Fisheries Research 288 (2025) 107449

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Relationship between size and condition metrics and the recapture probability of stocked landlocked Atlantic salmon and brown trout in lake fisheries

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ARTICLE INFO

Keywords:
Fin erosion
Fisheries
Growth traits
Hatchery
Recapture
Stocking

ABSTRACT

Stocking-derived catches serve as indicators of the feasibility of put-grow-and-take (PGT) fisheries for salmonids. Here, we report results from a large tagging program of landlocked Atlantic salmon and brown trout stocked at ages 2 and 3 in two large geographically close boreal lakes, Pielinen and Höytiäinen, in Finland. In addition to describing recapture patterns in these lake fisheries, we assessed whether the commonly measured phenotypic characters such as body length and condition, fin erosions, and early male maturity, were related to recapture probabilities. In both species and study lakes, the released fish recruited to fisheries at 3 or 4 years of age and were exposed to heavy total mortality rate ($Z = 1.06 – 2.07\ \mathrm{yr}^{-1}$) as estimated from catch curves. As in many previous studies, a positive relationship was found between fish length at release and recapture probability. Together with the influence of body condition, the effect of body length was particularly strong among fish stocked at age 2. In both species, recapture probability was lower for fish that showed precocious maturity and negatively associated with pectoral fin erosion. Our results complement existing knowledge on the relationship between fish condition indicators and stocking success, and provide data to set quality metrics for fish released for PGT purposes. The recapture patterns underline the role and responsibility of fisheries management in reducing the premature harvest of stocked fish to ensure positive net yields from the stocking programs and decreasing the overall mortality rate to reach conservation goals.

1. Introduction

Hatchery-reared fish are stocked for multiple reasons varying from conservation-oriented re-introductions and supplementation to releases intended to maintain put-growth-and-take (PGT) fisheries with mainly economic and social objectives (Cowx, 1994; Aprahamian et al., 2003; Hunt et al., 2017). Systematic information collected from catches of released fish serves as a relevant biological indicator for fisheries managers on the success of the chosen stocking protocol (Davis and Isermann, 2024). Such information can also be employed to adjust management measures applied in the supported fisheries to ensure the targeted benefits of stocking. Importantly, multi-year tagging and recapture studies provide generalizable data on how different hatchery-rearing and stocking protocols, and qualities of the released fish (e.g. length-at-release, condition factor or fin damages), explain variation in their post-release survival and growth (e.g. Kallio-Nyberg et al., 2009; Janhunen et al., 2021, 2023a). Such monitoring data can further be used to infer trait changes that could accumulate over long-term hatchery rearing due to unintended domestication and artificial selection (Claussen and Philipp, 2022). For example, in Atlantic salmon (*Salmo salar*), hatchery rearing may decrease migration tendencies (Ugedal et al., 1998; Kallio-Nyberg et al., 2011, 2013, 2015; Orell et al., 2018), and alter key life history traits (Kallio-Nyberg et al., 2007, 2015; Vainikka et al., 2010).

Of the traits affecting post-stocking survival, precocious sexual maturity has been identified as one of the most important. Rapid growth of hatchery-reared juveniles promotes precocious male maturity, as well as earlier smoltification (reviewed by Jonsson and Jonsson, 2006), both traits being considered size- and condition-dependent (Økland et al., 1993; Dodson et al., 2013; Ferguson et al., 2019). On the other hand, although large stocking size protects the released fish from predation and starvation (e.g. Salminen et al., 1995; Hyvärinen and Vehanen,

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https://doi.org/10.1016/j.fishres.2025.107449
Received 30 January 2025; Received in revised form 26 June 2025; Accepted 26 June 2025

2004a; Vainikka et al., 2021), thereby partly compensating for the generally poor ability of hatchery-reared salmonids to live in the wild (Kallio-Nyberg et al., 2004, 2007, 2009), it may also increase the vulnerability of the released fish to fishing (Hyvärinen and Vehanen, 2004b; Tsuboi et al., 2016; Janhunen et al., 2021; Vainikka et al., 2021).

Along with traits associated with growth, fin condition has been recognized as an essential welfare metric in hatchery fish (Arndt et al., 2001; Turnbull et al., 2005; Ellis et al., 2008), reflecting the level of chronic stress, aggressive contacts with other fish, mechanical abrasions, and bacterial infections (Schneider and Nicholson, 1980; Bosakowski and Wagner, 1995; MacLean et al., 2000; Berejikian and Tezak, 2005; Rosengren et al., 2017). In nature, pectoral fins in particular affect the accuracy of movement control (maneuvering ability), allowing fish to move and turn with less effort, and remain stationary in moving water (Ehlinger, 1990; Arnold et al., 1991). Comparisons of hatchery-reared salmonids with wild or stream-reared counterparts have consistently shown the negative impact of captive environments on fin growth and condition, together with other morphological divergence (e.g. Fleming et al., 1994; Pelis and McCormick, 2003). The reported association between fin damages and post-stocking survival has varied from undetectable (Heimer et al., 1985; Vehanen et al., 1993; Kallio-Nyberg et al., 2009) to clearly negative (ICES, 2009; Petersson et al., 2013).

