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Cover Letter

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To
Fisheries Research
Attn Editor

Bergen 03.05.10

Manuscript for submission in Fisheries Research

Attached you will find a manuscript intended for evaluation for publication in Fisheries Research.

The manuscript, called "Mortality of mackerel (*Scomber scombrus* L) after pursing and slipping from a purse seine" (written by Irene Huse and Aud Vold), deals with an important aspect of unaccounted fishing mortality in the purse seine fisheries for pelagic species. ICES has documented that the total mortality of the mackerel stock is significantly higher than the reported landings, and concealed sources of mortality must exist. This paper deals with one aspect of this discrepancy. We document for the first time in sea going experiments the unaccounted mortality caused by crowding and subsequent slipping of mackerel in purse seine fisheries. Our investigation reveals that this may indeed be one serious source of mortality in the fisheries for pelagic species. Mortality rates close to 100% were documented when mackerel were slipped after severe crowding in a purse seine nets. The experiments were done onboard commercial fishing vessels in the North Sea in order to mimic true fishing conditions. The methods used were developed during these experiments, and are therefore novel.
The findings in this study are novel, and have not been published elsewhere. It has the full approval of both authors.

We hereby hope that Fisheries Research finds our manuscript worthy for publication.

Yours sincerely

Aud Vold

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Mortality of mackerel (*Scomber scombrus* L.) after pursing and slipping from a purse seine

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ABSTRACT

A new method was used to study the effect of crowding and subsequent slipping from a purse seine on the mortality of Atlantic mackerel (*Scomber scombrus* L.). Mackerel were allowed to swim from a purse seine through a transfer channel into two identical large floating net-pens. One pen was used as a control and was left floating in the sea without further treatment. The other was used to simulate crowding and slipping. The volume of the pen was gradually decreased by hoisting the bottom of the pen using a crane until the fish started to show panic reactions, and this volume was maintained for 15 min (2006) or 10 min (2007). The volume was then allowed to return to normal and the net-pens were left to drift freely in the open sea for three to six days. Five repeat experiments were performed, all of which showed that crowding has a major effect on survival rates. In all five experiments, mortality was higher among the crowded fish (80 – 100 % mortality) than the controls (0.1 – 46 % mortality), and the difference was significant ($p = 0.01$). The experiments demonstrate that excessive crowding before slipping mackerel from purse seines should be avoided, if possible, in order to avoid massive fish kills.

Keywords: mackerel, purse seine, slippage, unaccounted mortality

1. Introduction

Catch regulation by slipping the whole or parts of a catch has traditionally been used in pelagic fisheries if catches are too large, or the size and/or quality of the fish are regarded as unsatisfactory (Stratoudakis and Marçalo, 2002; Borges et al., 2008). This is particularly the case when there is a large price differential among fish sizes or qualities (high grading). Until now, little has been known about how pelagic fish are affected by contact with fishing gears, although some studies of herring (Misund and Beltestad, 1995; Suuronen et al., 1996a and b), mackerel (Misund and Beltestad, 2000) and sardine (Marçalo et al., 2006, 2007 and 2010) suggest that these species are highly vulnerable to gear-inflicted injury. ICES has called attention to the fact that landed catches alone do not explain the total loss from the stock of NE Atlantic mackerel (ICES, 2007). A study by Simmonds et al. (2010), which performed detailed analyses of data from landed catches, tagging experiments and egg surveys, estimated that the total fishing related removals lies between 1.6 and 3.4 times the reported landings, with the most probable estimate being 2.4 times the catch. In addition to reported landings, real losses include unreported discards, slippage, escape mortality and undeclared landings. The relative importance of the individual fractions of the unaccounted mortality is unknown and may differ among fleet segments. The magnitude of unaccounted mortality is a key problem for marine fisheries management in terms of waste of the resource and uncertainty in estimating fishing mortality.

Lockwood et al. (1983) carried out a comprehensive small-scale study of the effects of crowding mackerel to various densities and for different durations. They observed severe mortalities when mackerel were held at densities similar to those in pursing before slipping. Although these experiments display excellent experimental data on the relationship between crowding and mortality, the fishing industry would not fully accept these results, claiming that small-scale experiments do not reflect conditions during fishing and that the experimental mortality rates cannot be considered valid for the commercial fishing fleet. The Norwegian fishing industry and fisheries managers have therefore demanded that these small-scale mortality rates be confirmed using full-scale fishing experiments in order to improve their credibility in the eyes of the industry.

The experiments described in this study are an attempt to meet these requirements. To carry out full-scale survival experiments in the field is certainly not straightforward (Suuronen 2005), as they are extremely expensive to execute and are sensitive to a range of influences such as weather and availability of fish, while time and costs will almost inevitably limit the number of valid replicates. The sea trials in our study were carried out under conditions as close as possible to those experienced in commercial fishing operations. A new method for studying the survival of mackerel caught in a purse seine and crowded before slipping is described. The method involves minimal handling of the fish beyond that caused by the catch process itself.

2. Materials and methods

The experiments were carried out in the North Sea in August/September 2006 and 2007. Two large purse seiners were chartered for the experiments. Circular net-pens, each with an inner diameter of 12 m, were attached to a stiff frame of double (2006) or triple (2007) 200 mm polyethylene tubes (Fig. 1). The frame of large plastic tubes made it possible to work from the pens after they were deployed in the open sea. The netting material used in the pens was identical to that used in the bunt of many purse seines. An entrance channel made of the same material was attached to the pen, and an identical one was attached to the bunt of the purse seine. In 2006 the net-pens were readied for a pump system built for removal of dead fish from aquaculture net-pens (Lift Up Akva AS, Eikelandsosen, Norway). As this did not work well, in 2007 it was replaced with a 30 m-long collecting bag attached to the bottom of the cone (Fig. 1). A 30 kg weight attached to the end of the bag ensured that the pens kept their shape while drifting in the sea.

