SLU ID: SLU.aqua.2020.5.5-2
2020-03-20

Discard mortality of salmon caught in different gears [1]

Johan Östergren, Christer Blomqvist, Johan Dannewitz, Stefan Palm, Arne Fjälling

Swedish University of Agricultural Sciences, Department of Aquatic Resources (SLU Aqua), Institute of Freshwater Research, Drottningholm

1. Background

Since 2015, salmon fisheries in the Baltic Sea have a landing obligation (LO)-exemption for salmon caught with trap-nets, creels/pots, fyke-nets and pound nets. The exemption makes it possible to release wild salmon back into the sea, as a measure to steer the exploitation towards reared (fin-clipped) salmon. The possibility to release salmon also makes it possible to catch other species outside the salmon fishing season or when the national salmon quota is filled.

The present LO-exemption is based on the assumption that fish has a high likelihood of survival after capture, handling and release (Commission delegated regulation (EU) 2018/211) although information about survival rates of released salmon caught in the Baltic Sea commercial fishery has remained limited. Until recently, studies focusing on long-term effects on survival and behavior of Baltic salmon released from trap-nets (the most common gear used in the commercial fishery targeting salmon) have been largely missing. In contrast, several studies exist from other parts of the world focusing on fisheries-related mortalities in salmon; however, a majority of those studies has investigated commercially exploited Pacific salmon (*Oncorhynchus* spp.) and recreational fisheries for Pacific and Atlantic salmon.

In this report, we summarize earlier studies that have analyzed survival/mortality of captured and released salmon from different types of gears, including those modified to give higher survival of released salmon. Several names and definitions of fisheries-related mortality exist in the literature. Here we focus on the discard mortality as defined by the International Council for the Exploration of the Sea, ICES (2004), viz. mortality of fish not retained (fish dying aboard or post-release). Our overall aim has been to summarize previous

[1] This summary of available knowledge represents an abbreviated and partly re-worked version of an earlier report by Östergren et al. (2020)

studies on discard mortalities relevant to the Baltic coastal salmon fishery and to provide scientific advice regarding:

1. Survival/mortality of captured and released salmon caught in traditional gears, with special focus on the so-called Pontoon-trap;
2. Survival/mortality of captured and released salmon in modified gears that have been designed for a more gentle (harmless) handling aboard, including technical descriptions of those gears;
3. Potential additional factors (other than type of gear and handling) affecting salmon post-release survival, e.g. effects of poor health (disease), that may be of relevance when interpreting results from previous studies.

We first provide a technical description of gears currently used in commercial fisheries of Baltic salmon and which are covered by the LO-exemption (section 2). We then provide a brief overview of the current health situation of salmon in Baltic Sea rivers, where disease outbreaks has been reported since 2014 (section 3). A summary of studies focusing on discard mortality of salmon, with specific reference to Baltic salmon, is given in section 4. Finally, we discuss our findings in relation to the main objectives and present our conclusions (section 5).

2. Gears used in the Baltic salmon fisheries

At present, the most common gear used in the Baltic coastal salmon fishery is the so-called Pontoon trap or Push-up trap (Figure 1 & 2; Appendix 1), followed by older types of trap-nets (Combi-trap and Fyke-net). For example, in 2018 there were > 300 Pontoon traps used along the Swedish coast, and the salmon catch with those traps represented c. 70% of the total Swedish commercial salmon catch in numbers that year.

The Pontoon trap was developed to avoid predation on caught fish by seals directly from the gears (Hemmingsson et al., 2008; Suuronen et al., 2006). The Pontoon trap is set under the water surface. When emptying the trap two pontoons are filled with air and the fish-chamber (Figure 1) is lifted above the water surface. In the “traditional” landing/emptying process, the fish is held above the water surface (lasting for one to several minutes) while becoming crowded in a plastic (or aluminum/steel) chute where they jump, twist and try to escape. The fish is then emptied directly into the fisherman’s boat (Figure 2).

Recently, the Pontoon trap design and handling procedure has been developed and modified further to improve possibilities for selective fishing, targeted mainly for whitefish (*Coregonus* spp.) (Lundin et al., 2015). One modification is the so-called “Vittjanpåse”, a knot-less net bag that is attached to the plastic chute (Figure 3). The knot-less net bag can be equipped with a grid for size selection of fish and a zipper for easy release. However, when performed as intended, the emptying process using “Vittjanpåse” may result in a more heavy and un-ergonomic working position for fishermen (Figure 4).

Two additional modifications include a double fish house and a so-called selection chute (Figure 5). Further technical descriptions and results from suitability tests of these modifications for selective commercial fishing of salmon and whitefish are presented in Nilsson (ed.) (2018a) and Nilsson (ed.) (2018b) (see also Appendix 1).

Additional gears (i.e. Combi-trap, Fyke-net, Gill-net etc) used in commercial salmon fisheries in the Baltic Sea will not be described in detail here (but see Appendix 1). The Combi-trap and Fyke-net are also well described in e.g. Suuronen et al., (2006), where they are referred to as trap-nets. These more traditional gears are deployed under the water surface, and at landing (or when emptying) it is possible to gently remove salmon from the gears "fish bag" one by one (by hand) and release them (Appendix 1). One drawback of these trap-nets, however, is the high risk of seal predation, and that some versions use capturing nets (i.e. similar to gill-nets).

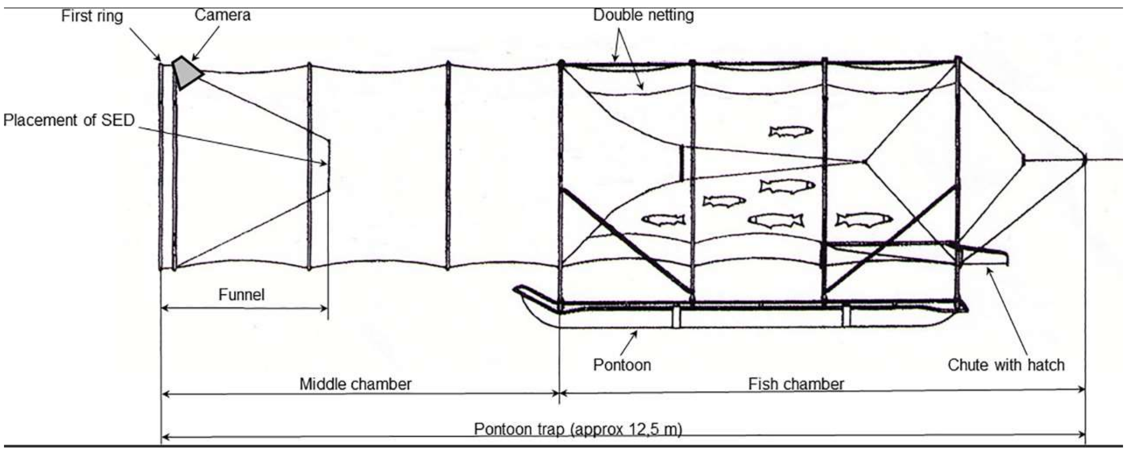

Figure 1. Schematic figure of the Pontoon trap, this one equipped with a camera for studying fish movement (from Calamnius et al., 2018).

Figure 2. The "traditional" emptying method for Pontoon traps (Photo: Christer Blomqvist).

