

Effect of the trap net emptying method on release mortality of Baltic salmon estimated by a Bayesian model

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Abstract

We evaluated the effect of emptying techniques of a pontoon trap on mortality of released Atlantic salmon on the Finnish coast of the northern Baltic Sea by tagging the released fish. Two methods currently used, a traditional emptying chute and a lifting bag, were compared. The lifting bag has been developed primarily for minimising injuries during emptying. A custom-built Bayes model was used for mortality estimation. We also explored external injuries of salmon and compared the probability of getting an injury between the emptying methods. The mean probability of salmon dying due to release from a trap with an emptying chute was 24% (90% HDI 3 – 43%), whereas that for salmon released from a trap with a lifting bag was 13% (90% HDI 1 – 24%). Results showed a higher probability of injuries and longer air exposure time in salmon caught with a trap with an emptying chute, which may explain the observed difference in mortality. Manual handling of a lifting bag appears to pose a clear work safety risk for fishers. It is noteworthy that the role of release mortality for northern Baltic salmon stocks is small, because the number of salmon released in coastal fisheries is currently low.

Keywords: Bayesian inference; Baltic Sea; coastal; fishing technique; injury; *Salmo salar*

Introduction

The commercial fisheries for Atlantic salmon (*Salmo salar*) in the Baltic Sea occurs mainly along the coasts of Finland and Sweden using trap nets (ICES 2021). Baltic salmon fishery is regulated by the European Union, and the total allowable catch is annually stated in a Council Regulation based on scientific advice (ICES 2020). A landing obligation has been set for the quota-managed species in EU fisheries, but there have been exemptions for Baltic salmon fisheries, based on the proven high survival after release from trap nets (STECF 2020; EU 2021).

In recent years, there have been concerns about potentially higher release mortalities of salmon (Östergren et al. 2020) than shown in studies conducted in the northern Baltic Sea in the early 2000s (Rivinoja et al. 2001; Siira et al. 2006). The suggested reasons for the higher mortalities documented include the different trap net designs used (Hemmingsson et al. 2008), different trap net hauling techniques (Östergren et al. 2020), the general health problems of Baltic salmon (Weichert et al. 2021), or their combinations, with varying environmental factors (e.g. a high water temperature in rivers and estuaries).

Fishing gear and operations can be developed to minimise unwanted mortality (Suuronen et al. 2012; Uhlmann & Broadhurst 2015). Swedish studies on Baltic salmon have suggested that an air-operated pontoon trap with an emptying chute may cause more injuries and higher releasing mortality than a pontoon trap equipped with a lifting bag, which was developed to decrease injuries during trap net emptying (Östergren et al. 2020). Ruokonen et al. (2022) found some evidence that salmon caught with the pontoon trap with a lifting bag had less external damage than salmon caught with a trap equipped with an emptying chute.

The estimation of release mortality is a complex task because several sources of mortality and affecting factors can be involved in the process, depending on the methods used (Patterson et al. 2017; Breen & Catchpole 2021). Tagging-recapture methods are often used to assess discard or release mortality, but data analysis often lacks sources of uncertainty related to the process. The best option would be to integrate tagging with captive observations or vitality assessments (Breen & Catchpole, 2021). However, the use of parallel approaches is not always possible. For such cases, Bayesian inference offers a possibility to combine existing information from various sources. The results of Bayesian models are presented as probability distributions, and they are therefore relatively easy to interpret even if a complex model framework is established (e.g. Michielsens et al., 2008). The utilisation of prior knowledge is beneficial, for example, when there is a need to estimate the relative magnitude of different sources of mortality related to handling and releasing fish and other factors related to the selected assessment method.

For the first time, we designed a rigorous tagging experiment that compared the effect of two emptying techniques of a pontoon trap on the mortality of released Baltic salmon. Compared to previous studies, which had tentatively indicated the effect of trap emptying techniques (Östergren et al. 2020, Ruokonen et al. 2022), the experimental design in our study was specifically designed to elucidate the effect of the emptying technique. The study was conducted by tagging salmon in the summer of 2021 in the Bothnian Sea during spawning migration. Fish were taken to the boat using two emptying techniques currently used in the Baltic coastal salmon fisheries. The external injuries of salmon were explored visually during tagging, and the types and probability of getting an injury were compared between the two emptying methods. A custom-built Bayesian model was employed to estimate mortalities and injuries.

2. Material & Methods

2.1 Study area, fish tagging and data collection

The study was conducted in collaboration with four commercial fishers on the coast of the Bothnian Sea in Merikarvia, Finland (ICES subdivision 30), between late May and early July 2021. In the traditional technique, salmon are transferred from the pontoon trap to a water-filled tank on board using a fibreglass emptying chute. In this technique, the salmon are out of the water during trap lifting. In the other method, salmon are lifted into a water tank on board with the aid of a lifting bag made of knotless mesh. As the fish chamber of a pontoon trap rises towards the surface during the lifting, fish slide into the submersed lifting bag, which can then be lifted onto the boat.

All the fishers had two pontoon traps with a similar basic design (Hemmingsson et al., 2008), and the traps were in the same area to ensure comparability between emptying methods. One of the traps of each fisher had a traditional emptying chute made of fibreglass, and the other trap was fitted with a lifting bag made from knotless netting (6 metres long, mesh size 25 mm) (Figure 1). Traps with a

lifting bag were emptied by lifting the bag with the salmon catch onto the boat by hand. If the catch was large, fish were lifted in two or three batches.

The salmon caught were emptied into a tarpaulin tank filled with water and tagged by trained personnel of Natural Resources institute Finland (Luke) with an arrow tag (type PDA, bright green, length 15 cm; Hallprint Ltd) at the base of the dorsal fin. Fish tagging was conducted following national guidelines on animal welfare, and no specific ethic statement needed for the study. A reward of €25 was offered for each tag recovery to all fishers in coastal areas and rivers in Finland and Sweden. Only wild salmon with an intact adipose fin were tagged. The seawater temperature rose from 8 °C to 17 °C during the tagging period (Figure 2).

In total, 202 salmon caught with a pontoon trap with an emptying chute and 211 salmon from PU traps with a lifting bag were tagged (Figure 2). All the tagged fish, except one, were multi-sea-winter (MSW) salmon. The size distributions of the tagged fish were similar in both tagging groups (Figure 3).

The condition of each tagged salmon was visually inspected, and detected injuries were recorded. Injuries were categorised as: scale loss = loss of scales divided into three categories (no scale loss, minor scale loss, major scale loss); fin injury = split fin or other injury; red eye = internal bleeding in the eye; mesh injury = meshing of fish; wounds = wounds, bites, and scratches by seals or other unidentified factors; mouth/jaw injury = mouth/jaw injury (e.g. ripped maxilla) caused by fishing gear.

2.2 Statistical modelling

The release mortality of salmon from pontoon traps with two different emptying methods was evaluated using a custom-built Bayesian model. The method was chosen because it allows a combination of different data sources, and the results are intuitively interpretable as probabilities. In Bayesian models, prior information is defined as prior distributions, which are updated through

other model assumptions and observed data sets to posterior distributions. To assess the magnitude of different sources of mortality based on tag returns, the use of prior information such as fishing and natural mortality is necessary.

