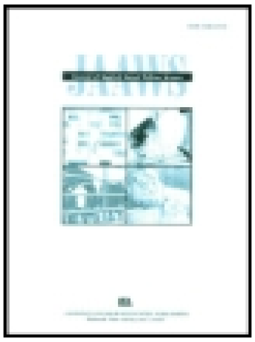

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Increasing Dip Net Mesh Size Results in More Fin Splits in Post-Smolt Atlantic Salmon (*Salmo salar*)

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ABSTRACT

Dip nets are widely used to retrieve fish from the water but can cause injuries to the fish. The objective of this study was to document the potential effects of dip net mesh size with respect to external injuries, more specifically fin splits and scale losses, in Atlantic salmon (*Salmo salar*). The study included 273 post-smolt Atlantic salmon from two fish batches referred to as the Tank group ($\bar{w}$ = 178 ± 36 g, n = 198) and the Cage group ($\bar{w}$ = 1319 ± 334 g, n = 75). Four identical dip nets with mesh sizes of 5, 10, 15, and 20 mm, respectively, were used to net fish out of their enclosures before the external injuries were assessed by visual inspection. The results showed that the number and severity of fin splits increased with dip net mesh size, but no effect of mesh size on the percentage of scale losses was found. Dip-netting of five fish at a time instead of one with the 20 mm dip net, had no statistically significant effect on the examined injuries. It is concluded that the use of dip nets with smaller mesh sizes can be positive for fish welfare by reducing fin splitting.

KEYWORDS

Gear effects; dip-netting; external injuries; fin splits; scale losses

Introduction

Dip nets (also called hand, scoop, or landing nets) are simple tools to retrieve single or smaller numbers of fish from the water, and are widely used in hatcheries, cultivation plants, fish farms, and research facilities, as well as during angling and environmental sampling. However, as fish are adapted to a life in water and have evolved relatively delicate integuments (Elliott, 2011a, 2011b), dip-netting can result in damage to their mucus layer and injuries to external structures like skin and fins (Barthel, Cooke, Suski, & Philipp, 2003; Colotelo & Cooke, 2011; Lestang, Griffin, Allsop, & Grace, 2008; Lizée et al., 2018; Powell, 2021b). External injuries can, for example, lead to osmoregulatory stress, increase the susceptibility to infections, possibly be painful, impair swimming performance, and increase mortality (Ashley, Sneddon, & McCrohan, 2007; Barthel et al., 2003; Svendsen & Bøgwald, 1997; Zydlewski, Zydlewski, & Danner, 2010). In addition to the various health and welfare consequences for the fish, external injuries can reduce the fish's product quality and market value (Hoyle et al., 2007; Mitchie, 2001; Olesen, Alfnes, Røra, & Kolstad, 2010) and influence the results of scientific experiments and welfare assessments (Folkedal et al., 2016; Noble et al., 2018).

Dip nets consist of a bag made of netting, a frame from which the bag hangs, and a handle. These parts vary in composition, size, and design between different dip nets. Recommendations regarding dip net selection are, however, very general. The Royal Society for the Prevention of Cruelty to Animals, for instance, states that hand nets must be a) of a suitable size, b) designed to avoid the occurrence of physical damage, and c) kept clean, in good repair, and disinfected before use with different fish populations or tanks (RSPCA, 2021). When selecting a dip net, operators often emphasize the length of the handle, the shape of the frame, and the size of the bag. For speed and maneuverability, it is also advantageous to choose a bag with low resistance, i.e., a bag with a large

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mesh size that lets water pass easily through while retaining the fish. Unfortunately, due to a constant pressure for efficiency and partly also a lack of awareness of the effects of dip nets on fish, such practical considerations may in many cases trump selecting the dip net most suited in terms of fish welfare (Medaas et al., 2021).

There is a modest but growing body of literature on the effects of various netting types on external injuries in fish. Alvarez-Rubio et al. (2020) found that hand nets with polypropylene or polyethylene netting cause less extensive skin lesions to yellowtail tetra (*Astyanax altiparanae*) than hand nets with nylon netting, and Powell (2021a, b) found that hand nets with rubber-coated netting reduce scale losses in Atlantic salmon (*Salmo salar*) compared to hand nets with conventional knotless netting. Furthermore, landing nets with knotless meshes have proven to be less injurious than landing nets with knotted meshes for bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), northern pike (*Esox lucius*), barramundi (*Lates calcarifer*), and Brook trout (*Salvelinus fontinalis*) (Barthel et al., 2003; Colotelo & Cooke, 2011; Lestang et al., 2008; Lizée et al., 2018). There is, however, a paucity of scientific documentation of isolated effects of dip net mesh size on external injuries in fish.