Since the 1960s, hatchery rearing has played a crucial role in maintaining fishable stocks of the critically endangered landlocked Atlantic salmon (*S. salar* m. *sebago*) and adfluvial brown trout (*S. trutta* m. *lacustris*) in the Vuoksi watercourse, Eastern Finland (Pursiainen et al., 1998; Urho et al., 2019; Janhunen et al., 2023b). In addition to state-managed broodstocks with the primary purpose of conserving the original salmonid populations in their original range, both fishes are stocked by private management organizations obtaining fish from commercial hatcheries to increase fishing opportunities in lakes, i.e. for lake ranching. These fish are recognizable from the wild fish and fish stocked for conservation purpose by their removed adipose fin. However, due to the widespread use of non-selective lethal gillnets in the study lakes, the captures of the fishable individuals likely also reflects the patterns of mortality occurring on the fish intended to rebuild the wild stocks creating a need to assess the realizing total mortality rates on stocked fish.

Here we present an analysis of large-scale tagging study on 2- and 3-year-old (= yo) landlocked salmon and brown trout stocked to support fisheries in two large and geographically adjacent lakes with apparently different environmental qualities. We characterize general catch patterns of both species in mainly recreational fisheries both by numbers and catch curves, and specifically focus on assessing whether some conventionally addressed and easily measurable phenotypic metrics, i.e. fish body length and condition, fin erosions, and early male maturity, would be associated with recapture rate, potentially reflecting variation in post-stocking survival. We use the general term metric as not all measurements characterize true biological traits. Based on previous literature (e.g. Lundqvist et al., 1994; Hyvärinen and Vehanen, 2004a,b; Kallio-Nyberg et al., 2009; Petersson et al., 2013), we predicted that large fish size would increase while fin erosions and precocious male maturity would decrease recapture probabilities, regardless of the species and stocking age. We further estimate how standard Fulton’s condition factor (length-mass relationship) contributes to the recapture probability by stocking age and species.

2. Materials and methods

2.1. Fish tagging and releases

The data comprise 82,514 individually tagged salmon and 65,562 trout from 57 and 40 release groups, respectively, released at 2 and 3 years of age into two large lakes of Eastern Finland (Vuoksi watercourse), Lake Höytiäinen (62°41–63°3’N, 29°25’–29°50’E; area 283 km^2, mean depth = 12 m, maximum depth = 56 m) and Lake Pielinen (62°54’–63°37’N, 29°07’–30°14’E, area 894 km^2, mean depth = 10 m, maximum depth = 60 m) during years 2008–2012 (Table 1, Fig. 1.). Most fish were redeemed by local fisheries managers, in which case the put-growth-take (PGT) stockings were intended to support recreational fishing that mainly utilizes gillnets and motorized trolling. Although the primary intention of the stocking activities was to support fisheries, the data of Lake Pielinen also include state-run stockings of salmon (12 release groups of 2-yo fish and one group of 3-yo fish), which were targeted to the downstream of River Lieksanjoki and mainly focused on preserving the partial life cycle (migratory phase) of the stock that lost its natural riverine breeding habitats for hydroelectricity production (Pursiainen et al., 1998). The fish released into the river presumably have a better ability to return there as adults, compared to fish released in the lake, and the spawners can be annually captured below the lowest hydropower plant for renewal of hatchery broodstock in the national supportive breeding programme. The proportion of 2-yo salmon stocked by the state for stock management was 51 % of all 2-yo salmon stocked in Lake Pielinen.

In Lake Pielinen, the minimum size limit for landlocked salmon was 600 mm and for brown trout 500 mm through the study period except for years 2014–2015 when the minimum size limit for brown trout was nationally increased to 600 mm by a governmental decree. In Lake Höytiäinen, on the contrary, the respective minimum size limit for both species was 500 mm between the years 2008–2013 and 600 mm between the years 2014 and 2015. From the beginning of year 2016, landlocked salmon and brown trout with adipose fin uncut (i.e. wild fish or those stocked for conservational purpose) were fully protected in the entire Vuoksi watercourse by a governmental decree. Simultaneously, the minimum size limit of stocked landlocked Atlantic salmon with adipose fin cut was kept in 600 mm and that of stocked brown trout with adipose fin cut was set to 500 mm. These changes in minimum size limits did not affect the recruitment of fish to fishing, since no respective technical management measures were implemented and also released fish are included in our data.