2.2.1 Probability model

The probability model comprises a timespan of 15 weeks, which corresponds to the period from the first tagging batch to the last date on which tagged fish have been reported to be caught. Tag recaptures are divided into two categories: recaptures from coastal fisheries and from river fisheries. River fisheries refer to all salmon rivers on the Finnish and Swedish sides of the Bothnian Bay to which tagged salmon may have been migrating.

In the model structure, we assume that the tagging and release mortalities take place immediately after releasing. This assumption is made for computational simplicity, although in practice, these mortalities are also highly likely to occur later during the migration. We therefore assume that the number of tagged salmon alive at sea after tagging mortality and release mortality induced by trap type j ($N_{t,j}^{alive}$) is binomially distributed:

$$(1) N_{t,j}^{alive} = \text{Bin}(p_j^{alive}, N_{t,j}^{tagged}),$$

where $N_{t,j}^{tagged}$ is the number of tagged salmon released from a trap type j during week t . Index j indicates the type of trap: $j = 1$ corresponding to pontoon trap with an emptying chute; and $j = 2$ corresponding to a PU trap with a lifting bag. Furthermore, p_j^{alive} is the probability that a salmon released from a trap type j survives from the tagging and releasing mortalities:

$$(2) p_j^{alive} = \exp(-(h_j + ip^{mark})).$$

Here h_j is the instantaneous trap induced mortality of trap type j , and ip^{mark} is the instantaneous mortality caused by the process of tagging and handling, regardless of the trap type.

Thus, the probability of dying because of release mortality induced by trap type j is derived as:

$$(3) p_j^{die} = 1 - \exp(-(h_j + ip^{mark} \cdot q^{hand})),$$

where q^{hand} expresses the share of mortality caused by handling of total mortality caused by the process of tagging and handling, i.e. excluding the tagging mortality. This division must be made, because all the released salmon in the experiment are tagged.

Furthermore, we denote the initial number of tagged salmon at sea available for coastal fisheries with:

$$(4) n_{1,1,j} = N_{1,j}^{alive}.$$

The first index of variable n indicates the area, later denoted with $i = 1$ for sea and $i = 2$ for river.

The initial number of tagged salmon in river areas is set as zero,

$$(5) n_{1,2,j} = 0,$$

indicating that no tagging takes place at rivers.

We assume that during a single week of the study period, a tagged salmon could either die, survive, and stay at sea or survive and move to a river. The fractions that survive are denoted as:

$$(6) \begin{cases} q_1^{SS} = p_1^{surv} \cdot p^{keep} \cdot (1 - p^{move}) \\ q_2^{SS} = p_2^{surv} \cdot p^{keep} \\ q^{SM} = p_1^{surv} \cdot p^{keep} \cdot p^{move} \end{cases},$$

where q_1^{SS} is the fraction that survives and stays at the sea, q^{SM} is the fraction that survives and moves from the sea to a river, and q_2^{SS} is the fraction that survives and stays in the river. The survival probability for one week in area i is denoted with p_i^{surv} , whereas the parameter p^{move} denotes the probability of moving from the sea to a river, and p^{keep} the probability that a tag will not be lost during a single week.

Thus, the total number of tagged salmon alive at sea during week $t + 1$ originally released from a trap of type j can be calculated as:

$$(7) n_{t+1,1,j} = n_{t,1,j} \cdot q_1^{SS} + N_{t+1,j}^{alive}.$$

Similarly, the total number of tagged salmon alive in rivers during week $t + 1$ originally released from a trap of type j is calculated as:

$$(8) n_{t+1,2,j} = n_{t,1,j} \cdot q^{SM} + n_{t,2,j} \cdot q_2^{SS}.$$

The number of recaptured salmon from area i during week t that were originally released from a trap of type j ($N_{t,i,j}^{recap}$) is assumed to be Poisson distributed:

$$(9) N_{t,i,j}^{recap} \sim \text{Poisson}(HR_{i,j} \cdot n_{t,i,j} \cdot r_i^{report} + 0.001),$$

where $HR_{i,j}$ is the harvest rate of salmon originally released from a trap of type j at area i and r_i^{report} is the reporting rate of tags at area i . A small constant is added for numerical stability. In the following step, informative prior distributions for natural and fishing mortalities in different areas, as well as for the probability that a tag is not lost, are defined and transformed into instantaneous mortalities for a one-week period. With these parameters, we can calculate the harvest rates of tagged salmon:

$$(10) \quad HR_{i,j} = p^{keep} \cdot (1 - p_{i,j}^{surv}) \cdot \frac{F_i}{M_i + F_i},$$

where F_i is the instantaneous fishing mortality, and M_i the instantaneous natural mortality at area i . Furthermore, the area-specific probability of surviving from natural and fishing mortalities is calculated as:

$$(11) \quad p_i^{surv} = \exp(-(M_i + F_i)).$$

2.2.2 Informative priors for causes of death and other types of fate

As described above, the tagging mortality and trap-induced release mortality is assumed to take place immediately after releasing. After this, a tagged salmon can be exposed to any of the following events during a single week in the model: death because of natural or fishing mortality; the loss of a

tag; movement from the sea to a river. Salmon that migrate to rivers are assumed to remain in the river and be exposed to the previously mentioned events each week until the end of the study period. In addition, tags from recaptured salmon can either be reported or remain unreported.

We derived informative priors for fates of tagged salmon from several literature sources. The prior distributions for natural and fishing mortalities were derived by averaging posterior estimates of the Baltic salmon stock assessment model outcome between 2018 and 2020 (ICES 2021). For example, the prior distribution for instantaneous mortality at sea during 11 weeks of coastal fishery was approximated as:

$$(12) \quad F^{sea} \sim \log N(-1.86, 0.131^2),$$

which was further transformed into instantaneous mortality for one week as:

$$(13) \quad F_1 = F^{sea}/11.$$

Similarly, we derived the prior distributions for instantaneous mortality at river fishery (F^{river}), natural mortality at sea (M^{sea}), and natural mortality in the river (M^{river}) as:

$$(14) \quad \begin{cases} F^{river} \sim \log N(-1.60, 0.324^2) \\ M^{sea} \sim \log N(-1.87, 0.313^2) \\ M^{river} \sim \log N(-2.38, 0.312^2), \end{cases}$$

which were again transformed into instantaneous mortalities for one week:

$$(15) \quad \begin{cases} F_2 = F^{river}/12 \\ M_1 = M^{sea}/8 \\ M_2 = M^{river}/52. \end{cases}$$

The number of weeks that each type of mortality is assumed to take place reflects the period of impact in the Baltic salmon stock assessment model (ICES 2021). In the model, the length of the fishing season is assumed to be 11 weeks for sea fisheries and 12 weeks for river fisheries respectively. For natural mortality in rivers, an annual estimate of natural mortality is utilised, and the estimates for one week are thus achieved by dividing the estimate by 52. For coastal fisheries,

the Baltic salmon model assumes increased natural mortality due to seal predation, and this estimate is therefore divided by 8 weeks, which corresponds to the assumed period it takes for salmon to migrate from the Baltic main basin into the rivers.