In salmonid aquaculture sea cages, dip nets are mainly used to sample fish for sea lice counts and welfare assessments, and to remove emaciated and behaviorally deviating fish. To facilitate dip-netting of the fast-swimming salmonids, dip nets with large mesh sizes (typically 20 mm) are often used. During welfare assessments, fin splits and scale losses are commonly detected on the fish, and lost scales are frequently observed in the dip net bags and the anesthetic bath containers (Noble et al., 2018). Some of the fin splits and scale losses may be due to the dip-netting of the fish when sampled (Folkedal et al., 2016). If injuries caused by the dip nets are included in the welfare assessments, this may incorrectly indicate poorer welfare of the fish in these facilities.

The objective of this study was to document the potential effects of dip net mesh size with respect to external injuries, more specifically fin splits and scale losses, in Atlantic salmon (*Salmo salar*). This is critical to raise awareness of the importance of dip net selection and thereby potentially improve the welfare and product quality of netted fish and obtain more reliable results from scientific experiments and welfare assessments.

Materials and methods

Experimental animals

The study included 273 post-smolt Atlantic salmon of the AquaGen strain reared at the Institute of Marine Research, Matre Research Station, Norway. The fish originated from two fish batches on-grown in indoor tanks and a sea cage, respectively, and are hereinafter referred to as the Tank group and the Cage group. The two groups were chosen to check the validity of the results across fish sizes and rearing systems.

The fish in the Tank group came from eggs hatched early in 2019. From August 2019, the fish were kept in groups of 165 pre-smolts in three replicate 1350 L tanks (l1.5 m × w1.5 m × h0.8 m) with aerated freshwater. On the 23rd of January 2020, when the smoltification was completed after 7 weeks of 12-hour light/darkness followed by 6 weeks of continuous light, the water source was switched to aerated seawater at ambient temperature (7–9 °C) and salinity (33–34 ppt), and the fish were subjected to the prevailing natural photoperiod. The direction of flow in the tanks was clockwise. The fish were not handled in the period between the transfer to the tanks and the sampling on the 5th of March 2020. At sampling, the stocking density was ~24 kg m^{-3}. The mean ± SD body weight, fork length, and condition factor of the fish were 178 ± 36 g, 24.6 ± 1.6 cm, and 1.2 ± 0.1, respectively (n = 198).

The fish in the Cage group, which had another origin than the fish in the Tank group, were transferred to a 12 m × 12 m wide and 17 m deep sea cage in April 2020 and stocked with ~6000 smolts at the Institute of Marine Research, Knappen Solheim Fish Farm, Masfjorden, Norway

(D_{dec} = 60.8851, 5.4623). Except for routine sea lice counts and welfare assessments of a negligible number of fish, the fish were not handled in the period between the sea transfer and the sampling on the 28th of September 2020. During sampling, the water temperature at 5 m depth was 14 °C and the stocking density in the cage was ~4 kg m^{-3}. The mean ± *SD* body weight, fork length, and condition factor of the fish were 1319 ± 334 g, 46.3 ± 3.5 cm, and 1.3 ± 0.1, respectively (n = 75).

Ethics

The study was conducted in accordance with Directive 2010/63/EU of the European Parliament and the Council on the Protection of Animals Used for Scientific Purposes (EU, 2010) and the Norwegian Regulation on the Use of Animals in Experiments (LovData, 2015). The fish in the Tank group had previously been used in an observational study (no manipulation or treatment groups) and were about to be euthanized. To obtain further data from these fish (3Rs: Reduction, Russell & Burch, 1959) the present study was conducted during the euthanization procedure. The study entailed that the fish in the Tank group were netted out of the stock tank and transferred to the euthanasia bath by means of dip nets with similar or smaller mesh sizes than the 20 mm dip net that would otherwise have been used. This presumably represented a refinement of the usual euthanization procedure (3Rs: Refinement, Russell & Burch, 1959). Examination of these fish was conducted postmortem. The fish in the Cage group were originally sampled for a routine sea lice counting and welfare assessment that takes place every week at the fish farm. The load from the additional examination of these fish was considered to be smaller than the load from the introduction of a needle in accordance with good veterinary practice, the latter being the degree of load set by the experimental animal legislation as the limit to whether the legislation applies (EU, 2010, Articles 1.2 and 1.5 f; LovData, 2015, §§ 2 f and 6). IMR Matre is a research facility approved by the Norwegian Food Safety Authority for work with salmonids (Norwegian Animal Research Facility ID No. 110).

Experimental procedure

In both samplings, four identical dip nets (Fish Tech, Inc., Vestby, Norway) with mesh (bar) sizes of 5, 10, 15, and 20 mm, respectively, were used (Figure 1). The dip nets had telescopic handles (l = 2.1–4.0 m) and pentagonal frames (55 cm × 40 cm) with rounded corners. The dip net bags (D ~ 43 cm) were cylindrical with tapered bottoms and made of dark dyed nylon netting with knotless, diamond-shaped meshes. The diameters of the netting twines were 0.6, 1.8, 2.0, and 2.1 mm, respectively, for the increasing mesh sizes.