The stocked salmon were produced in three private fish farms (identities not revealed for commercial confidentiality reasons) and in one state-owned aquaculture station (Kainuu Fisheries Research Station, Paltamo). All brown trout were reared in three private fish farms. The fish were tagged by experts of the Finnish Game and Fisheries Research Institute (FGFRI; currently Natural Resources Institute Finland) mostly 1–3 months before stockings (late February – early May). For 12 salmon and 5 trout groups, however, the tagging was performed already in the preceding autumn (late October – late November). During tagging, the fish were sedated with clove oil (70–80 mg L^{-1}) and equipped with an individually encoded T-bar anchor tag (Hallprint Pty Ltd., Hindmarsh Valley, Australia). Simultaneously with tagging, total body length was measured in millimeters and body mass to the nearest gram on all fish (Table 2). Fulton’s condition factor ($K = 100 \times \text{body mass (g)} \times \text{body length (cm)}^{-3}$) was used as a standard (uniform) and comparable measure of body condition index, instead of species- and age-specific mass-length relationships. Further, excluding seven groups of 2-yo brown trout released in 2008 (six groups in Pielinen and one group in Höytiäinen), erosion of dorsal fin, pectoral fins and pelvic fins was visually assessed from each tagged fish and categorized on a scale of 0–4: 0 = pristine, 1 = erosion < 25 %, 2 = erosion approx. 50 %, 3 = erosion approx. 75 %, 4 = full erosion (Table 3). Precociously mature males were identified based on their primary and secondary sexual characteristics (running milt, dark coloration).

In both study lakes, small pelagic fish, European smelt (*Osmerus eperlanus*) and vendace (*Coregonus albula*), are the main prey species for predatory salmonids. The natural predatory fish community comprises pikeperch (*Sander lucioperca*), pike (*Esox lucius*) and burbot (*Lota lota*) in both lakes. However, a relevant predation threat for the stocked salmon and trout is assumed to concern Lake Pielinen only due to the heavy fishing pressure and low abundance of large predators in Lake Höytiäinen (Turunen et al., 2024).

Table 1

Description of data structure for different lakes, fish species and their age groups: stocking years and groups, number of stocked fish, and tags returned (including their percentual proportions relative to number of stocked fish). All fish that were reported to be captured within the first month following the release were removed from the data. Tag return counts do not either include tags found in the intestines of predatory fish or otherwise from a dead or non-fished fish.

Species	Age	Lake	Years	Release groups	Fish released (n)	Tag returns (n)	Tag returns (%)
Landlocked Atlantic salmon	2	Pielinen	2008–2012	26	42,705	415	1.0
		Höytiäinen	2008–2011	15	17,104	2179	12.7
	3	Pielinen	2009–2011	9	14,766	985	6.7
		Höytiäinen	2009–2012	7	7939	2578	32.5
		Total		57	82,514	6697	8.1
Brown trout	2	Pielinen	2008–2011	20	36,845	256	0.7
		Höytiäinen	2008–2011	6	7947	1156	14.5
	3	Pielinen	2009–2011	8	12,855	903	7.0
		Höytiäinen	2008–2011	6	7915	2542	32.1
		Total		40	65,562	4857	7.4