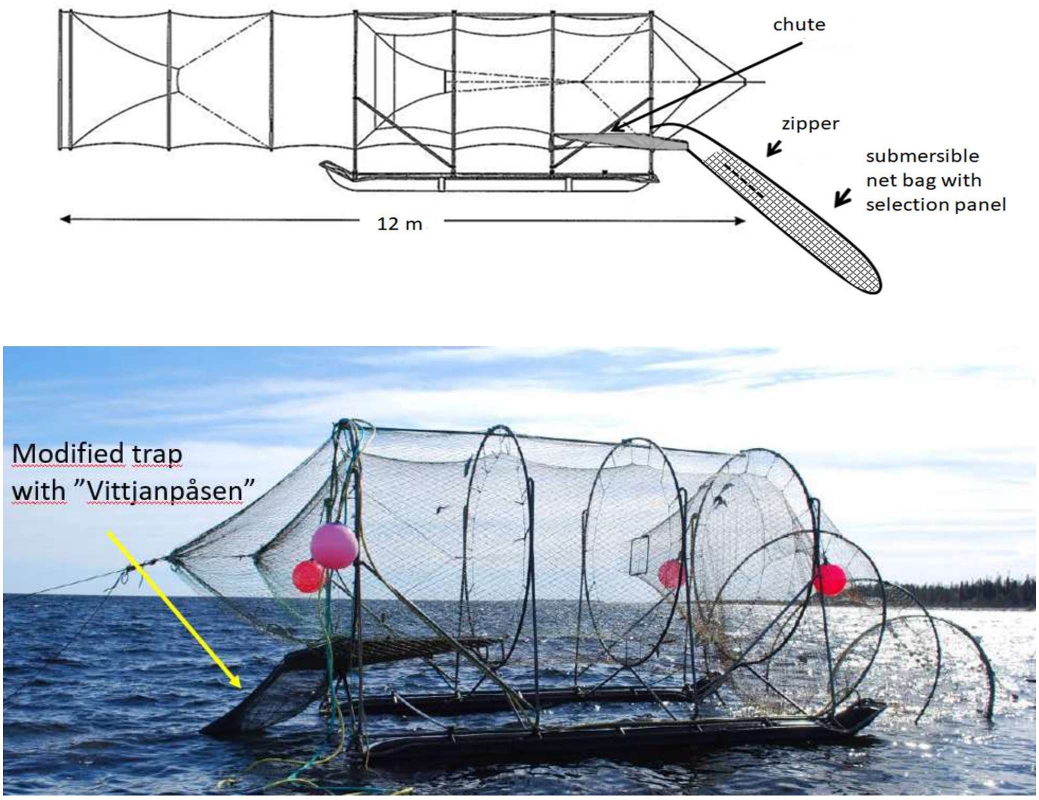

Figure 3. Modified Pontoon trap with the knot-less net bag (“Vittjanpåse”) attached. The zipper is indicated in the schematic picture (above). A photograph of the installed net bag when above water (below) (Photo: Maria Hedgärde)

Figure 4. The modified Pontoon trap with the knot-less net bag “Vittjanpåse” attached during emptying, showing an example of an un-ergonomic working position (Photo: Stefan Palm).

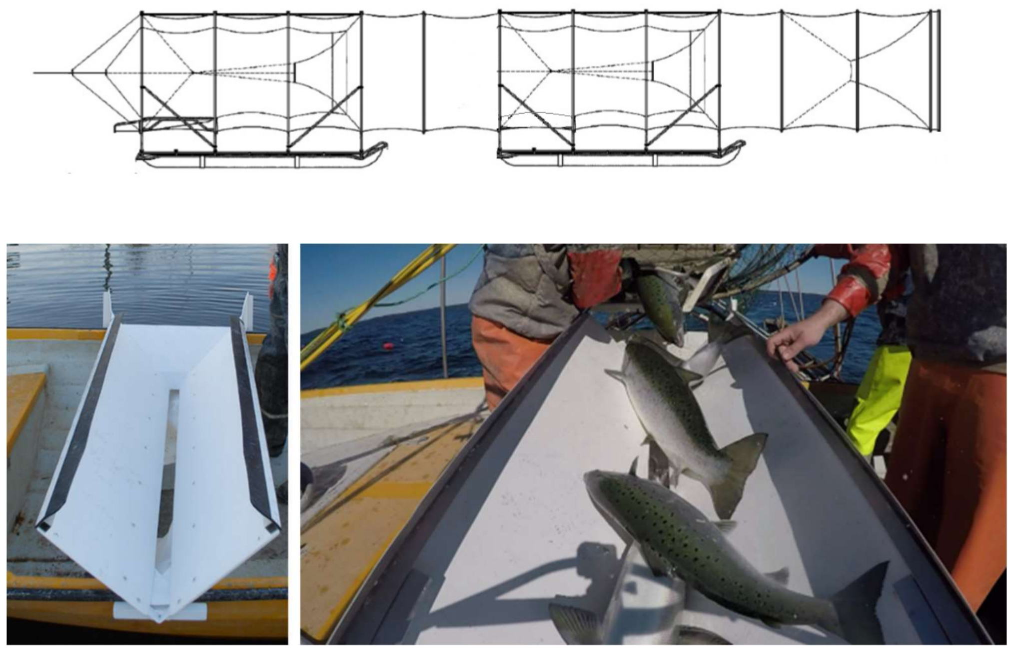

Figure 5. The double fish house (above) and a close up of the selection chute (below), from Nilsson (ed.) (2018b).

3. The salmon health situation in recent years

Since 2014, health issues for Baltic salmon have been reported by fishermen and local administrators. In particular, dying or dead salmon have been observed in Swedish and Finnish rivers, spanning from Torneälven (Tornionjoki) in the north to Mörrumsån in the south (ICES, 2019). The affected salmon have displayed various degrees of skin damages (often of red/pink color), from milder erythemas and bleedings to UDN-like (Ulcerative Dermal Necrosis) lesions and more severe ulcers and traumatic wounds, typically followed by secondary fungal infections causing death (SVA, 2017). The disease prevalence has varied considerably between rivers and years. In some cases, the number of observed dead salmon has been considerable, although quantitative estimates of total death rates are missing. In other rivers, there are so far no reports of elevated levels of dead salmon.

Besides visible skin damages, there are indirect indications from some rivers that seemingly healthy salmon may also be in poor condition. For example, following tagging at the Ume/Vindelälven river mouth (Figure 1) in 2017, only one out of 400 salmon (0.25%) managed to pass the nearby Norrfors fishway. Notably, most of the tagged fish did not die, but remained for some period in the river's lowermost parts before returning to the sea. In 2018, the proportion of tagged salmon passing the counter was higher (15%), but still low compared to previous years with tagging experiments (long term average: ~30%, highest proportion: 55%). In 2019, none out of 200 marked salmon passed the Norrfors fishway. Obviously, the standard way of catching, handling and tagging severely affected the fish's "willingness" (possibility) to migrate upstream in these particular years. Similar surprisingly low migration success rates of tagged salmon have also been detected within the ongoing tagging study of salmon outside River Torneälven/Tornionjoki (Palm et al., 2020; Riina Huusko, pers. comm.).