For tagging related events, informative prior distributions were derived from the study of Siira et al. (2006). Based on their analysis on tag retention rate, we assume that the probability that a tagged salmon loses the tag during a three-month period is Beta-distributed:

$$(16) \quad p^{lose} \sim \text{Beta}(12, 68).$$

We transformed this probability into instantaneous mortality for one week as:

$$(17) \quad ip^{keep} = -\log(1 - p^{lose}/12)$$

and again, back into a proportional scale as:

$$(18) \quad p^{keep} = \exp(-ip^{keep}).$$

Furthermore, we utilised the data from the tank experiment of Siira et al. (2006) to derive the prior distribution for the proportion of mortality caused by handling of total mortality caused by the process of tagging and handling, denoted by q^{hand} . We use the same procedure as in Ruokonen et al. (2022) to derive q^{hand} , based on data from the tank experiment. As a result, we formulate the prior distribution as:

$$(19) \quad q^{hand} \sim \log N(-0.723, 0.371^2) T(1).$$

The $T(1)$ notation indicates that the distribution is truncated to allow values up to a maximum of 1.

The prior distribution for the probability to die because of tagging or releasing (p^{mark}) during a three-month period is derived from the previous analysis by Ruokonen et al. (2022):

$$(20) \quad p^{mark} \sim \text{Beta}(1.8, 7.2).$$

This can be transformed into an instantaneous scale for one week as:

$$(21) \quad ip^{mark} = -\log\left(1 - \frac{p^{mark}}{12}\right).$$

In addition to informative priors, we gave an uninformative prior distribution for the movement probability from sea to river:

$$(22) \quad p^{move} \sim Unif(0,1).$$

Uninformative prior distribution was also assumed for trap-induced mortality as

$$(23) \quad h_j \sim Unif(0,12).$$

All prior distributions are listed in Table 1.

2.2.3. Expert-elicited priors for reporting rates

The reporting rates of recaptured tags are an essential piece of information when data from a mark-recapture study are analysed. Unfortunately, good data on the level of reporting seldom exist, and eagerness to report may vary in time between areas and groups of fishers. We chose the approach of expert elicitation to formulate priors for reporting rates at coastal and river fisheries. Three experts best familiar with these fisheries were interviewed independently from each other. The experts formulated their views on the reporting rates in terms of either modal or median value, and in terms of an interval covering either 90% or 95% of the probability mass. The experts were also asked to include their views of the differences in reporting activity in Finnish and Swedish fisheries in their assessments.

The expert views on the central tendency and the uncertainty of the reporting rates at sea and at river fisheries are shown in Supplement 1. A beta distribution was fitted for each distribution provided (Supplement 1; Table S1 & Figure S1). We used the method of Bayesian model averaging (BMA; Hoeting et al. 1999) to average the distributions provided by each expert to formulate prior distribution for reporting rates at area i :

$$(24) \quad r_i^{report} = E_{Y,i},$$

where Y follows a categorical distribution:

$$(25) \quad Y \sim \text{cat}(w[1:3]).$$

Equal weights $w[1:3] = 1/3$ were assigned for each expert.

2.2.4 Injury model

To estimate the probability that a salmon captured by either a pontoon trap with an emptying chute or one with a lifting bag will get an injury of a specific type, we fitted a small Bayesian beta-binomial model.

We assume that the observed number of salmon that have an injury i after being captured by a trap of type j ($x_{i,j}$) follows a binomial distribution:

$$(26) \quad x_{i,j} \sim \text{Bin}(p_{i,j}, N_j),$$

where N_j is the total number of salmon captured with a trap type j . Furthermore, we assume that the probability of an injury i when captured by a trap of type j ($p_{i,j}$) follows an uninformative beta-distributed prior:

$$(27) \quad p_{i,j} \sim \text{Beta}(1,1).$$

2.2.5 Details of the model runs

Posterior distributions for the release mortality model were estimated with JAGS software by running a sample of 200,000 iterations with two chains (burn-in 1,000 iterations). Posterior distributions for the injury model were estimated correspondingly with a sample of 10,000 iterations with two chains (burn-in 1,000 iterations). The models' convergence was ensured both visually (trace

plots) and numerically (Rubin-Gelman diagnostics). The full model code for the release mortality model can be found in Appendix A and for the injury model in Appendix B.

3. Results

3.1 Tag observations

By the end of December 2021, a total of 59 (14%) tags were returned, with a higher proportion from salmon released from pontoon traps with a lifting bag (Table 2; Figure 4). A higher proportion (59%) of tag observations was received from rivers than from coastal fisheries (Table 2, Figure 4).

3.2. Bayesian estimates for release mortality

Estimated posterior results (means and 90% highest density probability intervals, HDI) for parameters, as well as the corresponding statistics from prior distributions, are expressed in numerical form in Table 3 and as density graphs in Figure 5. The posterior distributions of fisheries mortality (F^{sea} and F^{river}) changed markedly from the given priors, whereas the posteriors of natural mortality (M^{sea} and M^{river}) were very close to the priors. This is understandable, because the tag recapture data are unlikely to carry information about the natural mortality at sea or in rivers. The posterior distributions of parameters for which uninformative prior distributions were assigned (h_1 , h_2 , p^{move}) were updated from the corresponding priors.

Parameters with informative prior distributions from the tank experiment of Siira et al. (2006), p^{lose} and q^{hand} , had posterior estimates that closely resembled their priors. This makes sense, because these informative distributions were derived from the tank experiment, as we did not gather data about the tag retention rate or tagging mortality in our study. The posterior distribution for the

probability of dying because of tagging or releasing (p^{mark}) was updated towards lower values from the prior, which was set up based on our previous study (Ruokonen et al. 2022). The posterior estimate of the tag reporting rate at sea fisheries (r_1^{report}) was updated into somewhat higher values from the prior, whereas the posterior in the tag reporting rate at river fisheries r_2^{report} was quite similar to its prior.

The posterior estimate for the probability of salmon dying due to release from a pontoon trap with an emptying chute was 24% on average (with 90% HDI 3 – 43%) (Figure 6). The estimate for salmon released from a trap with a lifting bag was 13% on average (90% HDI 1 – 24%) (Figure 6). Based on these posterior distributions, it can be stated with 78% probability that the mortality rate of salmon released from a trap with an emptying chute was higher than from a trap with a lifting bag. The release mortality from a trap with an emptying chute was on average 2.8 times higher than the release mortality from a trap with a lifting bag.

3.3. Injuries

Based on a visual external examination, the tagged salmon were in a good general condition. No acute immediate mortality was observed during the tagging and releasing process. However, most of the tagged fish had some mechanical injuries, the majority probably caused by the catching, handling, and tagging processes. The most common injuries were detached scales and fin injuries (Figures 7A, 7D). Some fish had skin injuries and bruises, probably caused by the abrasion with the netting of a trap (Figures 7A, 7B). Eye injuries (Figure 7C), injuries caused by meshing, as well cuts and wounds to the body and injuries in the mouth or jaws were observed. The results indicate that injuries are more probable when a salmon is caught with a trap with an emptying chute than when a salmon is caught with a trap with a lifting bag (Figure 8, Table 4). The probability of a lifting bag causing less injuries than a chute was 100% for minor scale loss, 99% for mouth or jaw injuries, 94% for mesh injuries, 90% for eye injuries, and 87% for wounds and scratches. Furthermore, it was more

probable for major scale loss or fin injuries to be detected when salmon are caught with a trap with a lifting bag (Table 4).

