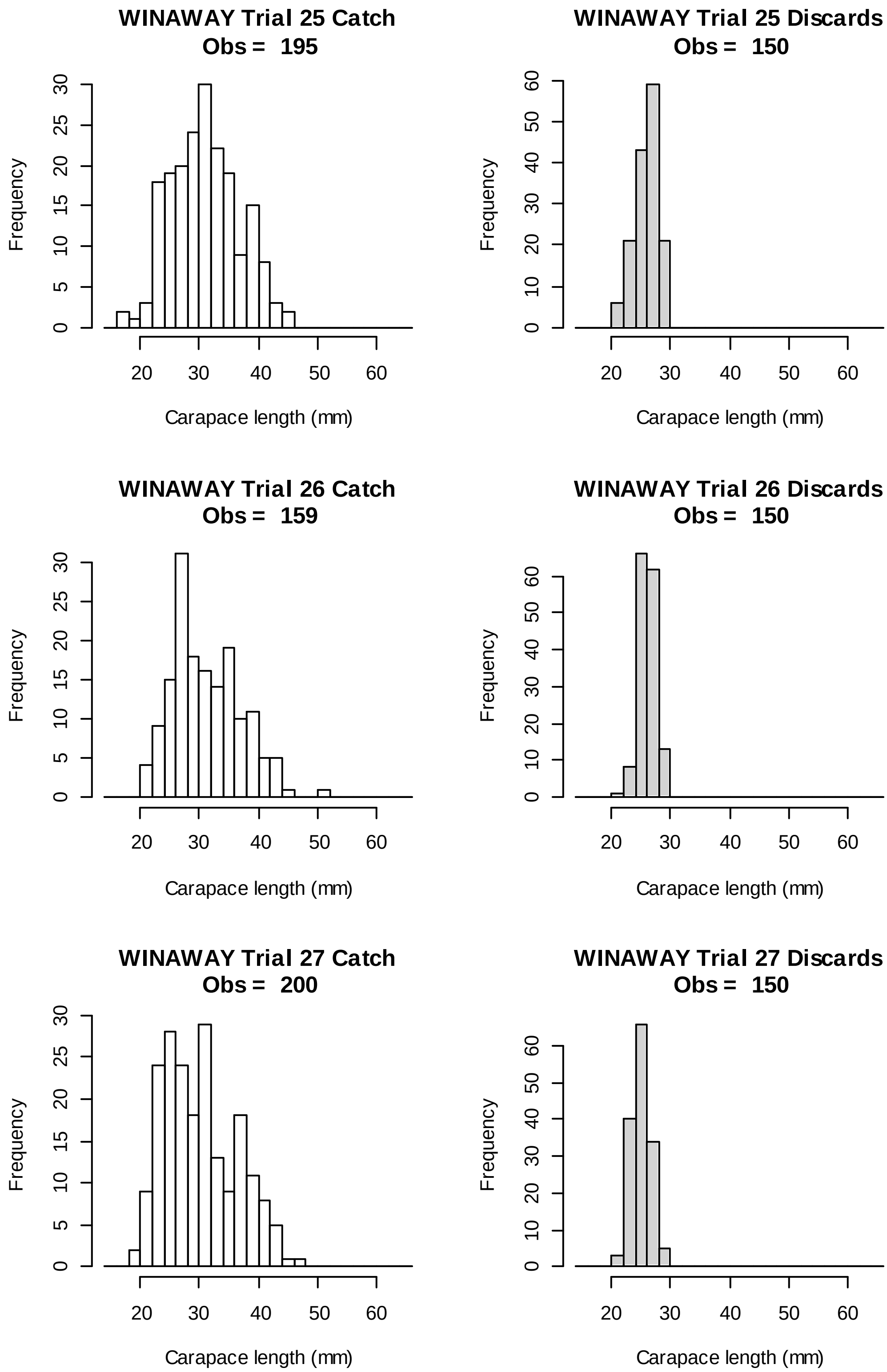


Figure 4-8: Length frequencies for sub-sampled Nephrops from total catch and the discard fraction, Winaway summer 2017 - trials 4 through 6 (gear TR 2).

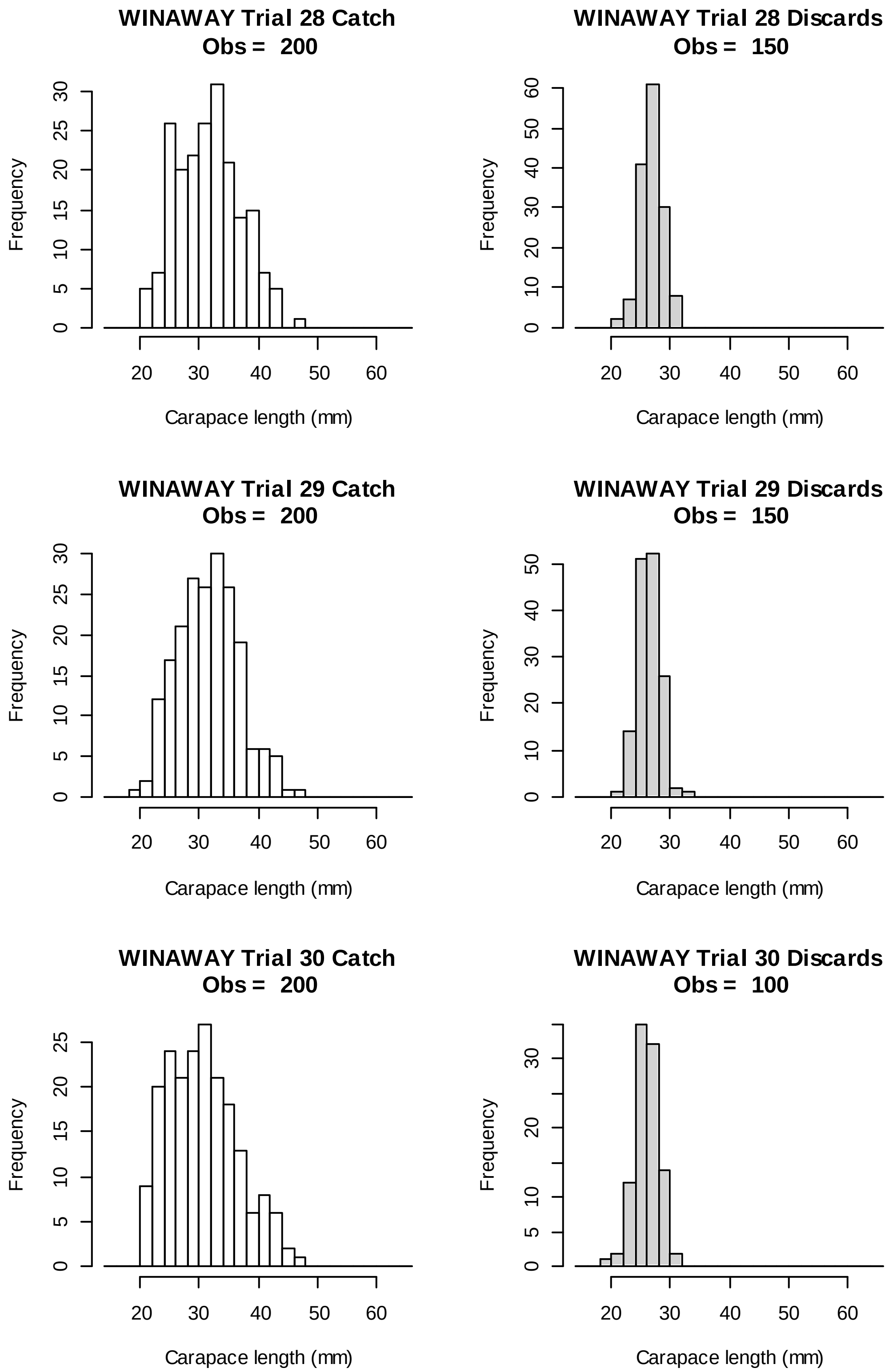


Figure 4-9: Length frequencies for sub-sampled Nephrops from total catch separated by sex, Winaway summer 2017 - trials 1 through 6 (gear TR 2).

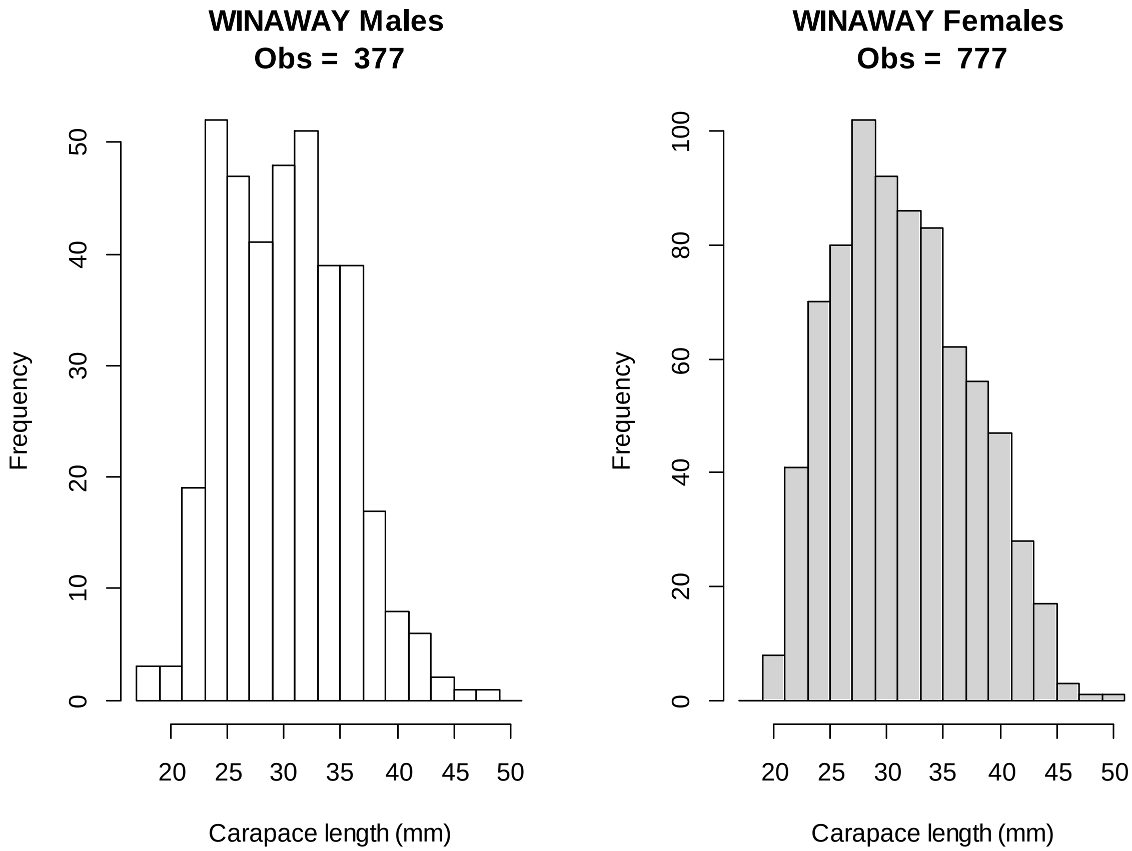


Figure 4-10: Length frequency for measured Nephrops in catch sub-samples across all Winaway trials – Solid line is log-normal fit to the length frequency data while the current Minimum Conservation Size limit for ICES Division IV is indicated by the dashed vertical line (25 mm CL).

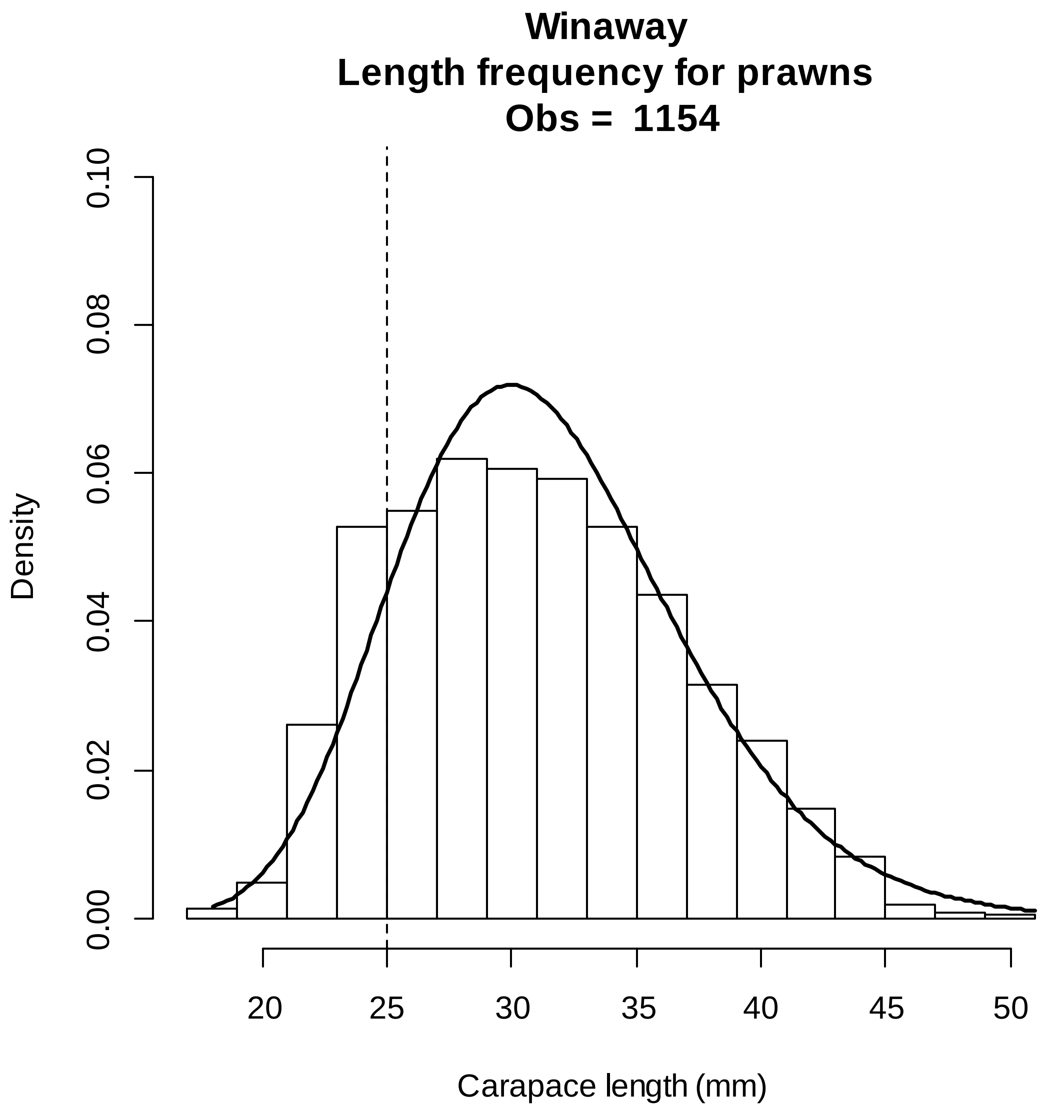


Figure 4-11: Length frequency for discard fraction Nephrops across all Winaway trials - Solid line is normal fit to the length frequency data while the current Minimum Conservation Size limit for ICES Division IV is indicated by the dashed vertical line (25 mm CL).

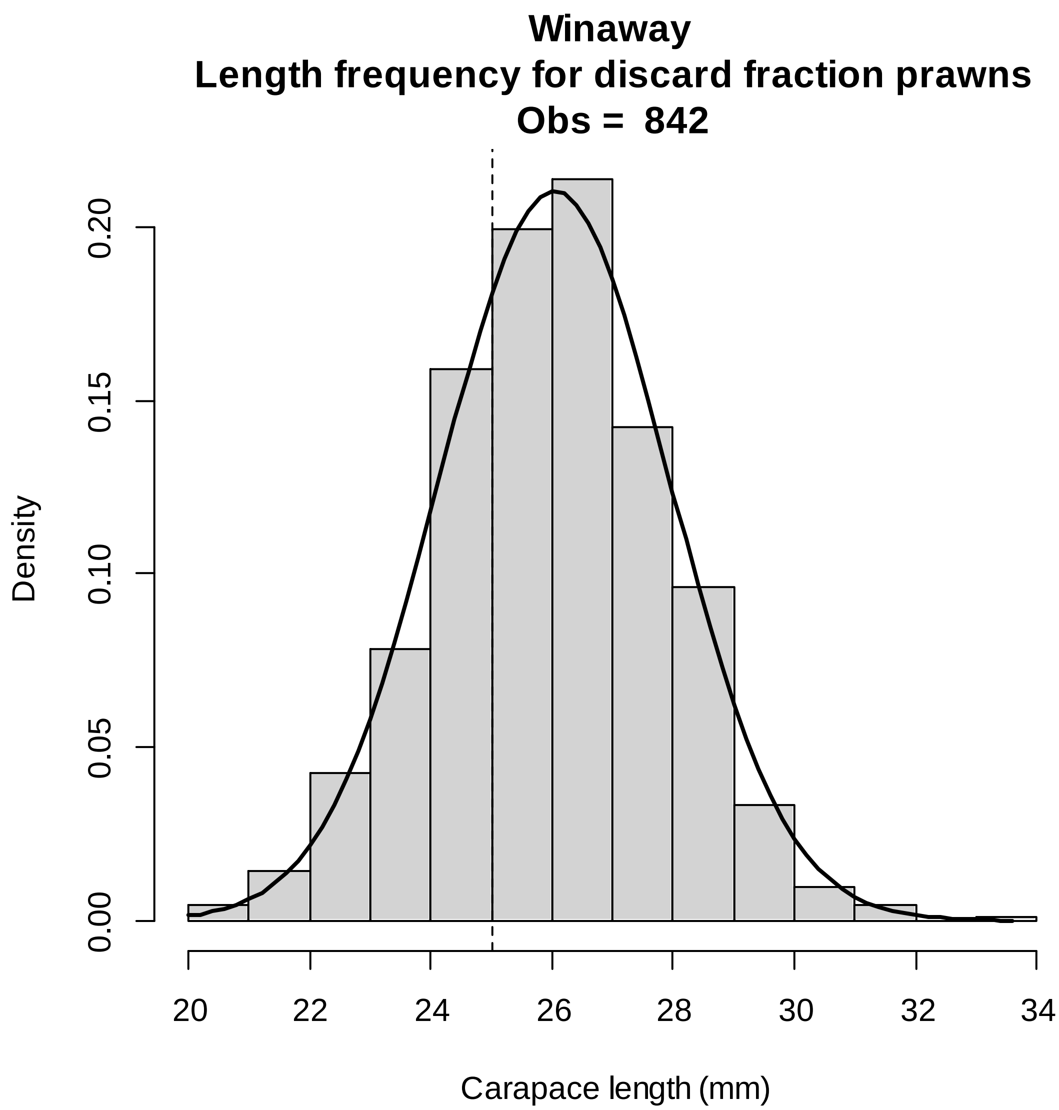


Figure 4-12: Relationship between the percentage of damaged discard fraction Nephrops from Winaway summer tows evaluated at the time of death or at the end of 13 days recovery, versus the catch weight per tow: left panel; total catch (Nephrops plus finfish) and right panel; Nephrops. Points labelled with trial number from Table 4.2.

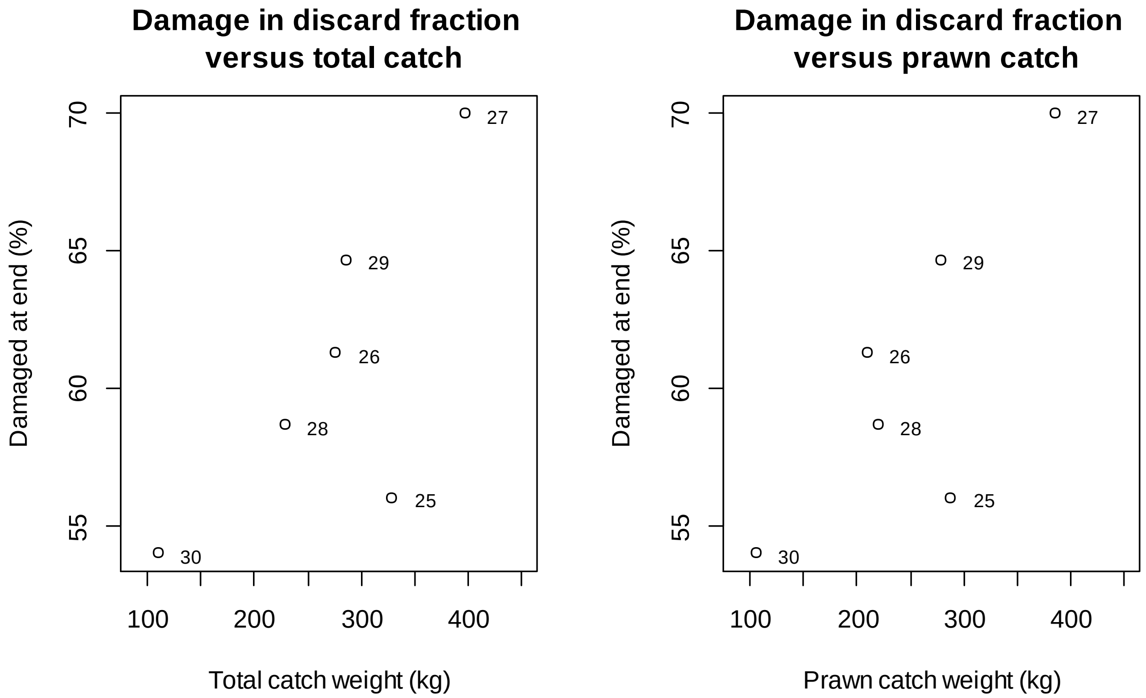


Figure 4-13: Relationship between the percentage of damaged discard fraction *Nephrops* from Winaway summer tows evaluated at the time of death or at the end of 13 days recovery when healed wounds were excluded, versus the catch weight per tow: left panel; total catch (*Nephrops* plus finfish) and right panel; *Nephrops*. Points labelled with trial number from Table 4.2.

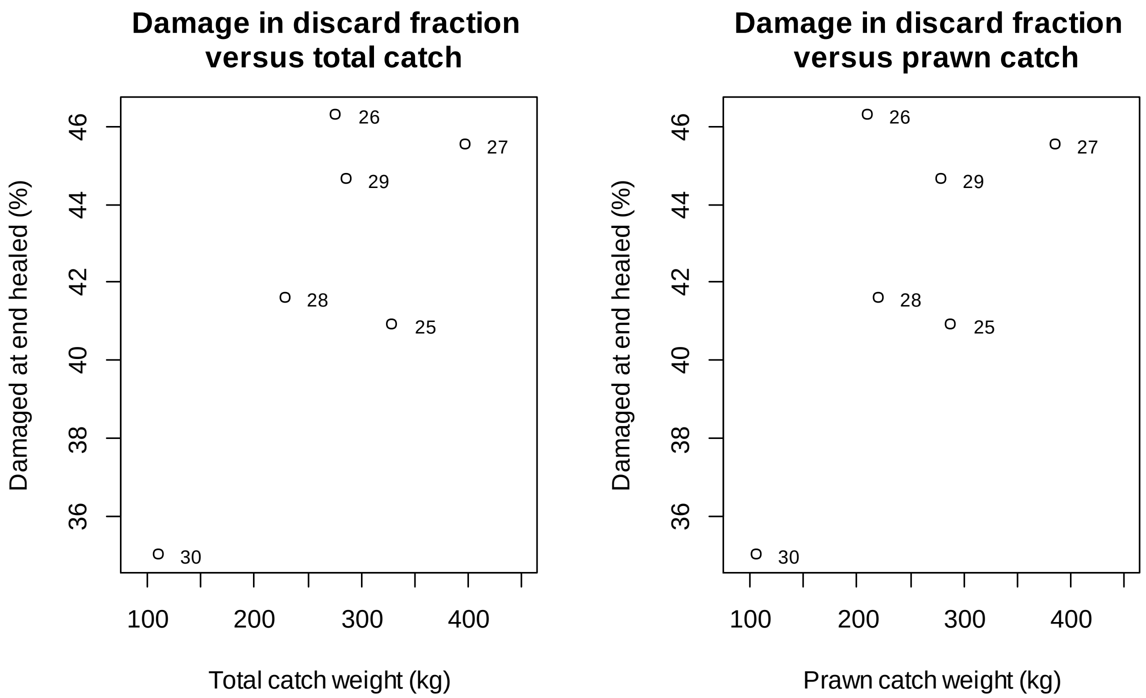


Figure 4-14: Kaplan-Meier plots for recovery of Winaway discard fraction Nephrops against observation time partitioned by whether the discard Nephrops were sampled towards start or end of the catch sorting time. Dashed lines indicate the 95% confidence intervals for the group survival.

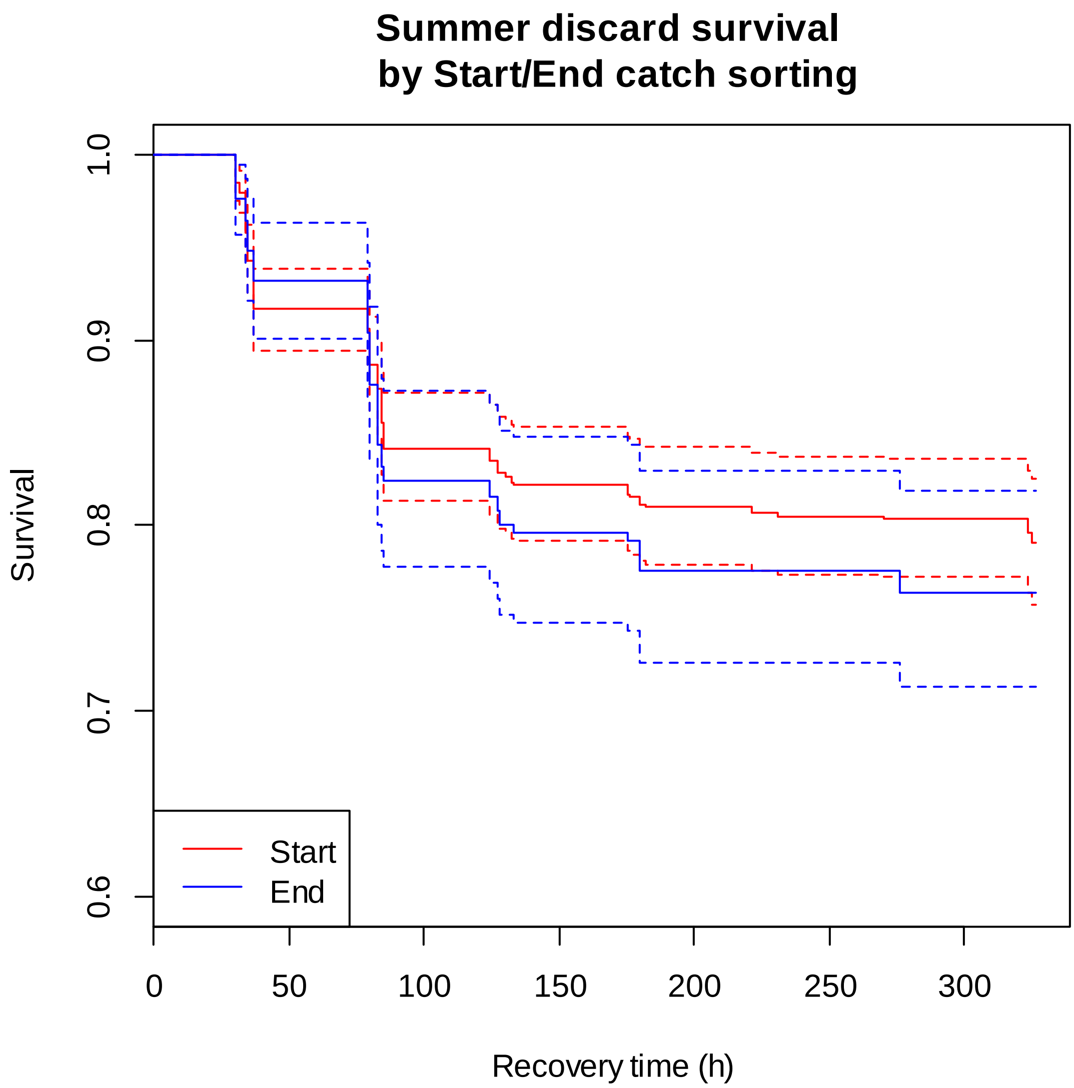


Figure 4-15: Kaplan-Meier plots for Nephrops survival from Winaway tows during the 13 day recovery period – Summer TR2 trials. Dashed lines indicate the 95% confidence intervals for the group survival; vertical ticks indicate the time of the observations.

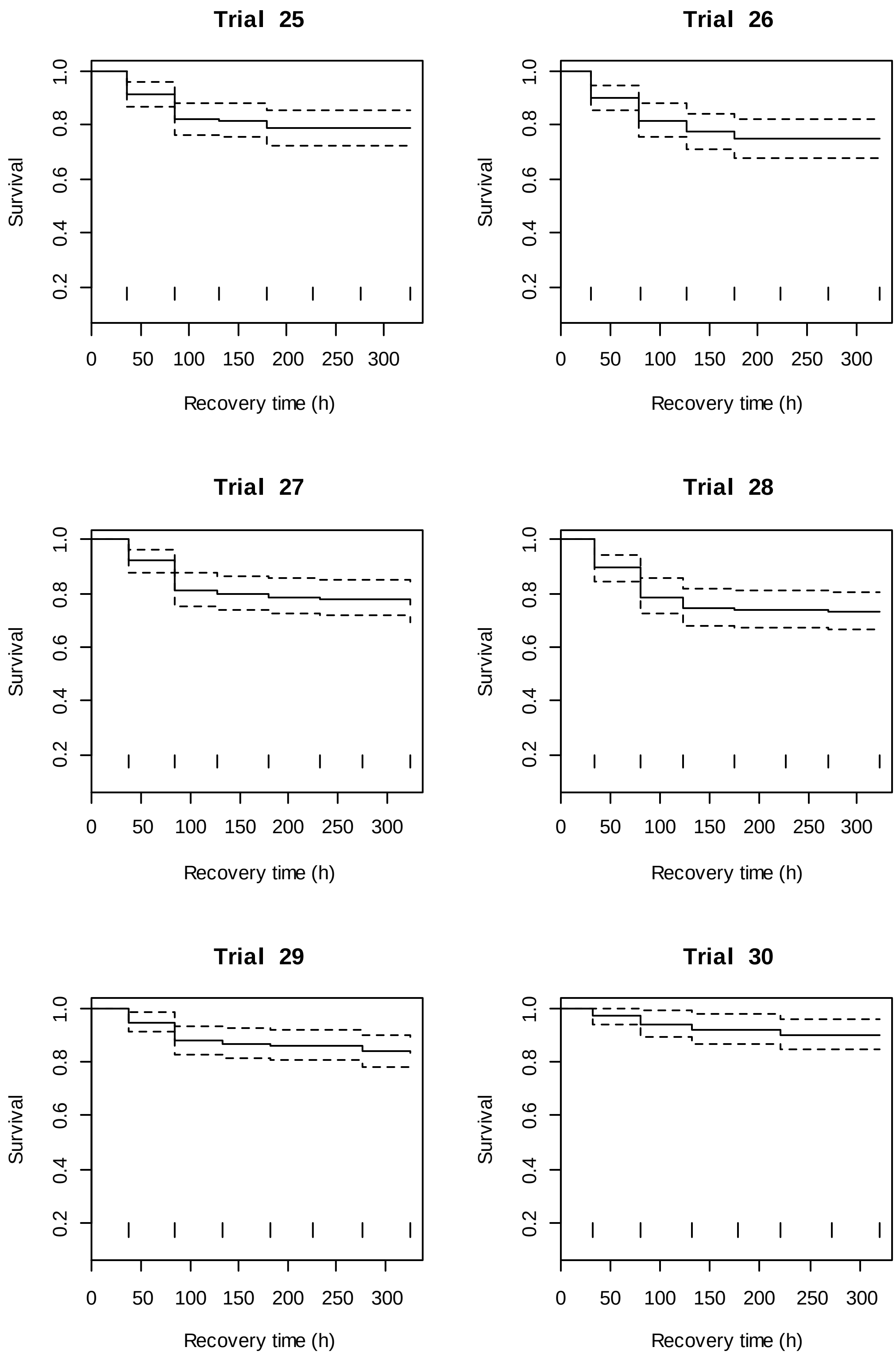


Figure 4-16: Winaway discard fraction survival estimates plus 95% confidence intervals (dashed lines) versus visible damage to the *Nephrops*. Dashed lines indicate the 95% confidence intervals for the group survival.