It appears likely that the health problems seen recently in Swedish and Finnish salmon rivers have a common cause, most likely linked to the marine (Baltic Sea) phase of the life cycle. However, the reason(s) behind the deteriorating salmon health, including potential links between observed skin problems and disturbed migration in tagged individuals remains largely unclear, despite repeated veterinarian investigations and ongoing studies (SVA, 2017; Axén et al., 2019).

4. Discard mortality of salmon in commercial fisheries

Factors affecting survival

The majority of studies on discard mortality and additional fisheries-related mortality on salmon have been done on Pacific salmon. For Atlantic salmon the focus so far has mostly been on recreational fisheries (i.e. angling). Several literature reviews on the subject exist, where the most recent and complete one seems to be Patterson et al. (2017). This review covers both commercial and recreational fisheries on Pacific salmon with a focus on factors affecting fishing-related incidental mortality (FRIM). This term includes (and separates) also incidental fishing mortality, which is mortality caused by gears alone, e.g. predation directly from gill-nets or mortality in fish that have escaped from a gear before being emptied.

Patterson et al. (2017) identified five key fisheries mortality risk factors; capture, handling, injury, water temperature, and predation. Similar to Raby et al., (2015), they underline the complexity and variability of effects that are context specific and which can vary depending on e.g. fishing-gear, location, species/population, experience of fishermen, and potential cumulative effects of combined factors including environmental factors as water temperature. Physiological stress during capture and handling, and injuries from gear encounter, are main reasons to mortality or behavioral changes, chronic stress, and increased risk of infection. The effect on mortality is highly dependent on the magnitude and duration of stressors, and can be increased by extrinsic environmental factors (e.g. water temperature) and linked to intrinsic factors (e.g. size and gender).

Patterson et al. (2017) also presented a risk-assessment framework that can be used for evaluating potential fisheries-related and post-release mortality in commercial fisheries. Their identified risk factors are applicable also to commercial fisheries of salmon in the Baltic Sea. However, the Pontoon trap is not used in Pacific salmon fisheries, and the review by Patterson et al. (2017) contains no specific information for this particular gear. Thus, to allow evaluation of expected discard mortality in the Baltic commercial coastal salmon fishery, there is a need for gear and location specific information from this region.

Summary of earlier studies in the Baltic Sea

Discard mortality of salmon captured in the Baltic Sea has not been rigorously studied. In particular, very few studies have been published in peer-reviewed journals, and we further have found no study specifically addressing effects of the Pontoon trap – the most common gear at present.

Siira et al (2006) performed the so far largest study on post-release mortality of Baltic salmon captured in trap-nets (Combi-trap and Fyke-net), but did not include Pontoon traps.

They concluded that average post-release mortality was 11% (range 4–21%). Notably, this tag-recapture study did not include immediate mortality estimates, and the average time from release to recapture was just 15 days (even though some tags were recovered after several months).

There are some additional reports (i.e. grey literature) showing that external injuries (bleedings, scale losses, eye damages) on salmon from Pontoon trap-fishery may be common (Blomqvist et al., 2013; Ikonen and Pakarinen, 2007; Pakarinen et al. 2007; Hasselborg and Karlsson, 2002; Jonsson et al., 2008). Fjälling (2013) presented a literature review on fishing-related mortality and injuries of different gears including Pontoon trap, Gill-net, Combi-trap, Fyke-net, and recreational fisheries (angling). His main conclusion was that only some gears (Combi-trap and Fyke-net) had the potential to give few injuries and low post-release mortality. It should be underlined, however, that when using more traditional Combi-traps or Fyke-nets, seal predation is likely to be high, and thus the total fisheries-related mortality may be substantial as it also includes non-visible seal-damage (Kauppinen et al., 2005; Fjälling, 2005).

<u>Pontoon traps and discard mortalities</u>

More recently (last five years) several studies focusing on post-release mortality of salmon captured in Pontoon traps have been initiated in Sweden (Table 1). These studies also have had the objective to compare mortality rates for the original Pontoon trap design to modified versions. So far, however, results from these studies have only been published as shorter reports or memorandums, or in manuscripts under preparation.

In Table 1, we have summarized preliminary results from these recent Swedish studies. Note that the original Pontoon trap design and emptying/landing process is here referred to as "Traditional" (see Figure 1 & 2) whereas "Modified" designates the modified Pontoon trap design equipped with an attached net bag ("Vittjanpåse"; Figure 4). The modified trap has potential to be gentle with salmon potentially released after handling without subsequent mortality or changed behavior, mainly because the catch is never lifted above the water surface or dumped directly in the boat (as with the traditional design). Thus, the extra stress, air exposure and physical injuries from hitting the gear, boat and other fish could potentially be reduced or eliminated using this design.

These recent results (Table 1) collectively indicate that there is an immediate mortality of ~20% in the Traditional Pontoon trap, while there is a zero immediate mortality in the Modified design (with Vittjanpåse). Further, crude average of total discard mortality across studies is 71% *vs* 48% for the Traditional and Modified design, respectively. When combining data from studies, an overall significant difference in discard mortality between Traditional and Modified exists (Fishers exact test: $p < 0.05$). However, these studies differ from one another in several aspects. Therefore, a brief explanation of each particular study is needed to fully understand the relevance and reliability of the results shown in Table 1.

The studies in 2014 outside Indalsälven and Umeälven (Lundin et al., 2014) only succeeded in tagging a few individuals (Table 1) at high water temperature (21–22°C), which likely increased the mortality risk. In addition, at Umeälven post-release mortality was estimated based on fish having migrated upstream in the river, although it is known that only a smaller part (30–50%) of the individuals normally find their way from the tagging location to the place of detection (Rivinoja et al., 2006). Thus, there is a risk that mortality rates in the studies by Lundin et al. (2014) were overestimated.

In the two-year study outside Torneälven (summers of 2018 and 2019), estimated post-release mortality (Table 1) was based on fish registered at the first automatic listening station (ALS) at the river mouth. There was no possibility to evaluate potential predation effects, or recapture rates in traps located between the tagging location and the first ALS. The salmon normally continue their spawning migration upstream the river to spawn later in autumn. However, in 2019, 85% of salmon captured and released from Traditional and 76% from the Modified trap that initially entered the river soon returned to the sea, months before the spawning season. This deviating behavior indicates some delayed tagging and handling effect, possibly linked to poor health status similar to what has recently been observed in Ume/Vindelälven (see section 3).

River Dalälven study

This study from 2019 (Blomqvist and Östergren, in prep.; Östergren et al., 2020) is the most detailed one carried out so far. It included a total of 183 salmon of which 102 were caught outside Dalälven in the Bothnian Sea using either traditional Pontoon traps or modified Pontoon traps (with *vittjanpåse* attached). The modified Pontoon traps were emptied following two different strategies: 1) correct handling - salmon were entering the net bag under the water surface prior to landing (Modified), or 2) incorrect handling - salmon were lifted above the water surface in the trap before released into the net bag prior to landing (Modified F). The 102 salmon caught with pontoon traps were radio-tagged immediately after capture, transported and released into an experimental semi-enclosed stretch of River Dalälven (cf. Dannewitz 2003).