Discussion

The Bayesian model developed in this tagging study indicated that the mortality of multi-sea-winter salmon released from pontoon traps with an emptying chute was higher than that of those released from a trap equipped with a lifting bag. We designed a rigorous pairwise experiment with the same fishing areas, same fishers, similar handling and tagging process by the same persons, and similar trap design, except for the comparison of the two emptying methods. As external factors were evidently similar for both groups, at least two factors could potentially cause the observed difference in release mortality: 1) the number and quality of injuries caused by the trap and emptying process; 2) the difference in physiological stress caused by the emptying process, for example, in the air exposure time between the methods (e.g. Patterson et al. 2017).

Injuries probably caused by fishing gear and/or the emptying process were observed in both emptying method groups. It is difficult to suggest causality between injuries and mortality based on our study design, but in general, the probability of an injury was higher in the emptying chute group for most of the injury types. For example, eye injuries were mostly recorded in fish caught with a trap equipped with an emptying chute, as was also found by Östergren et al. (2020) and Ruokonen et al. (2022). In this emptying method, fish jump for a while on a chute before the catch is emptied into a water-filled tank on a boat. It is possible that this causes internal injuries that cannot be seen by visual inspection and increases delayed mortality after release. On the other hand, the probability of major scale losses and fin injury was higher in the lifting bag group.

Air exposure is one of the critical factors during the emptying of fishing gear, because it can cause acute mortality or substantial physiological stress that affects survival (Cook et al. 2015). Salmonids are particularly vulnerable to hypoxia, and even short air exposure may reduce viability (Richard et

al. 2013, Papatheodoulou et al. 2022). Mortality can occur after a relatively short period (e.g. 1–2 minutes) in the air (Cook et al., 2015). In our study, air exposure differed between the two emptying methods: air exposure was apparently longer with the traditional emptying chute. In this method, salmon are often exposed to the air for about 30 to 60 seconds (or even longer) during the lifting of a fish chamber. With a lifting bag, fish are under the water during the final lifting phase of a trap, and the air exposure time is usually shorter, around 10 seconds. Patterson et al. (2017) concluded that the extension of handling time in the air to more than 10 seconds led to increased mortality in Pacific salmon. No specific studies on Atlantic salmon are available, but the difference in air exposure between emptying methods may be one of the main reasons for the difference observed in releasing mortality. Mortality caused by air exposure increases with an increasing water temperature (Richard et al. 2013; Patterson et al. 2017). Water temperatures rose from 7 °C to 16 °C during our study, but both groups were tagged following a similar schedule, so it is assumed that this effect was similar for both groups.

In the present study, release mortality estimates were roughly in the same range as in a previous study conducted in the same area, in which mortality for MSW salmon released from a trap with an emptying chute was estimated to be 25–31% at most (Ruokonen et al. 2022). However, the Bayesian model used in the present study was more detailed than that used in the previous study, because it accounted for the weekly numbers of tagged salmon available to the fisheries, weekly recaptures, and the probability distribution of all components affecting the survival estimates, including the reporting rates of recovered tags at coastal/river fisheries and the tag loss rate, which were treated as fixed quantities in the study of Ruokonen et al. (2022). Siira et al. (2006) estimated maximum release mortality at 20% for MSW salmon released from a traditional pound net used previously in a coastal fishery on the Bothnian Sea. In both recent studies by our group, mortality estimates were significantly lower than those found in Swedish studies based on telemetry experiments (Östergren et al. 2020). Their mortality estimates were in the range of 47–88% with the traditional emptying chute method, and between 17–63% when a lifting bag was used. However, the tagging and

mortality estimation methods used differed between the studies, and a direct comparison of estimates is not appropriate.

The release mortalities were estimated using a Bayesian model that utilised informative prior distributions derived from the literature and recent stock assessment results for Baltic salmon (ICES 2021). This approach enabled us to estimate separately with different fates what tagged salmon may experience during their migration. Those fates include tag loss, escapement to river, and several causes of death. The expert views on tag reporting rates were also elicited and formally averaged into prior distributions. Such a wide use of the available prior information is quite rare in modelling, but we argue that similar approaches would be beneficial for scientific learning in cases where versatile background information exists. Attempts to base the statistical models on biological and systemic realism should also be prioritised over data analytic methods, in which Bayesian methods show their strength (cf. Kuparinen et al. 2012).

The practical experiences from the present study suggest that the lifting bag type used in our study was unsuitable when the catch was abundant, or when there were large salmon in the catch. When the catch consisted of many large salmon, the opening of the lifting bag often became clogged, which caused fish to press against each other and the netting of the gear, apparently leading to scale loss and fin damage. Furthermore, lifting the bag by hand was quite difficult even when done for smaller proportions of the catch at a time, and during the lifting process, the fish may have suffered additional damage. Many minor injuries were observed in fish hauled by a lifting bag which could expose them to fungal infections later in the spawning river, for example (Weichert et al. 2020). Furthermore, lifting the bag manually is heavy and is a risk to the occupational health of fishers. Emptying the trap with a lifting bag by hand is a major safety risk, an important observation that was also raised by Östergren et al. (2020).

One possibility of reducing release mortality could be the development of the traditional emptying chute so that it causes less damage to salmon and minimises air exposure. However, it is important

to realise that the total effect of release mortality on the salmon population is related to the actual number of fish released. As Östergren et al. (2020) state, no accurate estimate of the number of released salmon is available in Baltic Sea salmon fishery, so an exact numerical estimate of absolute mortality is impossible. According to the current Finnish national fishing regulations for commercial salmon fisheries using traps, the catch must be taken and kept unselectively, except for salmon damaged by seals or cormorants, or after the salmon quota per fisher has been fulfilled. The total mortality due to the selection and release of salmon from coastal trap net fishing in Finland is probably low because only a small minority of the total catch is released. In the current situation, the release mortality is not a major issue. Yet if the fishing rules change in the future to require coastal trap net fishers to release all wild salmon or all large wild salmon, for example, release mortality will become an important issue.

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Figure 1. Emptying a pontoon trap using a fibreglass emptying chute (left) and a lifting bag (right).

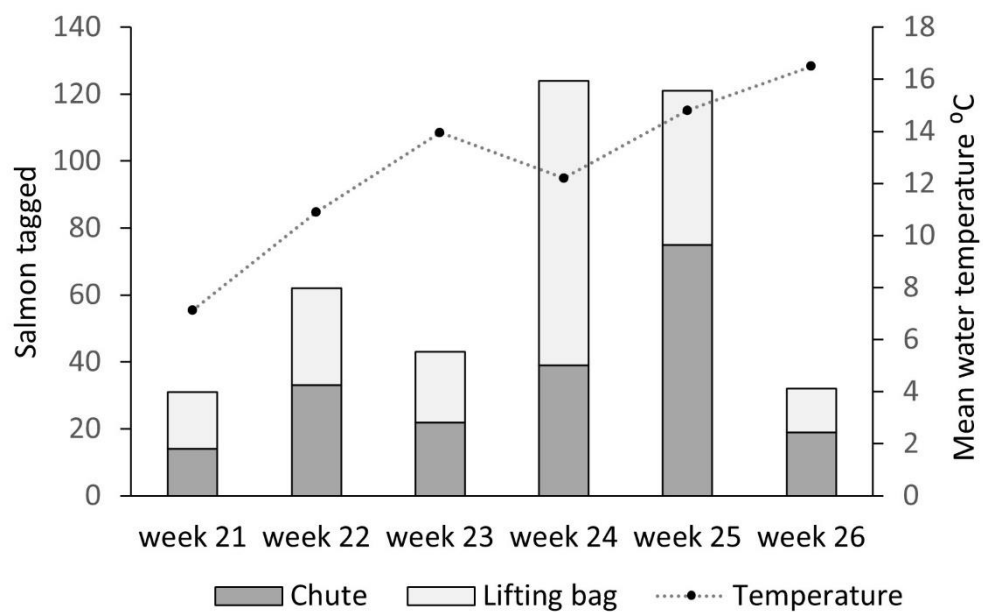


Figure 2. The number of tagged salmon on the coast of the Bothnian Sea, Finland, in the summer of 2021, caught with different pontoon trap types (emptying chute or lifting bag) and the weekly mean water temperature recorded during tagging.