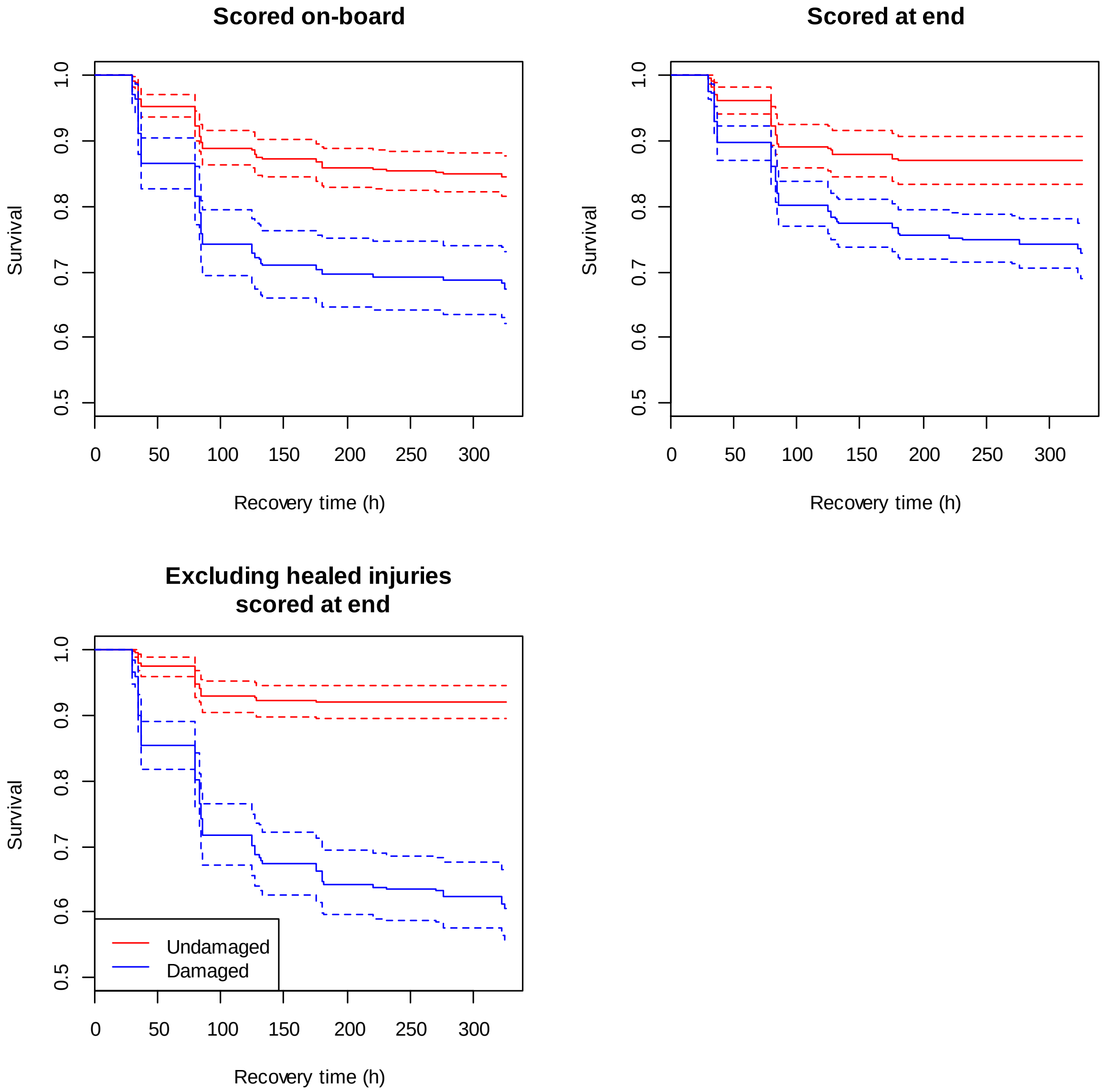
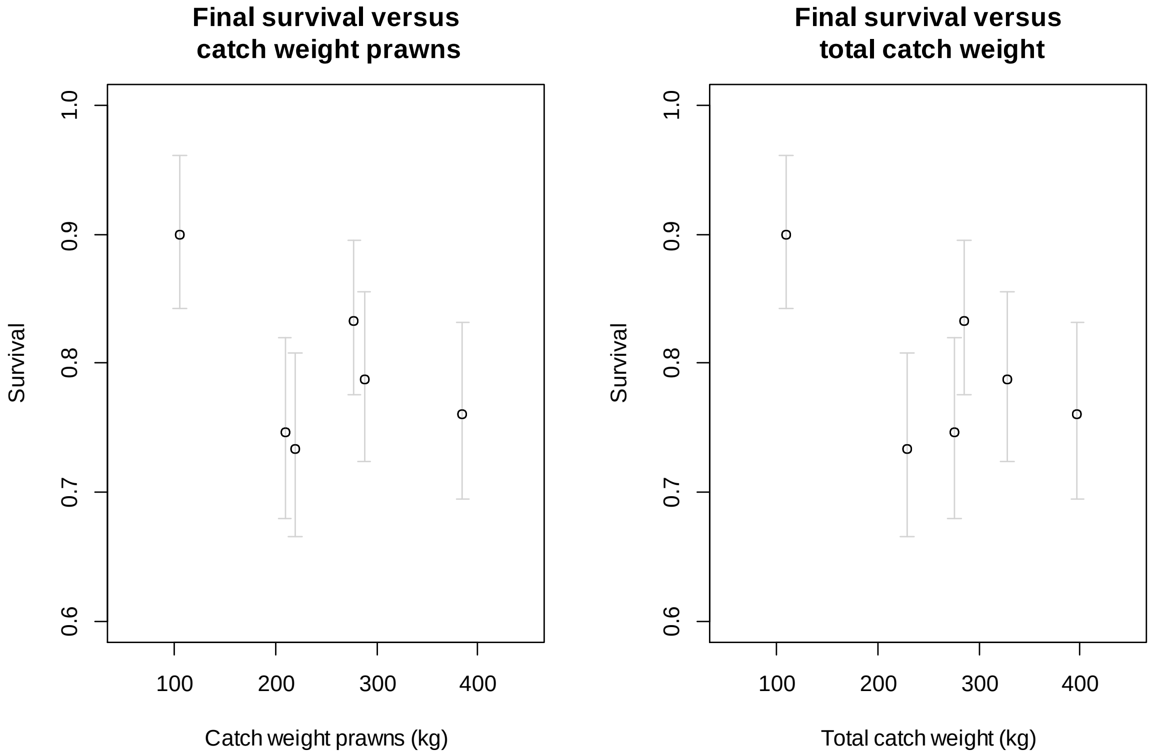


Figure 4-17: Final mean survival estimates for each trial ± 95% confidence intervals (light grey vertical bars) versus the catch weight of Nephrops (left panel) and total catch weight (right panel) in the tow.



5. Collection of further data on fishing patterns and discards from the Scottish trawl fleet and comparison with discard survival trial tows

Objective 2 (Objective 1 in the original proposal). Working with the SIDI program data manager and SFF to analyse existing data and collect further data on (i) fishing patterns in the west coast Nephrops fleet – areas fished and locations discarded, tow durations, total catch bulk, size composition, discarding routines and quantities of Nephrops discarded, and importantly, evaluate levels of physical damage of Nephrops after trawling.

5.1. Introduction

All discarded *Nephrops* survival trials in this project were undertaken using single commercial vessels, Ocean Trust operating in the Southern Minch (Division VIa) and Winaway fishing in the Firth of Forth (ICES Division IVb). The use of a single vessel to estimate survival for a particular fishing area is open to criticism because it might not be representative of other vessels operating in the same area. However, while STEFC have acknowledged that ideally discard recovery studies would be conducted using a range of vessels, in reality the cost and time associated with performing such studies would be prohibitive. STECF therefore recommended that results from discard recovery studies using single vessels should be acceptable, although additional evidence should be collected to evaluate whether the vessel used, and its mode of operation, is representative of the wider fleet.

Under this objective, data collected by Scottish Fisheries Federation (SFF) observers on commercial vessels operating in the areas where the *Nephrops* discard recovery trials were undertaken is compared to vessel characteristics and operating data from the survival trials (data from objective 1). The aim of these comparisons was to determine if discard survival estimates derived from the single vessels, Ocean Trust operating in the west coast and Winaway operating in the east coast, might be considered to be representative of other *Nephrops* trawlers working in those areas.

5.2. Materials and methods

During commercial fishing operations SFF observers recorded information on the tows: date, shoot and haul times, shoot and haul locations (latitude, longitude), water depth, haul duration and speed, weather (including air temperature) and surface seawater temperature; and details of the catch: weight of whole *Nephrops* and *Nephrops* tails retained, weight of discarded *Nephrops* and non-*Nephrops* catch. Furthermore, observers were requested to record the carapace length (CL), sex, reproductive status (berried/unberried) and damage from 100 individual *Nephrops* taken from the discard portion of the catch following the protocols used in the discard survival trials.

The damage index used by SFF observers was the same as in the discard survival trials (Table 3.2). Furthermore, the number of dead *Nephrops* in the discard fraction on-board were noted at the same time as damage was being recorded.

5.3. Results

5.3.1. West coast tows

Three SFF observer trips were undertaken during summer/autumn 2016 resulting in data on 10 tows for comparison with the 12 tows sampled for discards survival trials on 'Ocean Trust'. SFF observers sampled on the 'Dunam Star II', 'Margareta II' and 'Eilidh BRD149' (Table 5.1).

Six SFF observer trips were undertaken during the winter 2016 through early spring 2017 giving 14 tows for comparison with the 12 tows sampled for discards recovery on 'Ocean Trust'. Again, there was a temporal overlap between discard recovery trips and SFF observer trips most of the SFF data was recorded in December-February while the discard recovery trips took place between February and March (Table 5.1). SFF observer trips at that time period were on the 'Elidih BRD149' and 'Dunam Star II' (previously used) and the 'Golden Isles' and 'Caralisa' (used for the first time). The locations of the trawls are shown in Figure 5-1. In the summer, all SFF observer cruises were undertaken in the North Minch while University/SAMS survival trials took place in South Minch. Similarly, in the winter/spring most of the SFF observer trips took place in the North Minch (all except two) while the discard survival trial tows were conducted in the South Minch. This is because the test animals used in the survival trials needed to be returned to port relatively quickly in order to transport them to the SAMS aquarium in Oban for the recovery experiments, which logistically limited the sampling area to South Minch.

Information on tows is shown in Table 5.2 and Table 5.3. Tow durations on Ocean Trust in the summer/autumn ranged from 2.8 to 4.1 h (mean 3.5 h) and were significantly shorter (Kruskall-Wallis, $p=0.04$) compared with SFF trips which ranged from 3 to 6 h (mean 4.4 h). In winter trials, Ocean Trust tow durations were similar to during the summer/autumn with tow times ranging from 3.1 to 4.2 h (mean 3.8 h) while tow durations on SFF trips ranged from 3.5 to 5 h (mean 4.2 h). No differences in tow duration time were seen between Ocean Trust and SFF observer trips in the winter/spring (Figure 5-2). Shoot and haul depths ranged from 50 to 150 m with no significant differences between Ocean Trust and SFF trips (ANOVA, $F=1.5$, $p=0.17$) (Figure 5-2). Average towing speeds in Ocean Trust were significantly faster by 0.2-0.4 kts compared with the SFF observer trips (Kruskall-Wallis, $p<0.001$).

In terms of other vessel characteristics that could affect the catch once on-board, Ocean Trust had a covered deck protecting the catch while being sorted from direct sun, rain and wind although the hopper was of a large open flat-bottomed design. Having a covered deck seems to be common for twin-rig vessels operating in the Minches (Table 5.4). On the other hand, the single-rig vessels, Margareta II and Dunam Star II, had open decks or shelters (Golden Isles). In single-rig vessels the catch might therefore be more exposed to the elements during sorting although the hopper design seems to be similar.

Recorded air temperatures during catch sorting (Table 5.4; Figure 5-3) were similar comparing both the summer/autumn (two-tailed t-test, $p = 0.221$) and winter/spring discard survival trials with SFF observer trips (two-tailed t-test, $p = 0.151$). The weather conditions were variable with clear sky sunny days to cloudy/overcast in both sets of trials.

Other parameters such as surface water temperatures were lower in SFF trials (12.5 ± 0.9 °C) compared to trips on the Ocean Trust (14.0 ± 0.5 °C). Differences of this parameter should be taken with caution as the equipment used to measure surface water temperature was different between survival trials in the Ocean Trust and SFF (Table 5.4).

5.3.2. West coast catches

A significant difference in total catch weights was found when comparing twin-rig TR2 (80 mm cod-end mesh) and single-rig TR2 tows (Figure 5-4). Total catch weights were significantly higher in twin-rig tows (data from Ocean Trust and SFF compiled) compared to single-rig tows (SFF observer data), both in summer (Mann-Whitney Rank Sum Test, $p<0.001$) and winter (Two-tailed t-test, $p=0.001$). This result is not surprising because the twin-rig will have a wider mouth opening compared to single-rig gear. The amounts caught in each cod-end of the twin-rig tows were not recorded but is likely to be more comparable to the amount of catch in the single cod-end of the single rig gear.

No SFF observer trips used TR1 (100 mm) nets so it is not possible to compare Ocean Trust and SFF catches for this gear-type but no significant difference was found between TR1 and TR2 catches on Ocean Trust (ANOVA, gear $F=2.691$, $p=0.12$; season $F=3.3$, $p=0.08$; gear*season $F=1.872$, $p=0.186$). For summer/autumn tows total catch weights with TR2 (80 mm) nets were not significantly different (Kruskall-Wallis, $p=0.313$) comparing Ocean Trust tows with SFF observer trips using the same mesh size (Table 5.6 and Table 5.7; Figure 5-5).

Taking into account all trips (Ocean Trust and SFF compiled) there was a linear relationship ($R^2=0.60$) between total catch sorting time and total catch weights although some of the Ocean Trust tows in the summer took longer to sort than suggested by their weight (Figure 5-6). Sorting time was different among groups (Kruskall-Wallis; $p=0.004$) with sorting times on Ocean Trust significantly longer in the summer (mean 2.5 h) compared to SFF winter trips (mean 1.4 h) (pairwise Dunn's Method, $p=0.006$). However, all other pairwise comparisons were not significantly different indicating that the sorting times during survival trials in the Ocean Trust are similar to other vessels operating in the Minches (Table 5.4; Figure 5-7).

5.3.3. West coast *Nephrops* discards

Overall, the percentages of retained *Nephrops* were very variable ranging from as little as 16 up to 95% (Figure 5-8; Figure 5-9). However, significant differences in retained *Nephrops* were obtained (Kruskall-Wallis, p= 0.002). SFF twin-rig vessels (TR2) in the summer retained less *Nephrops* than Ocean Trust (TR1) in the summer (pairwise comparison, Dunn's Method p=0.024) and SFF single-rig vessels in the winter (pairwise comparison, Dunn's Method, p=0.025). This lower retention of *Nephrops* in this particular group (SFF-twin rig TR2 cod-end summer) is related to a couple of tows that were particularly poor in *Nephrops* (Table 5.4). No difference was found in the percentage of *Nephrops* discarded comparing data from Ocean Trust and SFF observed tows (Kruskall-Wallis, p=0.525). Discarded *Nephrops* ranged from 0.8 to 7.6% of the total catch weights of *Nephrops*. A weak negative correlation (-0.294; p= 0.04) was found between the percentage of *Nephrops* discards and the amount of *Nephrops* catch weight *per se* (Figure 5-10).

Mean carapace lengths of discard fraction *Nephrops* in the Ocean Trust tows was 24.3 +/- 1.98 mm CL (mean +/- 95% conf. int.) with a relatively small effect of season (see Section 3) but the mean carapace length of discard fraction *Nephrops* in SFF observer trips was larger at 28.7 mm. The size distributions of the discard fraction *Nephrops* are shown in Figure 5-11. This difference in CL size of discarded *Nephrops* was mainly driven by larger *Nephrops* being discarded in the summer, on both twin and single-rig SFF observer trips (Figure 5-12). The difference may reflect different sizes of *Nephrops* being caught on different fishing grounds (unfortunately full catch size profiles are only available from the Ocean Trust not SFF observer trips) but could also due to different sorting behaviours between vessels. According to data presented in Balestri (2015) the modal CL of discarded *Nephrops* was around 24 mm in Lochinver/Ullapool (North Minch) and 23 mm in Mallaig (South Minch). Therefore, while data from Ocean Trust is fairly consistent with Balestri (2015), the sizes of *Nephrops* discarded in SFF observer trips were, on average, larger than previously reported for this fishing area. In the winter trials, the size of discarded *Nephrops* from SFF vessels (CL 26 mm) was closer to that previously reported data (Balestri, 2015) and to that observed on Ocean Trust.

The vast majority of discard fraction *Nephrops* were above the legal minimum conservation size limit for Division VIa. This was the case in both the Ocean Trust and also SFF observer vessels indicating that most *Nephrops* discarding is occurring for commercial (high grading-market driven), and not legal, reasons.

5.3.4. West coast damage and mortality in discard fraction *Nephrops*

Overall the summer and winter combined mean percentages of discard fraction *Nephrops* scored (on-board) as having at least one sign of damage was 39.8 ± 3.7% for Ocean Trust and 40.1 ± 5.3% for SFF observer trips (mean ± 95% conf. int., n=24 OT; n=25 SFF; Table 5.8) (two-tailed p-value=0.929). Average levels of damage recorded in the discard fraction *Nephrops* on Ocean Trust TR2 tows were not significantly different to those recorded by SFF observer trips (twin-rig TR2) using the same gear combination (ANOVA; F=0.785, df 3; p=0.515). However, when all groups were compared significant differences in damage were found (ANOVA, F=7.857, df 7; p<0.001). Pairwise comparisons indicated that damage in SFF single-rig recorded in winter tows was significantly lower than damage recorded in Ocean Trust TR2 (summer; Holm-Sidak p<0.001) (winter; Holm-Sidak p<0.001), SFF twin-rig (summer; Holm-Sidak p<0.001) (winter; Holm-Sidak p=0.003) SFF single-rig in summer tows (Holm-Sidak p<0.001). Moreover, damage in SFF single-rig tows in the summer was significantly higher than Ocean Trust TR1 tows in the summer (Holm-Sidak p=0.019) and winter tows (Holm-Sidak p=0.021) (Figure 5-13; Table 5.8).

The most frequent types of damage recorded on Ocean Trust tows were D1 (loss of one chelae), THP (thorax puncture), TAC (tail/abdomen crush), D2 (loss of two chelae), TAP (tail/abdomen puncture) and DR (damaged rostrum). In SFF trips the most frequent type of damage recorded was D1, D2, THP, TAP and TAC (Table 5.11). Therefore, although some differences were found between the rank orders of categories, the top five most frequent damage categories were the same in both Ocean Trust discard survival trials and SFF observer trips.

Also as shown in Table 5.11 damage categorisation was not influenced by *Nephrops* size (ANOVA of CL varying with vessel and damage category had a significant effect (p<0.001) for vessel but no significant effect (p>0.05) of damage category).

The proportion of damaged *Nephrops* in the discard fraction was not significantly correlated with the total catch weight (p=0.464) or the weight of *Nephrops* caught (p=0.683). However, a significant positive correlation (correlation coefficient=0.354) was found with the weight of the non-*Nephrops* catch fraction (p=0.01) (Figure 5-14).

The number of discarded *Nephrops* alive or dead was also noted at the same time damage was scored on-board the vessels. The percentage of discarded *Nephrops* alive at the point of assessment (on-board) was similar between survival trial tows on the Ocean Trust and SFF observer tows (Figure 5-15). The effect of gear on survival of discarded *Nephrops* was not significant but season was (p=0.035) (Figure 5-16). The lowest mean percentage alive was recorded in Ocean Trust (twin-rig) TR1 summer tows (86.2 ± 3.7 %; mean +/- 95% conf. int.). This was mainly due to a low survival in the second tow (first sampling trip) of 69%. The rest of the tows in this vessel when operating with TR1 nets where all above 83%. The highest survival of discarded *Nephrops* recorded during catch sorting were in SFF single-rig TR2 winter tows (93.4 ± 3.1 %; mean +/- 95% conf. int.).

5.3.5. East coast tows

SFF observers participated in two trips in the Firth of Forth in the summer of 2017 resulting in six tows for comparison with the six survival trial tows undertaken on Winaway (Table 5.12). Survival trials carried out by University of Stirling/SAMS were conducted at the end of June while SFF observer trips were in August. The commercial vessel used by SFF observers was Launch Out KY which is larger than Winaway (16.8 versus 11.4 m) and according to personal observations was one of the bigger vessels operating from Pittenweem (Figure 5-17). According to data from Fishermen's Mutual Association (FMA) around 20 *Nephrops* trawlers are currently operating from Pittenweem, the majority being of similar size to the vessel used in the survival trials (Figure 5-18). The location of the trawls from both the discard survival tows and SFF observer trips are shown in Figure 5-19. Although both vessels were fishing in the Firth of Forth, Winaway was operating closer to the coast compared to Launch Out KY.

Both vessels were using twin-rig TR2 trawls but there were differences in the design of the hopper. In Winaway, the hopper has a sloping floor opening onto three exits and the animals are drawn through by hand (Figure 4-3) while in Launch Out KY it is of flat-bottomed design and *Nephrops* are raked onto the sorting tray, similar to the mode of operation on Ocean Trust (Figure 3-5). In terms of other vessel characteristics that could affect the catch once on-board, both Winaway and Launch Out KY had a covered deck protecting the catch while being sorted from direct sun, rain and wind.

Tow durations on Winaway ranged from 1.7 to 5.2 h with an average of 3.5 h while SFF observed tows were less variable ranging from 2.2 to 3.5 h with an average of 3.1 h (Table 5.13). There were no significant differences in mean tow time (2-tailed unpaired t-test $p=0.433$). There were differences in shoot and haul depths which were greater for Launch Out KY (Table 5.13) which was fishing further out into the Firth. Average speed while towing was also significantly different (2-tailed unpaired t-test p-value=0.019) with trawling speed being a little faster (0.3 kts) for Launch Out KY tows.

Both discard survival trial tows and SFF observer trip tows took place during the night as this is the normal summer fishing pattern for boats operating in the Firth of Forth. Air temperatures were therefore low relative to during the day (Table 5.14; Figure 5-20) but temperatures were not significantly different between data sources (2-tailed unpaired t-test p-value=0.054).

Other parameters such as surface water temperatures were also similar comparing Winaway and Launch Out KY tows (Table 5.14).

5.3.6. East coast catches

The range of total catch weights in east coast tows (Table 5.15) for Winaway tows (110-397 kg) were similar to Launch Out KY (148-450 kg). Catch sorting times in Winaway (survival trials) were not significantly different (2-tailed t-test p=0.11) compared to Launch Out KY (Figure 5-21). However, it is worth noting that sorting time in the survival trials was quite variable ranging from less than 1 hour to almost 3 hours.

In all the trials in the Firth of Forth the percentage of *Nephrops* retained was consistently above 70 % (mean 85% in Winaway and 94% in Launch Out KY (Figure 5-24). The average amount of non-*Nephrops* catch was around 8% of the total catch weight in Winaway and a little lower at 5% in Launch Out KY (Table 5.15). These values are considerably lower than recorded in west coast tows (see Section 3.3.1).

5.3.7. East coast *Nephrops* discards

The mean percentage discarded *Nephrops* relative to total *Nephrops* catch by weight was higher in Winaway 6.5 +/- 1.6 % compared to Launch Out KY 0.8 +/- 0.2 % (averages +/- 95% conf. ints.; Table 5.15; Figure 5-22). The values recorded for Winaway are also higher than the values recorded in the west coast summer tows on Ocean Trust which ranged between 0.9-3.6% (Table 5.7). The percentage of *Nephrops* discarded was not correlative to the weight of *Nephrops* catch (p=0.866) nor to the total weight of the catch (p=0.539).

Carapace lengths of discard fraction *Nephrops* in Winaway ranged from 20.0 to 33.7 mm (26.0 +/- 1.9 mm; mean +/- 95% conf. int.) while the size of discarded *Nephrops* in Launch Out KY ranged from 19.0 to 31 mm with a mean of 24.0 +/- 0.13 mm (Figure 5-24) with the difference being significant (Mann-Whitney Rank Sum test; p<0.001). The difference in size of discarded *Nephrops* between the two vessels could be due to fishing on different grounds or due to different sorting behaviours by the crew. Winaway is equipped with seawater tanks for holding live animals and has in the past supplied the tube-market in a similar manner to some vessels operating in the Clyde (Albalat et al., 2016; 2015). Although this practice was not currently taking place on Winaway it is possible that the crew are used to selecting larger animals and tend to reject more of the smaller *Nephrops* compared to Launch Out KY. For Winaway around 30% of the discarded *Nephrops* were smaller than the legal Mininum Conservation Size Limit in contrast to Launch Out KY where this value was more than 60% (Figure 5-24). These percentages contrast with west coast data where only between 0-3.4% of the discarded *Nephrops* were under the legal Minimum Conservation Size limit. However, the MCSL is different for east and west coasts and if one applies a comparable MCSL then the percentage of discards below the legal size limit would be similar. In both cases though the majority of *Nephrops* discarding is taking place for market, rather than legal, reasons.

5.3.8. East coast damage and mortality in discard fraction *Nephrops*

Overall the mean percentages of discard fraction *Nephrops* scored on-board as having at least one sign of physical damage was 35.4 ± 3.0 % in Winaway and 51.3 ± 10.8 % in Launch Out KY (means ± 95% conf. ints., n=6 both Winaway and Launch Out KY). Damage percentages by tow are shown in Table 5.16 and the difference in means between the two vessels is statistically significant (2-tailed unpaired t-test, p= 0.004).

There were also some differences in the most frequent types of physical damage recorded in Winaway compared to Launch Out KY (Table 5.17). In Winaway the top five injury types were D1 (loss of one chelae), TAP (tail/abdomen puncture), THP (thorax puncture), DR (rostrum damage) and others (sum of multiple injuries not represented in Table 5.17) while in Launch Out KY tows the most frequent injuries were D1, D2, TAC, THC and D1+THC. Therefore, while puncture wounds were more frequent in Winaway catches, abdominal and thoracic crushes were more common in Launch Out KY catches.

Damage categorisation was not influenced by the size of the individual *Nephrops* (ANOVA, p>0.05) and the proportion of damaged *Nephrops* in the discard fraction was not significantly correlated with either the weights of the *Nephrops* catch (p=0.16), non-*Nephrops* catch (p=0.644) nor the whole catch (p=0.205). The number of discarded *Nephrops* which were alive or dead during catch sorting was also noted. As shown in Figure 5-25 the percentage of discarded *Nephrops* alive during sorting was significantly (Mann-Whitney Rank Sum test p=0.002) higher 94.9 +/- 2.7 in Winaway compared to Launch Out KY 67.2 +/- 8.0 (means +/- 95% conf. ints.). The differences in damage frequency and percentage of discard *Nephrops* alive may reflect the different hopper designs and catch handling protocols of the two vessels.

5.4. Discussion

The data support the hypothesis that environmental conditions and operating practices on Ocean Trust are in the range seen for other *Nephrops* trawlers fishing in ICES Division VIa although some differences, such as the size of *Nephrops* discarded, were observed. Based on this is seems likely that survival estimates for discarded *Nephrops* derived from trials conducted on Ocean Trust will be representative of the broader fleet operating in the Minches.

For the Firth of Forth it must be remembered that the conclusions are drawn from a comparison of only two vessels. However, the data do not support the hypothesis that environmental conditions and operating practices on the vessel used for the discard survival trials, Winaway, cover the range of conditions and practices of other *Nephrops* trawlers fishing in the Firth of Forth. This is based on significant differences in the percentage of *Nephrops* being discarded (higher), the size of discarded *Nephrops* (larger), the percentage live during sorting (higher) and the percentage scored as being damaged (lower) comparing Winaway with SFF observer data, albeit that the latter data also coming from a single vessel, Launch Out KY. The crew in Winaway vessel seem to be discarding a higher percentage of *Nephrops* due to high-grading and this might be a reflection of their prior experience supplying the live tube- *Nephrops* market so that they are tending to retain larger, higher quality animals. Moreover, the disparity between injuries sustained to discard fraction *Nephrops* and the percentage of discarded *Nephrops* alive on-board indicates that practices on-board the two vessels, probably related to hopper design and catch handling, are not comparable.

Whilst survival results presented in Section 4 of this report for the East coast (Firth of Forth) may be applicable to smaller vessels with similar characteristics of size, hopper design and sorting practices to Winaway, these survival estimates should not be extrapolated to larger vessels operating in ICES Division IVb. Based on this it seems likely that some further survival trials using other vessels fishing in the area may be required to get robust *Nephrops* discard survival estimates applicable across the wider fleet working the Firth of Forth *Nephrops* functional unit.

Table 5.1: West coast discard survival trial and SFF observer trip tows.

Summer/Autumn season				Winter/Spring season			
Vessel	Tow	Date	Source	Vessel	Tow	Date	Source
Ocean Trust	OT-1	15/07/16	UniStirling/SAMS	Eilidh BRD149	EB-6	05/12/16	SFF
Ocean Trust	OT-2	15/07/16	UniStirling/SAMS	Eilidh BRD149	EB-7	05/12/16	SFF
Ocean Trust	OT-3	29/07/16	UniStirling/SAMS	Eilidh BRD149	EB-8	06/12/16	SFF
Ocean Trust	OT-4	29/07/16	UniStirling/SAMS	Eilidh BRD149	EB-9	06/12/16	SFF
Ocean Trust	OT-5	18/08/16	UniStirling/SAMS	Golden Isles	GI-1	13/12/16	SFF
Ocean Trust	OT-6	18/08/16	UniStirling/SAMS	Golden Isles	GI-2	14/12/16	SFF
Ocean Trust	OT-7	19/08/16	UniStirling/SAMS	Golden Isles	GI-3	15/12/16	SFF
Ocean Trust	OT-8	19/08/16	UniStirling/SAMS	Dunam Star II	DS-4	15/01/17	SFF
Margareta II	M-1	24/08/16	SFF	Dunam Star II	DS-5	16/01/17	SFF
Margareta II	M-2	24/08/16	SFF	Eilidh BRD149	EB-10	18/01/17	SFF
Ocean Trust	OT-9	16/09/16	UniStirling/SAMS	Eilidh BRD149	EB-11	19/01/17	SFF
Ocean Trust	OT-10	16/09/16	UniStirling/SAMS	Iris II	I-1	30/01/17	SFF
Ocean Trust	OT-11	17/09/16	UniStirling/SAMS	Iris II	I-2	31/01/17	SFF
Ocean Trust	OT-12	17/09/16	UniStirling/SAMS	Ocean Trust	OT-13	15/02/17	UniStirling/SAMS
Dunam Star II	DS-1	21/09/16	SFF	Ocean Trust	OT-14	15/02/17	UniStirling/SAMS
Dunam Star II	DS-2	21/09/16	SFF	Caralisa	C-1	15/02/17	SFF
Dunam Star II	DS-3	22/09/16	SFF	Caralisa	C-2	15/02/17	SFF
Eilidh BRD149	EB-1	06/10/16	SFF	Ocean Trust	OT-15	16/02/17	UniStirling/SAMS
Eilidh BRD149	EB-2	06/10/16	SFF	Ocean Trust	OT-16	16/02/17	UniStirling/SAMS
Eilidh BRD149	EB-3	06/10/16	SFF	Ocean Trust	OT-17	17/02/17	UniStirling/SAMS
Eilidh BRD149	EB-4	07/10/16	SFF	Ocean Trust	OT-18	17/02/17	UniStirling/SAMS
Eilidh BRD149	EB-5	07/10/16	SFF	Ocean Trust	OT-19	06/03/17	UniStirling/SAMS
				Ocean Trust	OT-20	06/03/17	UniStirling/SAMS
				Ocean Trust	OT-21	07/03/17	UniStirling/SAMS
				Ocean Trust	OT-22	07/03/17	UniStirling/SAMS
				Ocean Trust	OT-23	08/03/17	UniStirling/SAMS
				Ocean Trust	OT-24	08/03/17	UniStirling/SAMS

Table 5.2: Tow details for west coast summer/autumn discard survival trial and SFF observer trip tows.