The study also included 81 individuals in two control groups consisting of salmon caught in a fixed trap at the first hydropower dam in River Dalälven (c. 10 km from the river mouth) where returning salmon to be used as broodstock in the local hatchery are collected annually. Individuals in the first control group (Control RT) were radio-tagged with external transmitters (same procedure as for the treatment groups described above) and released into the semi-enclosed stretch in River Dalälven. The second control group (Control) was only netted, measured and tagged with Pit-tags, and then kept in an indoor holding pool in the hatchery. These salmon were selected to be used as hatchery broodstock; therefore only fish in seemingly good condition were selected (i.e. injured fish were discarded). See Östergren et al. (2020) for additional details about the study design.

Table 1. Studies (using telemetry) on discard mortality in the Swedish commercial fishery with Pontoon traps. Gear Type is either the traditional trap design or a modified version to increase survival of fish (i.e. with Vittjanpåse). Modified F is the same design as Modified, but the landing technique was different as catches were lifted above the water surface (i.e. against the original intention). Control RT and Control are control groups, not exposed to fishery (see text for details). Total n is the total number of salmon used in the studies. Immediate mortality is the proportion of total captured individuals used in the study that died directly upon emptying the trap or during tagging. Post-release mortality is the proportion of released individuals (i.e. not including immediate mortality) that died within 1–30 days (i.e. short term and delayed mortality combined) after release. Duration (PRM) is the average time period for estimates of post-release mortality, i.e. from release to dead/alive status, based on telemetric logger data. Discard mortality is the number of salmon (i.e. sum) of immediate and post-release mortality divided by the total number of tagged individuals minus tag-loss and escaped fish. Numbers used to calculate different proportions are given within brackets, e.g. 9% (n = 1/11).

Gear Type	**Total *n***	**Immediate mortality**	**Post-release mortality**	**Duration (PRM)**	**Discard mortality**	**Study area/year**	**Reference**
Traditional	11	9% (*n* = 1/11)	80% (*n* = 8/10)	~ 1	82% (*n* = 9/11)	Indalsälven/2014	a
	20		80% (*n* = 16/20)	~ 30	80% (*n* = 16/20)	Umeälven/2014	a
	19	32% (*n* = 6/19)	23% (*n* = 3/13)	~ 2	47% (*n* = 9/19)	Torneälven/2018	b
	57	23% (*n* = 13/57)	43% (*n* = 19/44)	~1.5	56% (*n* = 32/57)	Torneälven/2019	c
	50	24% (*n* = 12/50)	83% (*n* = 30/36)	= 7	88% (*n* = 42/48)	Dalälven/2019	d
Average		22% (*n* = 8)	62% (*n* = 15)	8	71% (*n* = 22)		
Modified	12	0%	58% (*n* = 7/12)	~ 8	58% (*n* = 7/12)	Indalsälven/2014	a
	27	0%	63% (*n* = 17/27)	~ 33	63% (*n* = 17/27)	Umeälven/2014	a
	32	0%	47% (*n* = 15/32)	~ 5	47% (*n* = 15/32)	Torneälven/2018	b
	134	0%	17% (*n* = 23/134)	~1.8	17% (*n* = 23/134)	Torneälven/2019	c
	26	0%	54% (*n* = 13/24)	= 7	54% (*n* = 13/24)	Dalälven/2019	d
Average		0%	48% (*n* = 15)	11	48% (*n* = 15)		
Modified F	26	15% (*n* = 4/26)	71% (*n* = 15/21)	= 7	76% (*n* = 19/25)	Dalälven/2019	d
Control RT	44	5% (*n* = 2/44)	23% (*n* = 7/31)	= 7	27% (*n* = 9/33)	Dalälven/2019	d
Control	37	0%	22% (*n* = 8/37)	= 7	22% *n* = 8/37)	Dalälven/2019	d

a) Lundin et al. (2014), b) Blomqvist and Östergren (2019), c) Riina Huusko (pers. comm.), d) Blomqvist and Östergren (in prep.)

Use of radio tags equipped with a mortality signal made it possible to study the fate of each salmon in the semi enclosed river section, and time of mortality could be determined rather exactly (± 15 min). The original aim was to follow individuals until the beginning of the spawning period (early October). However, all individuals in the treatment groups and one control group either died or escaped before 8 August.

A more comprehensive and detailed presentation of the analyses and results is provided by Östergren et al. (2020), and only the most important findings are presented below. The amount of injuries differed across the treatment and control groups (Table 2). Injured eyes was only noted for salmon that were caught using traditional Pontoon traps or modified Pontoon traps where the salmon were exposed to air (Modified F), whereas fin damages and various skin damages (RedBelly and ScaleLoss) were noted in all groups.

Table 2. Dalälven 2019 study: injuries noted for treatment and control groups.

	RedEye[1]	FinDamage[2]	RedBelly[3]	ScaleLoss[4]
Traditional	64%	32%	12%	12%
Modified F	50%	92%	50%	19%
Modified	0%	23%	19%	8%
Control RT	0%	11%	32%	11%

[1] visible blood in one or two eyes, [2] broken or damaged fins, [3] red or pink, often circular pattern on abdominal skin, and [4] loss of scales on >10% of fish surface.

Overall results on discard mortalities from the 2019 Dalälven study are presented in Table 1 (together with results from other studies of Pontoon traps). Mortality observed in the Dalälven study was further divided into immediate, post-release short term and post-release delayed mortalities, as explained below:

Immediate mortality (i.e. individuals that died during the emptying process or at tagging) was noted both in Traditional (24%), Modified F (15%) and in the radio-tagged Control RT (5%) groups (Tables 1 and 3, Figure 6). The immediate mortality was significantly higher in the Traditional group compared to in Modified, Control RT and Control (Fisher's Exact Tests, $p < 0.05$), but not compared to Modified F (Fisher's Exact Test, $p = 0.55$). The mortality in the Control RT was most likely an effect of too high water temperature at tagging (> +20°C). Earlier telemetry studies have shown that tagging at water temperatures above +20°C can be fatal (Östergren et al., 2011).

Post-release **short term mortality** (first 24 hours, excluding immediate mortality, escaped individuals and tag losses) was noted in Traditional

(58%), Modified F (29%) and in the Modified (20%) groups, but not in the control groups (Table 3, Figure 6). The short term mortality was significantly higher in the Traditional group compared to Modified, Control RT and Control (Fisher's Exact Tests, $p < 0.05$), but not compared to Modified F (Fisher's Exact Test, $p = 0.056$). There was a significantly higher short term mortality in the groups Modified F and Modified compared to in Control RT and Control (Fisher's Exact Tests, $p < 0.05$).

Post-release **delayed mortality** (between 25 and 168 hours after release, excluding immediate and short term mortality, escaped individuals and tag losses) was noted in the Traditional (60%), Modified F (60%), Modified (42%), Control RT (23%) and Control (22%) groups (Table 3). Delayed mortality was significantly higher in the Traditional compared to Control RT and Control (Fisher's Exact Tests, $p < 0.05$), but not compared to any other group (Fisher's Exact Tests, $p > 0.05$). Notably, the delayed mortality seen in the Control (22%) was much higher than for broodstock individuals in preceding years (collected during the same weeks) (e.g. 0% in 2018, and 7.5% in 2017).