One purse seine vessel set its net on a suitable sonar record of mackerel and hauled the net carefully until about half the seine was taken onboard. A purse boat helped to keep the seine open during hauling. The other seiner was used to carry the equipment and to help with handling the large net-pens during fish transfer and crowding. The pens were deployed on the surface when the purse seine had been hauled about half-way and the presence of fish in the catch had been ascertained. The transfer channels from the net-pen and the purse seine were then joined to make an escape opening from the seine into the net-pen. The first vessel continued hauling with extreme caution until part of the school was swimming calmly (visual inspection) through the channel and into the net-pen (Fig. 2). The fish did not appear to be particularly stressed during this procedure and were swimming freely, not touching the net. They maintained their organized and polarized schooling behaviour and continued circling calmly inside the pen. As soon as about 10 tonnes of mackerel, estimated visually by a skilled fisherman, had entered the net-pen, the transfer channel was closed and parts of the seine were slackened in order to provide more space for the remaining fish.

Two net-pens were filled with mackerel from each set of the seine: one for the control and one for the experimental group. The control and experimental pens were alternately filled first in order to avoid any effect of order. Two pairs of pens were filled with fish during the 2006 experiments and three pairs during 2007. The control pens were left floating freely in the open sea without further treatment, while the experimental pens were used for the crowding experiments. In order to simulate the crowding that occurs during pursing, a rope attached at the midpoint of the conic bottom of the pen was hoisted up by the crane of the purse seiner until the mackerel started to evince a panic reaction (Misund, 1994) similar to the flash expansion behaviour described by Pitcher (1986). At this stage, organized swimming structure was lost and fish rose rapidly to the surface, where individuals could be seen moving haphazardly at high speed. The crowding time was chosen to reflect the typical duration of pursing in the fishing fleet. In 2006, the crowding density was maintained for 15 min, and in 2007, for 10 min, after which the pens were returned to their full volume and left to drift freely in the open sea. The pens would then drift at nearly the same speed as the currents, and maintain their shape even during strong winds and currents. There was one exception to this treatment: in the first experiment in 2006, the control and the experiment pen were tied together when left drifting, in order to facilitate tracking during the observation phase. In 2007, each pen was equipped with an Argos satellite transmitter (Campbell Scientific Inc., Castillo de San Marcos, FL) for positioning.

In order to observe fish behaviour in the pens during the observation phase, a colour pan and tilt UV camera or a monochrome pan camera was suspended in the middle of the pens. The pens were inspected twice a day via a video link to the fishing vessel, which enabled observations to be made at a distance of 50-100 m from the pens with minimal disturbance of the fish. The original plan was to leave the net-pens drifting in the sea for 5 days, but due to windy conditions, the first experiment had to be terminated after only 3.5 days. We also noted that the major mortality occurred during the first two days, and therefore decided to reduce the observation time to 3 days. However, weather conditions caused the actual observation periods to vary from 2 days and 15 hours to 5 days and 23 hours. At termination, the collecting bag was hoisted onboard the vessel, and the number of dead fish counted. The fish that remained in the net-pens were considered as survivors, and were pumped onboard, counted and measured.

Previous experiments have shown that the mortality of mackerel after crowding is primarily dependent on crowding density and crowding duration (Lockwood et al., 1983). In our experiments, with one exception (2006B), the fish were crowded to the point of displaying a panic reaction. Fish density at that point is difficult to estimate with any accuracy, as no equipment exists that is capable of measuring fish densities *in situ* in relatively small volumes of water. We therefore calculated the approximate water volume of the net-pen at maximum crowding retrospectively on the basis of photographs taken during the experiments. We suggest that the shape of the remaining volume of water in the net-pen during crowding, when the middle of the bottom was lifted in the crane of the vessel, had the shape of half a ‘doughnut’ (a semi torus). The volume (V) and net surface area (S) could then be calculated as $V = (a-b)(\pi b)^2$, and $S = 2b(a-b)\,\pi^2$, where a = the major radius (of the large circle) and b = the minor radius (of the circular cross-section).

In order to combine crowding duration and density, Lockwood et al. (1983) calculated a Stress Index (SI) as the product of crowding density and crowding duration, and showed that the relationship between the instantaneous mortality rate and the stress index was described by a power curve. In order to enable our data to be compared with those of Lockwood et al., their indices were recalculated from number of fish per m^3 to kg per m^3, as the fish in our experiments were substantially larger (465 g against 216 g).

3. Results

A total of five parallel experiments, each comprising one control and one experimental pen, were performed in 2006 and 2007. The number of experiments was, as so often is the case in large-scale experiments, mainly limited by the weather, but also by the capacity of the vessels to transport and monitor the large and heavy experimental equipment needed to carry out experiments in the open sea. The method required manual operations to be performed on the floating net-pens while the transfer channel was connecting the seine to the pens and during transfer of fish. Windy conditions with high waves made this operation risky at times.

In experiment 2007A, we obtained mortality estimates only from the control group (1% mortality), while the experimental pen burst in bad weather because of a heavy load of dead fish at the bottom of the pen (Table 1). Although mortality estimates from the experimental group could thus not be obtained, it was obvious that there had been massive mortality among the crowded fish, while mortality in the control group was only 1%. The other four parallel groups provided data from both the control and experimental groups (Table 1 and Fig. 3). The mortality of the crowded fish was significantly higher than that of the control groups ($p = 0.01$, Paired t-test with pooled SD), although there was considerable variation between the parallel groups. The number of valid observations was too low to give a reliable estimate of variance.

Some methodological problems influenced the mortality rates in the two parallel experiments performed during the 2006 study. The first pair of net-pens launched (2006A) were linked in order to facilitate tracking during the observation period. Dead fish rapidly accumulated at the bottom of the experimental pen. The pump system for removing dead fish turned out to be extremely inefficient. One of the fishing vessels worked for 13 hours over two days, moored to the pen, trying to remove the dead fish. The presence of the vessel obviously stressed the fish, not only in the experimental pen but also in the attached control pen. This affected the survival rates of both groups, which reached 46 % in the control group and 100 % in the crowded group. In experiment 2006B, crowding was not complete because the crane on board the vessel was unable to lift the bottom of the net high enough. Only about one third of the pen (measured as surface area) was properly dried. In this experimental run, the two pens were left drifting separately, and this method was maintained for all subsequent repeats. We also refrained from removing dead fish during the observation period in order to avoid stressing the fish. Due to the incomplete crowding, mortality was low (27.9 %) in this experimental group. When this figure is compared to the mortality of the other replicates, it should be borne in mind that the crowding density was lower.