Figure 1. Dip nets with pentagonal frames (55 cm × 40 cm) and mesh sizes of (from the left) 5, 10, 15, and 20 mm, respectively.

Table 1. Dip-netting of fish in the tank sampling (n = 198).

Dip net mesh size (mm)	Number of hauls	Number of fish per haul	Total number of fish
5	7	4–11	47
10	7	5–9	51
15	7	6–9	48
20	7	6–9	52
Total	28	4–11	198

Tank sampling

In the tank sampling, a total of 198 fish were randomly netted out of the three stock tanks through seven hauls with each of the four dip nets in groups of 4–11 (median = 7) fish per haul (Table 1). The order in which the dip nets were used, was rotated irregularly by the operator. The retention time of the fish in the dip nets was about five seconds, which represented the time needed to lift the fish out of the tanks and transfer them to a euthanasia bath (tricaine methane-sulfonate, ~500 mg L^{-1}).

After euthanization, the fish were laid individually in white plastic trays containing sea water for examination of fin splits and scale losses. Fin splits refer to splits or clefts in epithelial tissue between skeletal fin rays, which leave the fin rays intact. Scale losses refer to points and/or areas on the fish where scales have been lost. Fin splits and scale losses can be observed macroscopically and give an immediate indication of mechanical impact on the external surfaces of the fish (Noble et al., 2018). The injuries on each fish were assessed by one of two examiners who were blinded to information on which dip net had been used. To increase the resolution of the data in this study, more detailed scoring scales were used than those given in, for example, the FISHWELL handbook (Noble et al., 2018) and the LAKSVEL protocol (Nilsson et al., 2022).

Fin splits in all fins, except the adipose fin, were manually counted and scored on a scale from 1 to 3 depending on the length of each split relative to the fin length at the split site, where 1 = [25–50 %⟩, 2 = [50–100 %⟩, and 3 ≥ 100 % (i.e., affecting adjacent tissue at the fin base) of the fin length (Figure 2a). Fin splits with a length below 25 % of the fin length at the split site were not recorded because they are likely a result of fin abrasion due to daily activities and seemingly all fish had such splits (Figure 2b). For paired fins (i.e., the pectoral and the pelvic fins), the total number of fin-split scores for both fins combined are given. Scale losses were subjectively estimated in intervals of 5 % of the torso area (the area of the fish's body except the head and fins) on each lateral side of the fish. After examination, the fish were weighed to the nearest gram and their fork lengths were measured to the nearest millimeter.

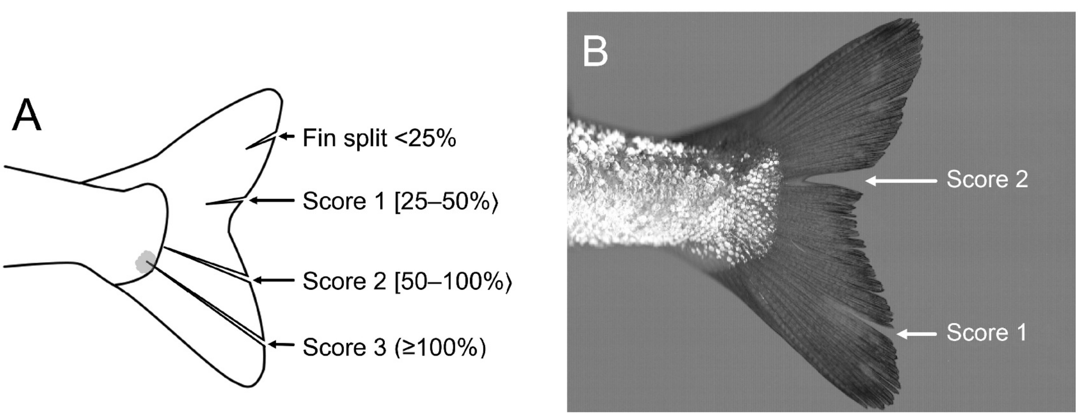

Figure 2. (a) Fin split scores (percent of fin length at the split sites). (b) Example of scoring. Fin splits with a length below 25 % of the fin length at the split sites, as here seen along the distal edge of the caudal fin, were not recorded.

Table 2. Dip-netting of fish in the cage sampling (n = 75).

Dip net mesh size (mm)	Number of hauls	Number of fish per haul	Total number of fish
5	15	1	15
10	15	1	15
15	15	1	15
20	15	1	15
20	3	5	15
Total	63	1 or 5	75

Cage sampling

In the cage sampling, the fish were lured toward the water surface by feed before 60 fish were singly netted out of the sea cage through 15 hauls with each of the four dip nets (Table 2). The order in which the dip nets were used, was rotated irregularly by the operator. In addition, 15 fish were netted out of the sea cage through three hauls with the 20 mm dip net in groups of five fish per haul to enable examination of the potential effect of the number of fish in the dip net bag (i.e., capture density). The reason for selecting five fish per haul, was that the previous Norwegian Regulation on Combating Lice in Aquaculture Facilities (LovData, 2009) set as a requirement for routine sea lice counts that there should be a maximum of five fish at a time in the anesthetic bath. The retention time of the fish in the dip net bag was about ten seconds, which represented the time needed to retrieve the dip net, lift it out of the sea cage, and transfer the fish to an anesthetic bath (tricaine methane-sulfonate, ~100 mg L^{-1}).