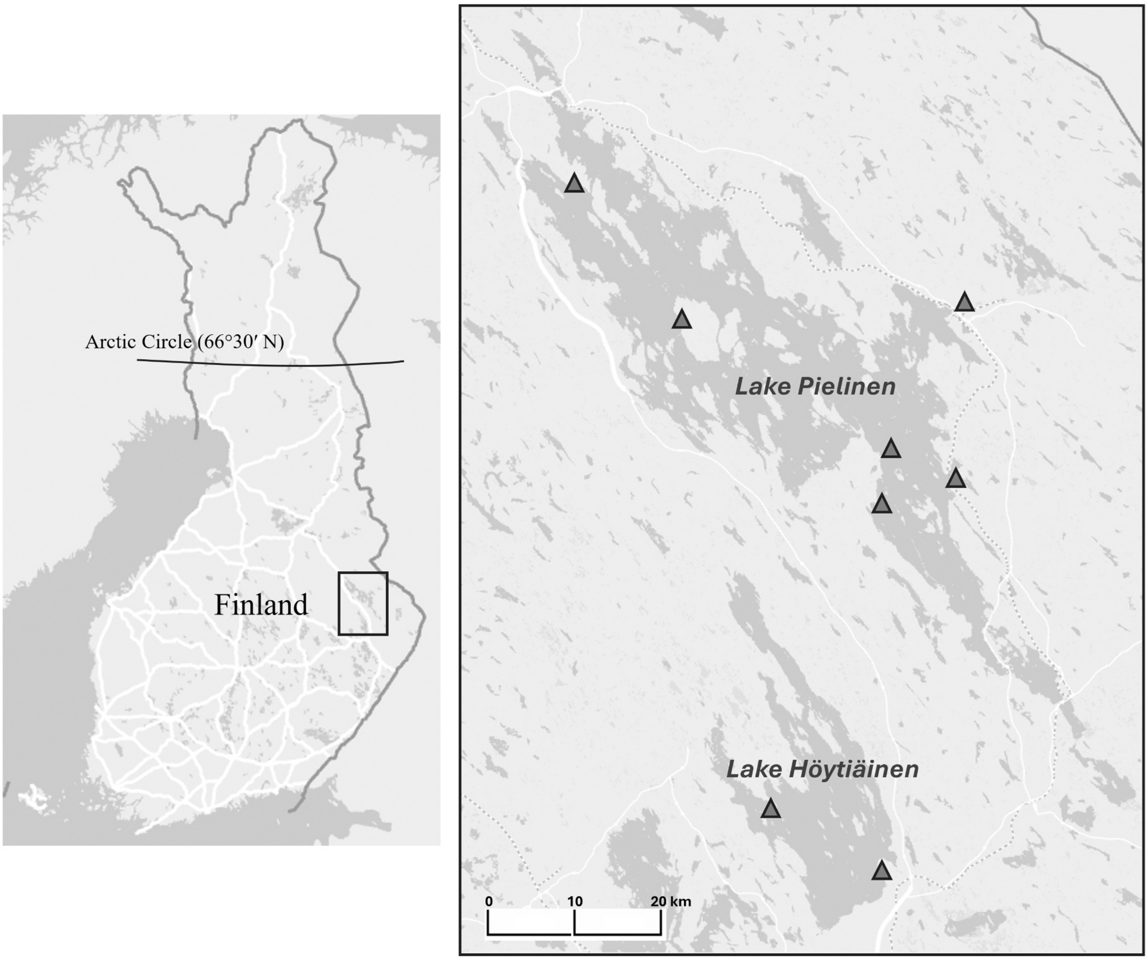

Fig. 1. Map of the study lakes Pielinen and Höytiäinen showing locations of release sites with triangles. Source: Finnish Environment Institute.

The stockings were performed during May, except for two groups of brown trout released in Lake Höytiäinen on 2 June 2008 and one trout group released in Lake Pielinen on 5 June 2008 (Fig. 1). The numbers of released fish were adjusted in proportion to the sizes of the lakes. Based on all salmonid stockings made over the study years, the average number of released fish was 1.3 ha^{-1} in Lake Pielinen and 1.0 ha^{-1} in Lake Höytiäinen. In the case of Lake Pielinen, the fish were released on the eastern side (Vuonislahti / Ala-Kelvä and river mouth of River Lieksanjoki), western side (Paalasmaa island and Koli) and northern side (Kynsiniemi / Lörsänsaari). In addition, two release groups of salmon and two groups of trout were distributed from a ferryboat to the pelagic Suurselkä basin in 2010. In Lake Höytiäinen, one release site was located on the eastern (Saunasaari) and another one on the western side (Kontioniemi) of the lake. The number of fish varied between 538–2001 in salmon release groups (average 1447 fish, $n = 57$ groups) and between 975–1999 in trout release groups (average 1639 fish, $n = 40$ groups). Along with phenotypic measures, the release group and release site of each fish were identifiable by individual tag code.

2.2. *Tag recoveries from lake fisheries*

Data on voluntary tag returns were collected from a national fish tagging database maintained by Luke. A small monetary reward was paid for each tag return (either electronic or postal), but the return rate

Table 2
Grand means of body length (mm), mass (g) Fulton's condition factor ($100 \times g \times cm^{-3}$) and fin erosions in release groups of 2- and 3-year-old landlocked salmon and brown trout. Minimum–maximum values of group averages are given in parentheses. Fin erosions were determined on a scale of 0–4, and average value was used for the paired fins of each individual. Fin erosions were not determined for 7 groups of 2-year-old brown trout.

	Landlocked salmon		Brown trout	
Trait	2-year-old (*n* = 41)	3-year-old (*n* = 16)	2-year-old (*n* = 26 or 19)	3-year-old (*n* = 14)
Body length	204 (174–275)	318 (267–341)	221 (203–231)	319 (303–338)
Body mass	91 (51–204)	330 (165–453)	118 (91–141)	356 (288–446)
Condition factor	0.98 (0.87–1.13)	1.00 (0.87–1.11)	1.06 (0.92–1.21)	1.06 (0.98–1.14)
Dorsal fin	1.15 (0.00–3.51)	0.30 (0.00–2.91)	0.14 (0.00–0.91)	0.08 (0.00–0.27)
Pectoral fins	0.19 (0.00–1.10)	0.30 (0.08–0.74)	0.20 (0.01–0.37)	0.19 (0.00–0.37)
Pelvic fins	0.08 (0.00–0.97)	0.07 (0.00–0.25)	0.06 (0.00–0.44)	0.00 (0.00–0.02)

of the obtained tags is not known. It was assumed that the tag return rate does not differ between the study lakes or the study groups of fish. Along with the tag return, the fishers were requested to report the date and site of the capture, fishing method used, and the body length and mass of the captured fish. In this study, fishing methods were grouped into three categories: 1) rod fishing gears involving trolling, spin fishing and ice fishing, 2) trap fishing gears involving mainly gillnets, and in a few cases, fyke nets, trawls, and seines, and 3) unknown gear (no information given). Only the first capture of each fish was used in the analyses, regardless of whether some fish were captured more than once (following their release at first capture time). The last reported date in the recapture data was 4 October 2016 for salmon and 10 October 2014 for trout.