Source	Vessel	Date	Tow	Gear	Mesh size (mm)	Shoot (hh:mm)	Haul (hh:mm)	Duration (h)	Shoot depth (m)	Haul depth (m)	Tow speed (kts)
Uni Stirling/SAMS	Ocean Trust	15/07/16	OT1	Twin-rig	100	03:28	07:00	3.5	79	73	2.5
		15/07/16	OT2		100	07:35	10:20	2.8	104	90	2.5
		29/07/16	OT3		100	05:15	08:30	3.3	93	106	2.6
		29/07/16	OT4		100	09:25	12:30	3.1	93	150	2.5
		18/08/16	OT5		100	04:48	08:55	4.1	106	88	2.8
		18/08/16	OT6		100	09:36	13:25	3.8	95	148	2.7
		19/08/16	OT7		80	04:33	07:53	3.3	60	75	2.5
		19/08/16	OT8		80	08:46	12:16	3.5	119	73	2.4
		16/09/16	OT9		80	06:10	10:04	3.9	88	95	2.6
		16/09/16	OT10		80	10:30	14:35	4.1	97	90	2.7
		17/09/16	OT11		80	05:37	09:05	3.5	128	144	2.7
		17/09/16	OT12		80	10:12	13:28	3.3	100	NA	2.5
Means								**3.5**	**97**	**103**	**2.6**
SFF	Margareta II	24/08/16	M-1	Single-rig	80	07:30	10:30	3.0	138	134	2.3
		24/08/16	M-2		80	12:20	16:20	4.0	135	146	2.3
	Dunam Star II	21/09/16	DS-1		80	06:30	11:30	5.0	92	104	2.1
		21/09/16	DS-2		80	12:00	17:30	5.5	89	92	2.3
		22/09/16	DS-3		80	05:30	11:30	6.0	94	96	2.3
	Eilidh BRD149	06/10/16	EB-1	Twin-rig	80	07:30	11:28	4.0	81	116	2.2
		06/10/16	EB-2		80	12:05	15:25	3.3	120	135	2.2
		06/10/16	EB-3		80	16:05	19:50	3.8	128	108	2.2
		07/10/16	EB-4		80	07:25	11:40	4.3	120	120	2.2
		07/10/16	EB-5		80	12:17	17:05	4.8	116	138	2.2
Means								**4.4**	**111**	**119**	**2.2**

Table 5.3: Tow details for west coast winter/spring discard survival trial and SFF observer trip tows.

Source	Vessel	Date	Tow	Gear	Mesh size (mm)	Shoot (hh:mm)	Haul (hh:mm)	Duration (h)	Shoot depth (m)	Haul depth (m)	Tow speed (kts)
Uni Stirling/SAMS	Ocean Trust	15/02/17	OT-13	Twin-Rig	100	07:50	12:00	4.2	86	110	2.5
		15/02/17	OT-14		100	12:50	16:45	3.9	101	128	2.7
		16/02/17	OT-15		100	07:20	11:08	3.8	104	117	2.8
		16/02/17	OT-16		100	11:30	15:35	4.1	90	88	2.5
		17/02/17	OT-17		100	06:46	10:45	4.0	104	121	2.4
		17/02/17	OT-18		100	11:15	14:49	3.6	104	128	2.5
		06/03/17	OT-19		80	07:45	11:40	3.9	115	118	2.4
		06/03/17	OT-20		80	12:15	16:15	4.0	126	127	2.7
		07/03/17	OT-21		80	08:20	11:25	3.1	100	130	2.5
		07/03/17	OT-22		80	12:00	15:20	3.3	55	62	2.5
		08/03/17	OT-23		80	07:10	10:45	3.6	55	51	2.6
		08/03/17	OT-24		80	11:15	15:00	3.8	49	51	2.0
	Means							**3.8**	**91**	**103**	**2.5**
SFF	Eilidh BRD149	05/12/16	EB-6	Twin-Rig	80	07:40	12:00	4.3	135	140	2.5
		05/12/16	EB-7		80	12:45	17:00	4.3	140	140	2.5
		06/12/16	EB-8		80	07:45	12:15	4.5	90	84	2.5
		06/12/16	EB-9		80	13:00	16:45	3.8	86	100	2.5
	Golden Isles	13/12/16	GI-1	Single-Rig	80	10:00	14:00	4.0	82	100	1.9
		14/12/16	GI-2		80	10:12	14:15	4.0	90	95	1.9
		15/12/16	GI-3		80	10:00	14:15	4.3	84	100	1.9
	Dunam Star II	15/01/17	DS-4		80	07:45	12:45	5.0	128	120	2.2
		16/01/17	DS-5		80	13:30	17:00	3.5	129	121	2.3
	Eilidh BRD149	18/01/17	EB-10	Twin-Rig	80	08:00	12:00	4.0	82	84	2.2
		19/01/17	EB-11		80	08:30	12:30	4.0	75	81	2.2
	Iris II	30/01/17	I-1		80	08:00	12:00	4.0	89	94	2.2
		31/01/17	I-2		80	07:55	12:25	4.5	84	92	2.2
	Caralisa	15/02/17	C-1		80	07:30	11:30	4.0	60	75	2.7
		15/02/17	C-2		80	12:15	17:15	5.0	75	60	2.7
	Means							**4.2**	**95**	**99**	**2.3**

Table 5.4: Weather and sea surface conditions during west coast summer/autumn discard survival trials and SFF observer trips.

Source	Vessel Name	Date	Tow	Gear	Type of deck	Weather	Air temp (°C)	Sea surface temp (°C)	Surface salinity	Catch sorting time (h)
Uni Stirling/SAMS	Ocean Trust	15/07/16	OT-1	Twin-Rig	Covered	Slight chop, overcast	14.3	13.6	34	3.0
		15/07/16	OT-2		Covered	Slight swell, rain	15.0	13.6	34	3.2
		29/07/16	OT-3		Covered	Calm, dry	13.8	13.3	34	3.5
		29/07/16	OT-4		Covered	Calm, dry, sunny	15.0	13.3	34	4.5
		18/08/16	OT-5		Covered	Calm, clear, sunny	19.0	13.8	34	2.3
		18/08/16	OT-6		Covered	Calm, clear, sunny	19.0	13.8	34	3.3
		18/08/16	OT-7		Covered	Cloudy, slight swell, dry	17.0	14.5	33	2.4
		19/08/16	OT-8		Covered	Cloudy, swell, dry	16.5	14.5	33	1.0
		16/09/16	OT-9		Covered	Clear, sunny, slight breeze	15.2	14.7	34	2.2
		16/09/16	OT-10		Covered	Clear, sunny, slight breeze	15.6	14.7	34	0.9
		17/09/16	OT-11		Covered	Overcast, slight breeze/chop	16.4	14.3	34	2.6
		17/09/16	OT-12		Covered	Overcast, breezy, slight swell	14.2	14.3	34	0.9
	Means						**15.9**	**14.0**	**34**	**2.5**
SFF	Margareta II	24/08/16	M-1	Single-Rig	Open	Calm	15.1	12.3	NA	1.7
		24/08/16	M-2		Open	Calm	16.1	12.2		1.8
	Dunam Star II	21/09/16	DS-1		Covered	Gentle Breeze, Slight Waves	17.5	11.5		1.0
		21/09/16	DS-2		Covered	Moderate Breeze, Slight-Moderate	16.0	11.5		1.3
		22/09/16	DS-3		Covered	Strong Breeze, Rough waves	14.0	11.0		1.1
	Eilidh BRD149	06/10/16	EB-1	Twin-Rig	Covered	Cloudy, dry	11.4	13.3		1.2
		06/10/16	EB-2		Covered	Clear sky and sunny	17.1	13.6		0.8
		06/10/16	EB-3		Covered	Clear sky and sunny	13.9	13.0		0.8
		07/10/16	EB-4		Covered	Clear sky	13.8	13.2		2.0
		07/10/16	EB-5		Covered	Clear sky and sunny	14.7	13.4		2.3
	Means						**15.0**	**12.5**		**1.4**

Table 5.5: Weather and sea surface conditions during west coast winter/spring discard survival trials and SFF observer trips.

Source	Vessel Name	Date	Tow	Gear	Type of deck	Weather	Air temp (°C)	Sea surface temp (°C)	Surface salinity	Catch sorting time (h)
Uni Stirling/SAMS	Ocean Trust	15/02/17	OT-13	Twin-Rig	Covered	Breeze, slight swell, overcast	11.5	8.4	34.6	1.8
		15/02/17	OT-14		Covered	Breeze, slight swell, overcast	10.1	8.4	34.6	1.5
		16/02/17	OT-15		Covered	Calm, overcast, slight precipitation	10.2	8.4	34.6	1.6
		16/02/17	OT-16		Covered	Calm, overcast, slight precipitation	9.6	8.4	34.6	1.7
		17/02/17	OT-17		Covered	Calm, overcast	10.4	8.4	34.5	2.2
		17/02/17	OT-18		Covered	Calm, overcast	10.1	8.4	34.5	2.1
		06/03/17	OT-19		Covered	Breeze, slight swell	10.4	8.2	34.5	2.1
		06/03/17	OT-20		Covered	Breeze, slight swell	10.5	8.2	34.5	1.3
		07/03/17	OT-21		Covered	Strong breeze, swell, cloudy	8.2	7.9	34.1	2.1
		07/03/17	OT-22		Covered	Strong breeze, swell, cloudy	6.9	7.9	34.1	1.3
		08/03/17	OT-23		Covered	Windy, strong swell to rough	7.5	8.1	34.5	1.7
		08/03/17	OT-24		Covered	Windy, strong swell to rough	7.5	8.1	34.5	1.3
	Means						**9.4**	**8.2**	**34.5**	**1.7**
SFF	Eilidh BRD149	05/12/16	EB-6	Twin-Rig	Covered	Clear sky and sunny	6.8	11.1	NA	1.3
		05/12/16	EB-7		Covered	Clear sky and sunny	5.9	11.1		1.4
		06/12/16	EB-8		Covered	Overcast, Fog	8.1	11.0		1.3
		06/12/16	EB-9		Covered	Overcast, Fog	6.2	11.0		1.2
	Golden Isles	13/12/16	GI-1	Single-Rig	Small covered	Calm	9.4	9.0		1.0
		14/12/16	GI-2		Small covered	Calm	9.0	9.0		1.2
		15/12/16	GI-3		Small covered	Gentle Breeze, Slight Waves	8.5	9.0		1.0
	Dunam Star II	15/01/17	DS-4		Open	No record	8.0	8.2		1.1
		16/01/17	DS-5		Open	No record	7.5	8.3		1.2
	Eilidh BRD149	18/01/17	EB-10	Twin-Rig	Covered	Gentle Breeze, Slight Waves	10.0	8.7		1.6
		19/01/17	EB-11		Covered	Gentle Breeze, Slight Waves	9.5	8.9		0.8
	Iris II	30/01/17	I-1		Covered	Moderate Breeze, Slight-Moderate	9.0	8.5		1.4
		31/01/17	I-2		Covered	Gentle Breeze, Slight Waves	9.5	8.5		1.7
	Caralisa	15/02/17	C-1		Covered	Cloudy, dry	11.0	13.0		1.2
		15/02/17	C-2		Covered	Cloudy, dry	10.0	13.0		1.5
	Means						**8.6**	**9.9**		**1.3**

Table 5.6: Catch details for west coast summer/autumn discard survival trials and SFF observer trips.

Source	Tow	Mesh size (mm)	Retained *Nep* whole (kg)	Retained *Nep* tails raised (kg)	Wt *Nep* retained (kg)	Wt *Nep* discarded (kg)	Total wt *Nep* (kg)	Wt non-*Nep* bycatch (kg)	Total catch wt (kg)	*Nep* from total catch (%)	Non-*Nep* discards from total catch (%)	*Nep* retained from *Nep* catch wt (%)	*Nep* discarded from *Nep* catch wt (%)
Uni Stirling/SAMS	OT1	100	57	114	171	6	177	15	192	92.2	7.8	96.6	3.4
	OT2	100	57	132	189	4	193	60	253	76.3	23.7	97.9	2.1
	OT3	100	57	306	363	7	370	82	452	81.9	18.1	98.1	1.9
	OT4	100	114	381	495	7	502	100	602	83.4	16.6	98.6	1.4
	OT5	100	64	228	292	12	304	45	349	87.1	12.9	96.1	3.9
	OT6	100	57	228	285	24	309	38	347	89.0	11.0	92.2	7.8
	Means		**68**	**232**	**299**	**10**	**309**	**57**	**366**	**85.0**	**15.0**	**96.8**	**3.2**
	OT7	80	48	114	162	6	168	64	233	72.4	27.6	96.4	3.6
	OT8	80	44	76	121	4	124	45	170	73.2	26.8	97.6	3.2
	OT9	80	127	76	203	2	205	141	346	59.2	40.8	99.0	1.0
	OT10	80	76	39	115	1	116	130	247	47.2	52.8	99.1	0.9
	OT11	80	57	135	192	3	195	124	319	61.1	38.9	98.5	1.5
	OT12	80	44	57	101	2	103	66	170	60.9	39.1	98.1	1.9
	Means		**66**	**83**	**149**	**3**	**152**	**95**	**247**	**62.0**	**38.0**	**98.0**	**2.0**
SFF	EB-1	80	15	23	38	3	41	64	105	38.8	61.2	92.7	7.3
	EB-2	80	12	6	18	2	20	96	116	16.9	83.1	90.0	10.0
	EB-3	80	28	47	75	2	77	64	141	54.4	45.6	97.4	2.6
	EB-4	80	37	99	136	5	141	90	231	61.0	39.1	96.5	3.5
	EB-5	80	47	126	173	4	177	70	247	71.6	28.4	97.7	2.3
	Means		**28**	**60**	**88**	**3**	**91**	**77**	**168**	**49.0**	**51.0**	**96.7**	**3.3**
	M-1	80	50	21	71	2	73	32	105	69.4	30.6	97.3	2.7
	M-2	80	60	21	81	1	82	30	112	73.2	26.8	98.8	1.2
	DS-1	80	63	18	81	3	84	2	86	97.7	2.3	96.4	3.6
	DS-2	80	36	21	57	3	60	15	75	79.9	20.1	95.0	5.0
	DS-3	80	40	42	82	4	86	21	107	80.3	19.7	95.3	4.7
	Means		**50**	**25**	**74**	**2**	**77**	**20**	**97**	**80.0**	**20.0**	**96.1**	**2.6**

Table 5.7: Catch details for west coast winter/spring discard survival trials and SFF observer trips.

Source	Tow	Mesh size (mm)	Retained *Nep* whole (kg)	Retained *Nep* tails raised (kg)	Wt *Nep* retained (kg)	Wt *Nep* discarded (kg)	Total wt *Nep* (kg)	Wt non-*Nep* bycatch (kg)	Total catch wt (kg)	*Nep* from total catch (%)	Non-*Nep* discards from total catch (%)	*Nep* retained from *Nep* catch wt (%)	*Nep* discarded from *Nep* catch wt (%)
Uni Stirling/SAMS	OT13	100	70	75	145	3	148	43	190	77.7	22.3	98.0	2.0
	OT14	100	64	57	121	3	124	54	177	69.8	30.2	97.6	2.4
	OT15	100	45	57	102	4	105	85	190	55.5	44.5	97.1	3.8
	OT16	100	76	75	151	5	156	48	204	76.4	23.6	96.8	3.2
	OT17	100	133	114	247	5	252	55	307	82.2	17.8	98.0	2.0
	OT18	100	152	153	305	6	311	62	373	83.4	16.6	98.1	1.9
	Means		**90**	**89**	**178**	**4**	**183**	**58**	**240**	**74.0**	**26.0**	97.3	2.2
	OT19	80	127	134	261	5	265	53	318	83.4	16.7	98.5	1.9
	OT20	80	76	76	152	3	155	41	196	79.1	20.9	98.1	1.9
	OT21	80	127	114	241	6	247	46	294	84.2	15.8	97.6	2.4
	OT22	80	76	96	172	6	178	26	204	87.2	12.8	96.6	3.4
	OT23	80	89	75	164	3	167	45	212	78.9	21.1	98.2	1.8
	OT24	80	64	57	121	3	124	29	152	81.2	18.8	97.6	2.4
	Means		**93**	**92**	**185**	**4**	**189**	**40**	**229**	**82.0**	**18.0**	97.9	2.1
SFF	EB-6	80	62	60	122	5	127	96	223	57.0	43.1	96.1	3.9
	EB-7	80	55	81	136	4	140	120	260	53.8	46.2	97.1	2.9
	EB-8	80	23	30	53	3	56	64	120	46.7	53.3	94.6	5.4
	EB-9	80	64	75	139	6	145	96	241	60.2	39.8	95.9	4.1
	EB-10	80	56	90	146	4	150	8	158	94.9	5.1	97.3	2.7
	EB-11	80	54	72	126	3	129	6	135	95.6	4.4	97.7	2.3
	I-1	80	80	75	155	3	158	64	222	71.1	28.9	98.1	1.9
	I-2	80	54	39	93	2	95	16	111	85.6	14.4	97.9	2.1
	C-1	80	105	90	195	4	199	64	263	75.7	24.3	98.0	2.0
	C-2	80	90	114	204	4	208	96	304	68.4	31.6	98.1	1.9
	Means		**64**	**73**	**137**	**4**	**141**	**63**	**204**	**71.0**	**29.0**	97.2	2.8
	GI-1	80	52	18	70	3	73	8	81	90.1	9.9	95.9	4.1
	GI-2	80	58	18	76	4	80	9	89	89.8	10.2	95.0	5.0
	GI-3	80	60	27	87	3	90	4	94	95.7	4.3	96.7	3.3
	DS-4	80	54	18	72	1	73	24	97	75.2	24.8	98.6	1.4
	DS-5	80	72	30	102	3	105	24	129	81.3	18.7	97.1	2.9
	Means		**59**	**22**	**81**	**3**	**84**	**14**	**98**	**86.0**	**14.0**	96.4	3.6

Table 5.8: West coast overall mean results of on-board scoring of discard fraction Nephrops having at least one physical sign of damage.

Source	Season	Gear	Mesh size (mm)	Scored on-board as being damaged (%)		
Ocean Trust	All	Twin	100 and 80	39.8	±	3.7
SFF	All	All	80	40.1	±	5.3
Ocean Trust	Summer	Twin	100 and 80	40.2	±	4.2
SFF	Summer	All	80	50.3	±	3.5
Ocean Trust	Winter	Twin	100 and 80	39.4	±	6.9
SFF	Winter	All	80	33.2	±	6.5
Ocean Trust	Summer	Twin	100	35.7	±	6.2
Ocean Trust	Summer	Twin	80	44.6	±	3.7
SFF	Summer	Twin	80	48.0	±	4.7
SFF	Summer	Single	80	52.6	±	6.5
Ocean Trust	Winter	Twin	100	35.9	±	6.0
Ocean Trust	Winter	Twin	80	42.8	±	14.6
SFF	Winter	Twin	80	39.3	±	6.7
SFF	Winter	Single	80	21.1	±	5.1

Table 5.9: Summer/autumn west coast discard survival trials and SFF observer trips on-board assessment of percentage of discard fraction Nephrops with at least one sign of physical damage.

Source	Vessel	Gear	Mesh size (mm)	Tow	Scored on-board as being damaged (%)
Uni/SAMS	Ocean Trust	Twin-rig	100	OT1	36.4
				OT2	33.0
				OT3	41.0
				OT4	33.3
				OT5	43.4
				OT6	27.0
			80	OT7	44.0
				OT8	40.0
				OT9	50.0
				OT10	46.0
				OT11	46.0
				OT12	42.0
SFF	Eilidh BRD149			EB-1	52.0
				EB-2	44.0
				EB-3	47.0
				EB-4	52.0
				EB-5	45.0
	Margareta II	Single-rig	80	M-1	47.0
				M-2	56.0
	Dunam Star II			DS-1	47.0
				DS-2	55.0
				DS-3	58.0

Table 5.10: Winter/spring west coast discard survival trials and SFF observer trips on-board assessment of percentage of discard fraction Nephrops with at least one sign of physical damage.

Source	Vessel	Gear	Mesh size (mm)	Tow	Scored on-board as being damaged (%)
Uni/SAMS	Ocean Trust	Twin-rig	100	OT13	31.3
				OT14	25.3
				OT15	41.3
				OT16	39.3
				OT17	42.7
				OT18	35.6
			80	OT19	66.7
				OT20	52.7
				OT21	37.4
				OT22	32.7
				OT23	35.3
				OT24	32.2
SFF	Eilidh BRD149			E-6	48.0
				E-7	37.0
				E-8	38.0
				E-9	42.0
				E-10	18.0
				E-11	32.0
	Iris II			I-1	44.0
				I-2	49.0
	Caralisa			C-1	37.0
				C-2	48.0
	Golden Isles	Single-rig	80	GI-1	24.0
				GI-2	16.9
				GI-3	18.9
	Dunam Star II			DS-4	26.7
				DS-5	19.0

Table 5.11: Main damage categories for discard fraction Nephrops recorded on-board during west coast discard survival trials or SFF observer trips.

Category	Ocean Trust		SFF	
	Occurence (%)	Mean CL (mm)	Occurence (%)	Mean CL (nmm)
Undamaged	63.38	24.35 ± 2.34	60.82	26.83 ± 4.12
D1	18.65	24.48 ± 2.49	22.63	28.53 ± 3.85
D2	2.60	24.21 ± 2.63	7.04	28.05 ± 4.10
THP	3.01	23.97 ± 2.45	1.85	26.24 ± 4.00
TAP	2.15	24.58 ± 2.16	1.23	26.62 ± 4.65
TAC	2.79	23.81 ± 2.41	1.19	27.80 ± 4.04
THC	0.80	23.70 ± 2.08	0.58	27.02 ± 3.94
DR	1.95	24.31 ± 2.83	0.00	NA
D1 THP	0.93	24.08 ± 2.55	0.33	30.13 ± 3.21
D1 DR	0.70	24.10 ± 2.02	0.00	NA
D1 TAC	0.58	23.07 ± 2.19	0.66	27.99 ± 4.48
D1 TAP	0.35	25.00 ± 2.11	0.33	29.05 ± 3.12
D1 THC	0.29	23.64 ± 1.61	0.49	26.40 ± 4.29
D2 TAP	0.26	23.3 ± 2.76	0.41	26.12 ± 5.53
D2 TAC	0.16	25.38 ± 3.02	0.66	27.71 ± 3.58
D2 THP	0.13	23.58 ± 2.40	0.21	27.24 ± 3.92
THP TAC	0.16	24.92 ± 1.42	0.00	NA
TAP TAC	0.00	NA	0.33	24.63 ± 2.50
D2 THC	0.00	NA	0.21	26.02 ± 5.02

Table 5.12: Dates of east coast (Firth of Forth) discard survival trials and SFF observer trips.

Source	Vessel	Tow	Date
Uni Stirling/ SAMS	Winaway	WN1	13/06/2017
		WN2	14/06/2017
		WN3	20/06/2017
		WN4	21/06/2017
		WN5	22/06/2017
		WN6	06/08/2017
SFF	Launch Out KY	LOK1	06/08/2017
		LOK2	06/08/2017
		LOK3	07/08/2017
		LOK4	14/08/2017
		LOK5	14/08/2017
		LOK6	15/08/2017

Table 5.13: Details of tows during east coast discard survival trials and SFF observer trips.

Source	Vessel	Date	Tow	Gear	Mesh size (mm)	Shoot (hh:mm)	Haul (hh:mm)	Tow (h)	Shoot depth (m)	Haul depth (m)	Speed (kts)
Uni Stirling/SAMS	Winaway	13/06/17	WN1	Twin-rig	80	18:46	22:35	3.8	47	33	2.7
		14/06/17	WN2		80	22:54	04:05	5.2	33	45	2.7
		20/06/17	WN3		80	19:56	23:44	3.8	45	29	2.3
		21/06/17	WN4		80	00:01	03:33	3.5	30	44	2.6
		21/06/17	WN5		80	19:40	22:38	2.9	44	24	2.6
		22/06/17	WN6		80	01:47	03:29	1.7	24	31	2.2
Means								**3.5**	**37**	**34**	**2.5**
SFF	Launch Out KY	06/08/17	LOK1	Twin-rig	80	18:30	21:30	3	55	58	2.8
		06/08/17	LOK2		80	22:00	01:30	3.5	52	52	2.8
		07/08/17	LOK3		80	01:50	04:00	2.2	54	56	2.7
		14/08/17	LOK4		80	18:30	21:30	3	56	57	2.8
		14/08/17	LOK5		80	22:00	01:30	3.5	55	49	2.7
		15/08/17	LOK6		80	02:00	05:10	3.2	49	51	2.8
Means								**3.1**	**54**	**54**	**2.8**

Table 5.14: Weather and sea surface conditions during east coast discard survival trials and SFF observer trips.

Source	Vessel	Date	Tow	Gear	Type of deck	Weather	Air Temp (ºC)	Surface water Temp (ºC)	Surface water Salinity	Catch sorting time (h)
Uni Stirling /SAMS	Winaway	13/06/17	WN1	Twin-Rig	Covered	Calm, overcast	14.6	11.2	33.8	2.2
		14/06/17	WN2			Calm, overcast	15.1	11.2	33.8	1.7
		20/06/17	WN3			Choppy, overcast	15.2	13.2	33.7	2.8
		21/06/17	WN4			Choppy, overcast	13.3	13.2	33.7	1.7
		21/06/17	WN5			Calm, rain	15.8	13.8	33.6	1.8
		22/06/17	WN6			Calm, rain	16.3	13.8	33.6	0.9
	Means						**15.1**	**12.7**	**33.7**	**1.9**
SFF	Launch Out Ky	06/08/17	LOK1	Twin-Rig	Covered		14	11.9	NA	1.6
		06/08/17	LOK2				11	11.7		1.5
		07/08/17	LOK3				10	11.8		1.2
		14/08/17	LOK4			Heavy rain, showers	14.7	12.9		1.2
		14/08/17	LOK5			Heavy rain, showers	14.5	12.8		1.5
		15/08/17	LOK6			Heavy rain, showers	14	12.8		1.3
	Means						**13.0**	**12.3**		**1.4**

Table 5.15: Catch details for east coast discard survival trials and SFF observer trips.

Source	Tow	Retained *Nep* whole (kg)	Retained *Nep* tails raised (kg)	Wt *Nep* retained (kg)	Wt *Nep* discarded (kg)	Total wt *Nep* (kg)	Wt non-*Nep* by-catch (kg)	Total catch wt (kg)	*Nep* from total catch (%)	Non-*Nep* discards from total catch (%)	*Nep* retained from *Nep* catch wt (%)	*Nep* discarded from *Nep* catch wt (%)
Uni Stirling/ SAMS	WN1	64	210	274	14	288	41	328	87.5	12.5	95.1	4.9
	WN2	48	153	201	8	209	67	276	75.8	24.2	96.2	3.8
	WN3	88	267	355	30	385	12	397	96.9	3.1	92.2	7.8
	WN4	53	153	206	14	220	9	229	96.0	4.0	93.6	6.4
	WN5	64	190	254	23	277	8	285	97.3	2.7	91.7	8.3
	WN6	24	72	96	9	105	4	110	96.1	3.9	91.4	8.6
Means		**57**	**174**	**231**	**16**	**247**	**24**	**271**	**92.0**	**8.0**	**93.5**	**6.5**
SFF	LOK1	216	216	432	2	434	16	450	96.4	3.6	99.5	0.5
	LOK2	63	119	182	2	184	16	200	92.0	8.0	98.9	1.1
	LOK3	45	138	183	1	184	8	192	95.8	4.2	99.5	0.5
	LOK4	36	278	314	2	316	10	326	96.9	3.1	99.4	0.6
	LOK5	36	99	135	2	137	11	148	92.5	7.5	98.5	1.5
	LOK6	36	177	213	2	215	8	223	96.4	3.6	99.1	0.9
Means		**72**	**171**	**243**	**2**	**245**	**12**	**256**	**95**	**5.0**	**99.2**	**0.8**

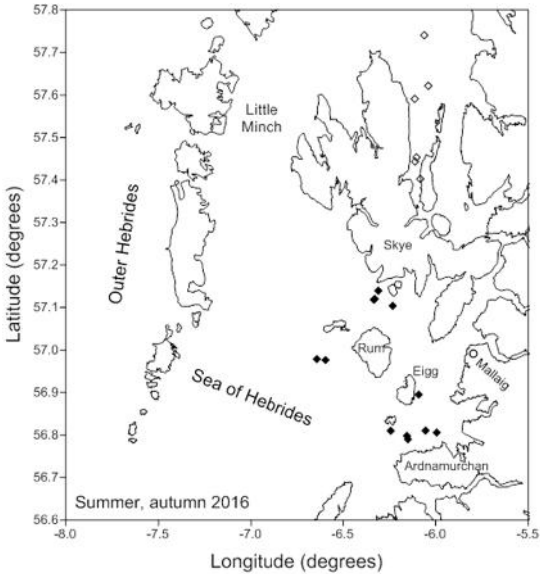
Table 5.16: East coast (Firth of Forth) discard survival trials and SFF observer trips on-board assessment of percentage of discard fraction Nephrops with at least one sign of physical damage.

Source	Tow	Scored on-board as being damaged (%)
Uni Stirling/SAMS	WN1	36.7
	WN2	36.7
	WN3	34.0
	WN4	34.7
	WN5	39.3
	WN6	31.0
SFF	LOK1	69.0
	LOK2	50.0
	LOK3	50.6
	LOK4	54.0
	LOK5	46.0
	LOK6	38.0

Table 5.17: Percentage of discard fraction Nephrops showing different categories of damage in the east coast discard survival trials (Winaway) and SFF observer trips (Launch Out KY). Values are the mean ± 95% conf. int. (n=6 Winaway; n=6 Launch Out KY).

Category	Winaway (%)			Launch Out KY (%)		
Undamaged	65.0	±	3.4	49.3	±	11.3
D1	14.8	±	4.1	28.5	±	9.7
D2	1.4	±	1.2	5.8	±	3.0
THP	4.2	±	2.4	0.5	±	0.6
TAP	6.1	±	2.5	0.9	±	1.2
TAC	0.7	±	1.1	4.0	±	2.4
THC	0.3	±	0.4	2.0	±	2.1
DR	2.4	±	3.0	1.6	±	1.9
D1 THP	0.8	±	0.5	1	±	0.9
D1 DR	0.6	±	0.8	0.0		NA
D1 TAC	0.1	±	0.3	1.3	±	0.8
D1 TAP	0.7	±	0.9	0.4	±	0.6
D1 THC	0.2	±	0.4	1.9	±	0.7
D2 TAP	0.2	±	0.6	0.5	±	0.9
D2 TAC	0.0		NA	1.4	±	1.1
D2 THP	0.0		NA	0.2	±	0.5
D2 THC	0.0		NA	0.7	±	0.5
Others	2.3	±	1.3	0.0		NA

Figure 5-1: Locations of 'Ocean Trust' discard survival trials (filled diamonds) and SFF west coast observer trips (open diamonds) during the summer/early autumn 2016 (left hand panel) and winter/ early spring 2017 (right hand panel).