When fully anaesthetized, the fish were laid on a wet cloth for scoring of fin splits and scale losses using the same scoring system as in the tank sampling. The scoring was conducted by one of the examiners from the tank sampling who was blinded to information on which dip net had been used. Unfortunately, 20 % of the fish (15 out of 75) had a completely worn or thickened dorsal fin for which fin splits could not be scored. (Thickening refers to a nodular distal edge of the fin, which appears to be the result of epithelial hyperplasia, MacLean, Metcalfe, & Mitchell, 2000; Noble et al., 2012; Turnbull, Richards, & Robertson, 1996). These fish were omitted from the later data analysis of that fin. After the scoring, the fish were returned to the sea cage.

Data analysis

Statistical tests were conducted in RStudio® (version 1.3.959, RStudio, Inc., Boston, Massachusetts, USA) running R (R Core Team, 2019). The condition factor of the fish was calculated using Fulton's formula (Ricker, 1975). Generalized Linear Model (GLM) (*glm, family* = *gaussian*) with «dip net mesh size» as explanatory variable and «body weight» as response variable (regression) was used to check that there was no significant bias in body weight with mesh size. As recommended for count data (Crawley, 2012), GLM with Poisson errors (*glm, family* = *poisson*), or quasi-Poisson errors (*glm, family* = *quasipoisson*) in cases where the residual deviance was larger than the degrees of freedom, was used to test whether there was no effect of dip net mesh size on the number of fin split scores (tested for score 1 + 2 + 3, score 2 + 3, and score 3). The tests were performed with «examiner» as a co-explanatory factor to account for any scoring differences between the two examiners in the tank sampling. The models were also tested with «body weight» as a co-explanatory effect to check whether the number of fin splits was affected by body weight. Whether there was no effect of capture density in the 20 mm dip net bag in the cage sampling, was tested similarly. Whether there was no effect of dip net mesh size and/or examiner on the percentage of scale losses, was tested by GLM (*glm, family* = *gaussian*) after arcsine transformation of the proportion data to get normally distributed errors (Crawley, 2012). Whether there was no difference in scale losses between the lateral sides of the fish, was tested by paired *t*-test (*t.test, paired* = *true*). The level of significance was set at 0.05.

Results

Tank group

There was no statistically significant difference between the body weights of fish netted with the various dip nets (t = –0.5, p = 0.596), and there was also no significant effect of body weight on the total number of fin splits (score 1 + 2 + 3: t = 1.0, p = 0.339).

Fin splits of score 1 and score 2 were found in all fin types for all dip net mesh sizes, while no splits of score 3 were found in any of the fins (Figure 3). There was no significant difference between the fin split scores of the two examiners (score 1 + 2 + 3: t = 0.3, p = 0.728; score 2 + 3: t = −1.7, p = 0.090). The total number of splits (score 1 + 2 + 3) was highest for the pectoral fins regardless of mesh size (Figure 3c), followed by the caudal fin (Figure 3f). For all fins combined (Figure 3a) and for the caudal fin, the total number of splits and the number of score 2 + 3 splits increased significantly with mesh size (all fins: score 1 + 2 + 3: t = 3.6, p < 0.001; score 2 + 3: t = 2.9, p = 0.004; caudal fin: score 1 + 2 + 3: z = 2.5, p = 0.015; score 2 + 3: t = 2.6, p = 0.011). For the dorsal, pectoral, and anal fins (Figure 3b, c, and e, respectively), there was a significant increase in the total number of splits, but not in the number of score 2 + 3 splits, with mesh size (dorsal fin: score 1 + 2 + 3: t = 3.1, p = 0.002; score 2 + 3: t = 1.9, p = 0.061; pectoral fins: score 1 + 2 + 3: t = 2.5, p = 0.013; score 2 + 3: t = 1.2, p = 0.230; anal fin: score 1 + 2 + 3: t = 2.4, p = 0.016; score 2 + 3: t = 1.8, p = 0.074). For the pelvic fins (Figure 3d), mesh size had no effect on the number of splits (score 1 + 2 + 3: t = –0.3, p = 0.745; score 2 + 3: t = –0.7, p = 0.492).

Lost scales were observed in the dip net bags and the euthanasia bath. Scale losses were, however, only estimated based on points and areas on the fish's torsos where scales had been lost. No significant effect of mesh size on the percentage of scale losses was found (t = 1.824, p = 0.0696). The scale losses were slightly larger on the right lateral side of the fish than on the left side (all mesh sizes combined, 10.1 ± 0.5 % vs. 8.5 ± 0.7 %, respectively, t = –6.5, p < 0.001).