2.3. Data analysis

Statistical analyses were performed using R 4.3.3 (The R foundation for Statistical Computing) and SAS 9.4 (SAS Institute, Cary, NC, USA) with a threshold value $\alpha = 0.05$ for the statistical significance. First, total numbers of tag returns were used to construct catch curves by species, lake and stocking age, and to assess temporal changes in total mortality by estimating the catch curves separately for each stocked cohort. The catch curves were fitted using function *catchCurve* included in package *FSA* (Ogle et al., 2025) in R 4.3.3 (The R foundation for Statistical Computing). The fits were based on non-weighted linear regression, and the fully recruited age groups were selected by visual and statistical significance -based assessment. The estimated annual total mortality rates were visualized using *ggplot2* package (Wickham, 2016).

Binomial generalized linear mixed models (GLIMMIX procedure in SAS with Laplace estimation method) with a logit link (1 meaning captured, 0 non-captured) were fitted to estimate the likelihood of recapture by fish metrics at tagging, i.e. body length, condition factor, fin erosions (on the scale 0–4) and maturity status (0 = immature, 1 = precocious male). Because the recapture proportions differed markedly in relation to stocking age, analyses were run separately for 2- and 3-yo fish (as referring to the release age) in both species. All observations where a tag return occurred within a month after stocking (by the end of June) were omitted from the data (*n* = 193 salmon and 164 trout) as such short time does not reliably reflect individual's fitness in natural conditions. Further, a tag return was ignored if the tag had been found inside a predatory fish or otherwise from a dead or non-fished fish. Brown trout from seven release groups (*n* = 13,907 fish stocked in 2008) were excluded from the analysis due to missing information on fin erosions.

The generalized linear model included stocking year, lake, and dorsal fin erosion and maturity status of fish (at tagging) as fixed factors, and body length and condition, and pectoral and pelvic fin erosion measures (average of each paired fins) as fixed variables. In addition, a random intercept nested within lake was defined for each release group to account for genetic and environmental variation amongst them, including their rearing conditions, and release site and time. In the case of 2-yo landlocked salmon, also each rearing group was treated as a random factor. This random term took into account a possible common rearing (and genetic) background of fish released to different lakes, though could not be incorporated in the models for 3-yo salmon and either age group of brown trout due to estimation issues. Factor Year included interannual variation due to environmental conditions, fishing, tag recovery rate, or the interaction among any of these. For 2-yo trout, the statistical model further included a significant interaction term of lake × body condition, whereas for 3-yo trout the significant interaction terms involved year × lake and lake × body length. The possible collinearity among predictors was checked by calculating variance inflation factors (VIF) in linear regression models (Proc REG in SAS), where each metric was used at a time as a dependent variable and all other metrics were independent variables. Since the VIF values were

Table 3
Percentual proportions of stocked 2- and 3-year-old landlocked salmon and brown trout belonging to different fin erosion categories. The data do not include fish that were captured within the first month following release.

Species	Age (*n*)	Erosion class	Dorsal fin	Right pectoral fin	Left pectoral fin	Right pelvic fin	Left pelvic fin
Landlocked Atlantic salmon	2	0	64.3	86.9	87.4	94.9	95.2
	(*n* = 59,809)	1	6.5	7.7	7.3	2.7	2.6
		2	8.2	3.2	2.9	1.2	1.0
		3	13.7	1.3	1.3	0.8	0.8
		4	7.2	0.9	0.9	0.4	0.5
	3	0	77.0	82.8	83.5	94.5	95.8
	(*n* = 22,705)	1	4.6	7.8	7.9	3.2	2.3
		2	5.2	3.9	4.1	1.6	1.3
		3	7.4	2.7	2.3	0.5	0.4
		4	5.7	2.8	2.2	0.2	0.2
Brown trout	2	0	90.5	87.7	85.2	96.8	97.9
	(*n* = 30,855)	1	7.1	7.2	8.4	0.8	0.7
		2	2.2	3.4	4.2	0.8	0.5
		3	0.2	1.2	1.6	0.9	0.5
		4	0.0	0.6	0.5	0.8	0.4
	3	0	95.6	89.5	88.5	99.7	99.9
	(*n* = 20,800)	1	3.2	5.0	4.9	0.1	0.1
		2	0.8	3.3	4.0	0.1	0.0
		3	0.3	1.2	1.6	0.1	0.0
		4	0.1	0.9	0.9	0.0	0.0

1.00–1.13 for salmon and 1.00–1.02 for trout, collinearity between the metrics was not considered a concern and their simultaneous use in the models was justified. We also considered that the estimates of dispersion as measured by Pearson's χ^2, divided by the degrees of freedom, were always close to one, indicating that the data were not overdispersed.

The phenotypic means of fish metrics were examined among release groups in relation to their net catch biomass (i.e. difference of biomass between captured and stocked fish). Here, net yields were calculated for each release group in kilograms per 1000 fish released. If the body mass was not reported for a captured fish, it was estimated from the age-specific return data using linear mixed-effect models (Proc MIXED in SAS), where either the reported fish length, including model terms length + length^2 ($n = 167 + 217$ salmon and $58 + 105$ trout at ages 2 and 3), or time spent in lake (days from release until capture; $n = 55 + 73$ salmon and $48 + 97$ trout) was used as a predictor. In addition, the regression model for body mass included stocking year and lake as fixed effects, and release group, nested within lake, as a random effect. If neither fish size nor the date of capture was reported even with a rough accuracy ($n = 37 + 70$ salmon and $21 + 74$ trout at ages 2 and 3), fish body mass was set to an age-specific average.