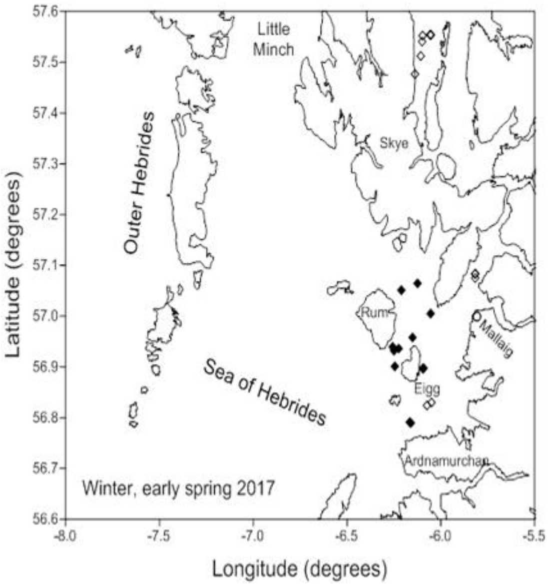


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Figure 5-2: Ocean Trust (OT) survival trials and SFF west coast observer trips (SFF) towing times in hours (upper panel) and depth in metres (lower panel). The horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits. Outliers (5th/95th percentiles) are shown as points.

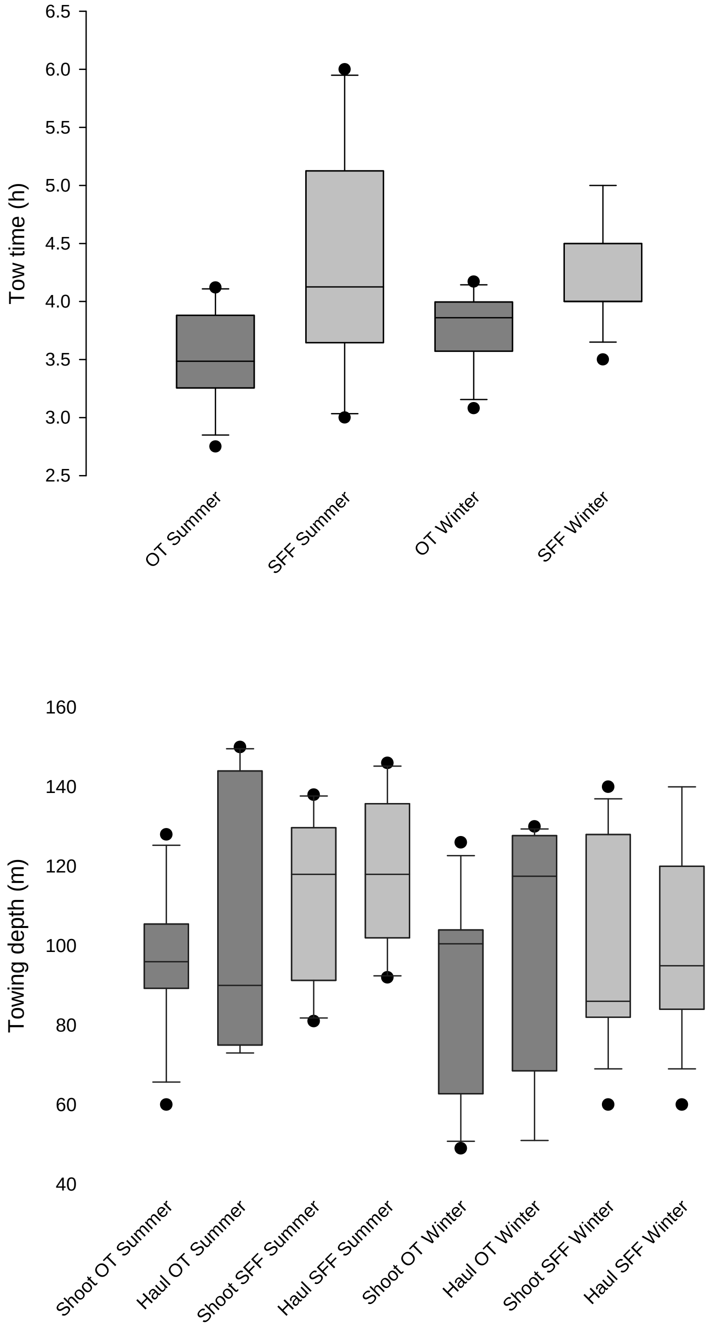


Figure 5-3: Air temperatures while sorting the catch on Ocean Trust (OT) discard survival trials and SFF west coast observer trips. The horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits. Outliers (5th/95th percentiles) are shown as points.

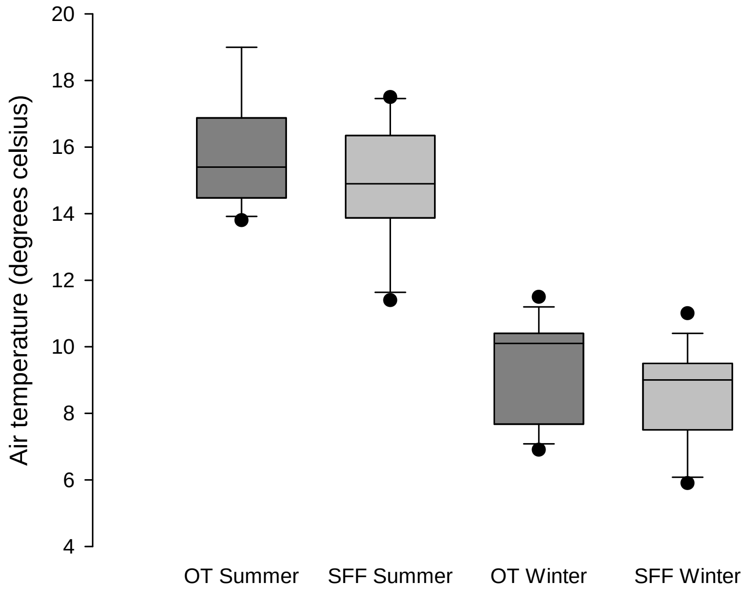


Figure 5-4: Total catch weights in the TR2 Ocean Trust survival trials (hatched infill) compared with TR1 SFF west coast observer trip catches by season. The horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits. Outliers (5th/95th percentiles) are shown as points.

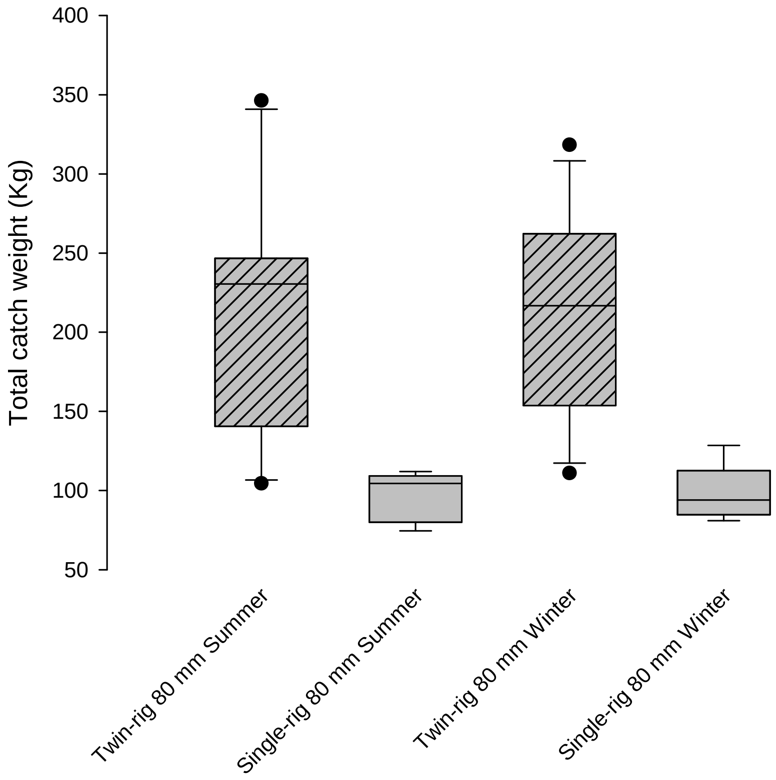


Figure 5-5: Total catch weights for Ocean Trust (OT) discard survival trial tows and SFF west coast observer trips by season, gear (twin or single-rig) and net mesh type (100-TR1; 80-TR2). The horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits. Outliers (5th/95th percentiles) are shown as points.

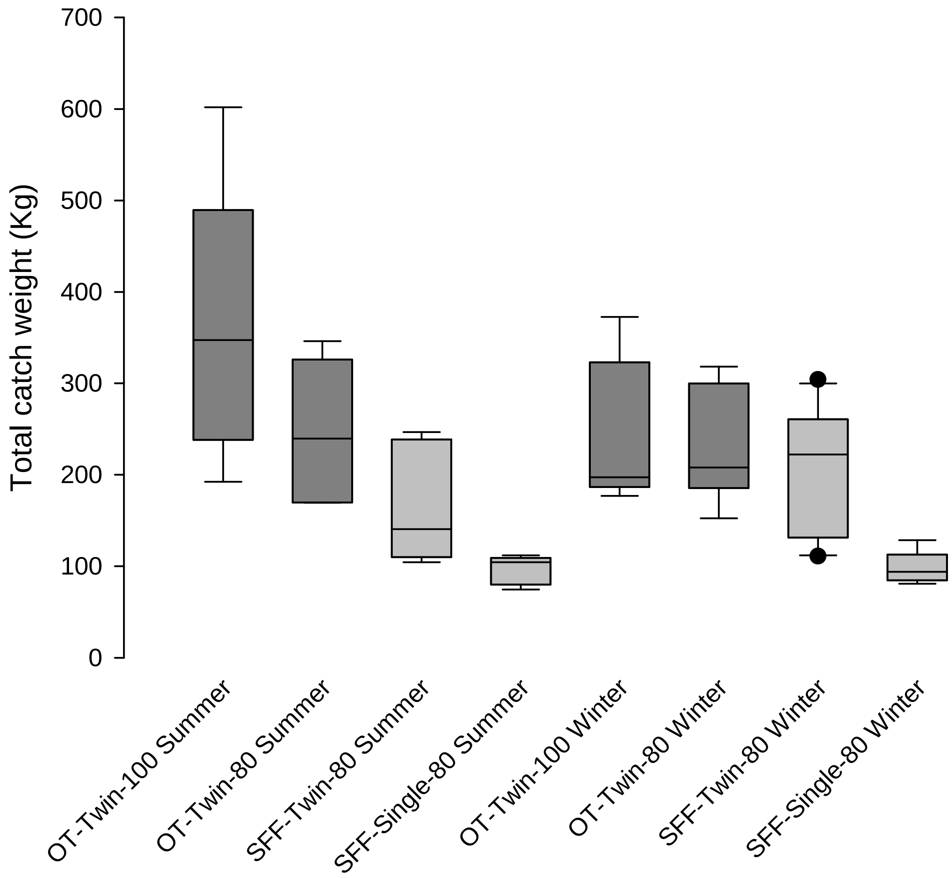


Figure 5-6: Relationship between sorting time (h) and total catch weight for Ocean Trust (OT) discard survival trials and SFF west coast observer trips by vessel, season, gear (twin or single-rig) and mesh size.

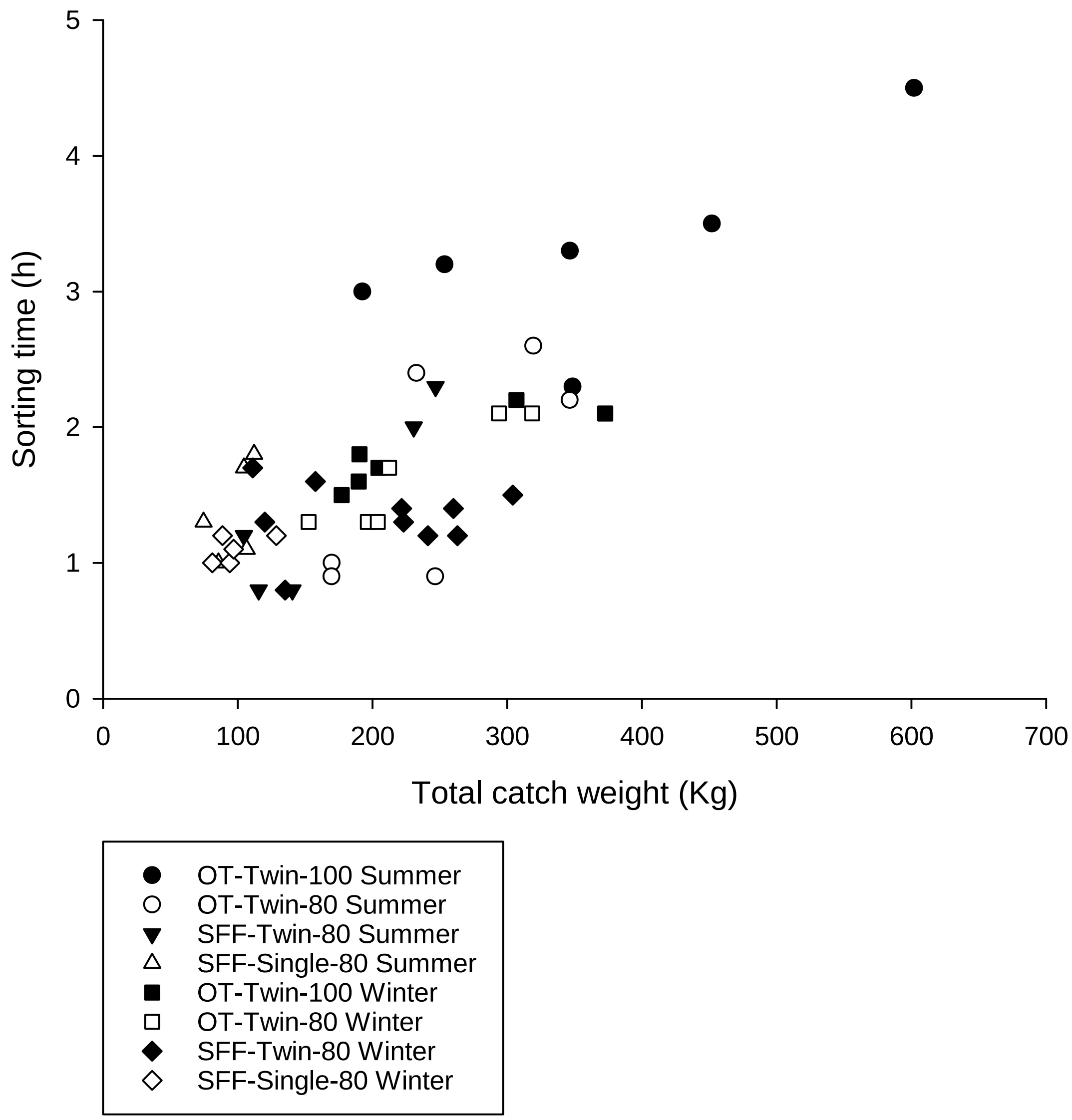


Figure 5-7: Total catch sorting time in hours for Ocean Trust (OT) discard survival trials and SFF west coast observer trips by season. The horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits. Outliers (5th/95th percentiles) are shown as points.

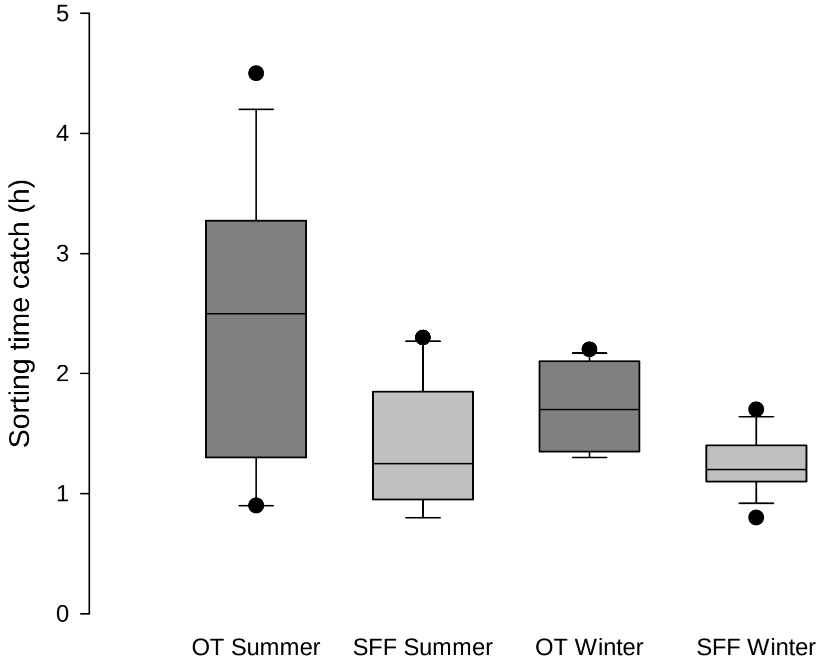


Figure 5-8: Retained Nephrops as a percentage of the total catch weight (upper panel) and non-Nephrops catch as a percentage of the total catch weight (lower panel) in Ocean Trust (OT) discard survival trials and SFF west coast observer trips by gear and season. The two components do not sum to 100% because Nephrops which were discarded comprise a third category. Horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits. Outliers (5th/95th percentiles) are shown as points.

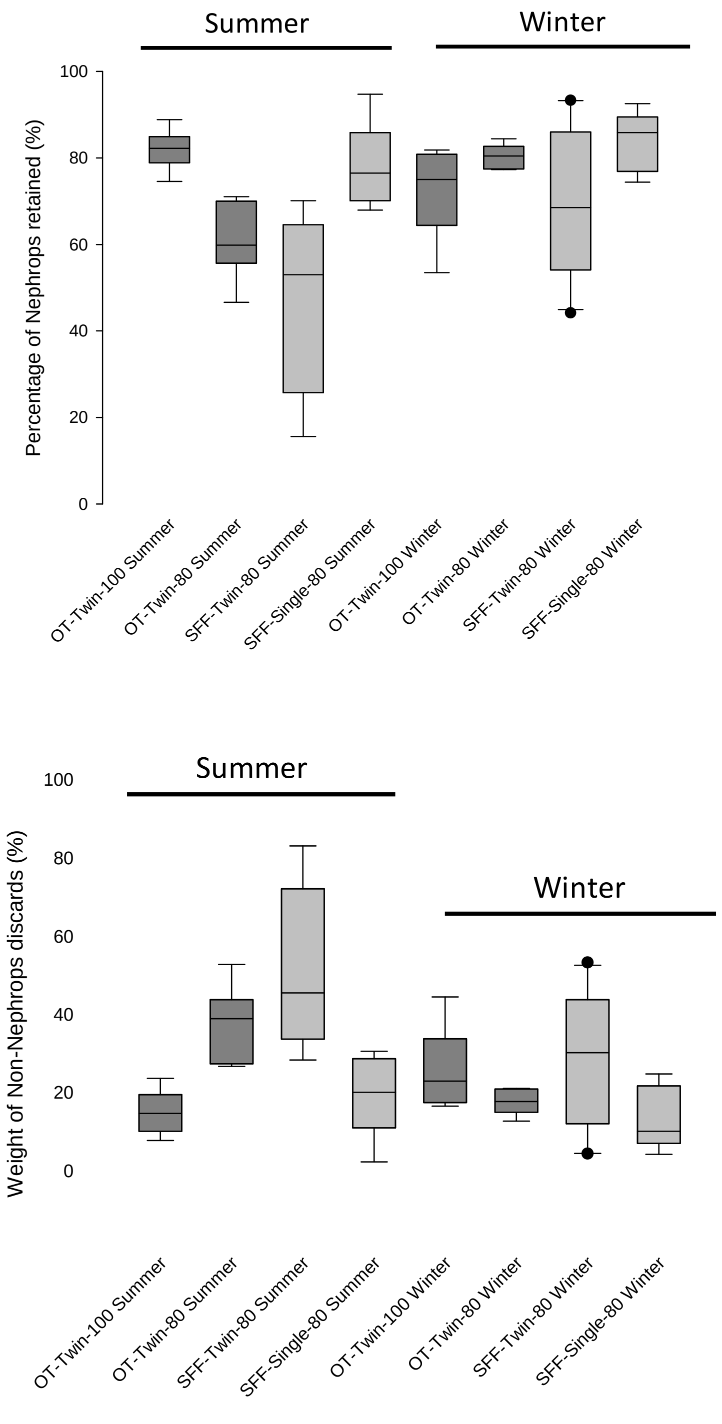


Figure 5-9: Breakdown of the fate of the catches as mean percentages of total catch weight in Ocean Trust (OT) discard survival trials and SFF west coast observer trips by gear and season.

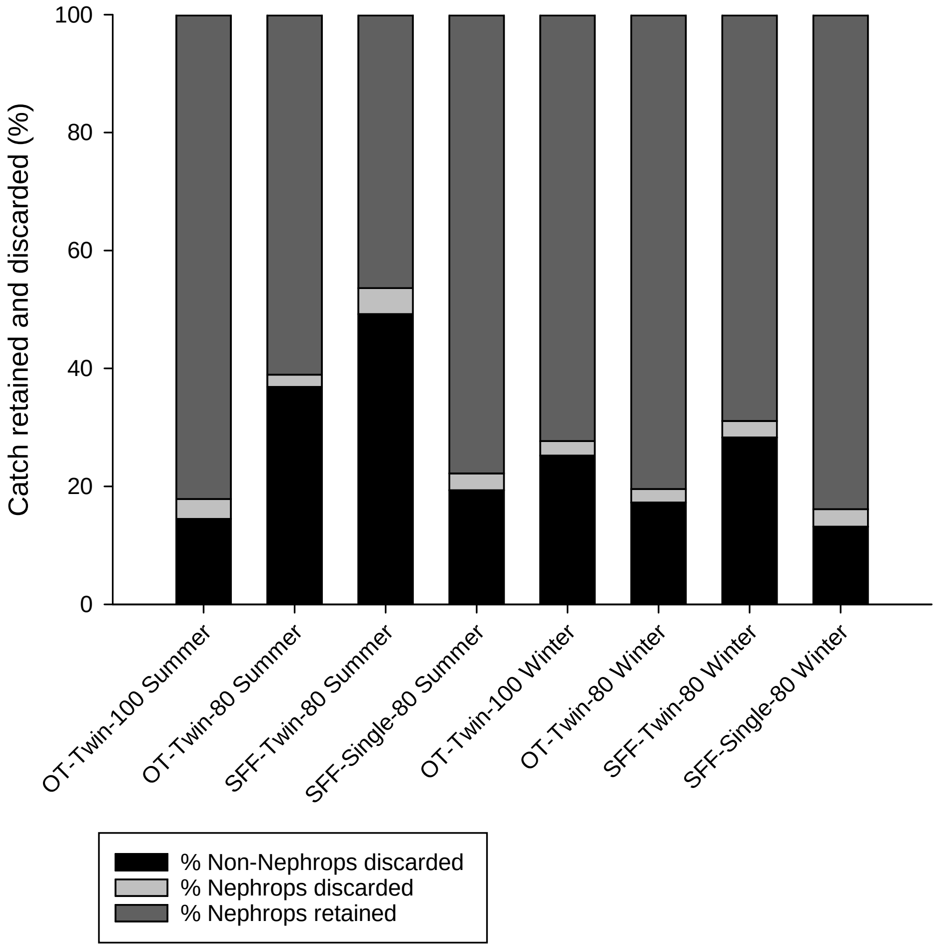


Figure 5-10: Percentage Nephrops discarded relative to the total weight of Nephrops caught in Ocean Trust (OT) discard survival trials and SFF west coast observer trips.

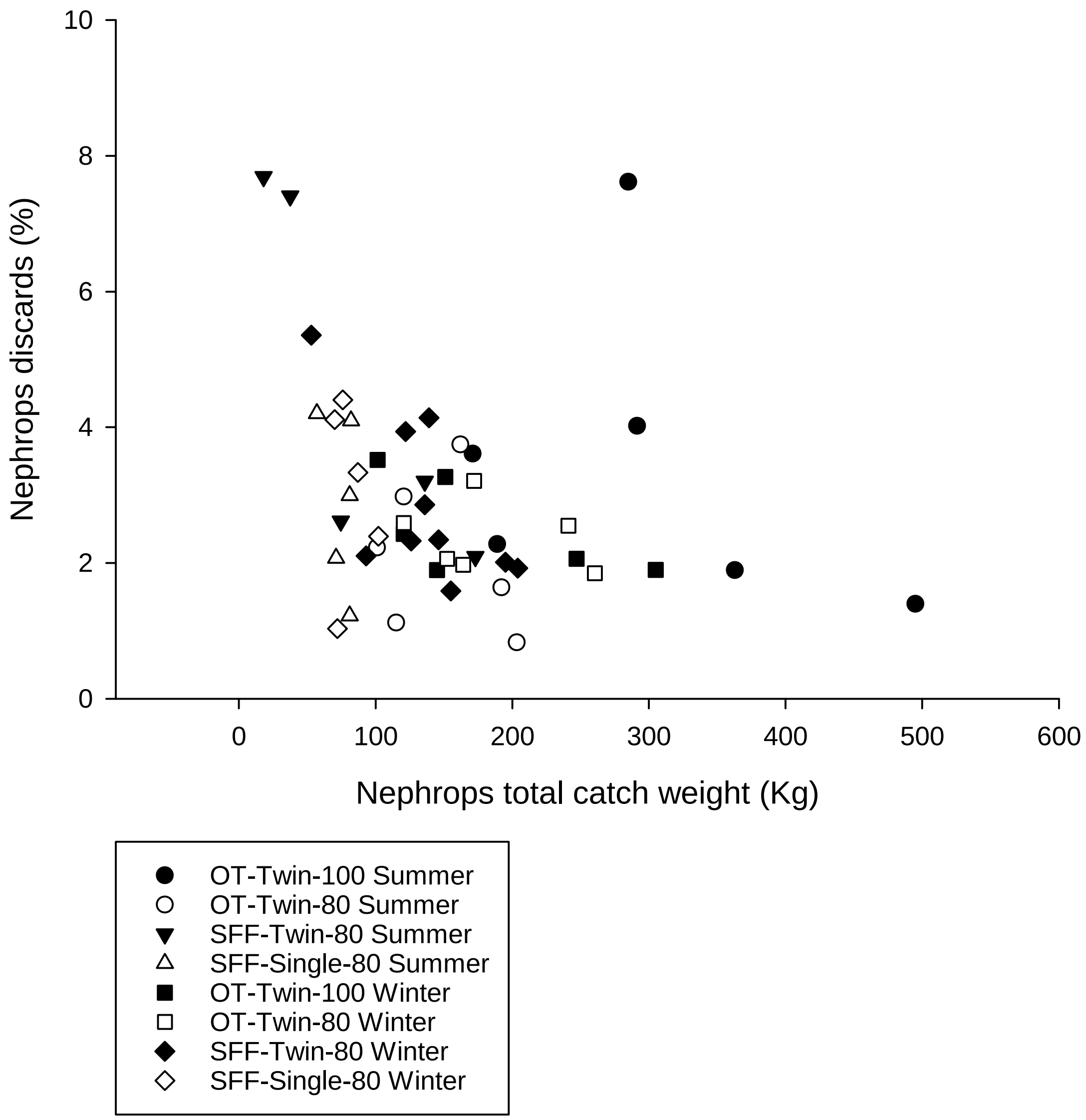
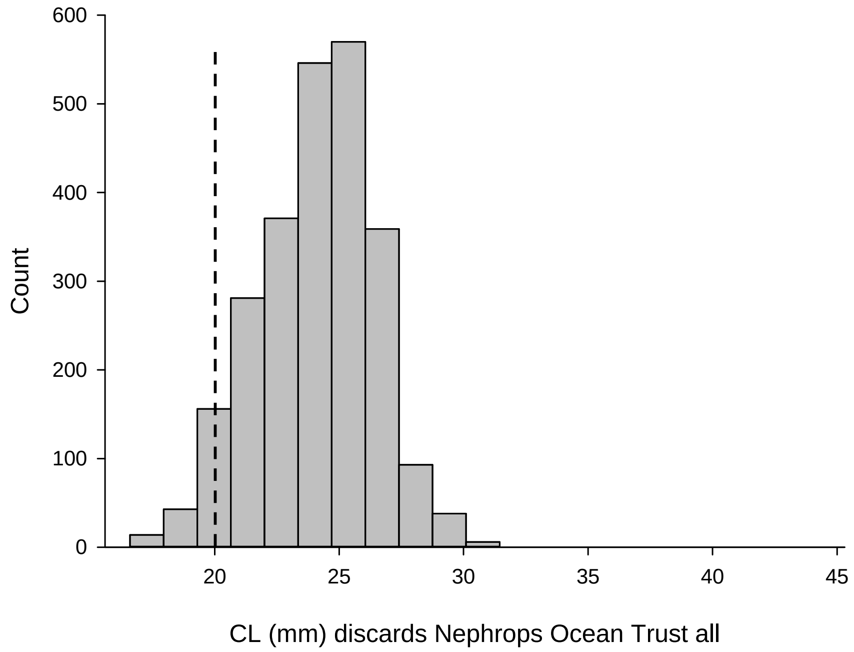


Figure 5-11: Frequency histograms for the carapace lengths of discarded Nephrops in Ocean Trust survival trials compared with SFF west coast observer trip data. Dotted line indicates the current Minimum Conservation Reference Size for ICES Division VIa.



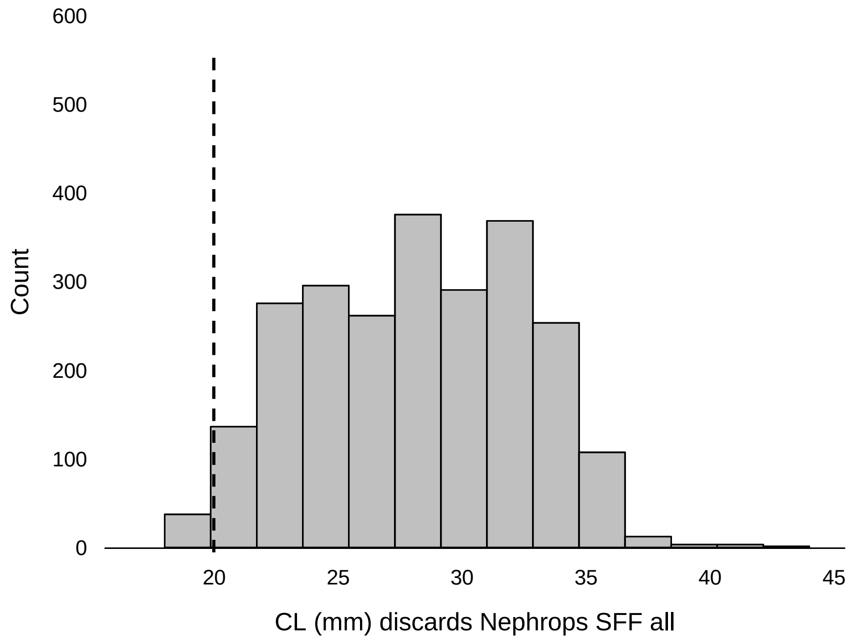


Figure 5-12: Carapace lengths of discarded Nephrops in Ocean Trust (OT) discard survival trials and SFF west coast observer trips by to season, gear (twin or single-rig) and mesh size. Horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits. Individual outliers (outside 10th/90th percentiles) are shown as points.