Cage group

There was no statistically significant difference between the body weights of fish netted with the various dip nets (t = –1.0, p = 0.304), and there was also no significant effect of body weight on the total number of fin splits (score 1 + 2 + 3: t = 1.3, p = 0.191).

Fin splits of score 1 and score 2 were found in all fin types for all dip net mesh sizes, while fin splits of score 3 were predominantly found in the caudal fin (Figure 4). The total number of splits (score 1 + 2 + 3) regardless of mesh size was highest for the pectoral fins (Figure 4c) followed by the caudal fin (Figure 4f). For all fins combined (Figure 4a) and for the caudal fin, the total number of splits, the number of score 2 + 3 splits, and the number of score 3 splits increased significantly with mesh size (all fins: score 1 + 2 + 3: t = 4.1, p < 0.001; score 2 + 3: t = 5.4, p < 0.001; score 3: t = 2.3, p < 0.024; caudal fin: score 1 + 2 + 3: t = 6.1, p < 0.001; score 2 + 3: t = 6.3, p < 0.001; score 3: t = 3.6, p < 0.001). For the pectoral fins, there was a significant increase in the total number of splits and the number of score 2 + 3 splits, but not in the number of score 3 splits, with mesh size (score 1 + 2 + 3: t = 2.2, p = 0.031; score 2 + 3: t = 2.8, p = 0.007; score 3: t = 0.0, p = 1.000). For the pelvic and anal fins (Figure 4 d and e, respectively), there was only a significant increase in the number of score 2 + 3 splits with mesh size (pelvic fins: score 1 + 2 + 3: t = 1.7, p = 0.087; score 2 + 3: t = 2.5, p = 0.015; score 3: t = –0.5, p = 0.650; anal fin: score 1 + 2 + 3: t = 2.0, p = 0.051; score 2 + 3: t = 2.6, p = 0.012; score 3: t = 0.0, p = 1.000). For the dorsal fin (Figure 4b), mesh size had no effect on the number of splits (score 1 + 2 + 3: t = 0.3, p = 0.802; score 2 + 3: t = 1.5, p = 0.142; score 3: t = 0.3, p = 0.752).

Lost scales were observed in the dip net bags and the anesthetic bath, but no significant effect of mesh size on the percentage of scale losses on the fish's torsos was found (t = –1.9, p = 0.067), and the scale losses did not differ significantly between the lateral sides of the fish (all mesh sizes combined, t = 0.4, p = 0.659).