In this study, no correction coefficients were applied to the return results to correct for effects caused by the non-return and detachment of tags, among other factors. Thus, the calculated biomasses (reported + predicted) only represent minimum estimates of catch in kilograms for each release group. In both species, relative net yield was explained by a linear mixed-effect model with the fixed variables mean fish length, mean condition factor and mean fin condition (grand mean values calculated for each fin variable) of each release group (salmon: $n = 57$, trout: $n = 33$ groups). In addition, the model included stocking year and lake as fixed factors, a significant interaction term between lake and average fish length, and rearing group as a random factor (dependency of release groups between different locations).

2.4. Ethical statement

The stockings were performed under national fishing law (286/82) and under an approval from the regional fisheries authority, Centre for Economic Development, Transport, and the Environment, to use the genetic strains native to the region. No animal experimentation was performed and therefore an ethical permission was not required.

3. Results

3.1. Catch patterns

3.1.1. Landlocked salmon

After excluding the fish captured within the first post-stocking month, tag recoveries were obtained from 6697 salmon (8 % of the released fish). Most of the salmon (56 % of tag returns) released in Lake Pielinen were reportedly captured with rod fishing gears, whereas in Lake Höytiäinen most salmon (62 %) were caught with stationary fishing gears, mainly gillnets. The fishers of Pielinen did not report the used gear in 14 % of the recoveries while in Höytiäinen only 5 % did not report the gear.

A total of 26 % of tag recoveries from 2-yo salmon released in Lake Pielinen was received within the first year from release, and the corresponding share in Lake Höytiäinen was 34 %. The largest proportion of tag returns from 2-yo salmon was received in the second lake year from both Pielinen (41 %) and Höytiäinen (55 %) (Fig. 2). In Pielinen, a considerable proportion of tags from 2-yo salmon was returned during the third year (28 %), while the returns during the fourth and fifth years totaled less than 6 % of all recoveries. Of the 3-yo salmon released in Höytiäinen, most tag returns were received during the first lake year (67 % of all tag recoveries; Fig. 2). In Pielinen, on the contrary, tag recoveries were rather equally shared between the first (41 %) and the