Table 3. Dalälven 2019 study: number of salmon in mortality categories Immediate, Short term (first 24 h), Delayed (25 – 168 h), and number of escaped salmon and tag loss per treatment and control group, after one week (168 h) following release. See text for details on treatments and controls.

Group	Mortality			Escaped	Tag	Alive	Total
	Immediate	Short	Delayed				
Traditional	12	21	9	1	1	6	50
Modified F	4	6	9	0	1	6	26
Modified	0	5	8	1	1	11	26
Control RT	2	0	7	7	4	24	44
Control	0	0	8	0	0	29	37

All individuals in the semi-enclosed experimental area died before 8 August. In comparison, the non-treated, non-radio-tagged control group (Control) held in the hatchery showed a 57% mortality until the same date. This strongly indicates a general problem with underlying background mortality, most likely caused by poor health status among salmon in Dalälven 2019 (as noted for Baltic salmon in recent years; see section 3). The observed mortality (i.e. mortality prior to 8 August) (57%) was clearly higher than for salmon collected for broodstock during the same period in 2018 (4%) and 2017 (21%).

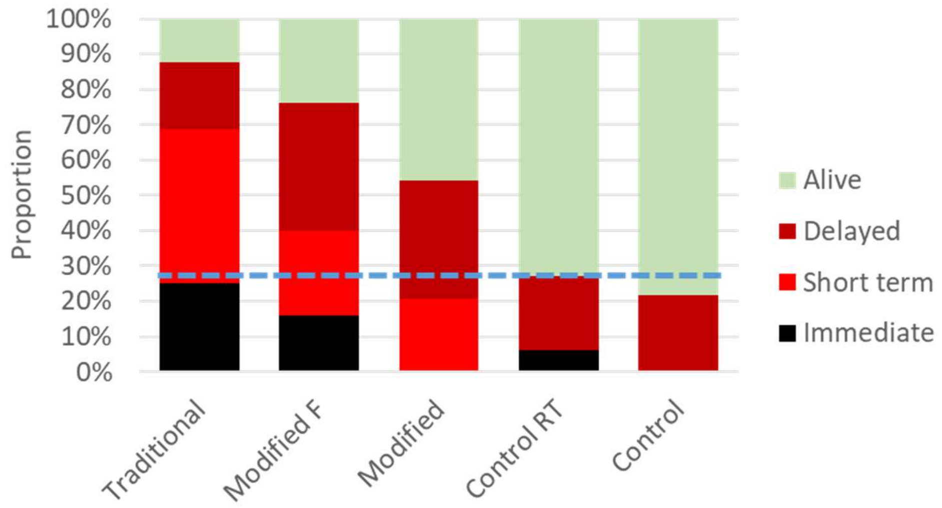

Figure 6. Dalälven 2019 study: fate of radio-tagged salmon captured and released showing immediate mortality (black), short term mortality (red), delayed mortality (=168 hours, dark red), and still alive (green) after 168 hours (one week). The blue dotted line indicates "background mortality" as determined from the radio tagged control (Control RT). See text for presence of statistically significant differences in mortality rate among groups.

When interpreting the results of the Dalälven study, it is thus important to consider the current poor health status of salmon in the Baltic Sea. The non-treated, non-radio-tagged Control salmon showed 22% mortality after one week, indicating that also salmon not caught and released from fishing gears experienced a rather high mortality during this period. One way of accounting for this background mortality, and potential tagging effects, is to subtract the immediate and delayed mortality in the Control RT group (Figure 6) from the mortality estimates in the treatment groups. This would yield total post-release mortalities (cf. Table 1) corresponding to 60%, 49% and 27% for Traditional, Modified F and Modified Pontoon traps, respectively.

5. Discussion

Based on peer-reviewed articles, grey reports, and ongoing studies on Pacific (e.g. Patterson et al., 2017) and Baltic salmon (e.g. Blomqvist and Östergren, in prep.; Östergren et al., 2020), we conclude that the total discard mortality in the Swedish Baltic salmon coastal fishery is strongly dependent on the type of gear used, as well as handling time and emptying procedures. Baltic salmon captured in the most common gear type (i.e. the Pontoon trap) typically show physical injuries (e.g. blood in eyes, scale losses) which together with physiological stress increases the risk of discard mortality. In addition, extrinsic factors, in particular high water temperature and poor health may have a large negative impact on post-release survival.

An earlier tag-recapture study of Baltic salmon caught in Combi-traps and Fyke-nets showed an estimated post-release mortality of only 11%, although it should be noted that the tagged fish was followed for just 15 days on average (Siira et al., 2006). Earlier studies on migrating Atlantic salmon, where individuals have been captured, radio-tagged and released from coastal trap-nets, indicate minimum levels of post-tagging mortality of a similar low magnitude (1–11%) (Heggberget et al., 1993; Erkinaro et al., 1999; Thorstad et al., 1998).

In estuaries of rivers Simojoki (Jokikokko, 2002) and Umeälven (Rivinoja et al., 2001) in the Gulf of Bothnia, 80–85% of Fyke-net caught and released radio-tagged salmon were detected in the rivers, indicating low discard mortality rates. Common for these earlier studies was that the salmon were healthy and were removed one by one from trap-nets, with minimal air exposure. These results indicate that gentle handling (within controlled scientific experiments) of healthy salmon may give a discard mortality in the lower range of the discard mortality presented above (Table 1).

There is evidence showing that discard mortality may be reduced through gear modifications, although not to zero. Capture and handling will always induce some level of physiological stress, increasing risks for discard mortality. Although studies on discard mortality of salmon in the Baltic Sea are few, there seems to exist a general pattern in that gear modifications and gentle handling decreases mortality significantly.

Based on recent studies in the Baltic Sea (Table 1), total discard mortality estimates from Pontoon traps are in the range 47–88% when using the traditional (commercial praxis) handling technique. These estimates include both immediate mortality (fish dying at landing) and subsequent post-release mortality (usually only estimated for shorter periods, in earlier studies on average 8 days; Table 1). Whereas immediate mortality was similar across studies (~20%), the post-release component was highly variable (23–83%). With a modified design of the Pontoon trap (attached net bag, "Vittjanpåse") the total discard mortality was reduced (to 17–63%; Table 1) when the fish was correctly/gently handled.

The large range of mortality estimates derived from studies on Baltic salmon most likely reflects a combination of several factors, including differences in study design and sample size, variation in water temperature, and potential tagging effects. In addition, the health situation for Baltic salmon has deteriorated in recent years, although with large variation across rivers and years (SVA, 2017; Palm et al., 2020; ICES, 2019). Hence, estimates of discard mortality might have been affected in certain cases, and there is likely a lack of more recent studies in the Baltic based on healthy salmon. Regarding the study in Dalälven 2019 presented above, however, effects of health related "background mortality" was possible to assess based on results from two control groups. In this comprehensive study of discard mortality, post release mortality was estimated to 60% and 27% for Traditional and Modified Pontoon traps, respectively, when accounting for seemingly health related background mortality (see above).