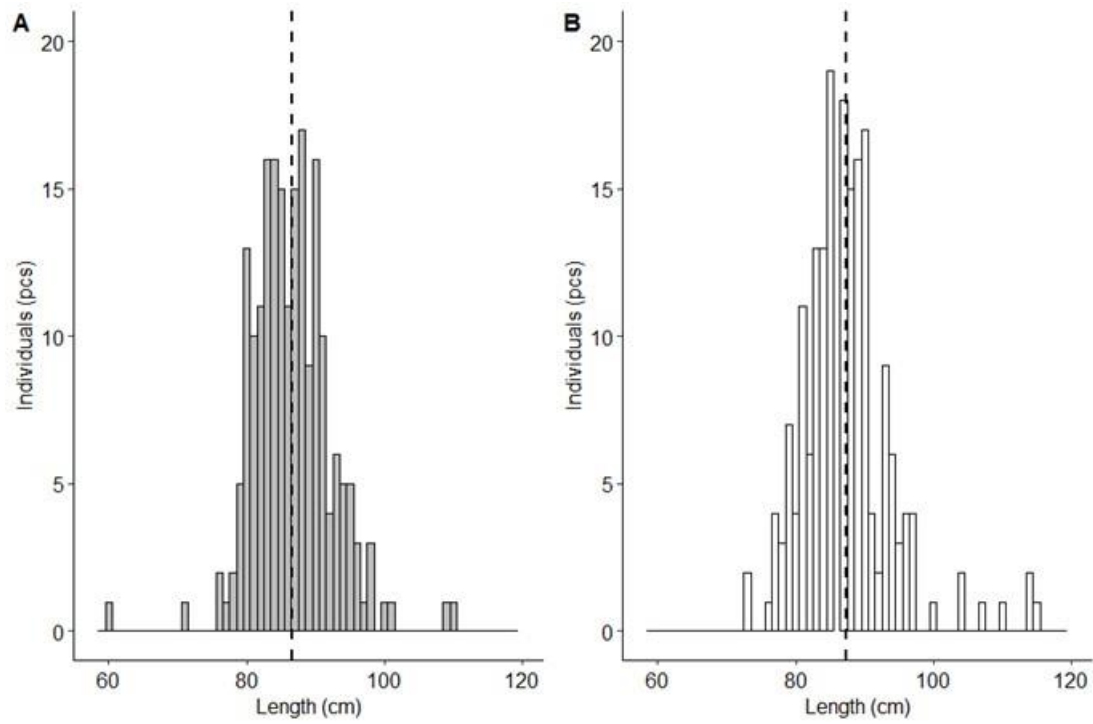


Figure 3. Size distributions of salmon tagged from traps with an emptying chute (A) and a lifting bag (B). The dashed line indicates the mean lengths of tagged salmon in both groups.

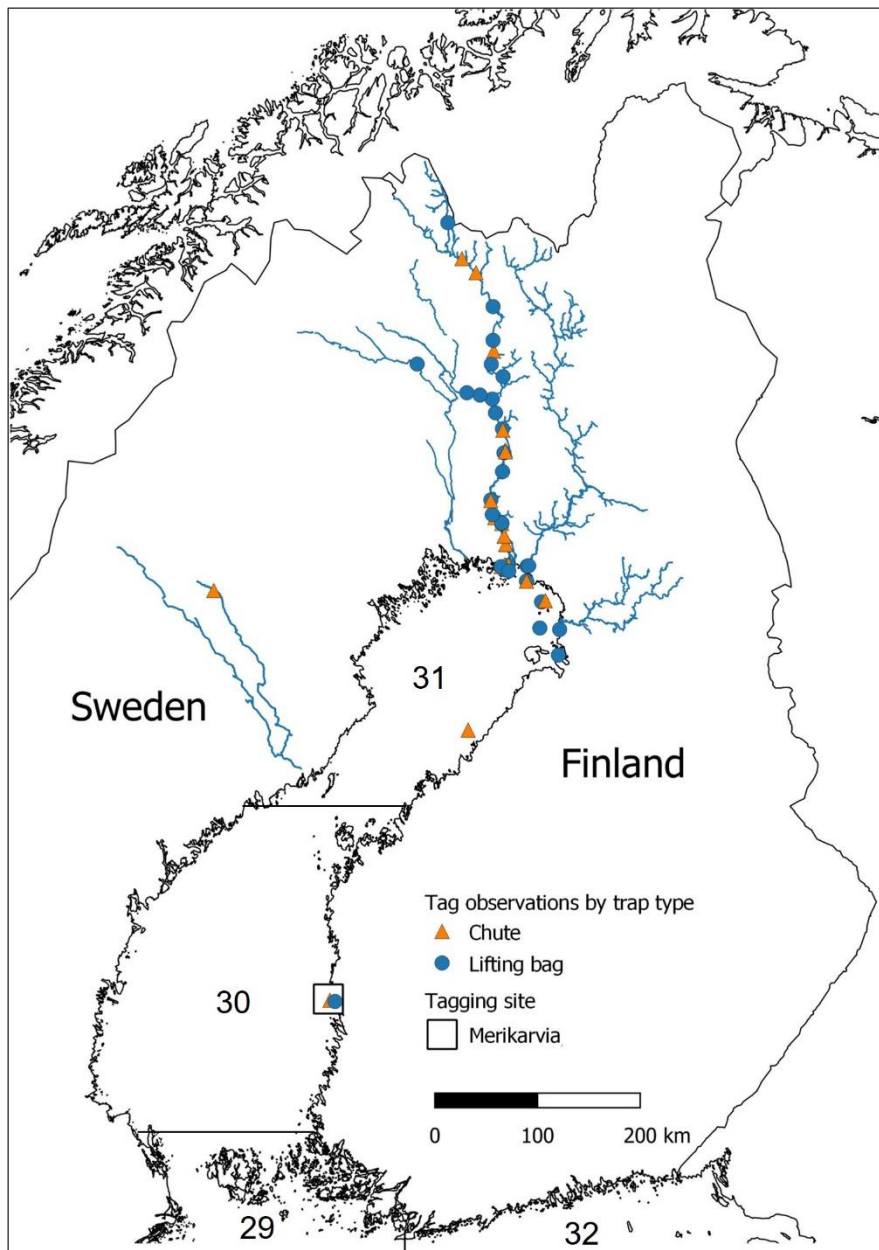


Figure 4. Tagging and tag recovery locations. ICES sub-divisions are marked by numbers.