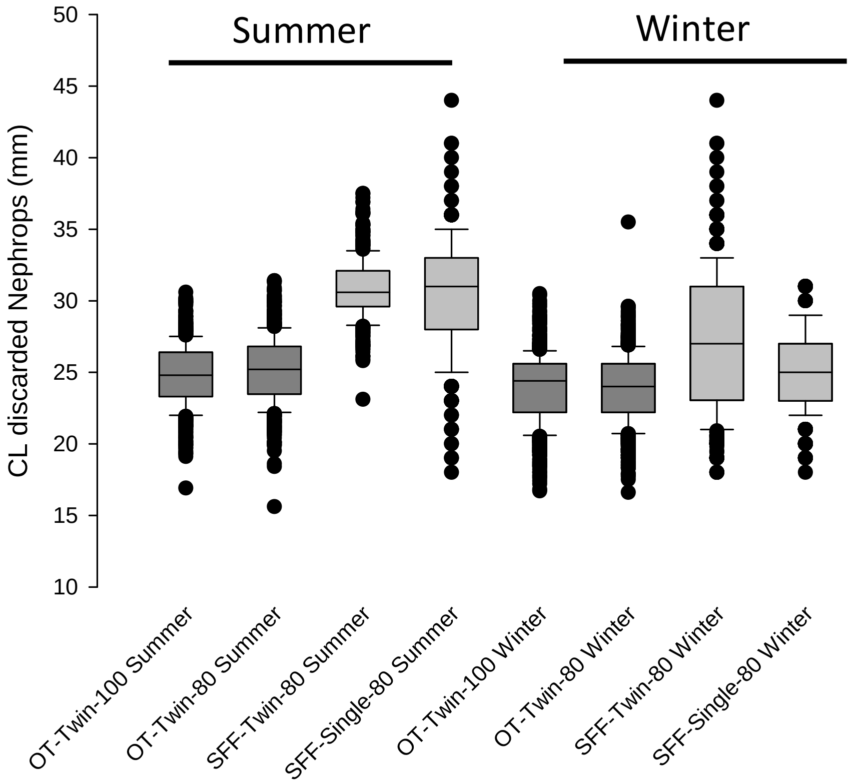


Figure 5-13: Percentage of discarded Nephrops recorded as being damaged when scored on-board the Ocean Trust (OT) discard survival trials or SFF west coast observer trips, by season, gear (twin or single-rig) and mesh size. Horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits. Outliers (5th/95th percentiles) are shown as points.

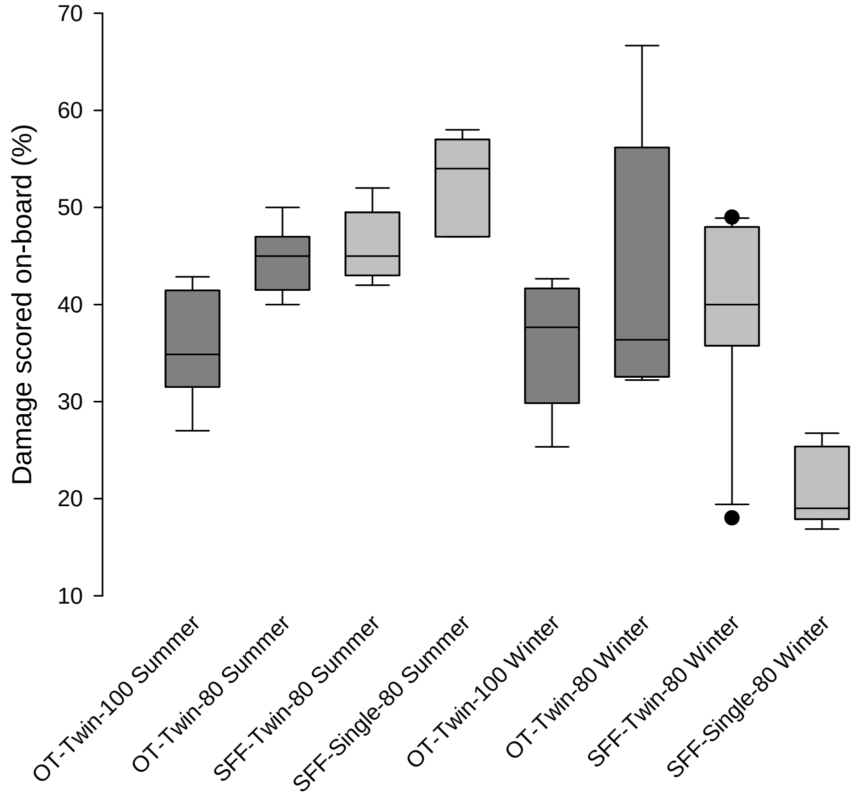


Figure 5-14: Percentage of discard fraction Nephrops scored on-board as damaged versus the weight of non-Nephrops catch by season, data origin (Ocean Trust, OT; SFF observer trips), gear and mesh size.

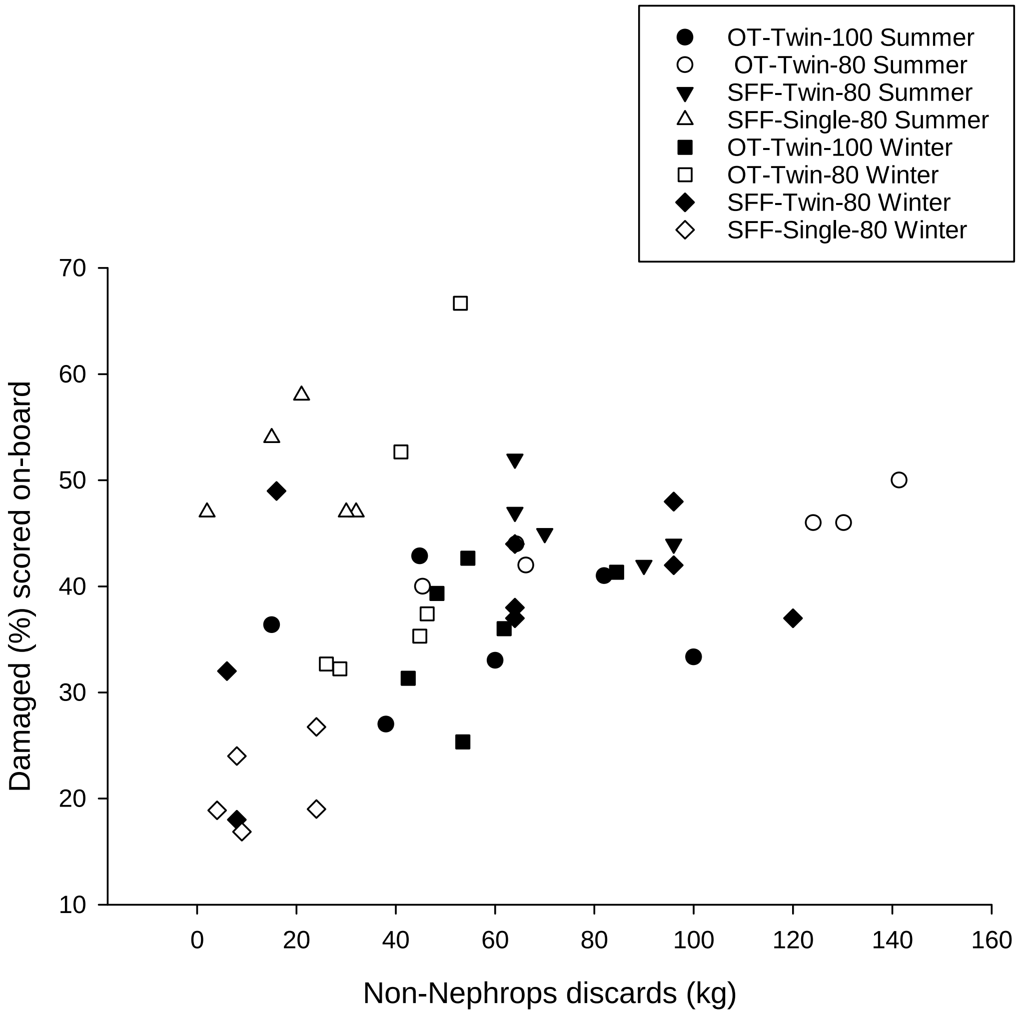


Figure 5-15: Percentage of discarded Nephrops alive during sorting in Ocean Trust (OT) discard survival trials and SFF observer trips according to season. Horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits. Outliers (5th/95th percentiles) are shown as points.

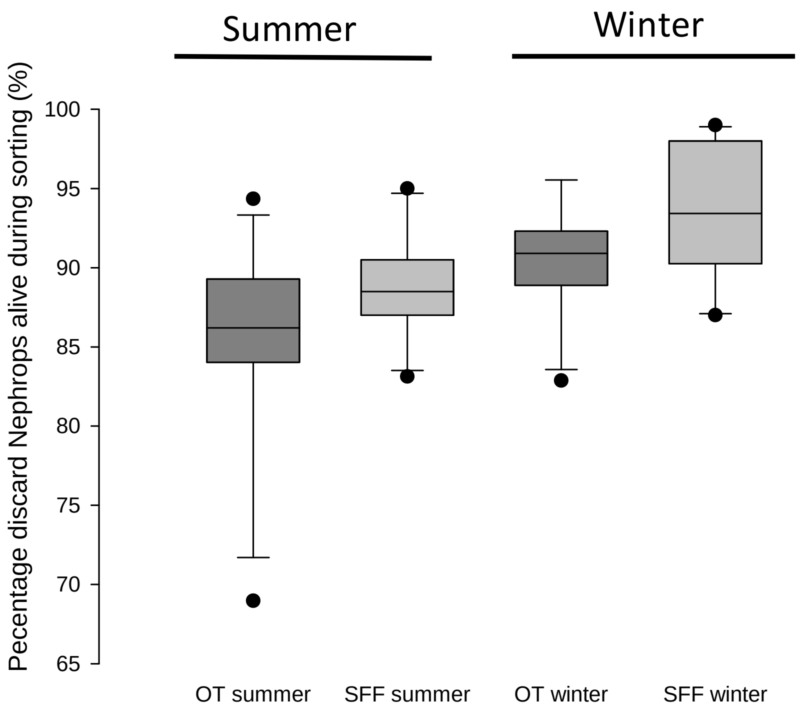


Figure 5-16: Percentage of discards Nephrops alive during sorting in Ocean Trust (OT) discard survival trials and SFF observer trips by season, gear (twin or single-rig) and mesh size. Horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits.

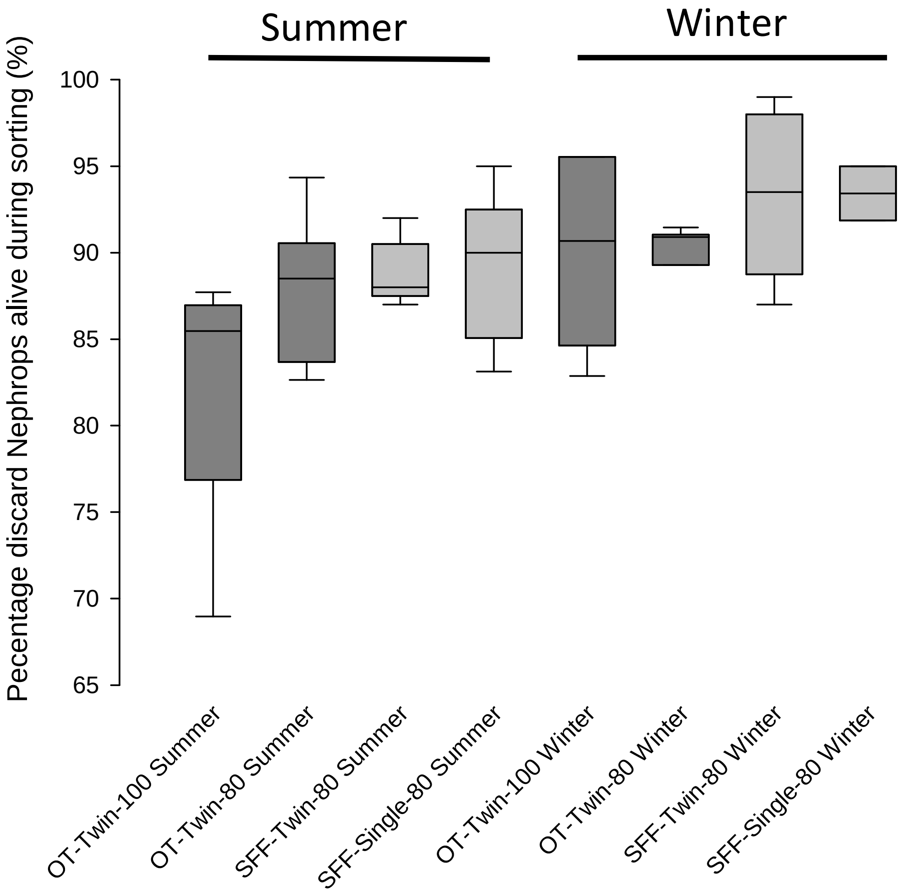


Figure 5-17: East coast twin-riggers 'Launch Out KY 374' (upper panel) used in SFF observer trips and 'Winaway' (lower panel) used in discard survival trials, both vessels are currently based in Pittenweem.

Figure 5-18: Distribution of Nephrops vessels operating from Pittenweem port according to their total length (m).

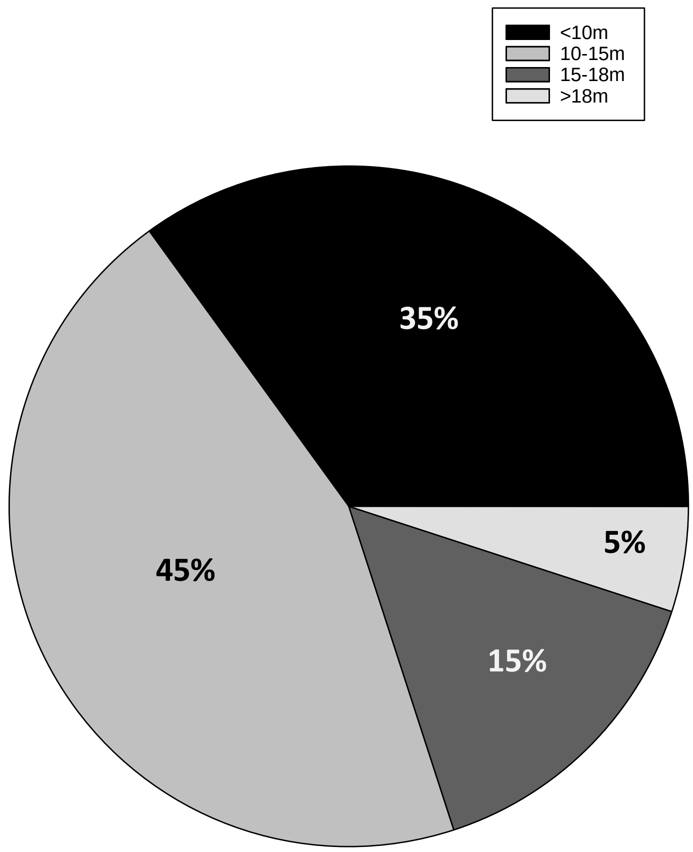


Figure 5-19: Locations of east coast early summer 2017 tows, Winaway (filled diamonds) and SFF observer trips (open diamonds).

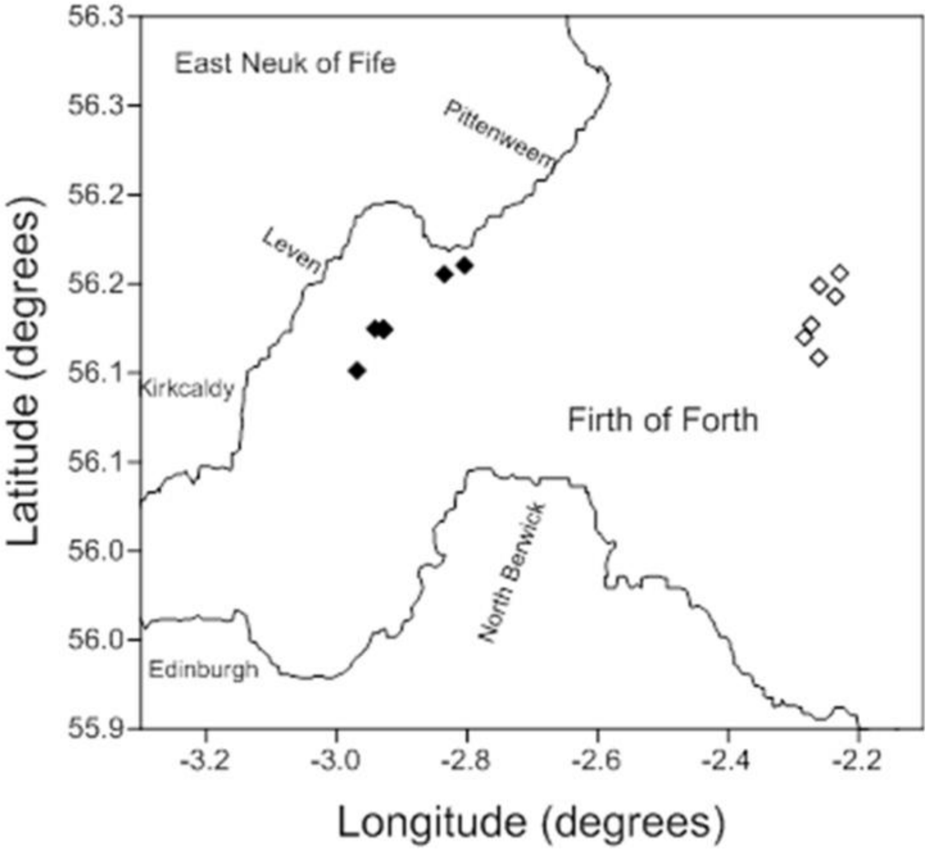


Figure 5-20: Air temperatures during catch sorting in east coast discard survival trials (Winaway) and SFF observer trips (Launch Out KY). Horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits.

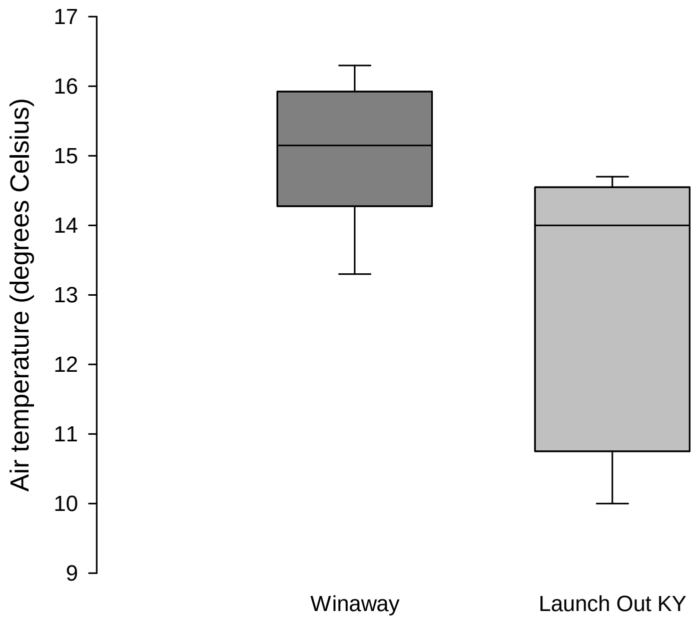


Figure 5-21: Sorting times comparing east coast discard survival trials (Winaway) and SFF observer trips (Launch Out KY). Horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits.

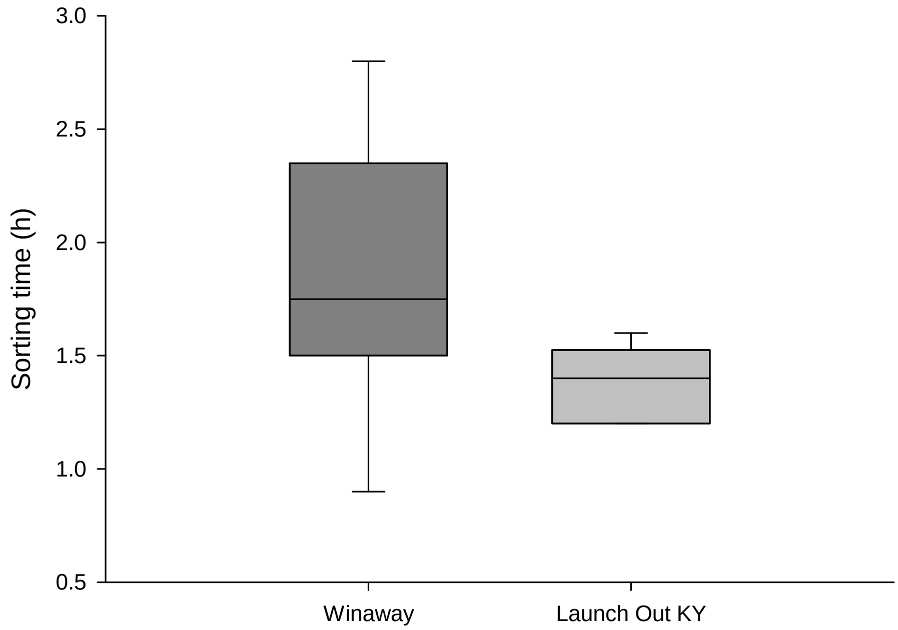


Figure 5-22: Catch retained or discarded by weight as mean percentages in Winaway discard survival trials and SFF east coast observer trips (Launch Out KY).

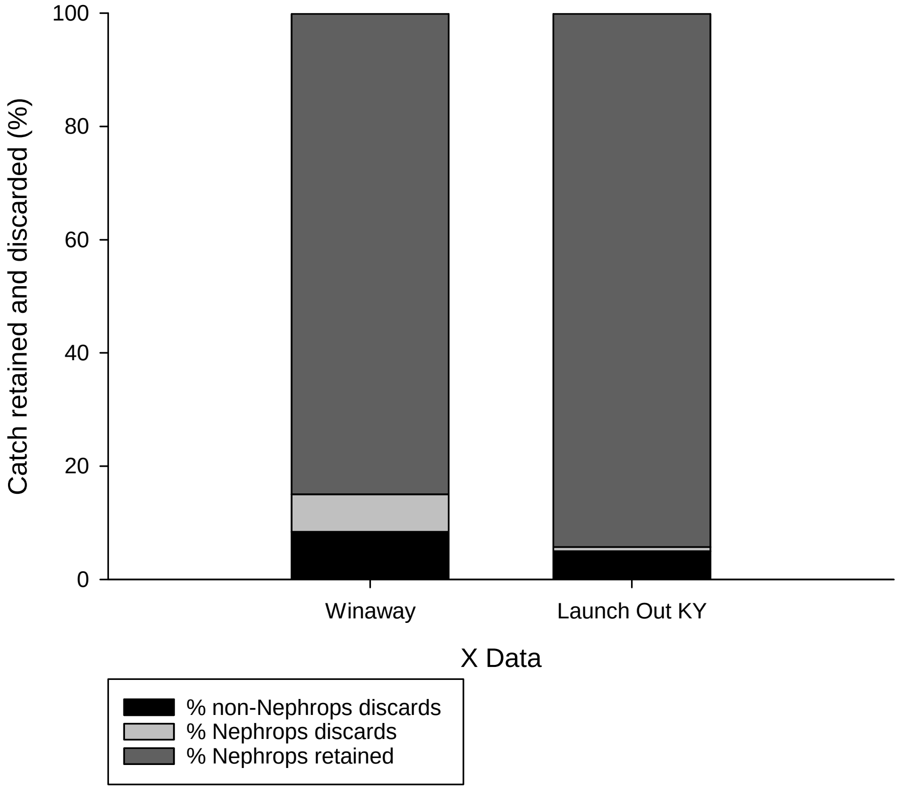


Figure 5-23: Carapace lengths of discarded Nephrops in Winaway discard survival trials and SFF east coast observer trips (Launch Out KY). Horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits. Individual outliers (outside 10th/90th percentiles) are shown as points.

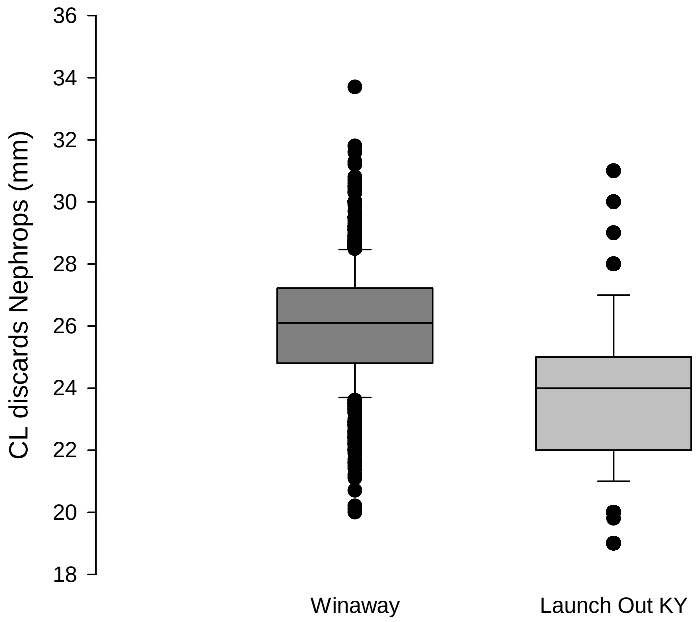


Figure 5-24: Frequency histograms for the carapace lengths of discarded Nephrops in Winaway discard survival trials compared with SFF east coast observer trip data (Launch Out KY). Dotted line indicates the current Minimum Conservation Reference Size for ICES Division IVb.

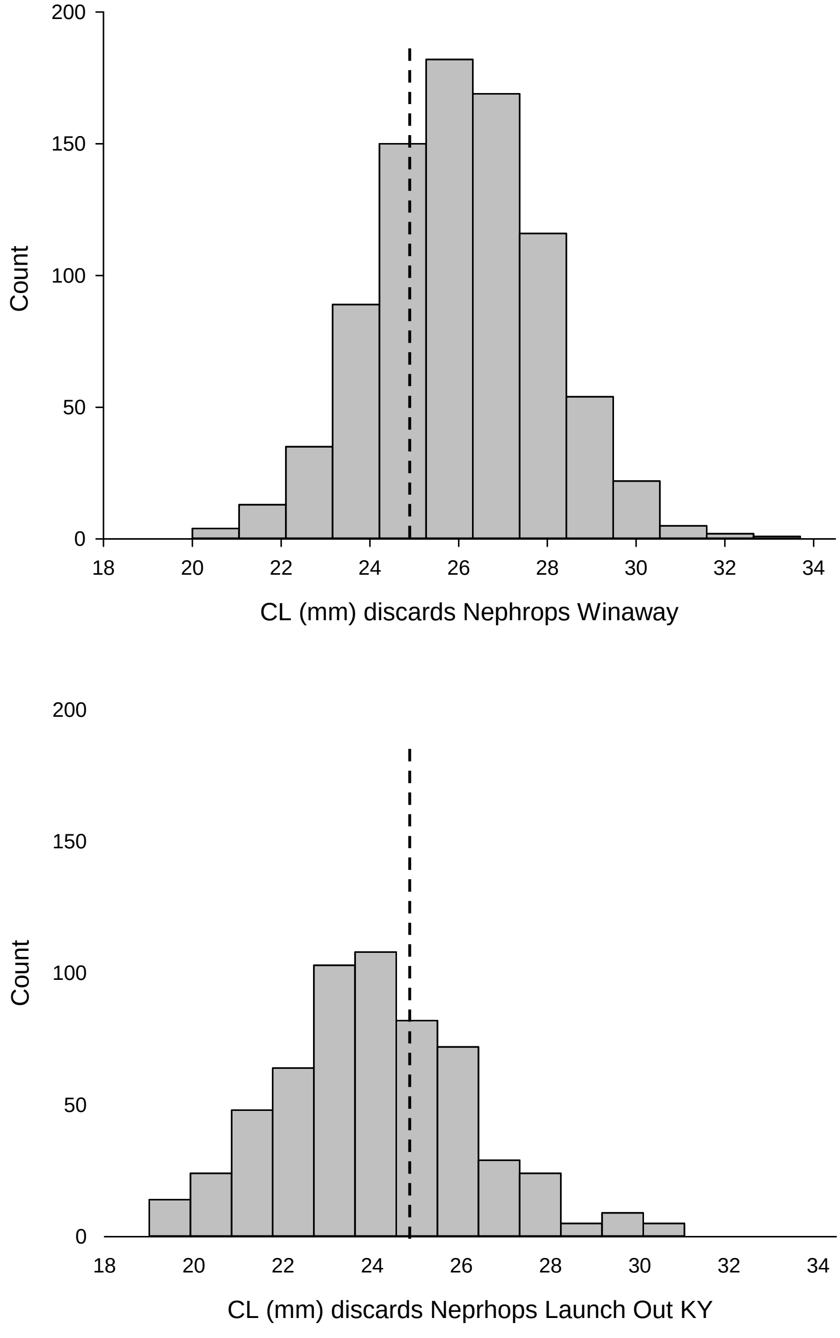
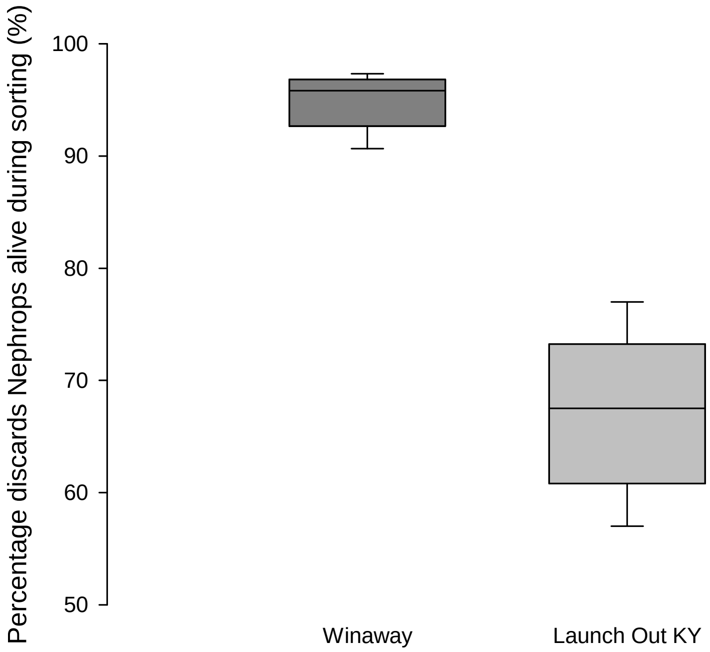


Figure 5-25: Percentage of discarded Nephrops alive during catch sorting in Winaway discard survival trials versus SFF east coast observer trips (Launch Out KY). Horizontal bars indicate the median, the boxes indicate first and third quartile and the whiskers indicate the lower and upper limits.



6. Behaviour studies of post-trawl discard *Nephrops* on the seabed

Objective 3. To conduct further behaviour observations on how post-trawl discard Nephrops with different degrees of damaged and exposed to different temperatures and length air exposure recover under natural conditions on the seabed and interact with potential predators using fixed and mobile underwater camera systems.

6.1. Introduction

The project proposal envisaged using the systems deployed in the Clyde (Albalat et al. 2016) to study *Nephrops* behaviour on the seabed after discarding. Early on during the current work off Mallaig it was realised that the depths of fishing were much greater than in the Clyde. This means that the camera system used in the Clyde, which is limited to < 50 m deployment depth, was not suitable for use in the present project.

The methodology was revised to make use of SAMS Remotely Operated Vehicle (ROV) which can work down to several hundred metres. Initial work was undertaken on the Northern Lights vessel 'Pharos' which is equipped with dynamic positioning (DP). Initial deployments worked well and some video of discard size *Nephrops* re-entering burrows was obtained. Unfortunately the ROV tether was then snagged on the vessel rail and damaged so that the ROV became inoperable. The tether was dispatched to Aberdeen for repairs meaning that further behaviour trials had to be delayed until December 2017. The FISA steering committee were informed of the situation and an agreement given that the results from the behaviour trials might be added to the report at a slightly later date. Three additional days were completed using SAMS research vessel 'Calanus'. This vessel does not have DP meaning that the ship had to be anchored during the operation. This did result in some loss of time and combined with short day length in December meant that a limited number of dives were completed. Despite these problems video were collected of discard size *Nephrops* behaviour on the seabed after various periods of aerial exposure. However, there was insufficient time to make observations on damaged *Nephrops* such as might result during commercial trawling and catch sorting.

6.2. Materials and methods

The ROV used was a Mojave (Forum Subsea Technologies, Abderdeen, UK) vehicle which was modified to carry an additional GoPro camera fitted with a supplementary Inon wide-angle lens, supplementary diving lights and a transport container for the *Nephrops*. The transport container consisted of a lidded Perspex jar attached to the ROV manipulator arm. The lid of the jar was connected to the ROV body by a short cord so that when the manipulator arm was extended the lid was pulled off and the *Nephrops* released (Figure 6-1). The estimated field-of-view (FOV) of the observational camera was around 1 m^2 of seabed.