The amount of fish caught in experiment 2007C was larger than in any of the other replicates. The catch contained about 200 tonnes of mackerel, and its weight caused the cork line to be drawn below the surface during hauling. This may have further stressed the fish before transfer from the seine to the pens, and thereby raising their mortality, which was 22% in the control and 99% in the crowded group. Only one experiment (2007B) was totally without problems. In this parallel, we found a mortality rate in the control group of only 0.1% after an observation period of almost five days, while that of the crowded group was 85%. In spite of all methodological problems, however, there was consistently higher mortality in each experimental group than in the corresponding control groups, showing that crowding has a substantial effect on mackerel survival.

The observation period between the parallels ranged from two and a half to almost six days (Table 1). This variation was not intentional, but was a result of the windy conditions during the experiment period, which prevented termination at predetermined times. The temperature in the upper water layers, where the mackerel schools were swimming before being caught and where the fish were stored during the observation phase, varied between 14.9 and 15.8^{o} C, which is in the upper range of the thermal preference for mackerel (Mendiola et al., 2006). Since the fish were stored at the same depth interval as their natural swimming depth, temperature is not expected to have had any detrimental effect on survival.

There was some variation in the number of fish in the different pens. We tried to transfer about 10 tonnes of fish from the seine to each net-pen, but we had no other means of quantifying the biomass of fish swimming through the transfer channel than visual evaluation by an experienced fisherman. This was not an easy task, and when the fish were counted at the termination of the experiments, their numbers ranged from 10,651 to 31,234. There seem to be a tendency for higher fish densities to be related to higher mortality (Fig. 3), but it is also clear that the mortality in the control groups was consistently lower than in experimental groups with similar fish densities. It must also be borne in mind that the number of replicates is low, and that experiment 2006A, which had the highest fish densities and mortality rates, included the groups that were stressed unintentionally hard when the removal of dead fish from the experimental pen also stressed the fish in the attached control pen.

The mean individual weights of the fish from each set, as well as the mean weights and lengths of surviving mackerel from each net-pen were measured (Table 1). Due to their state of decomposition, dead fish were not measured.

The fish density during crowding in experiment 2007B, when the fish exhibited panic behaviour, was estimated to be about 400 fish or 187 kg/m^3. In experiment 2006B, when the fish were not fully crowded, fish density was 67 fish or 31 kg/m^3. The three other experiments were partly confounded by unintended sources of stress, and have therefore not been used for calculations of density. The stress indices derived from these crowding densities and the corresponding crowding times (10 and 15 min) compared to those found by Lockwood et al (1983) are shown in Figure 4.

4. Discussion

Our full-scale experiments onboard fishing vessels confirm what has previously been documented in small scale experiments (Lockwood et al., 1983): that mackerel are extremely sensitive to handling stress, and even moderate handling may produce high mortality. In all five experiments in this study, mortality was significantly higher among fish that had been crowded to a density at which they displayed panic reactions for 10 or 15 min, than among unstressed control fish. Even though the number of replicates was too low (five replicates, of which four gave valid survival estimates) to give a reliable measure of variability, the evidence was clear that the process of pursing and slipping mackerel, as often practised by the purse seine fleet (Marçalo et al., 2007; Stratoudakis and Marçalo, 2002), has a substantial impact on the survival of the fish after release. The arguments for slipping may be that the encircled catch is too large, or that the species mix, size or quality is suboptimal. This practise certainly causes an unknown, but in all likelihood substantial, unaccounted mortality.

Ninety percent of Norwegian catches of mackerel, which have ranged from 120,000 to 185,000 metric tonnes per year during the last decade, is caught by purse seine. No systematic data have been collected on the frequency of slipping, but anecdotal information indicates that crowding and slipping occur frequently on the fishing grounds, particularly when the price differential between size groups is large or schooling densities are high. Norwegian newspapers have often reported that bottom trawlers operating in the same areas as the purse seine fleet, catch dead and decomposed mackerel, and routine ROV inspections along pipelines crossing the mackerel fishing grounds have observed dead mackerel scattered on the bottom. A more thorough understanding of the magnitude of slipping mortality caused by the purse seine fleet will depend on quantitative studies being performed, although these would not be easy.

Our experiments show that the survival of mackerel after crowding and slipping is highly dependent on how they are handled during the capture process. If the fish are kept in the seine for too long, or if they are prevented from swimming freely and synchronously out of the seine, high mortality can be expected. Similar findings were found for another pelagic species, *Sardinops sagax,* after a catch was forced over the headline of a purse seine (Mitchell et al., 2002). This should be taken into account when regulations for purse seine fisheries for pelagic species are being formulated. Reducing the unaccounted mortality caused by slipping, will require the development both of methods for the determination of the quantity, size and quality of pelagic fish schools prior to setting, and of net designs that permit the rapid release of any unwanted catch.

Lockwood et al. (1983) observed high mortalities at densities of 130 fish or 30 kg per m^3 or more. This is in line with our density estimates, where a mortality of 28% was found after crowding to 31 kg per m^3, but the duration of crowding is also important for fish mortality, and Lockwood et al. showed that mortality correlated with the product of crowding duration and density (Stress Index). The crowding duration in our trials was set to 15 min in 2006 and 10 min in 2007. This duration was chosen on the basis of video documentation of commercial purse seining provided by the Norwegian coast guard. Our experiments showed that a crowding duration of only 10 minutes may be fatal to mackerel.

One important factor that affects mortality is fish size (Davis, 2002; Suuronen et al., 1996a). Small fish are usually more sensitive than larger ones; they are more easily fatigued and do not have the same ability to swim rapidly or for long periods of time (Xu et al., 1993; Broadhurst et al., 2006). In our experiments, we have no length or weight measurements of dead fish, only averages from each set after the fish had been transferred to the net-pens, and from live fish at the end of the experiments. If the smallest fish die first after contacts with fishing gears, as has previously been found for other fish species, e.g., herring (*Clupea harengus* L.) (Suuronen et al., 1996a), the mean size of live fish should increase in the crowded groups relative to the mean of the total catch, and should also be higher than in the control groups. The data do not support such a hypothesis, as there were no systematic changes in mean fish size at the end of the experiment. One explanation may be that the size range of the individuals in the mackerel schools caught was too narrow to reveal differences of this sort, and also that the mackerel caught in this experiment were rather large and robust individuals (weight around 500 g).