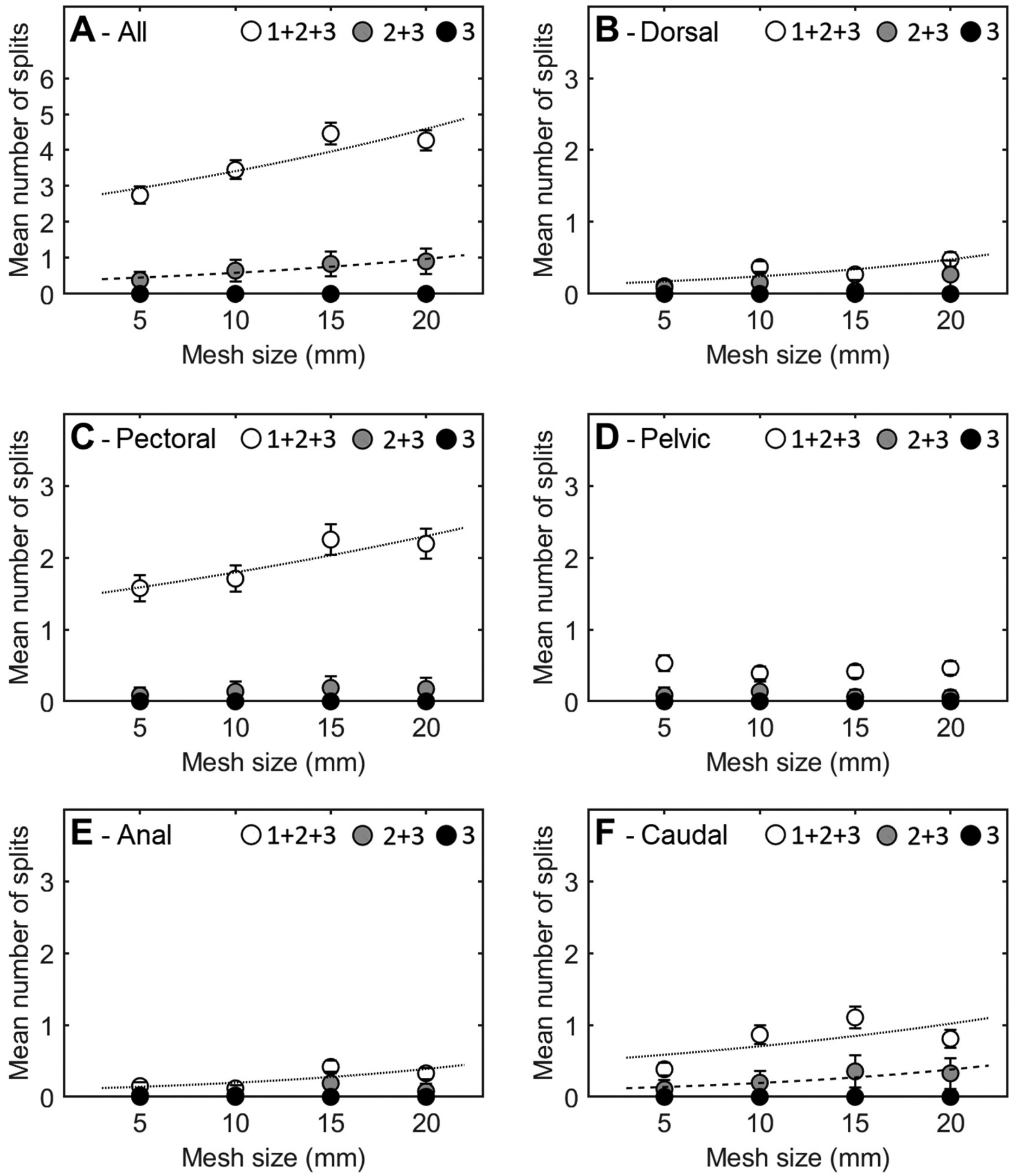

Figure 3. Fin splits in the Tank group (n = 198 fish). Mean number of score 1 + 2 + 3 splits (white markers), score 2 + 3 splits (grey markers), and score 3 splits (black markers) for (a) all fins combined, (b) the dorsal fin, (c) the pectoral fins, (d) the pelvic fins, (e) the anal fin, and (f) the caudal fin distributed by dip net mesh size. Regression lines indicate statistically significant relationships between mesh size and the mean number of score 1 + 2 + 3 splits (dotted line) and score 2 + 3 splits (dashed line). The scale of the y-axis is the same in all diagrams except diagram (a).

Capture density in the 20 mm dip net bag had no significant effect on the examined injuries (5 fish vs. 1 fish, fin splits: score 1 + 2 + 3: $t = -0.3$, $p = 0.727$; score 2 + 3: $t = -0.492$, $p = 0.628$; score 3: $t = 0.439$, $p = 0.665$; scale losses: $t = 1.000$, $p = 0.326$).