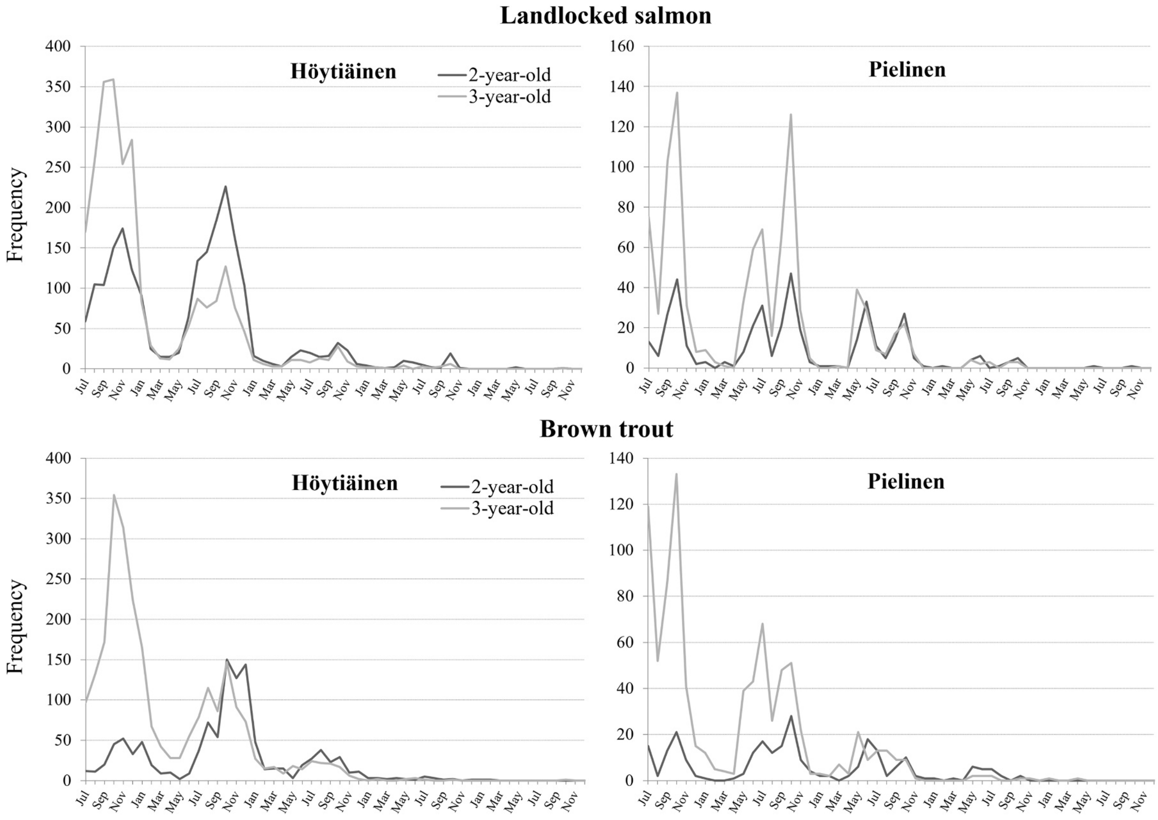

Fig. 2. Monthly tag return accumulations of 2- and 3-year-old landlocked salmon and brown trout from July of the stocking year until the end of the fifth post-stocking year in lakes Höytäinen ($n = 8278$ fish) and Pielinen ($n = 2463$). The graphs are missing 141 salmon returns (84 from Höytiäinen + 57 from Pielinen) and 132 trout returns (93 from Höytiäinen + 39 from Pielinen) for which the capture month was unknown.

second lake year (44 %), whereas the third lake year comprised 14 % of the returns. The return shares for the second and third year were thus clearly higher for Pielinen than for Höytiäinen (28 % and 5 %).

When pooling the stocking age groups, the estimated total mortality rate of salmon recruited to fishing was 1.22 (95 % C.I. 0.15–2.30) in Lake Höytiäinen and 1.06 (95 % C.I. −0.37–2.49) in Lake Pielinen. Only the 3-yo salmon stocked to Lake Pielinen showed recruitment to fishing at age 4, while in other groups already the 3-year-old fish showed full or statistically supported nearly full recruitment to fishing (Table 4). Total mortality rate did not vary consistently with stocking year but in Lake Pielinen, the salmon stocked at age 3 seemed to be exposed to higher total mortality rate than the salmon stocked at age 2 in some stocking years (Fig. 3).

3.1.2. Brown trout

After removing the trout observations yielding tag returns within a month from stocking, the total number of recaptures was 4857 (7 % of the released fish). In both lakes, brown trout were reportedly caught mostly with stationary gears, mainly gillnets (Pielinen: 68 %, Höytiäinen: 82 %), and to a lesser extent by rod fishing (Pielinen: 20 % of all recoveries, Höytiäinen: 12 %). The proportion of tag returns that lacked information on fishing method was 13 % for Lake Pielinen and 6 % for Lake Höytiäinen.

In relation to landlocked salmon, the 2-yo trout stocked in Lake Höytiäinen yielded relatively fewer returns (16 %) within the first year from stocking than those released in Lake Pielinen (24 %) (Fig. 2). In both lakes, the largest share of tag returns was received during the second year (Pielinen: 41 %, Höytiäinen 60 %). Even in the third year, the return shares accounted for 26 % in Pielinen and 22 % in Höytiäinen, whereas the return shares of the fourth year were 9 % and 2 %, respectively (Fig. 2). More than half of the tag returns from 3-yo brown trout were obtained already by the end of first lake year in both lakes (Pielinen: 52 %, Höytiäinen: 52 % of tag recoveries), but the captures were slightly more evenly distributed in time compared with salmon of the same age (Fig. 2). Correspondingly, the proportions of tag returns from 3-yo brown trout were similar between the lakes during the second (Pielinen: 36 %, Höytiäinen: 39 % of tag recoveries) and third year (Pielinen: 10 %, Höytiäinen: 8 %).

When pooling the stocking age groups, the estimated total mortality rate of brown trout recruited to fishing was 1.42 (95 % C.I. 0.07–2.78) in Lake Höytiäinen and 0.80 (95 % C.I. −0.02–1.58) in Lake Pielinen. All brown trout recruited to fishing already at age 3 (Table 4). Total mortality rate did not vary consistently with stocking year but in Lake Pielinen, the brown trout stocked at age 3 seemed to be exposed to higher total mortality rate than the brown trout stocked at age 2 in the same years when the pattern was observed in salmon (Fig. 3).

3.2. Relationships between qualities of the stocked fish and recaptures

3.2.1. Landlocked salmon

When all released salmon (captured later than during the first month from their release) were included in a binomial mixed model for capture probability, maturity, fish length, condition factor, and erosion of pectoral fins affected statistically significantly the probability of recapture at both stocking ages (Table 5). At both stocking ages, size at tagging correlated positively with likelihood of recapture, whereas male maturity and erosion of the pectoral fins reduced the likelihood of recapture. Maturity proportions were 1.3 % and 3.7 % among 2- and 3-yo salmon, respectively.