Gear-induced mortality is not necessarily instantaneous (Wassenberg and Hill, 1993; Sangster et al., 1996). Hours or days may pass from when the fish are damaged until they die, and survival rates may easily be overestimated if the observation period is too short. Due to difficult weather conditions, the observation period in our experiments varied from 2.5 to almost six days. Earlier experiments have shown (Lockwood et al., 1983) that most mackerel die within three days of exposure to crowding. The mortality levels in our experiments did not seem to be correlated with observation time. However, the lack of standardization in observation time is one argument for supplementing field trials with small-scale experiments, in which factors such as crowding densities and times, daily mortality rates and follow-up time can all be standardized.

The crowding experiments described here were all performed during the hours of daylight, while commercial purse seine fishing for mackerel in the North Sea often takes place at night. The proportion of night capture changes from year to year, depending on the distribution and migration pattern of the fish, among other factors. Traditionally, mackerel change schooling behaviour in a way that makes them more easily available for night capture during the autumn, when they occur in the form of dense shoals at night, producing large catches that increase the risk of having to regulate catches by slipping. During darkness, the schooling behaviour of mackerel is disrupted (Blaxter and Parrish, 1965), i.e. the school disperses in the water and the synchronised orientation vis-à-vis the net disappears. Therefore, it is likely that the fish may be more easily injured by collisions with the net or with other fish during the hours of darkness (Cui et al., 1991) with a risk of an even higher mortality of mackerel that are slipped at night than during the day (Olla et al., 2000). Trawl experiments have indeed shown that the gear induced mortality may be substantially higher during low light levels than during day-light hours (Suuronen et al., 1995; Olla et al., 1997).

In order to obtain a better understanding of mackerel mortality as a function of crowding time and density, and of the mechanisms that underlie the high mortality, more thorough experiments should be performed. Davis (2002) suggested that the complexity of the task means that the problem of fishery-dependent unaccounted mortality would best be addressed through a combination of laboratory investigations and field experiments under realistic fishing conditions, as has been successfully done with sardine (Marçalo et al., 2006, 2007 and 2010). The key stressors can then be studied individually as well as in interaction. A possibly less resource-intensive method of studying gear-induced mortality than the full-scale fishing experiments used today is the reflex impairment method (Davis 2007; Davis and Ottmar 2006). Once a relationship between reflex impairment and mortality in controlled experiments has been established, the method can be used to predict mortality during commercial fishing conditions without the costly interventions used in survival experiments today.

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Figure legends

Fig. 1. Construction of net-pen with transfer channel. The dead fish collector was only used in 2007. In 2006, attempts were made to remove dead fish by pumping.

Fig. 2. The purse seine and net-pen were connected by a channel for transfer of the fish.

Fig. 3. Mortality as a function of fish density (number of fish in the pen) in the net-pens. Red symbols mark control groups, while blue mark experimental groups. See text for details about experiment 2006A.

Fig. 4. Stress indices (fish density (kg m^{-1}) times crowding time) from Lockwood et al. (1983) (diamonds) and from our own experiments (triangles). The exponential line is fitted to the data from Lockwood et al..

Table 1

Table 1. Observed mortality, length and weight measurements of individual mackerel in the experiments performed in 2006 and 2007.

Year	Experi-ment	Crowding duration (min)	Duration observation phase	Total no of fish	Mortality (%)	Individual weight (g)		Length (cm)	Comments
						Total catch	Alive	Alive	
2006	A	0	3 days 13 hours	28684	46	0.493	0.497	34.1	Pens linked together. Fish stressed by pumping
		15		71294	100		0.477	35.4	
	B	0	3 days 1 hour	17678	0.2	0.465	0.466	35.6	
		15		10651	27.9		0.469	36.3	Only 1/3 of the net dried up
2007	A	0	5 days 23 hours	11887	1	0.462	0.521	36.9	
		10		?					Pen torn in bad weather due to much dead fish
	B	0	4 days 20 hours	15231	0.1	0.468	0.473	36.2	
		10		19740	83.5		0.504	36.6	
	C	0	2 dys 15 hours	14543	22.2	0.495	0.457	35.8	15 min stop in hauling, seine collapsed, cork down
		10		31234	99.2		0.405	35.1	15 min stop in hauling, seine collapsed, cork down