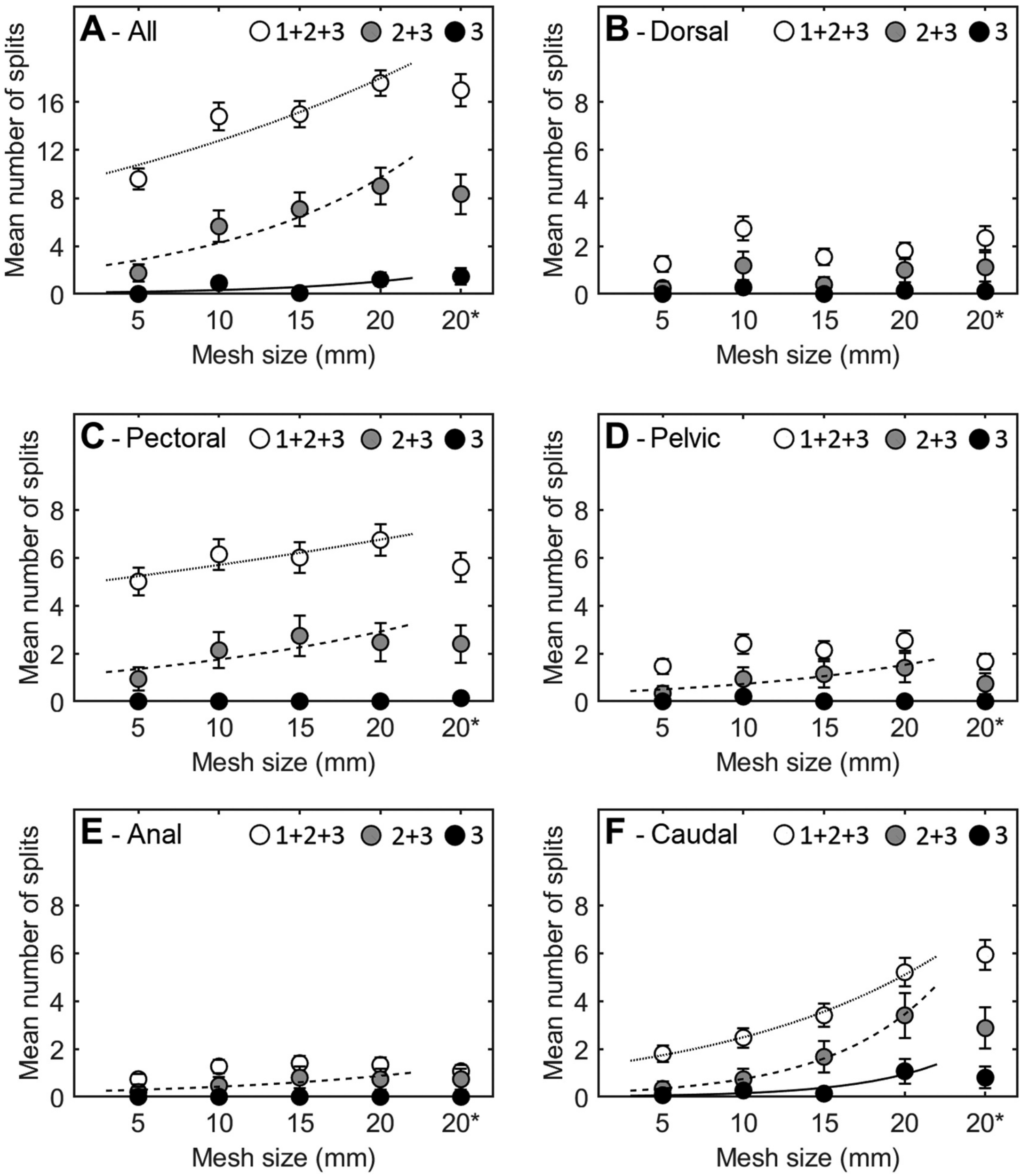

Figure 4. Fin splits in the Cage group (n = 75 fish except for diagram (b) where n = 60 fish). Mean number of score 1 + 2 + 3 splits (white markers), score 2 + 3 splits (grey markers), and score 3 splits (black markers) for (a) all fins combined, (b) the dorsal fin, (c) the pectoral fins, (d) the pelvic fins, (e) the anal fin, and (f) the caudal fin distributed by dip net mesh size. Regression lines indicate statistically significant relationships between mesh size and the mean number of score 1 + 2 + 3 splits (dotted line), score 2 + 3 splits (dashed line), and score 3 splits (solid line). The notation 20* refers to fish that were netted five at a time instead of one with the 20 mm dip net. The scale of the y-axis is the same in all diagrams except diagram (a).

Discussion

The number and severity of fin splits increased with dip net mesh size in both the Tank group and the Cage group. It seems reasonable to assume that larger meshes increase the risk that parts of the fish's body, especially the fins, will protrude through the meshes and get injured, while smaller meshes are more likely to support fins and other body parts (Lestang et al., 2008; Lizée et al., 2018). Lestang et al. (2008) found that fin membranes were generally damaged when fin rays were forced through meshes. A landing net of polyvinyl chloride-coated nylon with knotless 1 mm × 2 mm meshes prevented all but the exterior edge of the fins from pushing through the meshes, which resulted in fewer and significantly smaller fin tears relative to those caused by a landing net of polypropylene with coarse knotted 50 mm × 50 mm meshes. In the present study, mesh size had a larger effect on some fins than others. The extent of fin injuries due to dip-netting may therefore also be related to the size of the fins, their position on the fish, their ability to be laid next to the fish's body, and/or their flexibility.

No significant effect of mesh size on the percentage of scale losses on the fish's torsos was found although the fish obviously lost scales in connection with the dip-netting. Lizée et al. (2018), on the other hand, found that landing nets with smaller meshes (nylon netting with knotless 2 mm meshes and rubber-coated nylon netting with 6 mm meshes) resulted in more scale losses than landing nets with larger meshes (rubber netting with knotless 25 mm meshes and polypropylene netting with knotted 40 mm meshes). The effect of dip net mesh size was, however, not isolated from the effect of other properties of the dip nets in their study. One reason why no effect of mesh size on scale losses was found in the present study, may be the coarse and subjective method used when estimating the scale losses, which may have masked potential minor effects. Alternatively, since larger meshes are likely to increase the pressure from the fish against the netting twine while smaller meshes provide a larger contact area between the fish and the netting, potential differences in scale losses between the various mesh sizes examined here, may have been evened out. As was also the case for the dip nets used in this study, larger mesh sizes usually mean thicker netting twine and vice versa. If all the dip nets used in this study had had the same median twine diameter, the dip nets with larger meshes would have provided a smaller contact area between the fish and the netting, and the thinner netting twine would probably have been more injurious to the fish. The dip nets with smaller meshes would have provided a larger contact area between the fish and the netting, and the increased stiffness of the netting (with decreased mesh size at the same twine diameter) would probably have made the netting more injurious to the fish. In the Tank group in the present study, the scale losses were slightly larger on the right lateral side of the fish than on the left side. This may be due to the anticlockwise swimming direction of the fish (against the clockwise direction of flow in the tank) and hence more mechanical contact with the tank walls on the right side of their bodies, particularly during transitions between light and darkness (Folkedal, Torgersen, Nilsson, & Oppedal, 2010; Mork & Gulbrandsen, 1994).