Besides the modification ("Vittjanpåse") used in recent Swedish studies of salmon discard mortality, there are other designs developed and tested to improve the possibility for a selective fishery, targeting for example whitefish (e.g. Nilsson (ed.), 2018a; Nilsson (ed.), 2018b). One design, the selection chute, gave promising results with a rapid emptying process and few or no injuries noted on released salmon, even though post-release mortality was not studied. Worth noting is that, during the emptying process of the chute, salmon were lifted above water in the Pontoon trap before being selected for release (similar to the Modified F design presented above), which is likely to induce additional post-release mortality. There might also exist additional options for species selective gear development, e.g. using video analysis (Fjälling, 2013; Jonsson, 2015) with the aim to avoid capture of salmon altogether, i.e. no by-catch of salmon will exist.

To be able to evaluate potential population specific effects of different discard mortality rates with respect to stock assessment and fisheries advice, there is a general need of information on the amount discarded salmon in the Baltic commercial salmon fisheries. Today those kind of data is largely missing, and the quality of available information is questionable (ICES, 2019). If the true discard is low (say, just a couple of hundreds of salmon) the problem with this mortality is obviously smaller than if the discard amount would be much higher (say, thousands of salmon).

In summary, the dominating gear type used (Pontoon trap) with its original design and traditional landing procedure, gives a higher than 50% mortality risk for discarded salmon. However, there are potential gear modifications and designs that potentially can lower the discard mortality risk to levels well below 50%. These modifications may, however, also lead to un-ergonomic and risky landing procedures (for fishermen), or include high costs for gear development (Nilsson (ed.), 2018a; Nilsson (ed.), 2018b). At present, salmon in the Baltic Sea suffer from poor health, and there is evidence from recent studies that capture and handling alone is associated with an elevated risk for mortality or behavioral disturbances. Accordingly, and in line with the precautionary approach, a careful use of capture and release as a management measure appears warranted, at least until more information is available. For example, no study on Baltic salmon has so far examined more long term (several weeks/months) effects on survival or other negative effects, such as behavioral disturbances and impaired reproductive success.

6. Acknowledgements

We particularly thank the fishermen that took part in the studies mentioned in this report. Thanks also to people at SLU and LUKE, Finland, working with the studies outside rivers Torneälven and Dalälven. Further thanks to Daniel Valentinsson, SLU, Lysekil for comments on an earlier version. The recent Swedish studies mentioned have been financed by the Swedish Agency for Marine and Water Management (funds from 1:11 Åtgärder för havs- och vattenmiljö) and the Baltic Salmon Fund (Stiftelsen för Östersjölaxen).

7. References

AXÉN, C., STURVE, J., WEICHERT, F., LEONARDSSON, K., HELLSTRÖM, G. & ALANÄRÄ, A. 2019. Fortsatta undersökningar av laxsjuklighet under 2018. *Rapport till Havs- och vattenmyndigheten 2019-03-15* (in Swedish), 43 pp.

BLOMQVIST, C., FJÄLLING, A. & LUNNERYD, S.-G. 2013. Factors influencing catch/landing mediated injuries to fish in pontoon set traps for salmonids. (Manuscript). 12pp.

BLOMQVIST, C. & ÖSTERGREN, J. 2019. Överlevnad på kort och lång sikt hos frisläppt (utkastad) vildlax (*Salmo salar*) i fiske med PushUp-fälla (Interim report, in Swedish).

CALAMNIUS, L., LUNDIN, M., FJÄLLING, A. & KONIGSON, S. 2018. Pontoon trap for salmon and trout equipped with a seal exclusion device catches larger salmons. *Plos One,* 13.

DANNEWITZ, J. 2003. Genetic and ecological consequences of fish releases with focus on supportive breeding of brown trout *Salmo trutta* and translocation of european eel *Anguilla anguilla*. PhD thesis, Uppsala University.

ERKINARO, J., ØKLAND, F., MOEN, K. & NIEMELÄ , E. 1999. Return migration of the Atlantic salmon in the Tana River: distribution and exploitation of radiotagged multi-sea-winter salmon. *Boreal Environment Research*, 115-124.

FJÄLLING, A. 2005. The estimation of hidden seal-inflicted losses in the Baltic Sea set-trap salmon fisheries. *Ices Journal of Marine Science,* 62, 1630-1635.

FJÄLLING, A. 2013. Litteraturgenomgång och rådgivning gällande skonsamma och selektiva redskap för laxfiske. Biologiskt underlag till HaV från SLU Aqua (in Swedish), 17 pp.

HASSELBORG, T. & KARLSSON, L. 2002. Studier av skador på lax och öring fångad med fasta redskap vid Norrlandskusten 2000-2002 (in Swedish). Fiskeriverket.

HEGGBERGET, T. G., OKLAND, F. & UGEDAL, O. 1993. Distribution and migratory behavior of adult wild and farmed atlantic salmon (*Salmo-salar*) during return migration. *Aquaculture,* 118, 73-83.

HEMMINGSSON, M., FJÄLLING, A. & LUNNERYD, S. G. 2008. The pontoon trap: Description and function of a seal-safe trap-net. *Fisheries Research,* 93, 357-359.

ICES. 2004. Report of the Study Group on Unaccounted Fishing Mortality. ICES Fisheries Technology Committee. ICES CM 2004/B:09, Ref. ACFM. 3 pp.

ICES. 2019. Baltic Salmon and Trout Assessment Working Group (WGBAST). ICES Scientific Reports. 1:23. 312 pp.

IKONEN, E. & PAKARINEN, T. 2007. Raportti ponttonirysillä pyydettyjen lohien vahingoittumisesta pyynnin ja koennan aikana Pohjanlahdella kesällä 2006 (Interim report from RKTL, in Finnish). 5 pp.

JOKIKOKKO, E. 2002. Migration of wild and reared Atlantic salmon (*Salmo salar* L.) in the river Simojoki, northern Finland. *Fisheries Research,* 58, 15-23.

JONSSON, S., JOHANSSON, T. & BRÄNNSTRÖM, G. 2008. Observation och dokumentation av skador på lax fångad i Push- Upfälla i Byskeälvens fredningsområde 20080531-20080611. *Opublicerad rapport* (in Swedish).

JONSSON, F. 2015. Real-time fish type recognition in underwater images for sustainable fishing. Master thesis, Uppsala University.

KAUPPINEN, T., SIIRA, A. & SUURONEN, P. 2005. Temporal and regional patterns in seal-induced catch and gear damage in the coastal trap-net fishery in the northern Baltic Sea: effect of netting material on damage. *Fisheries Research,* 73, 99-109.

LUNDIN, M., HELLSTRÖM, G., LEONARDSSON, K. & LUNDQVIST, H. 2014. Överlevnad och beteende hos frisläppt lax efter skonsam och traditionell vittjning av push-up fällor. Umeå: SLU Istitutionen för vilt, fisk och miljö (in Swedish). 24 pp.

LUNDIN, M., CALAMNIUS, L. & FJÄLLING, A. 2015. Size selection of whitefish (*Coregonus maraena*) in a pontoon trap equipped with an encircling square mesh selection panel. *Fisheries Research,* 161, 330-335.

NILSSON, H. 2018a. Sekretariatet för selektiv fiske - Rapportering av 2014 års verksamhet (in Swedish). *Aqua reports* 2018:2. 63 pp.

NILSSON, H. 2018b. Sekretariatet för selektiv fiske - Rapportering av 2016 och 2017 års verksamhet (in Swedish). *Aqua reports* 2018:4. 211 pp.