Figure 1

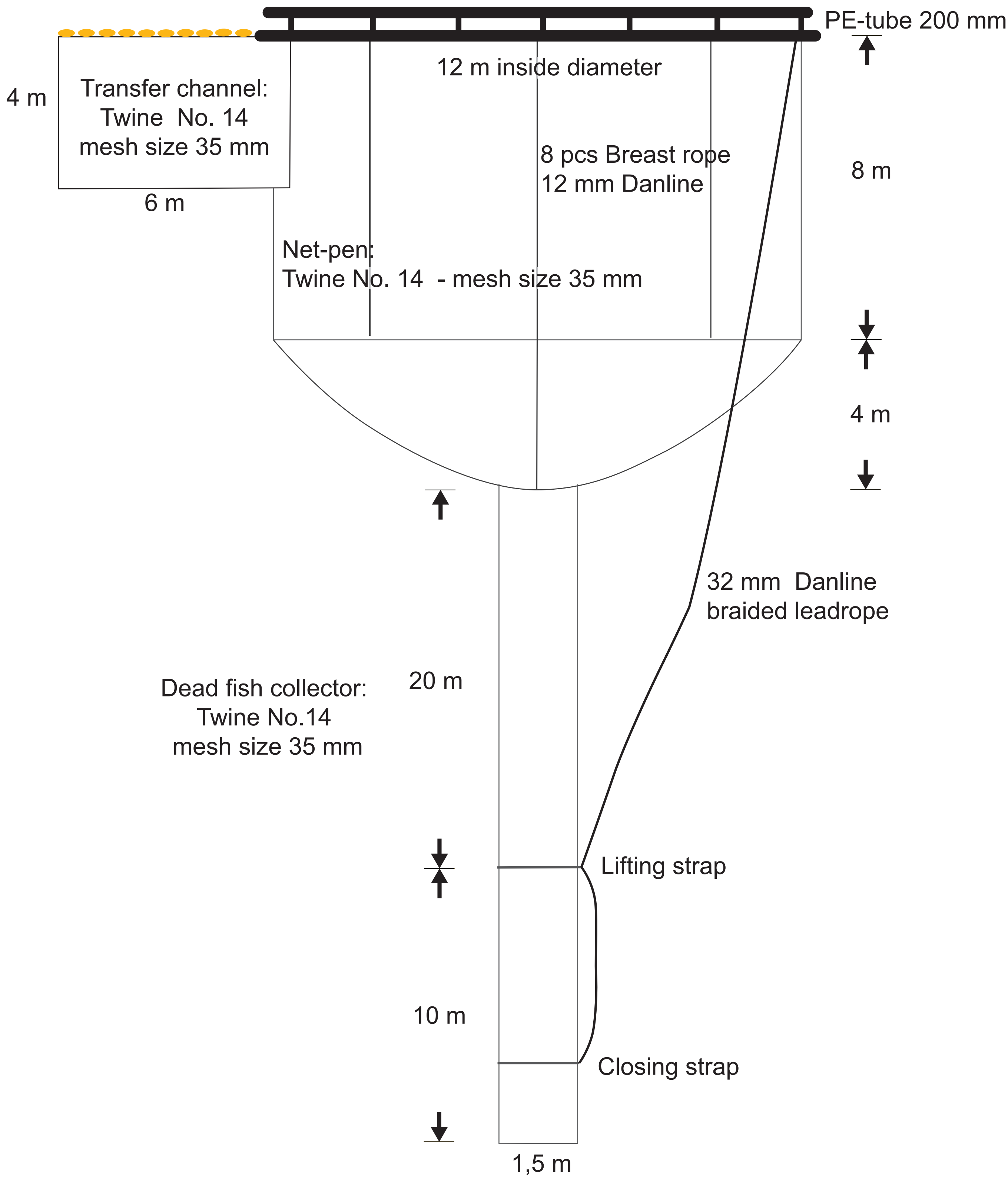
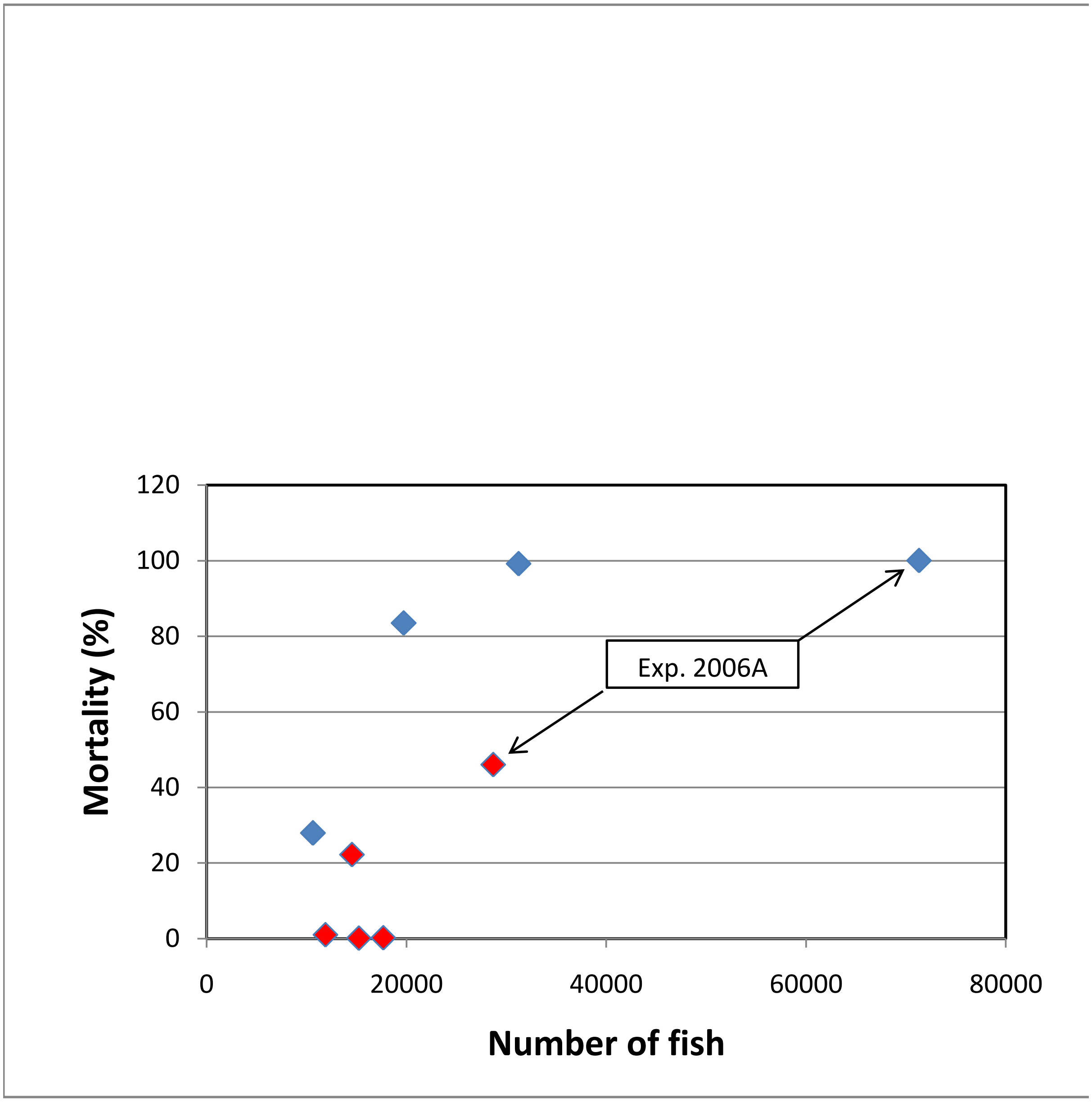