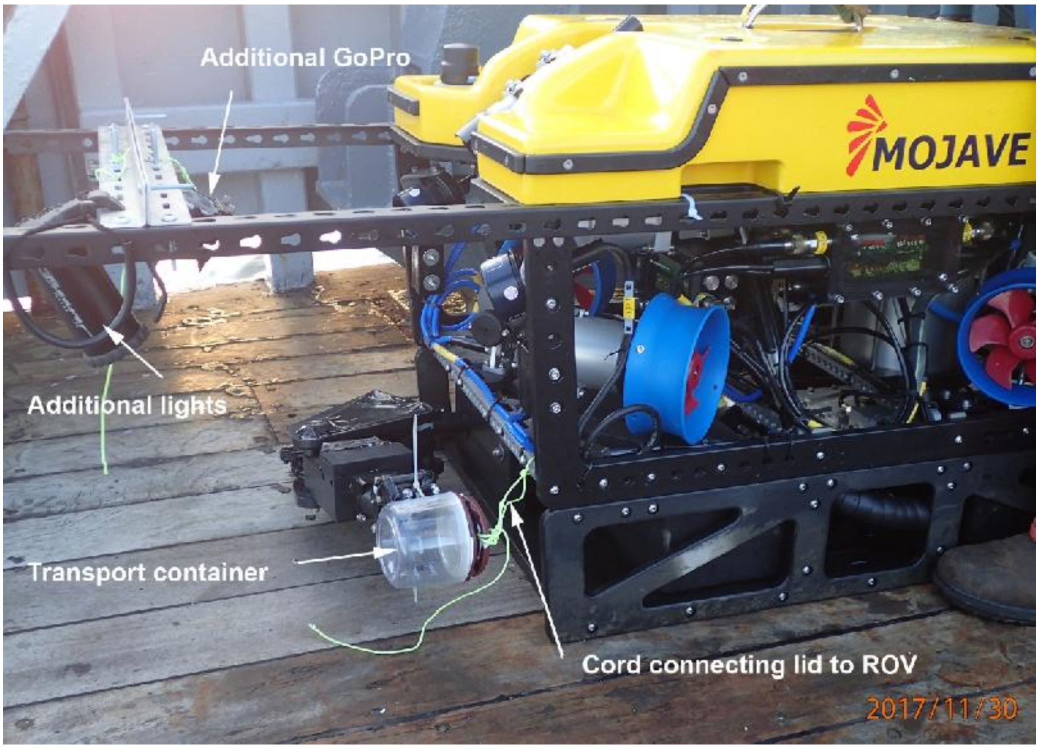


Figure 6-1: Mojave remotely-operated vehicle used in the behaviour trials

Four sets of dives were undertaken at three sites where local trawling or potting for *Nephrops* was known to occur (Figure 6-2).

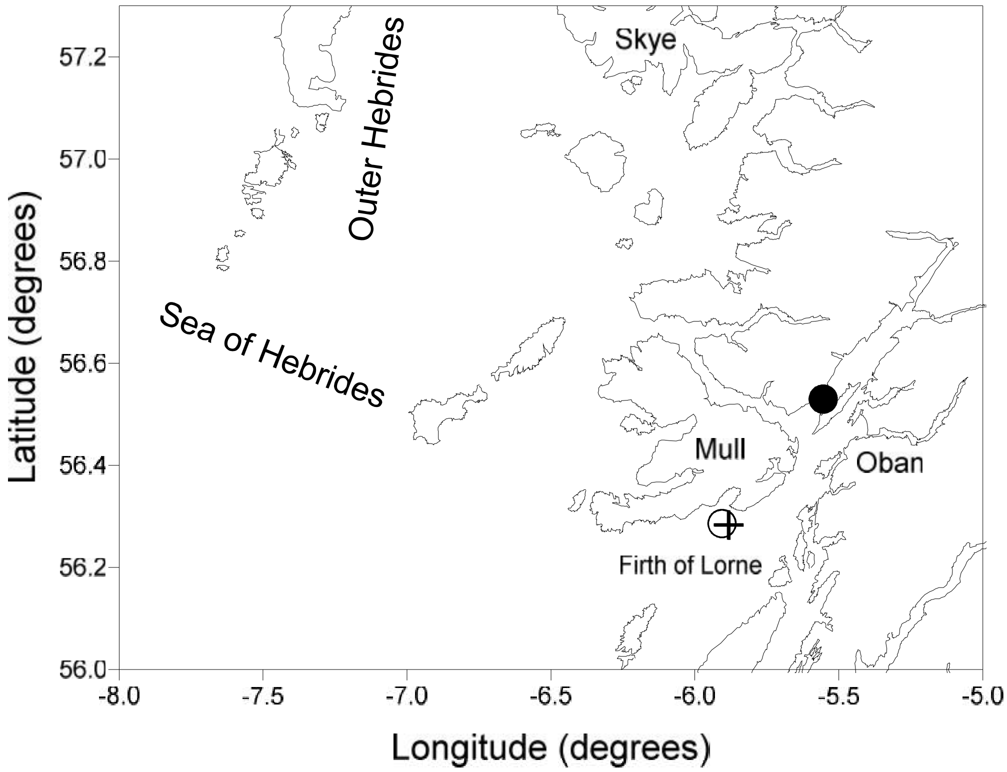


Figure 6-2: Locations for Nephrops behaviour dives. cross 30/03/2017; solid circle 30/11/2017; open circle 30/11/2017-01/12/2017

Because logistically it was not possible to run the behaviour trials meeting a trawler actively fishing, discard-fraction *Nephrops* which had survived the recovery trials were used. *Nephrops* were transported from the SAMS aquarium to the study sites in cool boxes. One to four *Nephrops* were placed in the transport container (Figure 6-3) and the ROV launched.

Figure 6-3: A Nephrops loaded into the transport container prior to launch.

On reaching the seabed it was necessary to wait for up to 5 minutes for sediment stirred up by the landing to clear at which point the lid was released. The behaviour of the *Nephrops* was monitored using the ROV video-camera (Figure 6-4) until either the *Nephrops* had left the field of view, entered a burrow or been lost from camera view.

Figure 6-4: ROV command station on board deployment vessel.

The ROV was then recovered on-board and the GoPro cameras downloaded. Water column temperature and salinity were recorded each day using a Castaway CTD (except for 30/11/2017 when the instrument failed to log).

6.3. **Results**

A summary of the air and water temperatures is given in Table 6.1. A range of technical problems were experienced which reduced the total number of dives completed each day including damage to the ROV tether on 30th Mar; flashing of the video lights caused by a power supply problem on 10th Nov; dragging of the vessel anchor due to increasing wind which halted work on 30th Nov and a water ingress alarm on the ROV which halted work on the 1st Dec. Despite these problems 15 dives were completed at between 70-115 m water depth observing the responses of 23 discard-sized *Nephrops* released on the seabed (Table 6.2).

Based on the initial set of dives from Pole Star the seabed at Loch Bouie was seen to consist of soft mud with numerous *Nephrops* burrows (Figure 6-5). On 10th Nov dives were attempted to the north of Lismore as this site was slightly closer to the SAMS laboratory. However, the seabed here seemed a little courser (muddy-sand) with fewer burrows being seen on the video (Figure 6-6). Even though *Nephrops* potting does occur in this area it seemed a less suitable so the vessel returned to the Loch Bouie site on 30th Nov and 1st Dec. On the last two days there was evidence of burrows on the video but not to the same extent as during the initial dives from 'Pole Star' (Figure 6-7 and Figure 6-8).

Observations from the videos are shown in Table 6.3. The edited videos are available as Supplementary Material to this report.

Nephrops were generally active in the transport pot i.e. exposure to seawater on the ROV dive seemed to revive them. The total time elapsed from entering the sea until release from the pot at the seabed, allowing for sediment stirred up on landing to clear, was around 5-10 minutes. Only *Nephrops* which had been exposed to air for more than 2.5 to 3 h (dives 4 and 15) remained moribund on the seabed when released and even these animals revived and began exploring their surroundings within 10 mins. Where the *Nephrops* were released near holes they generally entered a burrow within a few minutes. At landing locations where burrows were less abundant the *Nephrops* usually walked out of the field-of-view within a few minutes. Their behaviour once recovered therefore seemed normal i.e. moving about with claws raised in defensive postures or entering burrows.

Apart from a few small gadoid fish no other potential predators were seen at the release sites and there were thus no interactions between released *Nephrops* and potential predators.

Attempts to move the ROV in order to track released *Nephrops* for longer simply stirred up large amounts of sediment obscuring the view. Similarly engaging the ROV thrusters to skew the vehicle generated large sediment clouds. Manoeuvring of the vehicle on the seabed was abandoned after a couple of attempts.

6.4. Discussion

Making observations of *Nephrops* behaviour at natural depths is technically challenging. The use of the Mojave remotely-operated-vehicle to release and observe animals generally worked well although several technical problems did arise (see results).

Collection of these underwater observations was time consuming – on average we managed four dives each day taking account of the time required to reach the study locations, deploy anchors (Calanus only) and to prepare and deploy the ROV. For this reason we were unable to test the recovery of damaged animals as this would have required further ROV days than the budget permitted. Furthermore damaged *Nephrops*, particularly those with puncture wounds, have a lower chance of long-term survival as demonstrated in Sections 3 and 4.

The initial behaviour trials were conducted in early spring and the intention had been to continue trials during the summer when air temperatures would be highest. Unfortunately damage to the ROV umbilical on the first trials was not repaired until the autumn so that the remaining trials took place when air temperatures were relatively low. The results may thus not be representative of recovery of *Nephrops* from aerial exposure during summer months.

There was no evidence of potential predators in the videos although this may be site specific. Alternatively predators might have been scared-off by the ROV lights. In previous work in the Clyde released *Nephrops* did attract benthic scavengers after around 10 mins but that study was undertaken in much shallower water and on courser ground (Albalat et al., 2016). Once in burrows the *Nephrops* are probably reasonably safe. In the present study *Nephrops* were able to enter burrows within a few minutes of being released when holes were nearby. If released onto seabed with fewer burrows the *Nephrops* usually walked out of the field-of-view after a few minutes and their fate could not be tracked further.

In the present study the *Nephrops* were protected from predators on the journey to the seabed so this could have under-estimated predation losses in the water column. However, previous studies suggest that once discarded *Nephrops* are away from surface predators, such as seabirds, their descent to the seabed is relatively rapid and in-water column predation rates are low (Bergmann et al., 2002).

All our observations were made on discard-fraction *Nephrops* which had recovered from the earlier experimental trials and had been kept in the aquarium for several months. The original intention had been to conduct the behaviour trials in an area where a *Nephrops* trawler was operating and to transfer discard *Nephrops* to the research vessel. This idea however proved completely impractical in terms of being able to co-ordinate the location of multiple vessels working in the same area on the same days. However, use of recovered *Nephrops* which had been maintained in the aquarium for several months might have biased our results if these animals were stronger or fitter than the wider trawled population.

Given the challenges of conducting underwater behavioural observations on free-swimming animals, we believe the solutions adopted were a reasonable compromise. The behavioural observations collected confirm that undamaged discard-fraction *Nephrops* are able to rapidly resume ‘normal’ exploratory and burrowing behaviour when released on the seabed, even after as much as 3.6 h of aerial exposure, albeit at air temperatures of 6.5°C.

Figure 6-5: Appearance of the seabed at Loch Bouie 30th March 2017, dive 1 downward pointing camera.

Figure 6-6: Appearance of the seabed at Lismore 10th Nov 2017, dive 6, backward pointing camera.

Figure 6-7: Appearance of the seabed at Loch Bouie 30th Nov 2017, dive 10, downward pointing camera.

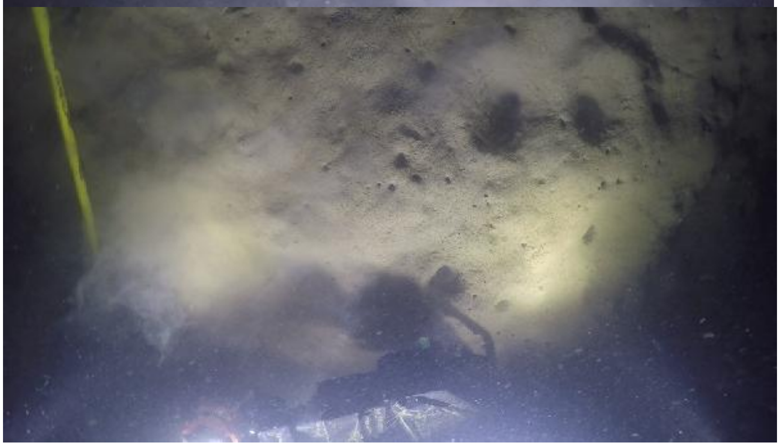


Figure 6-8: Appearance of the seabed at Loch Bouie 1st Dec 2017, dive 12, downward pointing camera.

Table 6.1: Temperature and salinities during the behaviour trials.

Dive	Date	Air temperature (ºC)	Surface water temperature (ºC)	Surface salinity	Bottom temperature (ºC)	Bottom salinity
1-4	30/03/2017	13.7	8.2	34.0	8.2	34.1
5-8	10/11/2017	5.6	12.1	31.6	13.0	33.0
9-13	30/11/2017	5.6	CTD failed			
14-18	01/12/2017	6.5	10.5	32.7	11.7	34.2

Table 6.2: Details of Nephrops behaviour dives.

Dive	Prawn	Site	Date	Lat	Lon	Dep (m)	Time dive	Time release	Carapace length (mm)	Sex	Berried	Damage	Vigour	Reflex	Time in air (h)
1	1	Bouie	30/03/2017	56.286	-5.906	110	08:30	08:37	25.4	M		0	1	0	0
2	2	Bouie	30/03/2017	56.286	-5.906	110	09:25	09:35	24.4	M		TAPH, THPH	1	0	0
3	3	Bouie	30/03/2017	56.286	-5.906	106	09:45	10:25	24.4	M		THP	1	0	0
3	4	Bouie	30/03/2017	56.286	-5.906	106	09:45	10:25	22.8	F	N	0	1	0	0
4	5	Bouie	30/03/2017	56.286	-5.906	115	11:40	11:50	27.0	M		0	4	2	2.75
4	6	Bouie	30/03/2017	56.286	-5.906	115	11:40	11:50	25.9	M		THP	3	1	2.75
4	7	Bouie	30/03/2017	56.286	-5.906	115	11:40	11:50	24.2	F	N	0	4	3	2.75
4	8	Bouie	30/03/2017	56.286	-5.906	115	11:40	11:50	26.6	F	N	0	3	1	2.75
5	9	Lismore	10/11/2017	56.530	-5.554	70	12:33	12:44	27.6	M		0	1	0	0
6	10	Lismore	10/11/2017	56.530	-5.554	70	13:20	13:24	27.4	M		0	1	0	0
7	11	Lismore	10/11/2017	56.530	-5.554	70	14:00	14:07	29.6	M		LEG	1	0	0
8	12	Lismore	10/11/2017	56.530	-5.554	70	14:47	14:55	24.8	F	N	0	3	3	0
9	13	Bouie	30/11/2017	56.283	-5.884	84	10:59	11:12	26.5	F	N	0	1	0	0
10	14	Bouie	30/11/2017	56.283	-5.884	84	11:55	12:06	27.4	M		0	1	0	0
11	15	Bouie	30/11/2017	56.283	-5.884	84	12:49	12:56	26.3	F	Y	0	2	3	0
12	16	Bouie	01/12/2017	56.283	-5.884	84	10:44	10:51	30.0	M		TAPH	2	0	1.3
12	17	Bouie	01/12/2017	56.283	-5.884	84	10:44	10:51	28.6	M		TAPH	2	0	1.3
13	18	Bouie	01/12/2017	56.283	-5.884	84	11:25	11:31	24.5	M		TAPH	2	0	2
13	19	Bouie	01/12/2017	56.283	-5.884	84	11:25	11:31	26.7	F	Y	0	3	1	2
14	20	Bouie	01/12/2017	56.283	-5.884	84	12:20	12:28	29.0	M		0	1	0	2.25
14	21	Bouie	01/12/2017	56.283	-5.884	84	12:20	12:28	24.6	F	Y	D2	2	0	2.25
15	22	Bouie	01/12/2017	56.283	-5.884	84	13:06	13:16	30.6	M		LEG	1	0	3.6
15	23	Bouie	01/12/2017	56.283	-5.884	84	13:06	13:16	26.8	M		TAIL	2	0	3.6

Table 6.3: Video observations – the video clips are in the Supplementary Materials accompanying this report.

Dive	Aerial exposure	Elapsed time (mins)	Observations - elapsed time from just before release
1	0	00:23	*Nephrops* active in pot, pot rotated
		00:44	Claw caught under pot edge, *Nephrops* escapes
		01:01	*Nephrops* exploring with claw up defensive posture
		01:17	*Nephrops* exited FOV bottom left
2	0	00:09	*Nephrops* released
		00:34	*Nephrops* exploring with claws up defensive posture
		00:43	*Nephrops* reverses into burrow
3	0	00:00	Only low resolution ROV camera footage available
		00:15	*Nephrops* released; One on seabed, one in pot; Both *Nephrops* active
		00:20	One *Nephrops* enters burrow just under ROV arm
		00:38	Second *Nephrops* lands on seabed
		00:43	Second *Nephrops* exploring seabed with claws up in defensive posture
		01:33	ROV arm moved to try and clear view
		01:43	Second *Nephrops* still moving around on seabed just behind ROV arm
		02:12	ROV arm moved again to try and clear view
		03:05	Still exploring
		03:57	*Nephrops* reverses into burrow or depression
		04:19	*Nephrops* partially reverses into burrow
		05:21	*Nephrops* emerged from burrow again and begins exploring seabed again
		08:15	Nephrops exploring another hole just in front of ROV arm
		08:39	*Nephrops* probably in burrow although FOV obscured by ROV arm
		09:44	ROV rotated slightly, confirm *Nephrops* almost into burrow; ROV departs
4	2.75	00:01	One *Nephrops* enters burrow immediately; Two *Nephrops* on seabed, limited movement
		01:54	*Nephrops* on seabed starting to show signs of recovery
		02:20	*Nephrops* on seabed starting to explore
		03:18	Second *Nephrops* reverses into a burrow but remains partially out

Table 6.3: Video observations – the video clips are in the Supplementary Materials accompanying this report.

Dive	Aerial exposure	Elapsed time	Observations - elapsed time from just before release
		04:55	Third *Nephrops* not very active
		06:15	Third *Nephrops* begins exploring
		07:02	Second *Nephrops* clearing burrow
		08:48	Interaction between second and third *Nephrops*
		09:52	ROV arm moved
		09:59	ROV departs
5	0	00:00	ROV lights pulsating, problems with video; Video trimmed to try and improve
		00:25	*Nephrops* moving around in pot
		01:15	*Nephrops* emerging from pot, beginning to explore
		02:22	*Nephrops* under ROV arm
		05:34	ROV arm retracted
		06:03	*Nephrops* buried under mud when ROV arm moved
		06:17	*Nephrops* exploring
		07:16	ROV departs as not much happening and need to check video for lights problem
6	0	00:00	*Nephrops* active in pot on descent; Less burrows visible in FOV
		00:13	*Nephrops* released
		00:46	*Nephrops* begins exploring with claws in raised defensive posture
		03:29	*Nephrops* exits FOV but then returns
		04:14	*Nephrops* under ROV arm
		04:49	*Nephrops* lost from camera view
7	0	00:12	*Nephrops* released, view obscured by ROV arm
		00:27	*Nephrops* moving around on seabed
		00:49	*Nephrops* walking across seabed away from ROV
		01:15	*Nephrops* at edge of FOV
		01:16	*Nephrops* moved out of FOV
8	0	00:00	*Nephrops* active in pot; RO floodlights not working, limited illumination field
		00:35	*Nephrops* released
		01:18	*Nephrops* exploring seabed but obscured by ROV arm
		01:41	*Nephrops* walking out of FOV
9	0	00:04	*Nephrop*s released; *Nephrops* active but doesn't want to leave pot

Table 6.3: Video observations – the video clips are in the Supplementary Materials accompanying this report.

Dive	Aerial exposure	Elapsed time	Observations - elapsed time from just before release
		00:23	Pot rotated
		00:34	On seabed, claws up defensive posture
		01:12	*Nephrops* exploring seabed
		01:58	ROV bouncing a little
		03:02	*Nephrops* left FOV
10	0	00:05	*Nephrops* exit pot
		00:14	*Nephrops* begins exploring, claws up in defensive posture
		00:53	*Nephrops* under ROV arm
11	1.3	00:25	Lights pulsating; *Nephrops* trying to get back into pot
		00:42	*Nephrops* on seabed
		01:24	Begins to explore
		01:49	Enters burrow head first
12	1.3	00:14	Release, one *Nephrops* escapes pot with tailflips, other to seabed
		00:26	First *Nephrops* walks out of FOV
		01:43	Second *Nephrops* under ROV arm but cleaning itself
		02:29	Not much more obvious movement
		07:07	Sediments stirred up by ROV umbilical
13	2	00:00	ROV umbilical dragging a bit
		00:29	Male *Nephrops* on seabed, female in pot
		01:01	Female *Nephrops* leaves pot and walks under umbilical
		01:02	Male *Nephrops* appears caught under pot
		01:44	Female *Nephrops* leave FOV
		01:58	Female *Nephrops* re-enters FOV
		02:31	Female *Nephrops* interacts with ROV umbilical
		02:57	Female *Nephrops* leaves FOV
		04:08	ROV umbilical moves under pot
		04:17	Male *Nephrops* moving around under pot
		06:19	ROV shifted by current
		06:33	Male *Nephrops* exploring, claws in defensive posture
		07:00	Male *Nephrops* moves out of FOV
14		00:00	*Nephrops* active in pot
		00:23	Lid released but *Nephrops* remain in pot
		00:28	Pot rotated
		00:58	One *Nephrops* hidden under pot, the other cleaning its legs

Table 6.3: Video observations – the video clips are in the Supplementary Materials accompanying this report.

Dive	Aerial exposure	Elapsed time	Observations - elapsed time from just before release
		01:13	One *Nephrops* headed to edge of FOV and becomes obscured by silt
		07:23	Second *Nephrops* appears to shelter by pot lid
		07:24	First *Nephrops* visible again at edge of FOV
		10:52	ROV arm moved out of way
		11:18	First *Nephrops* moving around, claws in defensive posture
		11:39	ROV departs
15	3.6	00:04	Lid released
		00:10	*Nephrops* on seabed - right themselves
		00:41	Moving around on seabed with claws in defensive posture
		03:52	One *Nephrops* actively exploring; second *Nephrop*s under ROV arm
		04:35	*Nephrops* exploring a depression or partially collapsed burrow
		04:46	*Nephrops* seems to be excavating partially collapsed burrow
		05:30	Second *Nephrops* moving around under ROV arm
		06:07	ROV water ingress alarm; Main ROV lights failed; Dive aborted

7. Summary of estimated survival rates for discarded *Nephrops*.

Objective 4. Based on 1-3, generate a robust estimated level of Nephrops discard survival that is representative of the investigated fisheries, with any assumptions clearly stated.

7.1. Introduction

In this section we summarise the results from the recovery trials carried out in the Minches and the Firth of Forth.

7.2. Methods

Weibull-based survival estimates for discard-fraction *Nephrops* were calculated using the animals sampled towards the end of catch sorting in order to check whether the length of catch sorting had any impact on survival. However, this was only possible for the Ocean Trust winter and Winaway summer trials because *Nephrops* were not sampled for recovery from the initial 12 trials (Ocean Trust summer).

The Weibull-based estimated final survival values for each discard recovery trial (Table *3.20* and Table 4.11) were corrected for the recorded proportion of discard fraction *Nephrops* alive during the sorting of each catch (Table 3.5, Table 3.6 and Table 4.3). The proportion alive during catch sorting on trial 1 was not recorded so the mean value for the Ocean Trust summer tows was used for that trial. For the Ocean Trust data, regression modelling (reported in Section 3.3.4) suggested that season but not gear was a significant factor affecting discard recovery. The overall estimates of the seasonal Weibull-based estimators were therefore corrected using the mean of the recorded proportion of discard fraction *Nephrops* alive during sorting for tows during that season.

Potential relationships between corrected final survival estimates and other variables measured during the trials were explored using pairs plots and multiple linear regression. In the latter non-significant variables were sequentially dropped testing model simplification at each step using ANOVA. The results were checked against automated stepwise regression using the step function which employs AIC to evaluate model simplification (R MASS library).

7.3. Results and discussion

The official landings statistics for both west coast (Table 3.1) and east coast, Firth of Forth (Table 4.1) indicated most *Nephrops* landings as coming from single-rig trawls which did not accord with impressions on the ground. It may be that landings are being mis-recorded to the OTB code (otter trawls bottom) rather than the OTT code (otter trawls twin) but investigating this further was outside the scope of the present project. This issue did however cause considerable confusion in terms of selecting appropriate vessels for the discard survival trials and trying to ensure that such vessels would be representative of the broader fishing fleet.

Plotting the discard-fraction *Nephrops* survival estimates based only on animals sampled towards the end of catch sorting against the total time taken to sort catches (Figure 7-1) indicated that there was no impact of the length of sorting time on survival (linear regression slope difference from zero $p>0.05$). This supports the use of animals sampled either towards the start of the catch sorting (trials 1-12, 30) or a mix of animals sampled towards the start and end of catch sorting (trials 13-29) for estimating survival of discard-fraction *Nephrops*. However, it must be cautioned that sorting times on 'Ocean Trust' summer tows were in some instances longer than the maximum catch sorting time for tows where start and end sampling could be compared. Furthermore, 'Winaway' summer sampling took place at night avoiding higher daytime air temperatures. The length of catch sampling might thus have an impact on discard-fraction *Nephrops* survival, particularly for daytime summer tows, but this could not be tested using the available data.

A summary of the final recovery trial results, including the correction for discard fraction *Nephrops* alive during sorting, is given in Table 7-1. Boxplots of the final survival estimates are shown in Figure 7-2. All three groups were statistically different (ANOVA followed by Tukey HSD, $p<0.05$). On the west coast survival was therefore better during winter versus summer trials. However, survival on the east coast summer trials was markedly better than on either of the west coast trials. The corrected final mean survival estimates were thus 53.8% for the west coast in summer, 59.9% for the west coast in winter and 78.4% for the Firth of Forth in summer.

A number of factors were recorded during the trials which could explain these differences (Table 7.2). Pairwise comparisons of these relationships are shown in Figure 7-3. A number of the significant relationships are considered to be trivial e.g. it is not surprising that total catch weight and the catch weight of *Nephrops* were strongly correlated or that the percentages of *Nephrops* in the different vigour classes are linked (because each animal had to be assigned to one of four classes). These trivial relationships are indicated in Figure 7-3 with light grey shading and are not considered further. The pairs plot suggests that corrected final survival might be negatively linked with total catch weight, the percentage of animals damaged at end (healed injuries excluded), the weight of non-*Nephrops* catch and the percentage of animals in vigour category 4. A potential positive relationship with the percentage of animals in vigour category 3 was also identified. The pairs plot did not suggest any other obvious non-linear relationships which might be worth exploring further. The five significant relationships are shown in more detail in Figure 7-4. There does appear to be reasonably linear relationships between corrected final survival and these factors, albeit with a large scatter. For non-*Nephrops* catch the variance increases strongly with the weight so a log-transformation might be appropriate. The relationships also show clear grouping of Winaway versus Ocean Trust datapoints. For the damage score, Winaway tows are grouped to the upper left showing low damage and high survival whilst the majority of the Ocean Trust tows had higher levels of damage and lower survival. Similarly for non-*Nephrops* catch the values for Winaway tended to be at the low end of the range seen in Ocean Trust. Total catch weights and vigour scores covered more of the Ocean Trust range, although Ocean Trust still tended to include a greater proportion of higher values.

The factors can be combined in a single multiple regression model (Table 7.5). Two of the factors are themselves correlated, percentage damaged at end (healed) with vigour category 3 (Figure 7-3), and one would expect one of these to be dropped in the multiple regression model. The results for Model 1 (all factors included) suggested that total catch weight and vigour 3 should be dropped. This results in the simplified final model (Table 7.5) which explained around 67% of the variance in the survival results. The same final model was arrived at using the step function in the R MASS library. Decreased final survival is this associated with increases in percentage of *Nephrops* damaged scored at time of death or end of the recovery period (excluding healed wounds), the weight of non-*Nephrops* catch in the tow and the percentage of discard fraction *Nephrops* in the poorest vigour category during catch sorting.

Our interpretation of this result is that the recovery of discard fraction *Nephrops* is most strongly related to the amount of major trauma (percentage of animals damaged at end excluding healed wounds) and stress (percentage of animals in vigour category 4 during catch sorting) generated during trawling and subsequent handling. This makes sense from the physical damage aspect in particular because previous studies have shown *Nephrops* to be susceptible to puncture injuries (Wileman et al. 1999). Furthermore, the Weibull-regression modelling undertaken in sections 3.3.4 and 4.3.4 clearly showed large differences in survival between undamaged and damaged *Nephrops* at the individual level. The amount of non-*Nephrops* catch also seemed to be important. However, it was not possible to directly link final survival to factors, which might be expected to impact trauma and stress, such as air temperature, tow length or catch weights (Figure 7-3).

Nevertheless, one of the factors retained in the final multiple regression model, vigour in category 4, was itself correlated with hopper air temperature (Figure 7-3 and Figure 7-5). For the Ocean Trust data this link might explain the significant relationship between survival and air temperature previously noted. However, percentages of *Nephrops* in vigour category 4 from the Winaway summer trials were more comparable to the vigour 4 percentages on Ocean Trust during winter trials. When these data are combined (Figure 7-5), the previously significant direct relationship between survival and air temperature became non-significant.

The combined data indicate that discard fraction *Nephrops* on Winaway generally had lower levels of serious physical damage compared to Ocean Trust (Table 7.3) and the percentage of *Nephrops* in the lowest vigour category was closer to the values recorded during winter on Ocean Trust (Table 7.4). Taken together this seems to have resulted in very high levels of recovery (> 70%) for discarded *Nephrops* sampled from the Firth of Forth. In the combined data (Figure 7-5) these very high survivals for discards from the Firth of Forth also had the effect of over-riding the previously noted relationship between survival and hopper air temperatures from the west coast data (Figure 3-37). Because winter survival data are not available from the Firth of Forth at present is was not possible to examine if any air temperature or water temperature during recovery effect might be apparent for the east coast.

It is difficult to identify the reasons behind the difference between the Minches and Firth of Forth results given that the studies were undertaken on single vessels in each area. One notable difference between the two vessels was in their hopper design. Ocean Trust has a large flat-bottomed hopper and *Nephrops* are pulled through a single opening onto the sorting tray using a rake. On Winaway the hopper has a sloping floor opening onto three exits and the animals are drawn through by hand. It is tempting to speculate that it is this difference in hopper design which resulted in the different levels of physical damage and stress to the discard fraction *Nephrops* comparing the Minches and Firth of Forth. However, there was another factor which was also retained in the final multiple regression model (Table 7.5), namely the amounts of non-*Nephrops* discards which tended to be higher in the Minches compared with the Firth of Forth (Figure 7-4). Further data collected across multiple vessels would be required to investigate whether it is the hopper design or the amount of non-*Nephrops* catch which is affecting damage and stress in the discard fraction *Nephrops*. Nevertheless, measures to reduce physical damage and stress could improve discard recovery rates further and are discussed in section 8.

Table 7-1: Final estimates for discard fraction Nephrops survival combining Weibull-based estimation with the proportion of discard fraction Nephrops alive during catch sorting.

Trial	Ship	Season	Gear	Survival	LCL	UCL	Alive during catch sorting (%)	Corrected survival	Corrected LCL	Corrected UCL
1	Ocean Trust	Summer	TR1	0.753	0.661	0.859	85[4]	0.640	0.562	0.730
2			TR1	0.500	0.411	0.608	69	0.345	0.284	0.420
3			TR1	0.490	0.401	0.598	85	0.417	0.341	0.508
4			TR1	0.310	0.231	0.415	88	0.273	0.203	0.365
5			TR1	0.455	0.366	0.564	85	0.387	0.311	0.479
6			TR1	0.660	0.573	0.760	86	0.568	0.493	0.654
7			TR2	0.610	0.522	0.713	83	0.506	0.433	0.592
8			TR2	0.707	0.623	0.803	89	0.629	0.554	0.715
9			TR2	0.560	0.471	0.666	84	0.470	0.396	0.559
10			TR2	0.663	0.576	0.764	89	0.590	0.513	0.680
11			TR2	0.469	0.380	0.79	88	0.413	0.334	0.510
12			TR2	0.410	0.324	0.519	94	0.385	0.305	0.488
		Total summer	Both	0.538	0.510	0.569	85	0.457	0.434	0.483

[4] The proportion alive during discard sorting was not recorded on the first trial so the mean of the Ocean Trust summer tows has been used

Table 7-1: Final estimates for discard fraction Nephrops survival combining Weibull-based estimation with the proportion of discard fraction Nephrops alive during catch sorting.