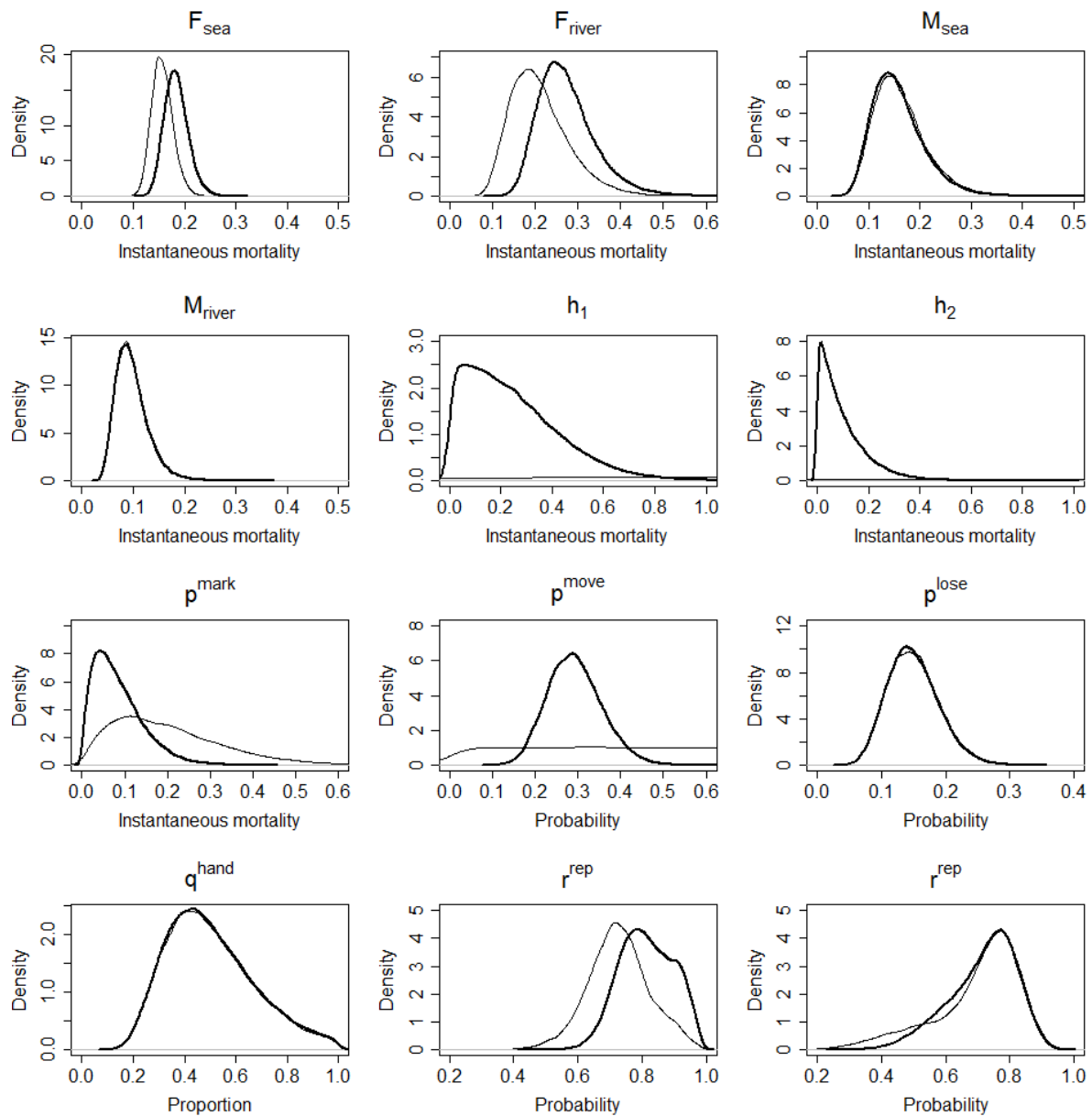


Figure 5. Prior (narrow line) and posterior (thick line) for parameters of the Bayesian release mortality model.

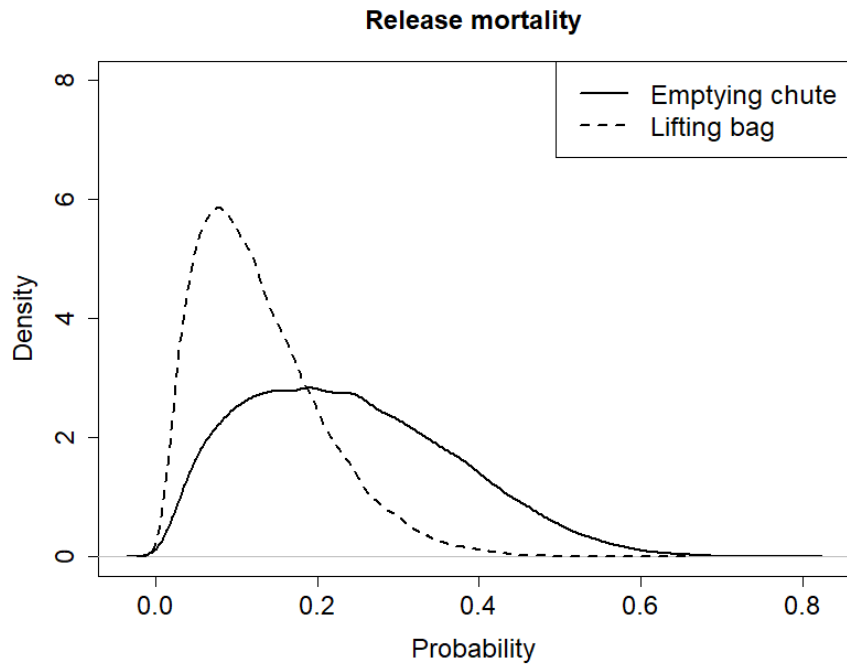


Figure 6. The estimated posterior distributions for probability of a salmon dying due to release from a pontoon trap with an emptying chute or with a lifting bag.

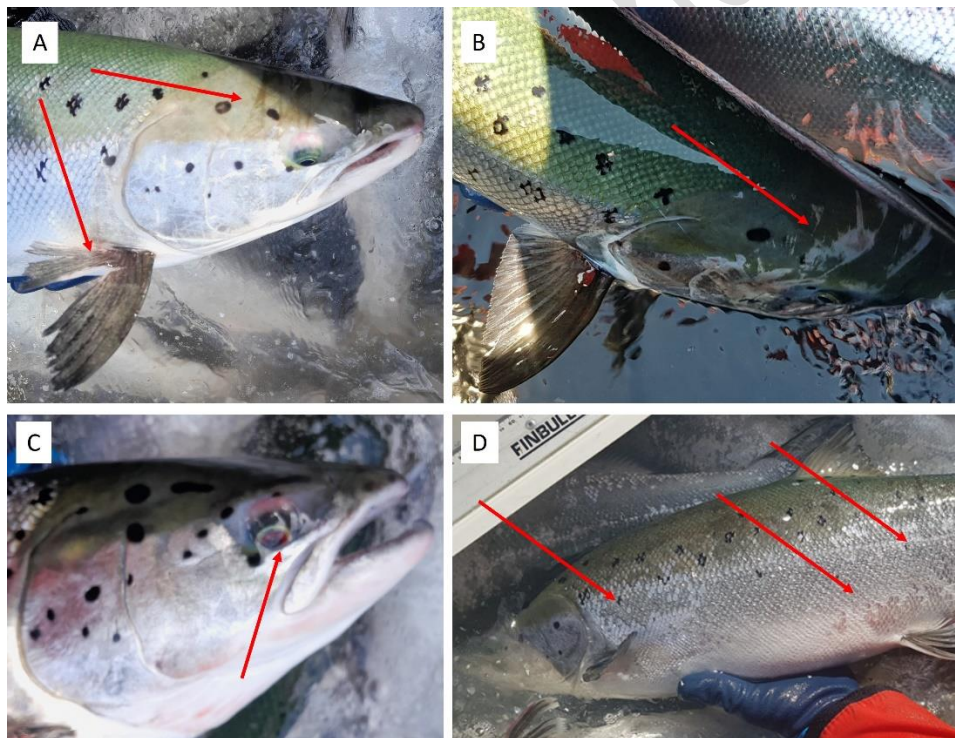


Figure 7. Observed injuries in tagged salmon. A) Fin and mesh injuries; B) injuries caused by meshing; C) eye injury; D) major scale loss. Injuries are marked with red arrows.