PE-tube 200 mm
12 m inside diameter
4 m
Transfer channel:
Twine No. 14
mesh size 35 mm
6 m
8 pcs Breast rope
12 mm Danline
8 m
Net-pen:
Twine No. 14 - mesh size 35 mm
4 m
32 mm Danline
braided leadrope
Dead fish collector:
Twine No.14
mesh size 35 mm
20 m
Lifting strap
10 m
Closing strap
1,5 m

Figure 3



Mortality (%)
120
100
80
60
40
20
0
Exp. 2006A
0
20000
40000
60000
80000
Number of fish

Figure 2

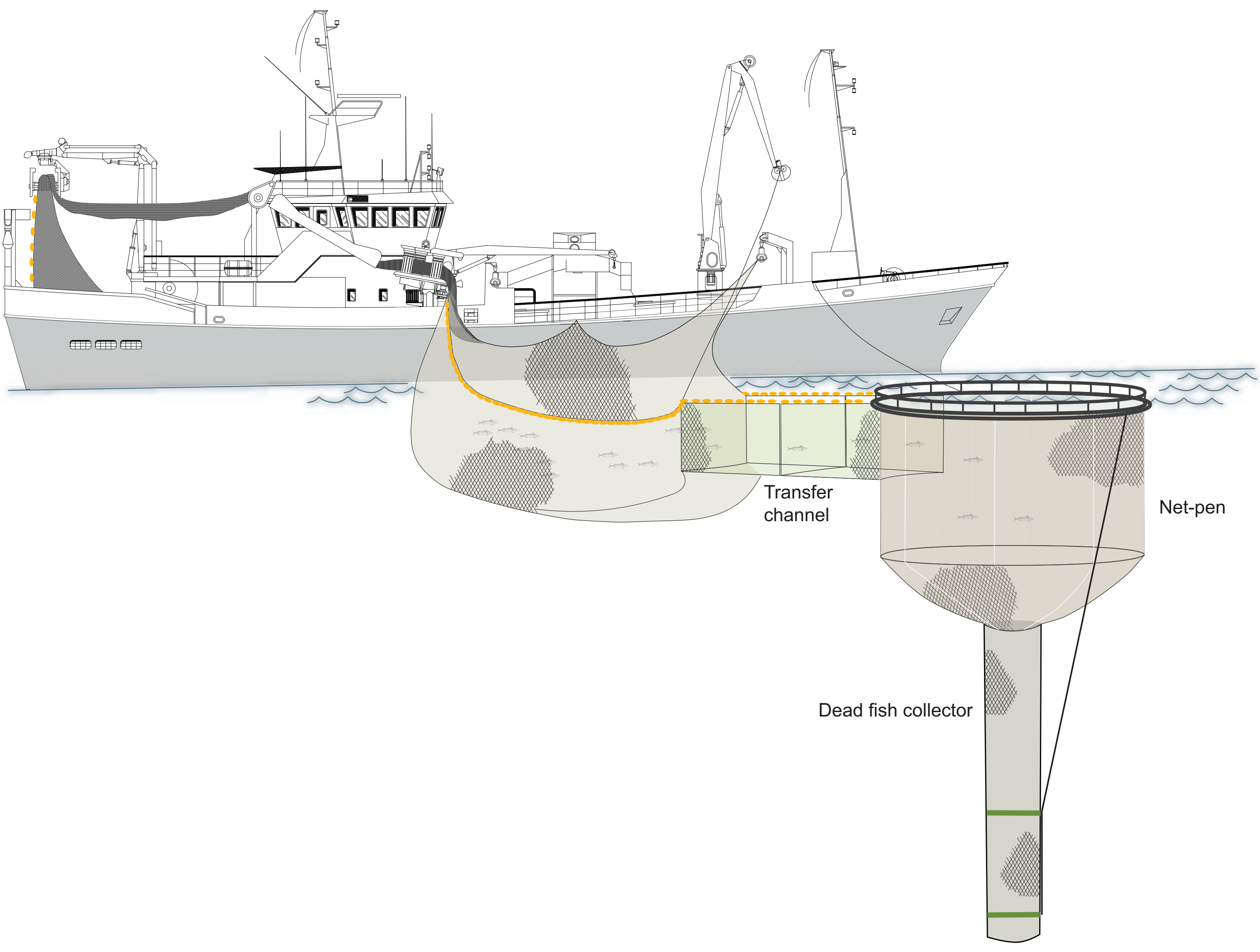
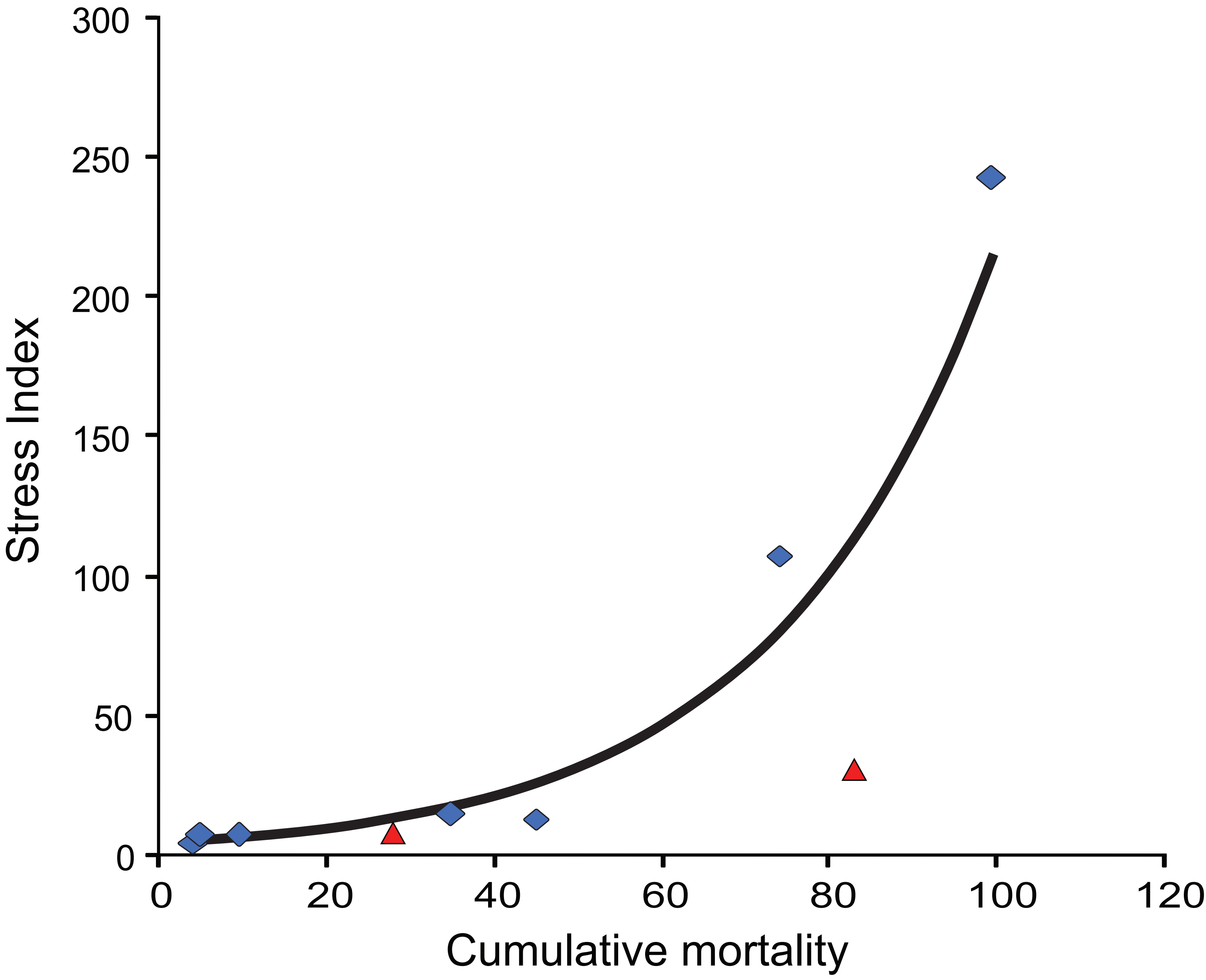