Table 7-1 continued.

Trial	Ship	Season	Gear	Survival	LCL	UCL	Alive during catch sorting	Corrected survival	Corrected LCL	Corrected UCL
13	Ocean Trust	Winter	TR1	0.664	0.593	0.745	96	0.637	0.569	0.715
14			TR1	0.718	0.649	0.794	96	0.689	0.623	0.762
15			TR1	0.707	0.637	0.783	93	0.658	0.592	0.728
16			TR1	0.720	0.652	0.796	89	0.641	0.580	0.708
17			TR1	0.660	0.588	0.740	85	0.561	0.500	0.629
18			TR1	0.753	0.687	0.826	83	0.625	0.570	0.686
19			TR2	0.467	0.393	0.554	89	0.416	0.350	0.493
20			TR2	0.567	0.493	0.652	91	0.516	0.449	0.593
21			TR2	0.701	0.630	0.779	91	0.638	0.573	0.709
22			TR2	0.720	0.652	0.796	91	0.655	0.593	0.724
23			TR2	0.610	0.534	0.698	89	0.543	0.475	0.621
24			TR2	0.651	0.579	0.732	91	0.592	0.527	0.666
	Ocean Trust	Total winter	Both	0.626	0.594	0.660	90	0.563	0.535	0.594
	Ocean Trust	Both	Both	0.599	0.578	0.620	88	0.527	0.509	0.546
25	Winaway	Summer	TR2	0.787	0.724	0.855	97	0.763	0.702	0.829
26			TR2	0.747	0.680	0.820	97	0.725	0.660	0.795
27			TR2	0.760	0.695	0.832	91	0.692	0.632	0.757
28			TR2	0.733	0.666	0.808	97	0.711	0.646	0.784
29			TR2	0.833	0.776	0.895	94	0.783	0.729	0.841
30			TR2	0.900	0.843	0.961	95	0.855	0.801	0.913
	Winaway	Total summer	TR2	0.784	0.756	0.812	95	0.745	0.718	0.771

Table 7.2: Summary of final survival estimates with other potentially important factors measured during the trials.

Trial	Ship	Season	Gear code	Corrected survival	Corrected LCL	Corrected UCL	Hopper temperature (ºC)	Total catch (kg)	Catch *Nephrops* (kg)	Non-Nephrops catch (fish etc) (kg)	Damaged scored at time of death or recovery (%)	Damaged scored at time of death or recovery excluding healed injuries (%)
1	Ocean Trust	Summer	TR1	0.640	0.562	0.730	14.3	207	177	30.0	47.9	38.4
2			TR1	0.345	0.284	0.420	15.0	253	193	60.0	52.0	41.0
3			TR1	0.417	0.341	0.508	13.8	452	370	82.0	62.0	55.0
4			TR1	0.273	0.203	0.365	15.0	602	502	100.0	61.0	53.0
5			TR1	0.387	0.311	0.479	19.0	348	304	44.8	66.7	55.6
6			TR1	0.568	0.493	0.654	19.0	347	308	38.0	51.0	43.0
7			TR2	0.506	0.433	0.592	17.0	232	168	64.2	72.0	60.0
8			TR2	0.629	0.554	0.715	16.5	170	124	45.4	53.5	46.5
9			TR2	0.470	0.396	0.559	15.2	346	205	141.4	64.0	54.0
10			TR2	0.590	0.513	0.680	15.6	246	116	130.2	59.2	51.0
11			TR2	0.413	0.334	0.510	16.4	319	195	124.1	67.3	59.2
12			TR2	0.385	0.305	0.488	14.2	169	103	66.2	59.0	50.0
13		Winter	TR1	0.637	0.569	0.715	11.5	190	148	42.5	49.0	43.6
14			TR1	0.689	0.623	0.762	10.1	177	124	53.5	49.0	36.7
15			TR1	0.658	0.592	0.728	10.2	189	105	84.5	68.0	50.7
16			TR1	0.641	0.580	0.708	9.6	204	156	48.3	69.3	52.7
17			TR1	0.561	0.500	0.629	10.4	306	252	54.5	78.0	60.7
18			TR1	0.625	0.570	0.686	10.1	372	311	61.8	78.0	56.7
19			TR2	0.416	0.350	0.493	10.4	318	265	53.0	90.0	76.7
20			TR2	0.516	0.449	0.593	10.5	196	155	41.0	72.0	59.3
21			TR2	0.638	0.573	0.709	8.2	293	247	46.3	59.2	43.5
22			TR2	0.655	0.593	0.724	6.9	203	178	26.0	66.7	57.3
23			TR2	0.543	0.475	0.621	7.5	212	167	44.8	68.4	64.2
24			TR2	0.592	0.527	0.666	7.5	152	124	28.7	60.0	55.3

Table 7.2 continued.

25	Winaway	Summer	TR2	0.763	0.702	0.829	14.6	328	288	40.9	56.0	40.9
26			TR2	0.725	0.660	0.795	15.1	276	209	66.7	61.3	46.3
27			TR2	0.692	0.632	0.757	15.2	397	385	12.4	70.0	45.6
28			TR2	0.711	0.646	0.784	13.3	229	220	9.1	58.7	41.6
29			TR2	0.783	0.729	0.841	15.8	285	278	7.8	64.7	44.7
30			TR2	0.855	0.801	0.913	16.3	109	105	4.3	54.0	35.0

Table 7.3: Distribution (mean ± 95% CI) of discard fraction Nephrops physical damage scores comparing Ocean Trust and Winaway.

Ship	Season	Gear	Damaged scored on-board (%)	Damaged scored at time of death or recovery (%)	Damaged scored at time of death or recovery excluding healed injuries (%)
Ocean Trust	Summer	Both	40.2±4.2	59.6±4.7	50.5±4.5
	Winter	Both	39.3±7.0	67.2±7.6	54.8±6.7
	Both	Both	39.8±3.7	63.4±4.4	52.7±3.8
Winaway	Summer	TR2	35.3±3.0	60.8±6.2	42.4±4.4

Table 7.4: Distribution (mean ± 95% CI) of discard fraction Nephrops vigour categories scored during catch sorting comparing Ocean Trust and Winaway.

Ship	Season	Gear code	Percentage in vigour categories			
			1	2	3	4
Ocean Trust	Summer	Both	2.0±1.3	14.4±2.9	54.1±4.0	29.4±4.1
	Winter	Both	4.2±2.0	25.8±9.1	55.6±12.0	14.5±3.5
Winaway	Summer	TR2	6.3±5.5	16.7±11.9	60.0±11.2	17.2±7.6

Table 7.5: Multiple linear regression models for final survival versus damage and catch weight.

Starting model: Final survival ~ DamageEndHealed + Total catch wt_kg + log(non-Nephrops catch) + Vigour 3 + Vigour4

Coefficients	Est	s.e.	t value	P(>|t|)
Intercept	1.377	0.170	8.080	<0.001
Damaged End Healed (%)	-0.005	0.002	-2.346	0.028
TotalCatchWt (kg)	0.000	0.000	-1.076	0.293
log(Non-*Nephrops* Catch)	-0.070	0.022	-3.226	0.004
Vigour 3 (%)	-0.001	0.001	-0.658	0.517
Vigour 4 (%)	-0.006	0.002	-3.478	0.002
Residual s.e.	0.083			
Multiple R^2	0.686	Adjusted R^2	0.621	
F statistic	10.49	DF (5,24)	p	<0.001

Final model: Final survival ~ DamageEndHealed + log(non-*Nephrops* catch) + Vigour4

Coefficients	Est	s.e.	t value	P(>|t|)
Intercept	1.280	0.097	13.192	<0.001
Damaged End Healed (%)	-0.004	0.002	-2.406	0.024
log(Non-*Nephrops* Catch)	-0.075	0.021	-3.585	0.001
Vigour 4 (%)	-0.006	0.002	-3.965	0.001
Multiple R^2	0.667	Adjusted R^2	0.629	
F statistic	17.39	DF (3,26)	p	<0.001

Figure 7-1 Relationship between total time taken to sort catches and the survival estimates for discard-fraction Nephrops when the animals were sampled towards the end of catch sorting.

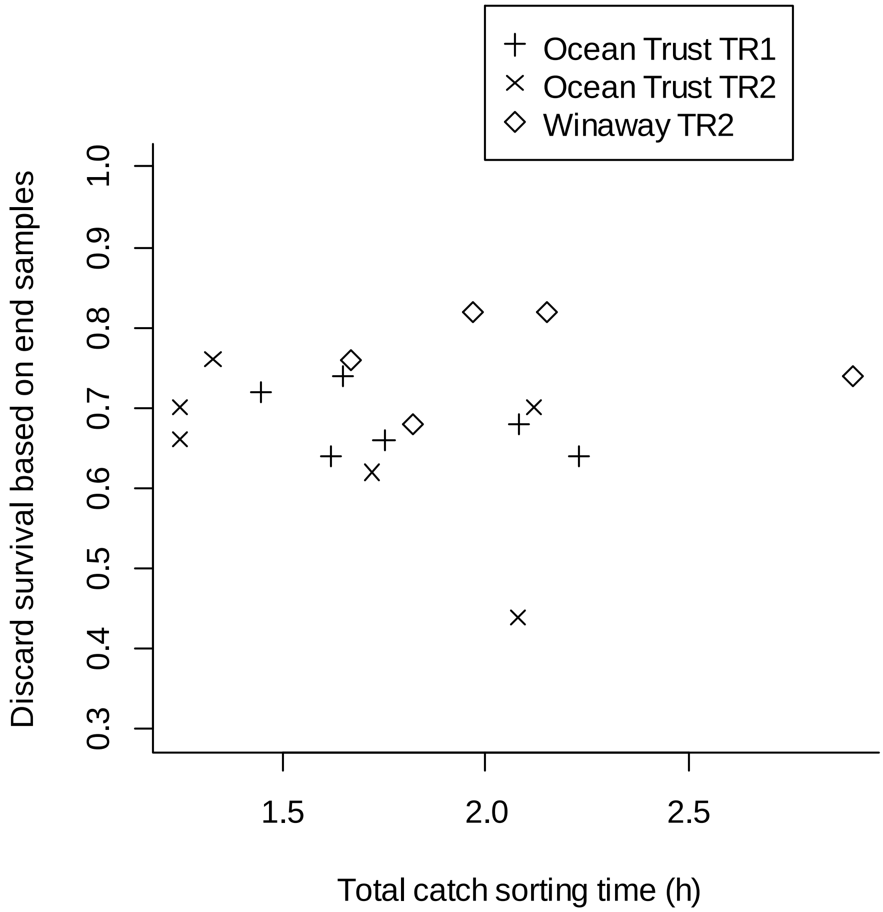


Figure 7-2: Boxplots of the final survival estimates (left panel) and final survival estimates corrected for proportion of discard fraction Nephrops alive during catch sorting (right panel) from the discard recovery trials partitioned by season.

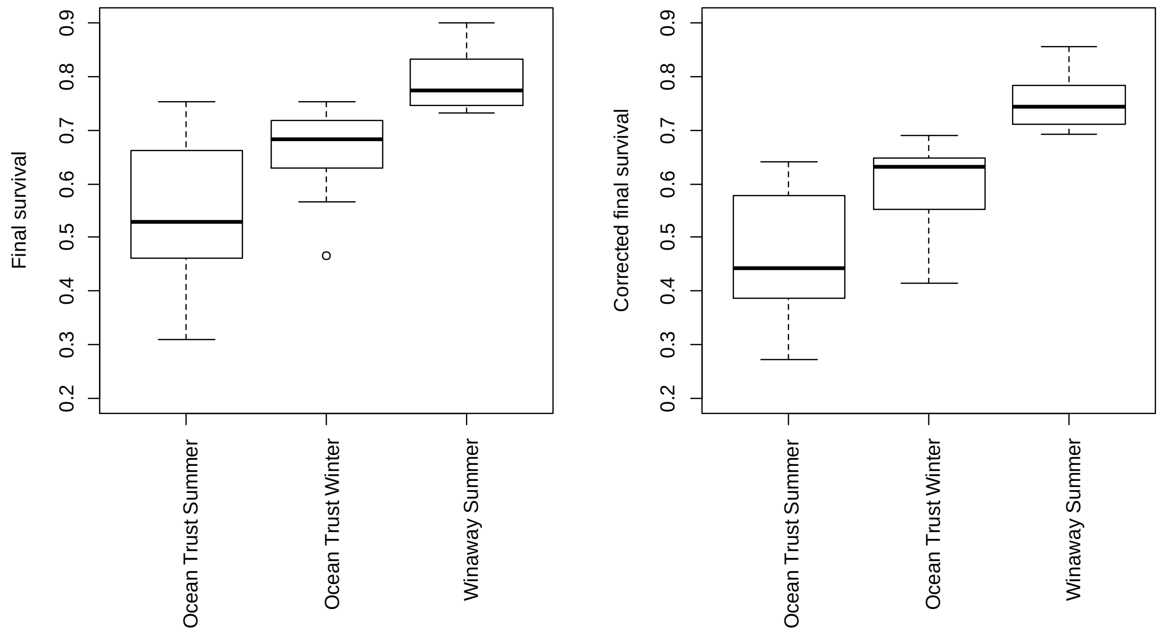


Figure 7-3: Pairs plot for the final survival estimates against other variables measured during the trials. Comparisons marked with asterisks are significant correlations (using the standard p<0.05, <0.01 or <0.001 levels); pink shading indicates relation with corrected final survival, light blue shading indicates relation between other variables, light grey shading indicates trivial relationships.

Figure 7-4: Scatterplots for the relation between corrected final survival by trial and other variables identified as potential significant factors related to corrected final survival in Figure 7-3.

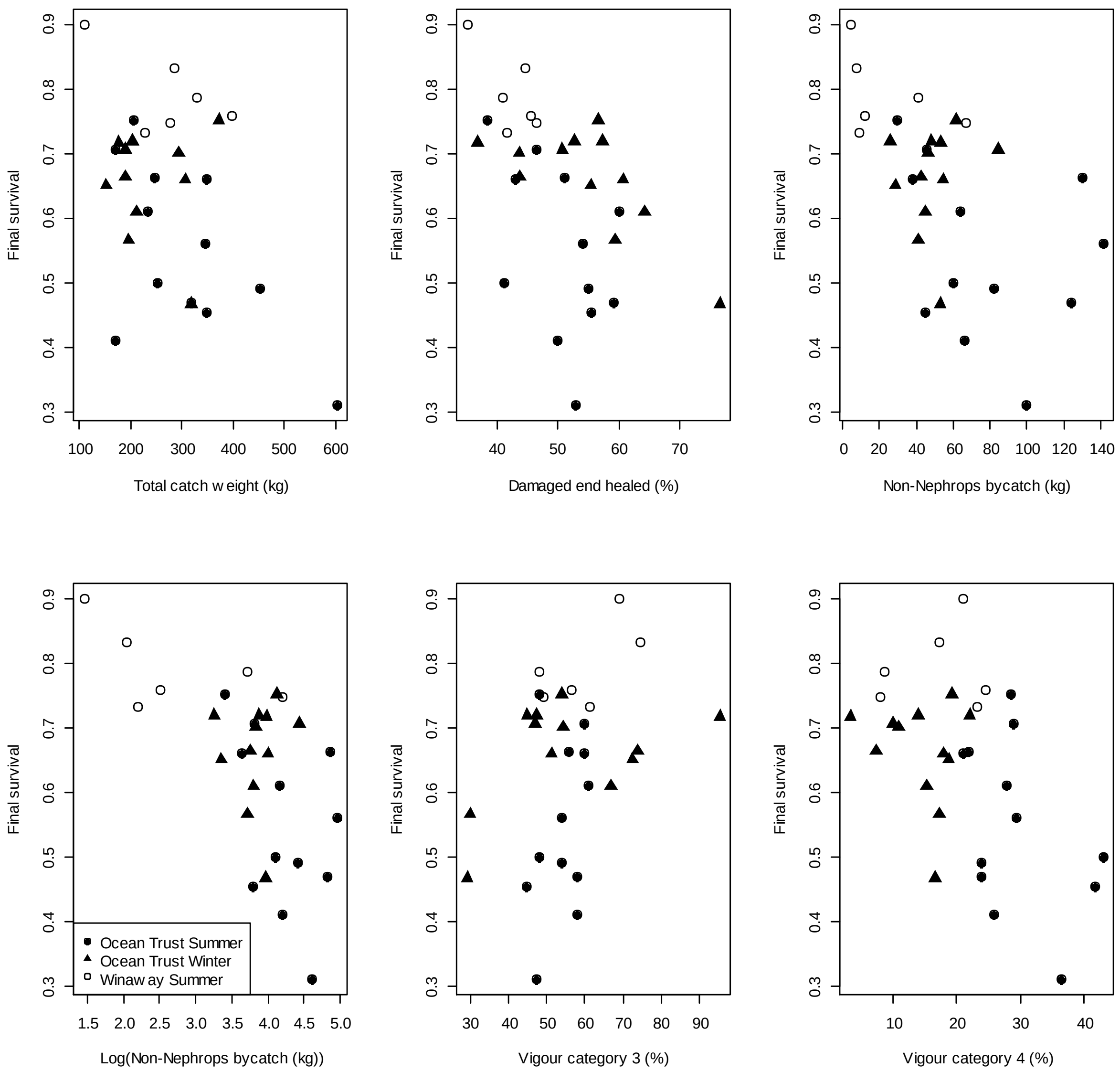
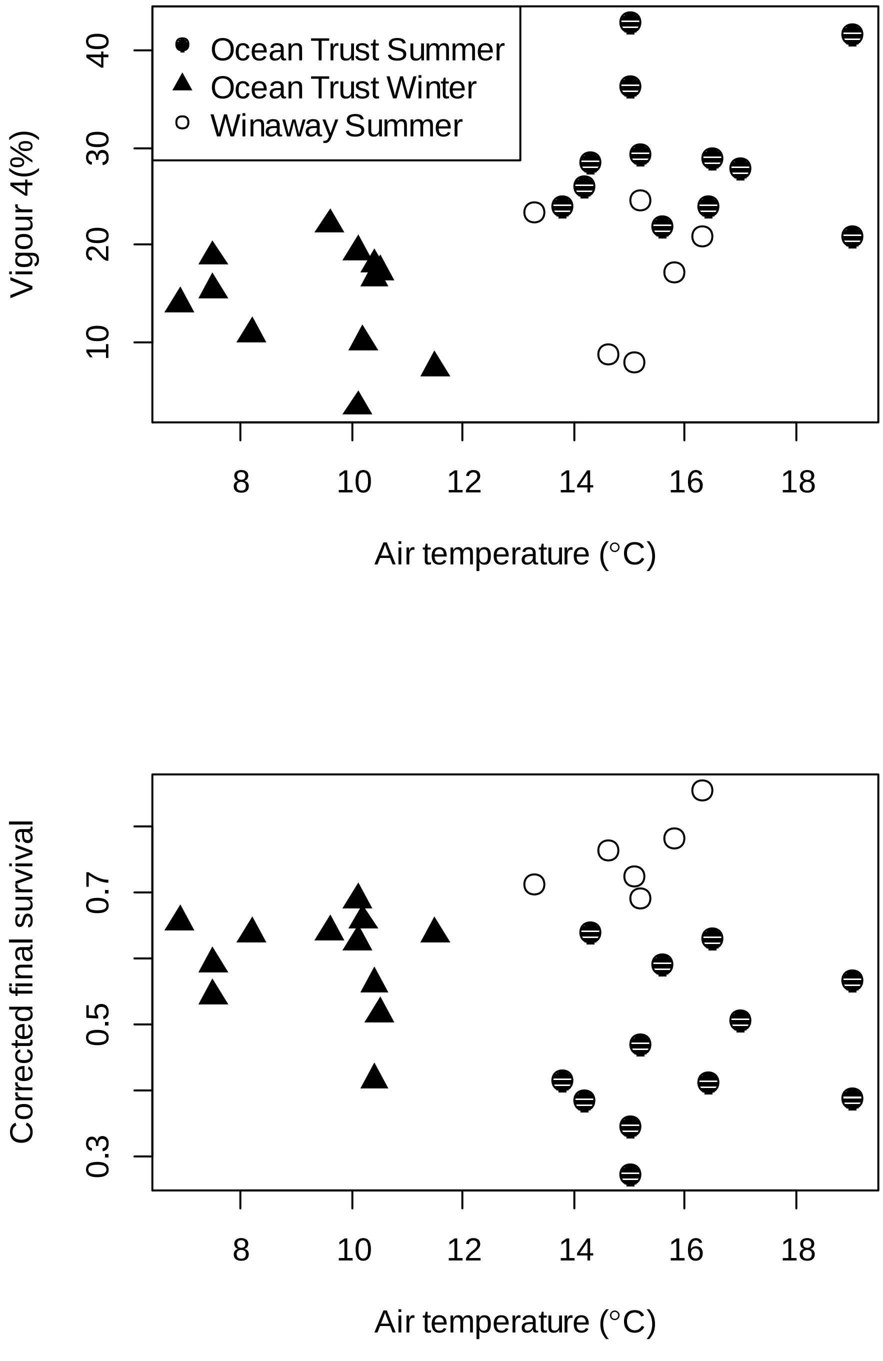


Figure 7-5: Relationship between percentage of discard fraction Nephrops assigned to vigour category 4 during catch sorting (upper panel) and the corrected final survival versus hopper air temperatures (lower panel).



8. Recommendations for best-practice to minimise post-discard mortality rates.

Objective 5. Taking into consideration data collected the project will evaluate which environmental and on-board factors are causative determinants for survival and will produce recommendations for best practice to minimise post-discard mortality rates.

8.1. Summary of main factors linked to post-discard survival and leading to some recommendations

Survival estimates taking into consideration mortality after catch for the west coast (Minches fleet) were determined to be between 43.4-48.3% in the summer, between 53.5-59.4% in the winter and between 71.8-77.1% for the Firth of Forth in the summer.

According to the data analysis carried out in section 7, lower final survival estimates are associated with the percentage of discard fraction *Nephrops* in the poorest vigour category (VC=4) during catch sorting, increases in the percentage of *Nephrops* damaged and the weight on non-*Nephrops* catch. Therefore, recommendations in this section are targeted at these identified survival-related factors. Furthermore, as the percentage of discards *Nephrops* scored as vigour index 4 was associated with air temperature controlling measures to mitigate the effect air temperature are included.

8.2. Recommendations

Potential Mitigation Measures

To identify mitigation measures that would potentially increase the probability of survival for discarded *Nephrops,* each of the significant results were explored:

- Air temperature
- Vigour of discarded *Nephrops*
- Damage of discarded *Nephrops*
- Catch weight

Air temperatures

In this project, a higher percentage of animals with vigour index 4 after capture was found in the summer (29.4 ± 4.1 %) compared to the winter (14.5 ± 3.5 %) suggesting an association of air temperature and vigour condition. Moreover, the effect of air temperature was not only shown when looking at the vigour index after capture but also partially shown in the west coast estimates of survival as higher estimates were obtained in the summer compared to winter trials (Weibull-survival regression, $p<0.001$).

Stressors associated with trawling include a tail flipping response as animals try to escape from the net (Newland and Chapman, 1989) and oxygen deprivation as a result of emersion in air while animals are been sorted (Spicer et al., 1990). During emersion, most likely, a combination of air exposure time and temperature are potential causative factors of decreased vigour condition and subsequent survival (Lund et al., 2009; Albalat et al., 2009).

Air temperature is a factor that cannot be directly controlled. However, strategies to reduce the air temperature in the hopper could be potentially beneficial. This could be achieved by protecting the catch from direct sun and/or by spraying the catch with seawater to keep it cool. A potentially simple modification worth investigating is whether a fine seawater mist spray can be installed in the catch sorting hoppers. This should have the effect of keeping air temperatures in the hopper cooler than the surrounding air at minimal cost. Closing the hatch over the sorting hopper once the nets are emptied is also recommended.

Fishing activity in the Firth of Forth was mainly nocturnal. Given the daily variations in air temperature during the summer, this practice could represent, although unintentionally an approach that could have positively affected the survival of discarded *Nephrops* although no trials during daytime were conducted in the Firth of Forth during the summer to draw any definitive conclusions.

Vigour of discarded Nephrops

This study showed that discard survival estimates are associated with a higher percentage of *Nephrops* in the poorest vigour category. Similarly, according a recent published study the process of visual selection using a vigour index reflects with good accuracy the underlying physiologically state of *Nephrops* (Albalat et al., 2017).

Here it is shown that vigour was significantly correlated with the air temperature in the hopper, whereby the vigour is adversely affected with increasing temperature. It is anticipated therefore that measures that reduce the temperature in the hopper, as described above, would have a positive benefit on survival levels. Although not statistically shown in this study, there are other aspects of the fishing operation that are likely to affect the vigour of the discarded *Nephrops*.

Damage to discarded Nephrops

There was a significant relationship between the degree of damage (when excluding healed wounds) and the survival of discarded *Nephrops*. To develop mitigation measures it would be necessary to know when/where is damage occurring. In this study, the degree of damage was not significantly related to the measured factors (e.g. catch weight, tow duration). However, it is still considered that animals could be damaged during the trawling, hauling, sorting processes or most probably a combination of those. For example, Milligan et al. (2009) showed that damage increased with trawling time. In this project, trawling times in were (~1.5-5 hours) and varied according to a number of uncontrollable factors such as tides, skipper logistics and so on. While towing time could be reduced, the benefits to discard survival are unknown, moreover, short tows are unlikely to be commercially feasible.

It is considered that on-board practices targeted at minimising damage while animals are on-board could also potentially improve survival. In this respect, some differences were noted between 'Ocean Trust' (vessel used in west coast, higher levels of damage and lower survival) compared to 'Winaway' (Firth of Forth vessel). While in 'Ocean Trust' the hopper was of flat-bottomed design and *Nephrops* were raked onto the sorting tray, in 'Winaway' the hopper has a sloping floor opening onto three exits and the animals were drawn through by hand. Whether the lower damage recorded in the vessel from the Firth of Forth is due to the hopper design or the way animals are 'delivered' to the sorting tray (not racked), is unknown. Reducing the damage sustained during the catch, hauling and sorting process would improve the survival of discarded *Nephrops* and further discussion with fishermen would likely reveal some modifications to the fishing operation that could achieve this.

Catch weight

This study showed that *Nephrops* discard survival estimates decrease with increasing weight of non-*Nephrops* catch. Therefore, reducing the non-*Nephrops* catch would be expected to improve survival rates.

A previous study highlighted the potential effect that multi-species catch weight can have on *Nephrops* condition, which could have a detrimental effect on damage and/or physiological condition. In an Icelandic fishery, it was found that the onset of 'skyrhumar' or 'mushy tail' is caused by the release of proteases from the hepatopancreas of *Nephrops* into the abdominal muscle (tail meat). This process was associated with harsh treatment of the catch and by the crushing of animals in large, multi-species trawl catches, which can cause crushing of the cephalothorax and release of hepatopancreas enzymes into the abdominal muscle (Neil 2012).

Non-*Nephrops* catch can be reduced by using modified trawls designs that change the selectivity. Catches of unwanted fish can be high in *Nephrops* targeting trawl fisheries, and this is primarily due to the relatively small mesh size of the cod end that is needed to retain this species. Whilst challenging, more selective *Nephrops* trawls are likely to improve the survival of discarded *Nephrops* and many such trawl designs have been tested in recent years that demonstrate the potential to modify the catch composition by releasing fish. Examples, of these trawls designs include, separator (Swedish) grids (Valentinsson and Ulmestrad, 2005), inclined separator (Rihan and McDonnell, 2003), net-grids (Armstrong and Catchpole, 2013) and the SELTRA trawl (Madsen and Valentinsson, 2010). In practical trials, these designs have shown to be effective at releasing unwanted catches of fish while retaining the target *Nephrops* catch.

Although no direct comparative experiments between conventional and selective trawl designs have been conducted, the discard survival of *Nephrops* from more selective trawls has been estimated. Using a similar methodology as in this study, the survival of discarded *Nephrops* when using the selective net-grid trawl in the North Sea Farne Deeps *Nephrops* fishery was estimated at 62% (58-84%) (Armstrong et al, 2016). In a study by Nilsson et al (2015) in the Swedish *Nephrops* trawl fishery, estimated discard survival rates were 59% and 75% for

Nephrops caught with a SELTRA trawl and the Swedish grid, respectively. In support of benefits of selective fishing, in this study, in the east coast trial, where catch was minimal (mean 24kg per haul; range 4-67kg), discards survival estimates were 74.5% (range 71.8-77.1%).

This study suggests that survival might be improved by use of more selective gear. The implementation of the Landing Obligation is anticipated to provide motivation for fishermen to take up more selective gear so that unwanted catches can be avoided rather than landed for little or no profit.

Recommendations

These recommendations are based on the exploration of practical measures that are associated significant results from the statistical analysis of factors affecting discard survival of discarded *Nephrops*. While the recommendations are considered to provide the most likely measures to improve survival, the absolute and relative benefits of each cannot be determined with experimental investigation:

1. A fine seawater mist spray could be installed in the catch sorting hoppers. This should have the effect of keeping air temperatures in the hopper cooler than the surrounding air at minimal cost.
2. Closing the hatch over the sorting hopper or covering the hopper once the nets are emptied is also recommended. This should have the effect of keeping air temperatures in the hopper cooler than the surrounding air at minimal cost.
3. Handling strategies that minimise damage would have a positive effect on discards survival (i.e. not walking on top of the catch and reducing the use of a metal rack to handle the catch).
4. This study suggests that survival might be improved by use of more selective gear.

Behavioural observations carried out in this project indicate that even physiological impaired discarded *Nephrops* have the behavioural capability to be aware of their surroundings when they reach the seabed and the capability to hide into a burrow if available. Therefore, it would seem plausible to suggest that while predation of discarded *Nephrops* while sinking is probably unavoidable once animals have reached the seabed they do have an intrinsic behavioural response to examine their surroundings and hide into a burrow. However, it also seems plausible that unless discarded *Nephrops* are landed in suitable areas with burrows the risk of post-release predation would be higher.

During the survival trials it was noted that for most of the tows sorting and discarding of *Nephrops* took place as the vessel was fishing for its next tow. This means that, in general, sorting and discarding occurs in areas where *Nephrops* are trawled. However, *Nephrops* grounds are patchy and there is no certainty that discarded *Neprhops* will reach a suitable ground. This practice should be directed and planned by the fishing skipper based on their knowledge of the grounds. Survival would be improved if sorting and discarding of the last tow in the day could be done while the vessel is still located in suitable grounds rather than whilst steaming back to port. The practicalities of such change in practice would need to be discussed with fishing associations.

5. Increase the chances of releasing discarded *Nephrops* into suitable grounds.

9. Appendix I - Preliminary experiment to Objective 1 to test the impact of different sizes of tube-sets on *Nephrops* survival

Before beginning field-trials the suitability to use of standard tube-set boxes to monitor survival for up to 13-15 days was tested. Therefore, a preliminary trial testing the effect of different sizes of tube-set compartments on damage and post-catch survival was performed.