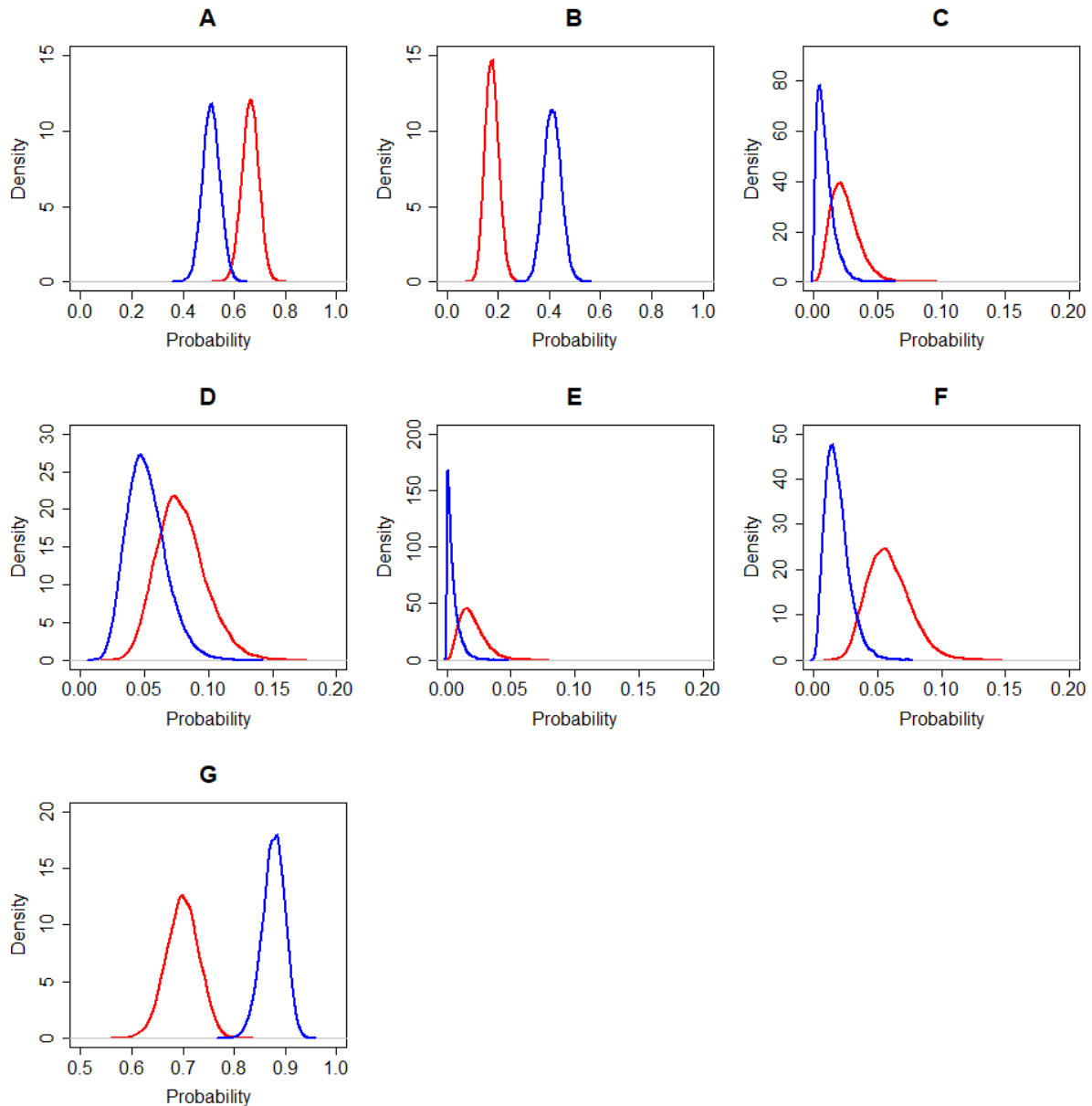


Figure 8. Estimated posterior distributions for probability of a specific type of injury when releasing from a trap. A) minor scale loss, B) major scale loss, C) eye injury, D) wounds and scratches, E) mesh injuries, F) mouth or jaw injury, and G) fin injury. Red line: trap with an emptying chute; blue line: trap with a lifting bag.

Table 1. List of symbols, descriptions, and prior distributions

Symbol	Description	Prior distribution
Indices		
t	Week from 1 to 15	-

i	Area; 1: sea, 2: river	-
j	Trap type; 1: pontoon trap with an emptying chute, 2: pontoon trap with a lifting bag	-
Data		
$N_{t,j}^{tagged}$	Number of tagged salmon released in week t from trap of type j	-
$N_{t,i,j}^{recap}$	Number of tagged salmon released from trap type j recaptured in week t at area i	-
Latent variables		
$N_{t,j}^{alive}$	Number of tagged salmon released from a trap of type j alive in week t	-
p_j^{alive}	Probability of a salmon released from a trap of type j surviving from the tagging and releasing mortalities	-
p_j^{die}	Probability of a salmon dying because of release mortality induced by trap type j	-
$n_{t,i,j}$	Number of tagged salmon released from trap type j that are available for fisheries at area i in week t	-
q_i^{SS}	Surviving fraction of tagged salmon that stay at area i	-
q^{SM}	Surviving fraction of tagged salmon that move from sea to river	-
F_i	Instantaneous fishing mortality for one week at area i	-
M_i	Instantaneous natural mortality for one week at area i	-
$HR_{i,j}$	Harvest rate of tagged salmon originally released from a trap of type j at area i	-
p_i^{surv}	Probability that a salmon released from a trap of type j survives from natural and fishing mortalities for one week at area i	-
r_i^{report}	Tag reporting rate at area i	-
p^{keep}	Probability of keeping a tag for one week	-
ip^{keep}	Probability of keeping a tag for one week at instantaneous scale	-
ip^{mark}	Instantaneous mortality due to tagging and releasing	-
Parameters		
h_j	Trap induced mortality for trap type j	U(0,12)
p^{move}	Probability of moving from sea to river for one week	U(0,1)
p^{lose}	Probability of a tag loss for 12 weeks	Beta(12,68)
q^{hand}	Proportion of mortality caused by handling of total mortality caused by tagging and handling	logN(0.723, 0.371 ²)T(,1)
p^{mark}	Probability of dying because of tagging mortality or release mortality for 12 weeks	Beta(1.8,7.2)
F^{sea}	Instantaneous mortality at coastal fisheries for 11 weeks	logN(-1.86,0.131 ²)
F^{river}	Instantaneous mortality at river fisheries for 12 weeks	logN(-1.60,0.324 ²)
M^{sea}	Instantaneous natural mortality on coast for 8 weeks	logN(-1.87,0.313 ²)
M^{river}	Instantaneous natural mortality in rivers for 52 weeks	logN(-2.38,0.312 ²)
$E_{k,i}$	Expert k 's prior for reporting rate at area i	See Table 2

Table 2. Tag recoveries by trap type and location.