Capture density in the 20 mm dip net in the cage sampling, had no effect on fin splits or scale losses. Powell (2021b) found, however, that scale losses in farmed Atlantic salmon smolts ($\overline{w}$ = 145 g) and post-smolts ($\bar{w}$ = 900 g) captured in rubber-coated or standard knotless hand nets (mesh sizes = 6 mm) in groups of ≤15 and ≤3 fish, respectively, were generally proportional to capture density. One reason why no such effect was found in the present study, may again be the coarse and subjective method used when estimating the scale losses. On the other hand, it also seems reasonable to assume that the presence of other fish in a dip net bag will reduce some fish's physical contact with the netting and thus the risk of skin abrasion and fins protruding through the meshes. If more than five fish had been netted at a time in this study, the pressure on the fish lying at the bottom of the dip net bag would have increased and presumably caused more injuries.

Damage to the fish's mucus layer and injuries to external structures like skin and fins, can lead to osmoregulatory stress (Elliott, 2011b; Olsen, Oppedal, Tenningen, & Vold, 2012; Zydlewski et al., 2010) and render the fish more susceptible to pathogens (Barthel et al., 2003; Svendsen & Bøgwald, 1997; Ventura & Grizzle, 1987). The injuries can also activate nociceptors and possibly be painful for the fish (Ashley et al., 2007; Chervova, 1997; Ellis et al., 2008; Roques, Abbink, Geurds, van de Vis, & Flik, 2010). Fin injuries have been suggested to impair the fish's swimming performance (Abbott & Dill, 1985; Barthel et al., 2003; Huntingford et al., 2006; Turnbull et al., 1996). It is likely that dip-netting can also result in injuries to eyes (Noble et al., 2012) and gills, which can cause reduced vision or blindness and reduce the fish's uptake of oxygen, respectively.

External injuries can thus cause disturbances in physiology, health, and behavior, and can in some cases result in mortality (Barthel et al., 2003; Cooke & Hogle, 2000; Svendsen & Bøgwald, 1997). Besides inflicting injuries on the fish, being chased and captured by a dip net in a sense mimic a predatory attack and can induce stress responses and possibly cause fear in the fish (Barton, Peter, & Paulencu, 1980; Madaro et al., 2016; Schreck, 1981; Yue, Moccia, & Duncan, 2004). Dip-netting also involves the removal of the fish from water into the air, with the welfare consequences air exposure entails (e.g., collapse of the gill lamellae, asphyxia, and stress) (Arends, Mancera, Munoz, Wendelaar Bonga, & Flik, 1999; Cook, Lennox, Hinch, & Cooke, 2015; Ferguson & Tufts, 1992). Use of dip nets should therefore be limited to when it is strictly necessary.

This study addressed mesh size, but there are also other properties of dip nets that should be investigated. The size of the dip net bag determines the maximum size and number of fish that can be netted at a time. Even though no effect of capture density was found in this study, it seems reasonable to assume that fish may suffer bruising, crushing, and compression injuries as well as asphyxiation when many fish are crowded in a dip net bag (Gregory, 1998; Noble et al., 2018). The shape of the bag will affect the weight distribution of the fish: bags with flat bottoms can support the fish horizontally, thus spreading the weight of the fish relatively evenly, while bags with tapered bottoms hold the fish in a more vertical position, causing the weight of the fish to be supported primarily by the head or the caudal fin. The size and design of the bag also impacts the fish's ability to move and potentially wrap themselves in the netting, which can lead to prolonged handling and air exposure times. The netting itself can be made of a variety of materials and subjected to treatments such as rubber-coating, dyeing, and/or impregnation with antioxidant or ultraviolet protectors, which may all influence the effect of the netting on the fish. Effects of dip nets can also depend on the fish themselves as fish of different species and in different life stages have different behavior, size, body morphology, skin anatomy, and sensitivity to external injury (Colotelo & Cooke, 2011; Kryvi & Poppe, 2021). This highlights the challenges and trade-offs faced by operators when selecting a dip net. Further investigation into dip net bag size and design and netting properties with respect to external injuries in fish is therefore needed for each species and life stage to enable more specific recommendations regarding which dip nets are best suited to safeguard fish welfare.

Conclusion

Dip-netting of post-smolt Atlantic salmon using four identical dip nets with mesh sizes of 5, 10, 15, and 20 mm, respectively, showed that the number and severity of fin splits increased with mesh size, but no effect of mesh size on the percentage of scale losses was found. Dip-netting of five fish at a time instead of one with the 20 mm dip net, had no statistically significant effect on the examined injuries. It is concluded that the use of dip nets with smaller mesh sizes can be positive for fish welfare by reducing fin splitting.

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