Figure 4



300
250
200
150
100
50
0
Stress Index
0
20
40
60
80
100
120
Cumulative mortality

REVISION NOTES

The authors wish to thank the reviewers for excellent revision of the manuscript. Their comments are clear and relevant, and by taking their suggestions into account, we feel that the quality of the manuscript is significantly improved.

Below you will find the reviewers notes *(in italics)*, added how the authors have dealt with their comments.

REVIEWER 1:

Line 5: Please add the family name of the second author.

- The name of the second author is correctly written in the manuscript. She changed her name from Aud Vold Soldal to Aud Vold two years ago.

Line 25-26: Please consider whether it would be better and more realistic to recommend that excessive crowding before slipping should be avoided in order to avoid massive fish kills. After all, it is the crowding density and duration, and the overall handling of fish, that is causing the mortality, not necessarily the slipping. Please also compare to what you are saying on lines 279-282; a rapid release technique might indeed be one solution?

- The reviewer's comments are indeed valid. It is the handling, and not the slipping per se that is the problem. We have changed the sentence to comply to his/hers notes.

Line 43: I believe the wording "total mortality" is not quite correct here. Perhaps a better wording would be "total fishing related removals" or "total fishing mortality"? Total mortality includes natural mortality and that is not what you mean.

- Again, the reviewer's comments are correct, and we have changed the text as he suggests.

Line 83: Please say a few more words about this pump: how it was like and how did it operate?

- The authors feel that adding too much detail about this pump system is a waste of journal space, as it was only tested in the first experiment and found unfit for further use. We have, however, added a few words, and also given reference to the dealer so that readers may track the system if desired.

Line 84: Did you observe the 'behaviour' of the net-pen and the 30 m collecting bag in strong current? Did they stay in shape? Did the bag have a weight under, or how did it maintain the proper shape?

- This is also a valid point. We suppose that the reviewer concern is a possible collapse of the net-pens in strong currents that would damage/stress the fish. However, this would have been a major problem if the pens were anchored to bottom. Our pens were drifting freely with the currents in order to prevent mis-shaping. We have added a few words about this in the text.

Line 94: How do you know that fish were swimming calmly?

- By visual inspection – also added to the text.

Line 108: Is the rope that was attached to the midpoint of the conic bottom of the net-pen presented in Figure 1 or Figure 2? On the basis of text on lines 107-109 it is not clear enough where the rope was attached.

- We have added a better description of the attachment point in the Materials and Methods chapter.

Lines 135-137: The sentence on these lines is not clear enough. Please try to make it clearer. Please also note that the word "torus" is not very common and readers may not understand its meaning.

- We have tried to solve this problem by comparing a torus to a doughnut, and also to give a bit more detailed description of how the volume is calculated.

Line 141: What are the two factors referred here?

- This omission is an oblivion from the authors side. "Crowding duration" and "crowding density" are now added to the manuscript.

Line 144 and many subsequent lines: Cubic metre is m3 not m-3.

- This error is corrected

Line 157: It is not necessary to state that results are shown in Table 1 and Figure 3. It is better to describe the most important results and add the table or figure in parentheses after the sentence, e.g. (Table 1, Fig. 3).

- We have changed the wording to comply with the reviewer's suggestion.

Line 176 and subsequent lines: How the survival rates were calculated? How did you treat those fish that were alive but likely to die in the near future (did you register them as live or dead)? In survival experiments there are often fish that are still alive after a few days caging but are about to die soon because of injury. This issue could have been addressed in the materials and methods.

- Again a valid comment from the reviewer. We have added a section in the Material and methods chapter about estimating mortality.

Line 184: I do not think the incomplete crowding was relevant for the control group because they were not crowded; please rephrase the sentence.

- This is changed according to the reviewer's suggestions.