Pontoon trap type	Tagged	Sea	River	Total	%
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Chute	202	10	14	24	12
Lifting bag	211	14	21	35	17
Total	413	24	35	59	14

Table 3. Prior and posterior means and 90% highest density probability intervals (HDI) for parameters of release mortality model.

Parameter	Prior mean	Prior 90% HDI	Posterior mean	Posterior 90% HDI
q^{hand}	0.5	[0.23,0.78]	0.5	[0.23,0.78]
r_1^{report}	0.73	[0.57,0.9]	0.82	[0.69,0.96]
r_2^{report}	0.69	[0.47,0.89]	0.72	[0.54,0.88]
h_1	5.96	[0.00,20.79]	0.25	[0.00,0.5]
h_2	6.00	[0.67,11.44]	0.1	[0.00,0.22]
F^{sea}	0.16	[0.12,0.19]	0.18	[0.15,0.11]
F^{river}	0.21	[0.1,0.32]	0.27	[0.17,0.38]
M^{sea}	0.16	[0.08,0.24]	0.16	[0.08,0.23]
M^{river}	0.10	[0.05,0.14]	0.10	[0.05,0.15]
p^{move}	0.5	[0.01,0.91]	0.29	[0.19,0.39]
p^{mark}	0.2	[0.01,0.39]	0.09	[0.00,0.17]
p^{lose}	0.15	[0.09,0.21]	0.15	[0.08,0.21]

Table 4. Estimated posterior means and 90% highest density probability intervals (HDI) for salmon getting a specific injury when being caught with a pontoon trap with an emptying chute or with a pontoon trap with a lifting bag

Injury	Emptying chute		Lifting bag	
	mean	90% HDI	mean	90% HDI
Minor scale loss	0.67	[0.61,0.72]	0.51	[0.46,0.57]
Major scale loss	0.18	[0.13,0.22]	0.41	[0.36,0.47]
Eye injury	0.03	[0.01,0.04]	0.01	[0.00,0.02]
Wounds and scratches	0.08	[0.05,0.11]	0.05	[0.03,0.07]
Mesh injury	0.02	[0.00,0.03]	0.01	[0.00,0.01]
Mouth or jaw injury	0.06	[0.03,0.08]	0.02	[0.00,0.03]
Fin injury	0.70	[0.65,0.75]	0.88	[0.84,0.92]

Appendix A. JAGS model code for Bayesian release mortality model

```

model{
  for(t in 1:T){
    for(j in 1:2){ # Gear (1: pontoon trap with an emptying chute, 2: PU trap with a lifting bag)

```

```

N_alive[t,j]~dbin(p_alive[j],N_tagged[t,j])

for(i in 1:2){ # Area (1: sea, 2: river)
  N_recap[t,i,j]~dpois(HR[i]*n[t,i,j]*r_rep[i]+0.001)
}
}

for(j in 1:2){
  p_alive[j]=exp(-(h[j]+ip_mark)) # probability of surviving from tagging and release mortalities
  p_die[j]=1-exp(-(h[j]+ip_mark*q_hand)) # probability of dying because of releasing

  n[1,1,j]=N_alive[1,j]
  n[1,2,j]=0 # no releases in the river

  # Number of fish at sea over time
  for(t in 1:(T-1)){
    n[t+1,1,j]=n[t,1,j]*q_SS[1]+N_alive[t+1,j]
  }

  # Number of fish in river over time
  for(t in 1:T){
    n[t+1,2,j]=n[t,1,j]*q_SM+n[t,2,j]*q_SS[2]
  }
}

# Surviving fractions
q_SS[1]=p_surv[1]*p_keep*(1-p_move) # survives and stays at sea
q_SS[2]=p_surv[2]*p_keep # survives and stays in river
q_SM=p_surv[1]*p_keep*p_move # survives and moves from sea to river

for(i in 1:2){
  p_surv[i]=exp(-(M[i]+F[i])) # survival from natural and fishing mortalities for one week
  HR[i]=p_keep*(1-p_surv[i])*F[i]/(M[i]+F[i]) # harvest rate
}

# Uninformative priors
p_move~dunif(0,1) # probability of moving from sea to river, 1 week

for(j in 1:2){
  h[j]~dunif(0,12) # trap-induced mortality
}

# Informative priors based on Baltic salmon stock assessment model
F_sea~dlnorm(log(0.1566)-0.5/T_Fs, T_Fs) # sea F, 11 weeks
T_Fs=1/log(pow(0.02062/0.1566,2)+1)
F_river~dlnorm(log(0.2119)-0.5/T_Fr, T_Fr) # river F, 12 weeks
T_Fr=1/log(pow(0.07043/0.2119,2)+1)
M_river~dlnorm(log(0.0975)-0.5/T_Mr, T_Mr) # river M, 52 weeks
T_Mr=1/log(pow(0.0312/0.0975,2)+1)
M_sea~dlnorm(log(0.1622)-0.5/T_Ms, T_Ms) # sea M, 8 weeks
T_Ms<-1/log(pow(0.052/0.1622,2)+1)

```

```

# Instantaneous mortalities per week
M[1]=M_sea/8
M[2]=M_river/52
F[1]=F_sea/11
F[2]=F_river/12

# Other informative priors

p_mark~dbeta(1.8,7.2) # mortality due to tagging + handling, 12 weeks
ip_mark=-log(1-p_mark/12) # instantaneous tagging + handling mortality, 1 week

# Share of handling mortality in total tagging + handling
q_hand~dlnorm(-0.723,7.2485)T(,1)

p_lose~dbeta(12,68) # probability of losing a tag, 12 weeks
ip_keep=-log(1-loose_tag/12) # probability of keeping tag for one week, instantaneous scale
p_keep=exp(-keep_tag_inst) # probability of keeping a tag for 1 week

# Priors for reporting rates of tags based on expert elicitation
r_rep[1]=E[Y,1] # sea fisheries
r_rep[2]=E[Y,2] # river fisheries

Y~dcat(w[1:3])

for(i in 1:3){
  w[i]=1/3 # Equal weights given to each expert
}

# Expert 1
E[1,1]~dbeta(17.25,7.75)
E[1,2]~dbeta(23.1,6.9)

# Expert 2
E[2,1]~dbeta(42.6,17.4)
E[2,2]~dbeta(37.75,12.25)

# Expert 3
E[3,1]~dbeta(10.14,2.86)
E[3,2]~dbeta(7.28,5.72)
}

```

Appendix B. JAGS model code for Bayesian injury model

```

model{
  for(i in 1:7){ # injury type
    for(j in 1:2){ # gear type
      x[i,j]~dbin(p[i,j],N[i])
    }
  }
}

```

```
    p[i,j]~dbeta(1,1)
  }
}
}
```

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