PAKARINEN, T., IKONEN, E. & KOLJONEN M.-L. 2007. Väliraportti Pohjanlahdella vuosina 2005-2007 voimassa olevan valikoivan lohenkalastuksen vaikutuksista luonnonvaraisiin lohikantoihin vuonna 2006 (Interim report from RKTL, in Finnish). 16 pp.

PALM, S., ROMAKKANIEMI, A., DANNEWITZ, J., PAKARINEN, T., HUUSKO, R., JOKIKOKKO, E. & BROMAN, A. 2020. Torneälvens bestånd av lax, havsöring och vandringssik – gemensamt svensk-finskt biologiskt underlag för bedömning av lämpliga fiskeregler under 2020. Biologiskt underlag till Havs- och vattenmyndigheten (in Swedish). 49 pp.

PATTERSON, D. A., ROBINSON, K. A., LENNOX, R. J., NETTLES, T. L., DONALDSON, L. A., ELIASON, E. J., RABY, G. D., CHAPMAN, J.

M., COOK, K. V., DONALDSON, M. R., BASS, A. L., DRENNER, S. M., REID, A. J., COOKE, S. J. & HINCH, S. G. 2017. Review and Evaluation of Fishing-Related Incidental Mortality for Pacific Salmon. *DFO Can. Sci. Advis. Sec. Res. Doc. 2017/010. ix.*

RABY, G. D., DONALDSON, M. R., HINCH, S. G., CLARK, T. D., ELIASON, E. J., JEFFRIES, K. M., COOK, K. V., TEFFER, A., BASS, A. L., MILLER, K. M., PATTERSON, D. A., FARRELL, A. P. & COOKE, S. J. 2015. Fishing for Effective Conservation: Context and Biotic Variation are Keys to Understanding the Survival of Pacific Salmon after Catch-and-Release. *Integrative and Comparative Biology,* 55, 554-576.

RIVINOJA, P., MCKINNELL, S. & LUNDQVIST, H. 2001. Hindrances to upstream migration of Atlantic salmon (*Salmo salar*) in a northern Swedish river caused by a hydroelectric power-station. *Regulated Rivers-Research & Management,* 17, 101-115.

RIVINOJA, P., LEONARDSSON, K. & LUNDQVIST, H. 2006. Migration success and migration time of gastrically radio-tagged v. PIT-tagged adult Atlantic salmon. *Journal of Fish Biology,* 69, 304-311.

SIIRA, A., SUURONEN, P., IKONEN, E. & ERKINARO, J. 2006. Survival of Atlantic salmon captured in and released from a commercial trap-net: Potential for selective harvesting of stocked salmon. *Fisheries Research,* 80, 280-294.

SUURONEN, P., SIIRA, A., KAUPPINEN, T., RIIKONEN, R., LEHTONEN, E. & HARJUNPAA, H. 2006. Reduction of seal-induced catch and gear damage by modification of trap-net design: Design principles for a seal-safe trap-net. *Fisheries Research,* 79, 129-138.

SVA 2017. Sjuklighet och dödlighet i svenska laxälvar under 2014–2016: Slutrapport avseende utredning genomförd 2016 (in Swedish). 58 pp.

THORSTAD, E. B., HEGGBERGET, T. G. & OKLAND, F. 1998. Migratory behaviour of adult wild and escaped farmed Atlantic salmon, Salmo salar L., before, during and after spawning in a Norwegian river. *Aquaculture Research,* 29, 419-428.

ÖSTERGREN, J., LUNDQVIST, H. & NILSSON, J. 2011. High variability in spawning migration of sea trout, Salmo trutta, in two northern Swedish rivers. *Fisheries Management and Ecology,* 18, 72-82.

ÖSTERGREN, J., BLOMQVIST, C., DANNEWITZ, J., PALM, S., FJÄLLING, A. 2020. Scientific advice regarding the landing obligation and salmon fisheries in the Baltic Sea. Report to the Swedish Agency for Marine and Water Management, 31 pp.

Appendix 1.

Technical description of the Pontoon trap for salmon

This fishing gear is comprised by two parts: Firstly, a set of net panels forming a series of separate compartments, stepwise corralling fish forward. Secondly, at the end, there is a fish chamber (Fig. 1). The fish chamber has double wall netting, stretched over an aluminum pipe framework that rests on two inflatable pontoons. The fish chamber module can be used with a variation of trap nets adapted to certain fish species. For lifting, the pontoons are inflated with compressed air which cause the fish chamber to ascend from fishing depth. As the chamber ascends above the water surface the catch aggregates on a chute of fiberglass or metal, located on the fish house floor. The catch is then collected by opening a manually controlled hatch, through which the catch simply slides though and down and onto the fishing boat's flooring.

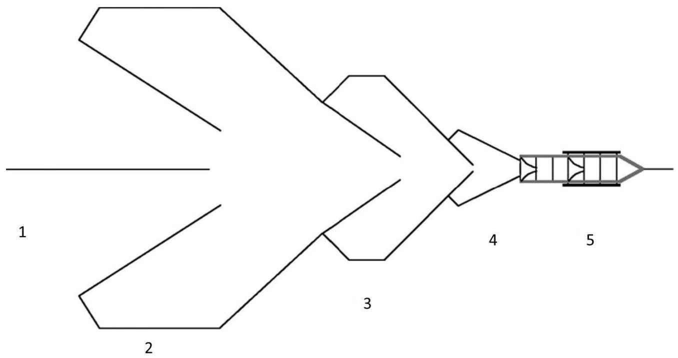

Figure 1. Pontoon trap seen from above. (1) leader net, (2) wings, (3-4) middle chambers, (5) pontoon fish chamber.

The Pontoon trap equipped with a submersible net bag, Vittjanpåse

The emptying process of the traditional pontoon trap is rather harsh to fish, therefore modifications have been made to the fish chamber (Figure 2). In one modification the pontoon trap is equipped with a submersible net bag secured around the hatch and the outlet of the chute. The hatch is opened prior to lifting the fish chamber. As the fish chamber during lifting begin to rise towards the surface, fish slide into the submersed net bag from which it then can be leniently removed though a zipper, one fish at a time. The submersible net bag has selection-panels which allow undersized fish to escape. It can be easily fitted to the trap and decreases physical injuries in catch, and bycatches. A drawback is that it is heavy to handle large amount of salmon and may be risky and non-ergonomic for fishermen.

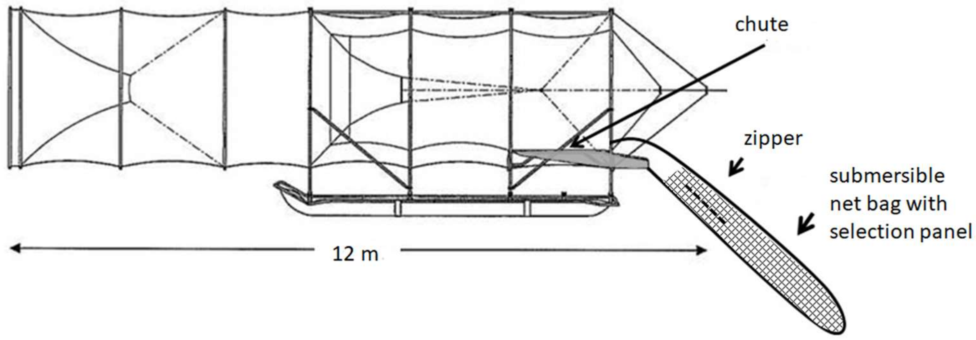

Figure 2. Pontoon fish chamber, seen from the side, having chute, submersible net bag for lenient fish handling, and zipper for emptying.