9.1. Materials and methods

This preliminary trial was conducted in the Firth of Clyde on the 31st May 2016. The commercial vessel Eilidh Anne GK2 was used. Fishing was conducted using a single-rig Harkess, rockhopper trawl with 85 mm mesh codend and fitted with a Cod Recovery Zone Panel (standard commercial net and rig). On the days of the trials the skipper was asked to follow his normal fishing and catch handling practices. This vessel's operations are characterised by relatively short tows as the skipper concentrates on obtaining a high-quality catch the majority of which is 'tubed' for the live *Nephrops* market. Animals not fit for commercial purposes according to the skipper's criteria were placed in tube-sets and stored in on-board tanks containing running seawater. Once on port (Largs harbour) animals were transported in a refrigerated van to Scotprime Ltd (Troon harbour) where tube set boxes were kept in tanks filled with running seawater. The next day animals (day 1) were sampled (sex, CL, damage, vigour) and distributed in tube-set boxes where the internal compartments were of different sizes (Figure 9-31). Thereafter, damage and vigour (including dead animals) were assessed on days 3, 6, 8, 10, 13 and 15.

Survival estimates were generated using the Kaplan-Meier analysis with 95% confidence intervals, using Prism 6. Survival estimates between different vigour categories were statistically compared by log-rank test.

9.2. Results

Nephrops CL was similar between animals distributed in different tube set boxes: CL in small = 28.6 ± 3.5 mm; medium = 28.9 ± 3.5 mm and in large CL = 28.7 ± 4.4 mm. Similar proportion of males and females (1:1) were distributed in the different tube-set boxes.

Average CL of discarded *Nephrops* used in this trial was similar to the average CL of discarded *Nephrops* reported in previous FIS funded project FIS007 (Albalat et al., 2015) when using the same vessel (Eilidh Anne GK2) (CL around 28 mm).

At this point of the project we were unsure if discarded *Nephorps* would be of similar CL when working in larger vessels operating in the Minches (not targeting the live market). Therefore, the size distribution of discarded *Nephrops* used in this preliminary trial with Eilidh Anne GK2 vessel were compared afterwards to discarded *Nephrops* used in the survival trials with Ocean Trust. *Nephrops* discarded by crew from Ocean Trust were smaller than those discarded by the skipper from Eilidh Anne GK 2 (Figure 9.2). However, some overlap in size distribution can be observed indicating that data obtained from smaller animals in this trial would be applicable to discarded *Nephrops* from other vessels such as Ocean Trust.

When assessing damage, a similar percentage of animals showing external damage were initially recorded but over time animals placed in medium and large internal compartments faced increased damage possibly related to the fact that as the area in the internal compartment increases that triggers for the animals to move in a restricted space increasing the chances of damage (Figure 9-3).

Similar responses were observed in terms of survival with animals kept in the smallest compartments showing highest survival estimates (Figure 9-4).

Damage and survival data were plotted according to tube-set boxes in order to analyse if there was a correlation between mortality (percentage of dead animals) and damage. As shown in *Figure 9-5*, a positive correlation between damage and mortality was obtained for all tube-set boxes (ranging from 0.91 to 0.86).

Given these results it was decided that survival trials in this project would be carried out using tube-set boxes with small internal compartments. Furthermore, data obtained from this preliminary trial suggest that there is a correlation between damage and survival after 15 days recovery period.

Figure 9-1: Tube-set boxes with different sizes of internal compartments used in the preliminary survival trial. Left panel: small (3x3 cm); central panel: medium (10x3 cm) and right panel: large (10x6.5 cm).

Figure 9-2: Size distribution of discarded Nephrops from Eildih Anne used in this preliminary trial compared to discarded Nephrops from Ocean Trust used for survival trials in Objective 2.

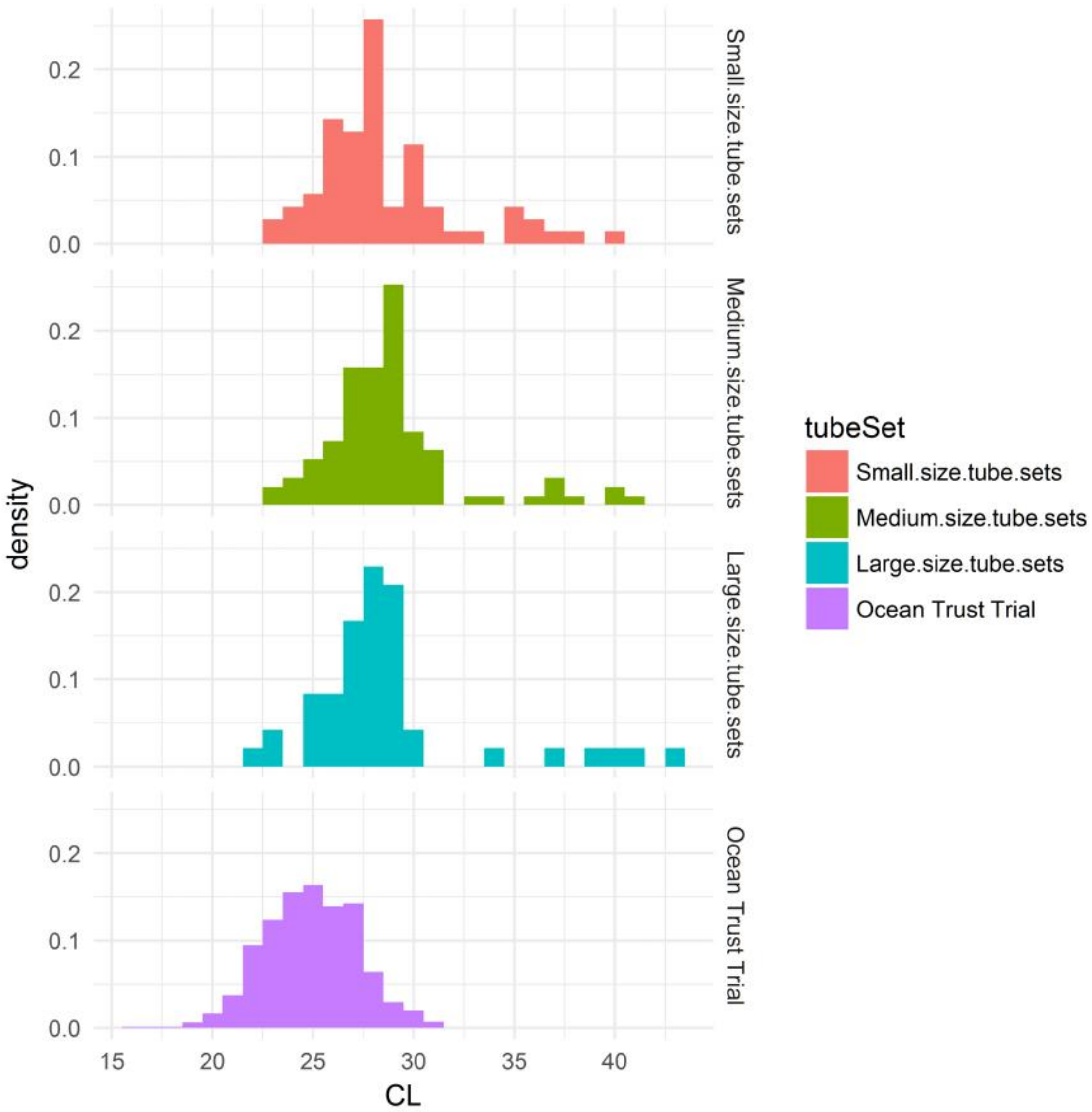


Figure 9-3: Cumulative percentage of animals damaged over time according the tube-set boxes tested.

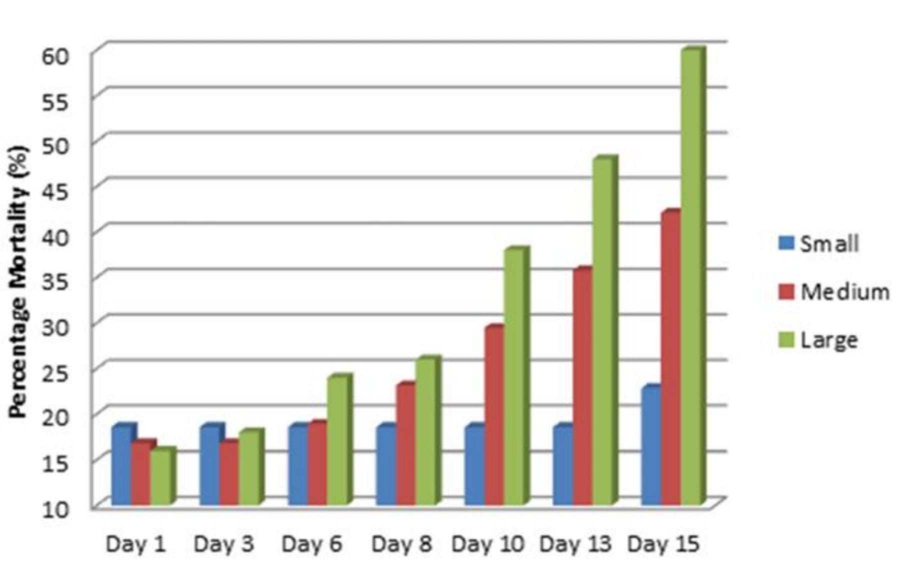


Figure 9-4: Survival estimates for Nephrops stored in tube-set boxes with different internal compartment sizes.

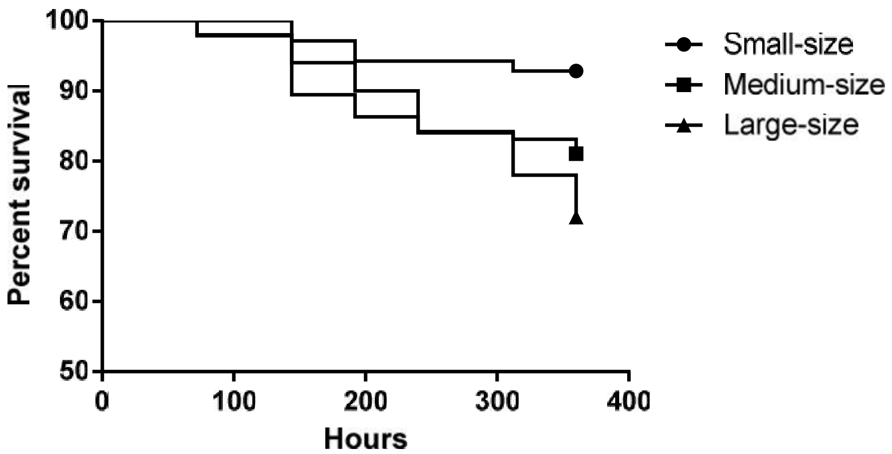
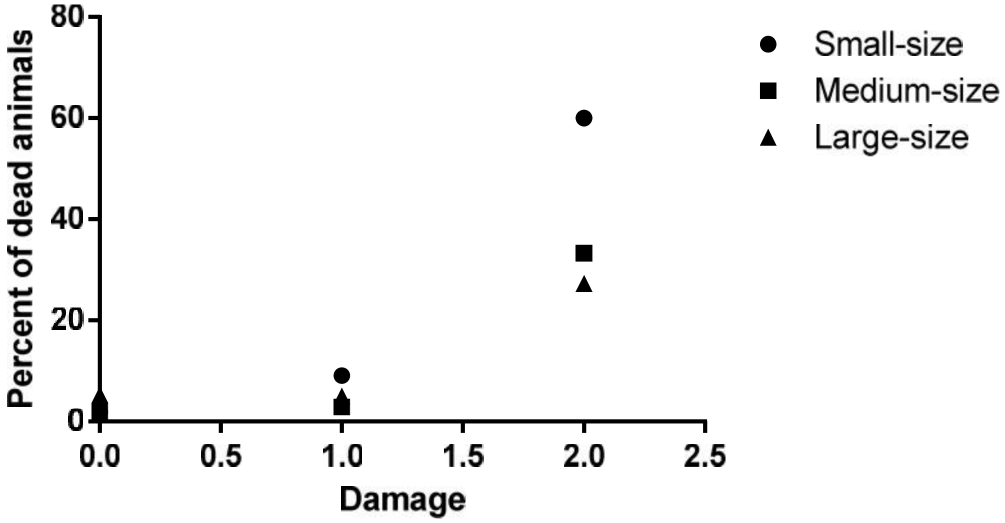


Figure 9-5: Correlation between percentage of dead animals on day 15 according to the damage scoring in Nephrops stored in tube-set boxes with different internal compartment sizes.



10. Appendix II – Analysis of L-lactate as an indicator of stress

10.1. Introduction

The process of trawling *per se* has been shown to be extremely stressful for crustaceans in general, and in particular for the species studied in the present work, *N. norvegicus* (Albalat et al., 2009). Trawling produces an increase in muscle and haemolymph L-lactate (Harris and Andrews, 2005; Ridgway et al., 2006b; Albalat et al., 2009) due to the fact that during the trawling process energy requirements exceed the capacity of the aerobic metabolism of the animal, and therefore anaerobic metabolism is activated in order to maintain ATP levels. In this project, the amount of L-lactate in the muscle was analysed as an indicator of anaerobic metabolism, which can be used as a proxy for muscle metabolic stress. Samples selected for L-lactate analysis and shown in this report are those from the highest and lowest survival recorded in the summer trials- west coast using TR1 and TR2 nets. These trials were selected as they show the largest difference in terms of survival and therefore are interesting to be further examined from a physiological perspective.

10.2. Material and Methods

L-lactate in the muscle was analysed in samples taken after catch and after the recovery period. Samples analysed and here presented are those from the trials with the highest and lowest survival recorded in west coast survival trials performed in the summer with both net types (TR1 and TR2). Therefore, the L-lactate presented in this section corresponds to the following trials with its corresponding survival rates (see Table 10.1).

On all survival trials, muscle samples were taken after catch (time zero) (n=10/tow) and after the recovery period (n=25/tow). In each case and prior to sample collection, animals were sexed, carapace length was taken, damage and vigour recorded. *Nephrops* were sacrificed by splitting (approved by AWERB committee, University of Stirling, num. 78) and muscle samples were collected and placed in dry ice and subsequently stored at -80 °C until analysis.

Muscle samples were thawed and around 1 g was homogenized on ice with 5 x volume (w/v) of chilled 0.6 M perchloric acid using an Ultra Turrax T25 homogenizer. Samples were centrifuged at 4°C for 15 min at 4,000 rpm and supernatants were stored at -20 °C until analysis. L-Lactate concentration was measured in abdominal muscle homogenates using the method described by Bergmeyer & Bernt (1974) and further modified by Hill et al. (1991) using a 96 well plate. In each well, 85 µl of Hydrazine buffer (6 M hydrazine hydrate, 5.6 mM EDTA, 1 M glycine, pH 9.5) was added as well as 5 µl of NAD^+ (50 mM) and 5 µl of each sample. At this point absorbance was recorded using a spectrophotometer (Biotek Synergy HT) set at 340 nm wavelength and noted as Abs_1 time=0. Once the first absorbance was taken, 1 unit of lactate dehydrogenase (rabbit LDH, Sigma-Aldrich, Dorset, UK) was added and the plate was incubated for 1 h at 37°C. Absorbance was recorded again (Abs_2 time=1 h) and the results obtained (Abs_2-Abs_1) were converted using a calibration curve of known concentrations (1mM-10 mM) of L-lactate.

10.3. Results

Muscle L-lactate was higher at time zero (after capture, while sorting) compared to the end of the recovery period (13 days). This differences were significant (T-test, $p<0.001$) for each trial (Figure 10-1).

However, when comparing the L-lactate level at time zero and also at the end of the recovery period between trials where survival estimates were high compared to trials where survival estimates were low no differences in muscle L-lactate were obtained (ANOVA $P>0.05$). There were also no differences in L-lactate levels between TR1 and TR2 nets (ANOVA $P>0.05$).

Results indicate that according muscle L-lactate the metabolic state of the muscle was similar in all discarded *Nephrops* irrespectively of the cod-end net used and irrespectively of the subsequent survival estimate (high versus low). Therefore, no significant correlations were found between L-lactate levels at time zero (after capture) ($p=0.568$) or L-lactate levels at the end of the recovery period ($p=0.741$) versus final survival estimates (Figure 10-2). This lack of correlation indicates that other factors rather than the metabolic condition in the muscle are responsible for the differences observed in survival of discarded *Nephrops*.

Table 10.1: Selected trials for muscle L-lactate analysis in the West coast survival trials. Trials were selected according to high or low survival within a particular season and gear code.

Trial	Location	Season	Gear	Mean survival	Std error	Survival
1	West	Summer	TR1	0.753	0.050	High
4	West	Summer	TR1	0.310	0.046	Low
8	West	Summer	TR2	0.707	0.046	High
12	West	Summer	TR2	0.410	0.049	Low

Figure 10-1: L-lactate concentration (umol/g) in muscle samples of discarded Nephrops after capture and after the recovery period on selected survival trials performed in the summer in the West coast. Trials 1 (TR1, high survival), trial 4 (TR1, low survival), trial 8 (TR2, high survival) and trial 12 (TR2, low survival).

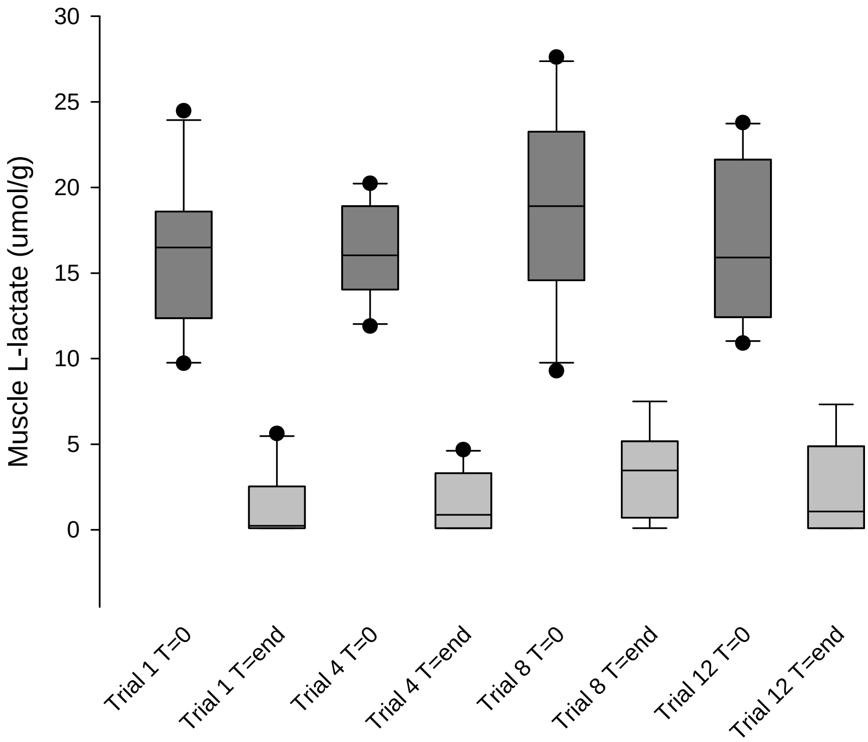
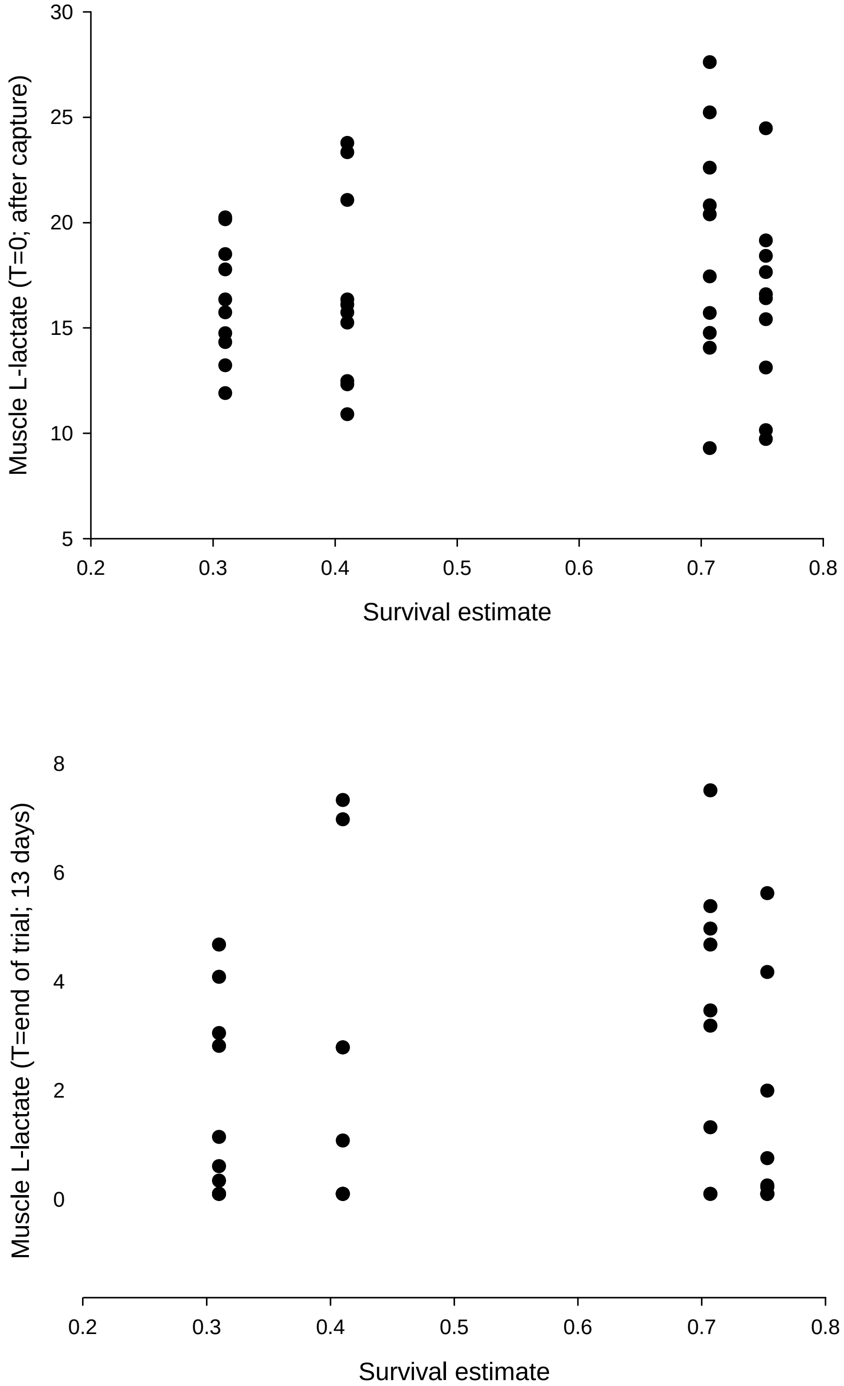


Figure 10-2: Muscle L-lactate concentration (umol/g) in discarded Nephrops after capture versus final mean survival estimate (upper panel) and muscle L-lactate concentration (umol/g) in discarded Nephrops at the end of the trial versus final mean survival estimate (lower panel).



11. Appendix III – Development and testing of a video-based recovery observation system

When the original project was proposed it was uncertain whether transporting Nephrops back to the aquarium for recovery would be feasible. The original proposal therefore included prototyping and testing a video-based recovery observation system which might enable recovering Nephrops to be observed at sea for up at least 10 days.

11.1. Materials and methods

The proposed prototype consisted of a flat illumination system which would back-light the recovering Nephrops. Animal movements would be recorded using a video camera mounted above the recovery cells. The illumination and camera would be synchronised using microprocessor controls. The prototype was constructed during the project and tested during spring 2017.

The background illumination was provided by 12V white LED light strips (Noza Tec) which were embedded in Polytek EasyFlo PU casting resin (MB Fibreglass Ltd.) and powered from a sealed 12V battery (NX-SLA 18 Ah). Timing was controlled using a microprocessor timer (Misol). The battery and timer were water-proofed by embedding them in Polycraft FC6600 slow-setting resin. The video camera (GoPro Hero 4+) was housed in a deep underwater housing (rated to 60 m) coupled with a CamDo Blink timelapse control unit. The timer for the lights and the Blink controller were set to turn on between 00:03 and 00:13 daily from the start of the test deployment. Bench tests of the GoPro camera with a fully charged battery and 32 Gb memory card suggested that 130 minutes of video at 24 fps wide-view could be recorded before the battery became depleted. The duration for recording 10 minute video bursts was therefore estimated to be 13 days.

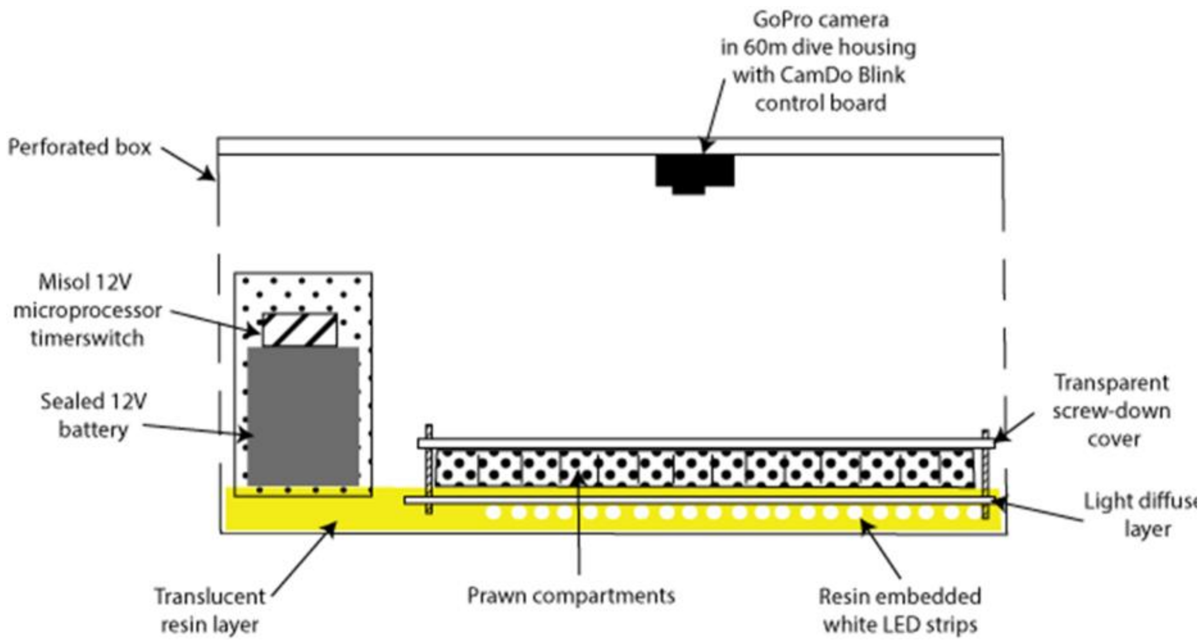


Figure 11-1: Vertical plan, prototype design video recovery box.

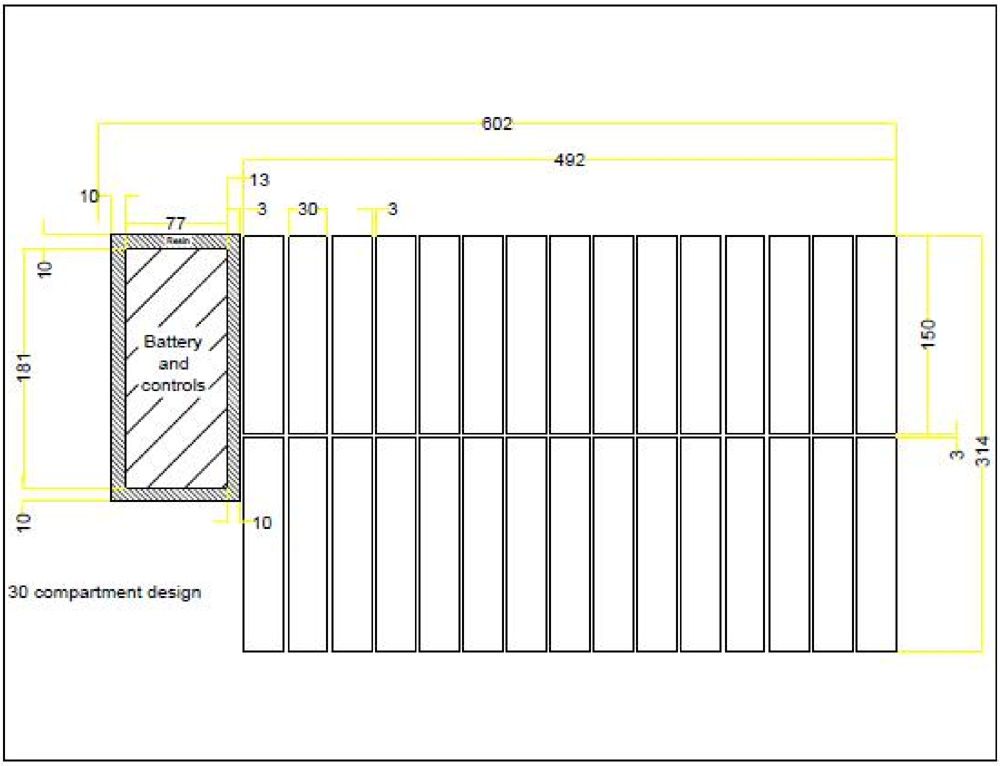


Figure 11-2: Horizontal plan, dimensions in mm.

The completed prototype is shown in Figure 11-3.

Figure 11-3: The completed prototype video recovery box. Upper photo shows the main unit with illumination controller and battery on the left and Nephrops compartments on the right; Lower photo shows the underside of the box lid with the GoPro and Blink control board mounted in their underwater housing.

Ten discard-size *Nephrops* which had been kept in the SAMS aquarium from the summer/autumn recovery trials were placed into recovery compartments in the video-box on morning of 11th May 2017. The transparent cover to restrain the Nephrops within the perforated *Nephrops* compartments was installed and the box suspended at a depth of 5 m from the SAMS pontoon. Because this was a trial of the system the unit was recovered every two days and the camera swapped over for a second unit allowing the video to be checked before returning the box to the sea. The box was recovered for a final time after 12 days of deployment.

11.2. Results

Animals in most of the recovery compartments were clearly visible to the camera although compartments at the edges were obscured by the compartment walls (Figure 11-4).

Video clips were recovered for 1, 2, 5, 6, 9, 10, 11 and 12 days post-first deployment and are available in the Supplementary data. Animal movement was obvious in all the video clips, usually within 2-3 minutes. Ten minutes of video therefore appears to be more than sufficient to evaluate whether individual animals are alive.

The illumination battery in the prototype design was not rechargeable so the box was disposed of at the end of the test.

Some problems were experienced with the GoPro Blink control boards failing to trigger the video daily but further bench testing suggests these issues have been resolved with a new version of the CamDo Blink firmware (V2.01).

Figure 11-4: Still from the video captured on day 12 at 00:03. Movement of all the animals within their compartments was clearly seen in the video although some compartments to the edge of the field of view were obscured by the compartment walls.

11.3. Discussion

The prototype design was successful but a number of issues were identified which might impact its use in the field.

If the box were deployed at sea for 13-15 days and fully loaded with discard-fraction *Nephrops* we would expect (based on the recovery trials described earlier) around 40-50% of the animals would die during the recovery period. The presence of dead animals in the box might lead to increased mortality rates in the remaining animals.

The prototype design only had 30 compartments for *Nephrops*. For the recovery trials described earlier we used sample sizes of 100 or 150. The design of the compartments in the video box could be changed from horizontal to vertical to accommodate this but this design change would need re-testing as it would affect the visible area for the camera and might mean animal movements would be harder to observe on the video.

Because of the fish-eye effect with GoPro lenses some recovery cell contents at the edges of the field of view were obscured by the recovery cell walls. This could be overcome by adding a second GoPro camera and Blink control board.

Because of these issues we suggest that the video behaviour recovery box should only be used if logistics prevent returning discard-fraction *Nephrops* from fishing vessels for recovery in shore-based facilities.

11.4. Conclusions

The proposed *Nephrops* recovery monitoring box employing time-lapse video was successfully built and tested for 12 days. It recorded movements of animals within the compartments, generally within 2-3 minutes of each video burst. However, because of worries about the impact of dead animals within compartments we suggest that the video-recovery box should only be considered as a tool for evaluating recovery rates of post-discard *Nephrops* if discard-fraction *Nephrops* cannot be returned from fishing vessels to onshore recovery facilities. Recovery of *Nephrops* in shore-based facilities with daily manual monitoring and removal of dead animals is a preferable option for estimated recovery rates.

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