Line 203: What was the predetermined time?

- We initially aimed for 5 days, but as the first experiments had to be terminated after about 3 days due to bad weather conditions (and also because the major mortality happened within the first couple of days), this was what we aimed for thereafter. But as may be seen from table 1, we were not able to fulfill this goal either. This was also due to weather conditions. This is now described in the Material and methods chapter.

Line 205: What does the word "upper quartile" mean here, not clear.

- Upper quartile is replaced with a more general description

Line 215: Please do not say what figure 3 shows. Instead, describe the results/observations and refer then to the figure (Fig. 3).

- Changed according to reviewer's comments

Lines 216-219. Please try to make the very long and complex sentence on these lines a bit shorter and a bit clearer. It also appears a bit speculative for the results-section.

- We have reworded this to make it clearer

Line 224: Please do not say what Table 2 shows; instead, write out the observation and then refer to the table (Table 2).

- Changed according to reviewer's comments

Lines 229-230, Lines 285-286. I believe the correct expression = kg/m3

- Changed according to reviewer's comments

Line 234: ". shown in Figure 4". Please correct this! The readers are not that interested what you show in figure, they are more interested to read about your main observations.

- Again, the reviewer is right, and we have changed the text according to reviewer's comments

Lines 249-254: These sentences pretty much repeat what is said in the introduction although here is mentioned also the discarding. This type of repetition is not necessary and not useful. Please check if you could combine these sections is one.

- The repetitive text in the Discussion chapter is removed.

Lines 265-267: This sentence would benefit if there would be a reference or at least the source of information.

- Of course the reviewer is right in his opinion, but the information mentioned in the text is anecdotal, often given as some lines in the daily newspapers etc. We have tried to solve this by mentioning 'Norwegian newspapers* in the text.

Line 297: Chopin and Arimoto (1995) in fact do not specifically address in their review the issue of fish size in relation capture-induced stress and mortality. This issue is much more thoroughly addressed for instance by Broadhurst et al. (2006) in their review, and in many other more recent papers.

- This is a relevant comment. We have changed the references according to referee's suggestions.

Lines 303-307: The size of fish is an important biological factor affecting mortality of fish that are in contact with a fishing gear. Several studies have demonstrated negative correlation between length and skin injury or mortality (reviewed e.g. by Broadhurst et al. 2006). Smaller individuals are less able to avoid tactile stressors and have less endurance to make sustained swimming inside *a gear. I believe the size range of fish in your experiment is too narrow to make any strong conclusions regarding the size-related mortality. And the fish in your experiments were relatively large. If there had been fish less than 100 g, then the situation may well have been different, and you may have seen even higher mortalities.*

- It seems that the reviewer and the authors are fully in line here. We have already suggested that the reason for not finding any size dependency in mortality is that the size range in the mackerel schools caught is to narrow to reveal such differences. We have added some words about the mackerel in our experiments being large and robust.

Line 313: . varied from 2.5 to almost six days (not five).

- This was a typing error that is now corrected.

Line 314: Lockwood et al investigated only mackerel. Is that what you mean by the sentence and the wording "most fish"? Broadhurst et al (2006) made a review where many species are addressed. Please consider rephrasing the word "most fish".

- By 'most fish' we mean mackerel. This is now changed.

Lines 330-333: The availability of light is an important environmental factor potentially affecting gear-and handling-induced mortality on fish, and therefore should be addressed properly here. Low light level may indeed be a cause of a high gear-induced mortality for pelagic fish. This has been demonstrated at least in one full-scale study made with vendace (Coregonus albula); significantly more juvenile vendace died after gear contact at night than during the day (Suuronen et al. 1995). Olla et al. (1997), on the other hand, demonstrated in laboratory experiments that a reduction in light intensity affected the ability of walleye Pollock and sablefish to avoid contact with meshes and their subsequent physical damage and stress.

- Again, this is a very relevant point raised by the reviewer, and the effect of night fishing with purse seines is something that the authors are really worried about. We have extended the discussion of this topic with 3-4 lines to comply with the reviewer's comments.

Figure 1: Mesh size is usually written as "mesh size", and not as "meshsize". What does the "EK" mean?

- Meshsize is changed to mesh size, and EK removed from the figure

Figure 2. This is a really beautiful and well-designed illustration!

- Thank you, very much. It is drawn by IMR's excellent technician Anne Britt Tysseland.

References:

Broadhurst, M. K., Suuronen, P. & Hulme, A. 2006. Estimating collateral mortality from towed fishing gear. Fish and Fisheries 7: 180-218.

Olla, B.L., Davis, M.W. & Schrek, C.B. 1997. Effects of simulated trawling on sablefish and walleye Pollack: the role of light intensity, net velocity and towing duration. Journal of Fish Biology 50: 1181-1194.

Suuronen, P., Turunen, T., Kiviniemi, M. & Karjalainen, J. 1995. Survival of vendace (Coregonus albula L.) escaping from a trawl cod end. Can. J. Fish. Aquat. Sci. 52 (12): 2527-2533.

- Very good suggestions for extension of the reference list. They are added to the list and referenced in the text. The reference list is also updated with recent publications by Simmonds (2010) and Marcalo et al. (2010).

REVIEWER 2.

Reviewer 2 has mainly given comments on language and grammar, which are accepted by the authors (who are not English spoken by birth).

On page 11 in the manuscript he/she gives a comment on the number of replicates in our experiments, which is valid. We have deleted a short section to comply with these comments.

Table 2 is corrected according to the reviewer's guidelines.

ASSOCIATE EDITOR (ANDRE PUNT)

The editorial suggestions have been accepted.

"Significant" has been replaced with "substantial" in all cases where it does not mean statistical significance.

Comment 3: Line 25, P=0.19. This is an unfortunate typing error. In the Results chapter it is written "The mortality of the crowded fish was significantly higher than that of the control group (p = 0.01, Paired t-test ……)". We have therefore changed the text in the Abstract accordingly.

Fig. 4. The line is now explained in the figure text.

Anon. 2008 is deleted.

Table 1 and 2 is merged into one Table (Table 1).

Bergen 30.06.2010

Aud Vold