A fish-selection chute supporting the emptying process of pontoon traps

The fish-selection chute is a separate aid for fishermen during the emptying process of pontoon traps. The chute is placed on top of the boat's rail leading across the boat from starboard to port side. With the fishing boat in position beneath the emptying hatch of the pontoon trap and the fish-selection chute in line with the trap's outlet, fish slide down and into the fish-selecting chute. As the fish slide across, the fisherman selects which fish to keep and which to discard. Fish to keep is swiftly removed manually from the chute. Fish to discard are allowed to continue to slide across the chute and to its end outside the fishing boat. The fish-selection chute shortens the time needed for emptying but also decreases the degree of physical injuries in caught fish. A disadvantage is that the fish-selection chute is weather sensitive and requires good sea conditions to operate. Used as intended, by design the fish-selection chute is ergonomic and easy to handle for the fisherman.

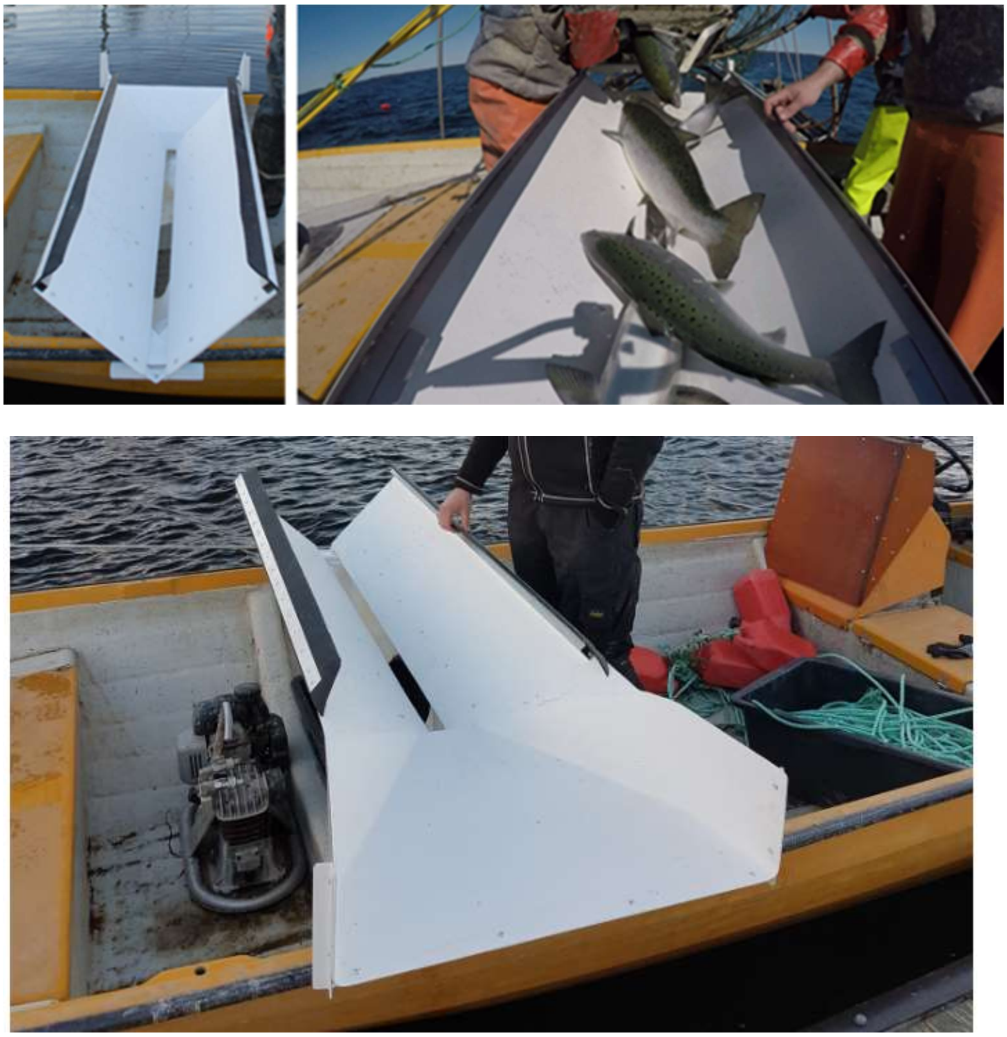

Figure 3. The fish-selection chute attached to the rail of a fishing boat (left and below) and the cute in operation with fish passing across the chute.

Fyke-net and Combi-trap, often referred to as trap-net

The Fyke-net and Combi-trap are often referred to as trap-net. These gears are considered to be any floating, bottom-anchored fishing gear (this concept includes trap- and pound-nets) (Figure. 4). Depending on the type and materials of a trap, fish may be guided into the fish-bag (by trapping) or they may become entangled in the netting of the 'wings' and 'middle chambers' (by gilling). Conventional monofilament traps are designed to catch mostly by gilling and entangling. Conventional traps made of twisted nylon with certain mesh sizes catch mostly by gilling, but also by trapping to some extent. If the leader net, wings and chambers are made of nets with small mesh size, most salmon will be captured in the fish bag (Figure 4). From the fish bag, individual salmon can then be lifted one by one and be treated gently, and released.

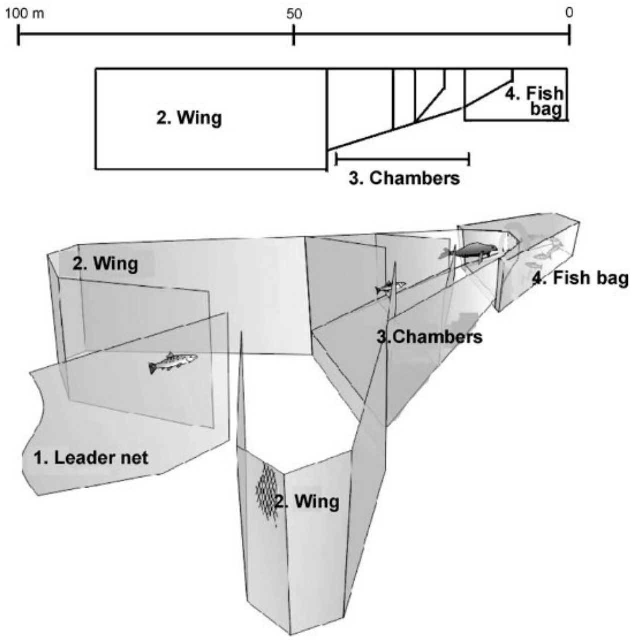

Figure 4. Design of trap-net (Fyke-net/Combi-trap). A schematic view and the overall dimensions of a trap-net. A long, large-meshed leader net (1) leads fish into the wings (2). Wings guide the fish onwards to the inner parts of the trap. Fish swim through middle chambers (3) and finally into the fish-bag (4). The figure is from Kauppinen et al., (2005).