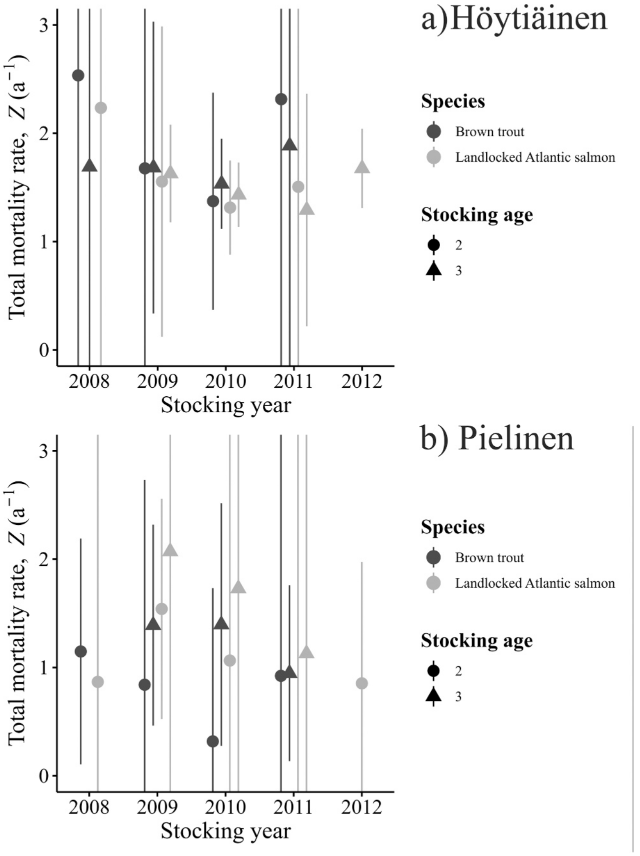

Fig. 3. The estimated annual total mortality rates by lake, species, stocking age and stocking year with 95 % confidence intervals (that may greatly overlap the feasible range of Z): a) for lake Höytiäinen and b) for Lake Pielinen. The estimates are based on catch curve analysis and linear regression slope of the log (catch numbers) in fully recruited age groups.

Relating the proportions of captured and all stocked salmon to each other in different size classes, 2-yo fish gave positive yields when their stocking length was at least 200 mm in both lakes (Fig. 4). The effect of fish tagging length on recapture rate was less clear in 3-yo salmon, compared to their younger counterparts, but the ratio of recaptured fish to released ones was positive only when the length-at-release was longer than 300 mm (Fig. 4). Fulton's condition factor also showed a significant positive relationship with recapture proportions (Table 5), but depending on age class, the condition factor appears to have optimal values between 0.80–0.95 and should not exceed 1.00 (Fig. 5).

The average mimimum catch among 2-yo salmon groups was 194 kg

Table 4
Estimated total mortality rates of the stocked fish by species, lake and stocking age. The age range assessed to be fully recruited to fishing is indicated in the last column.

Species	Lake	Stocking age	Z	S.E.	t	p-value	Age range
Landlocked salmon	Höytiäinen	2	1.45	0.54	2.69	0.115	3–6
		3	1.63	0.14	11.51	0.001	3–7
	Pielinen	2	1.06	0.33	3.19	0.086	3–6
		3	2.07	0.61	3.37	0.184	4–6
Brown trout	Höytiäinen	2	1.72	0.62	2.78	0.109	3–6
		3	1.59	0.41	3.82	0.032	3–7
	Pielinen	2	1.15	0.24	4.74	0.042	3–6
		3	1.39	0.29	4.77	0.017	3–7

Table 5
Statistical significance of fixed main effects on the recapture probability of landlocked salmon and brown trout in their different stocking age classes. Regression coefficients (± SE) of covariates are also given. Statistically significant effects are shown with bolded fonts ($p < 0.05$). Fin erosions were determined on a scale of 0–4, and average value was used for the paired fins of each individual (treated as covariates).

	Landlocked salmon					
	2-year-old			3-year-old		
Effect	Estimate	*F*-value	*p*-value	Estimate	*F*-value	*p*-value
Year		1.50	0.198		2.53	0.055
Lake		275.53	**<0.001**		273.78	**<0.001**
Maturity		5.36	**0.021**		4.39	**0.036**
Body length	**0.020** (0.001)	378.20	**< 0.001**	**0.007** (0.001)	72.16	**< 0.001**
Condition factor	**0.688** (0.318)	4.69	**0.030**	**0.543** (0.238)	5.18	**0.023**
Dorsal fin		0.23	0.922		0.17	0.955
Pectoral fins	−**0.269** (0.063)	18.05	**< 0.001**	−**0.107** (0.035)	9.34	**0.002**
Pelvic fins	0.091 (0.094)	0.96	0.328	−0.091 (0.064)	2.06	0.151
	Brown trout					
Year		0.04	0.959		7.10	**<0.001**
Lake		32.57	**<0.001**		52.25	**<0.001**
Maturity		0.29	0.591		9.52	**0.002**
Body length	**0.026** (0.002)	253.68	**< 0.001**	**0.011** (0.001)	104.78	**< 0.001**
Condition factor	**1.685** (0.600)	5.61	**0.018**	0.117 (0.235)	0.25	0.618
Dorsal fin		1.42	0.224		0.84	0.500
Pectoral fins	−0.029 (0.066)	0.19	0.664	−0.084 (0.041)	4.18	0.041
Pelvic fins	−0.104 (0.128)	0.65	0.419	0.145 (0.305)	0.23	0.634

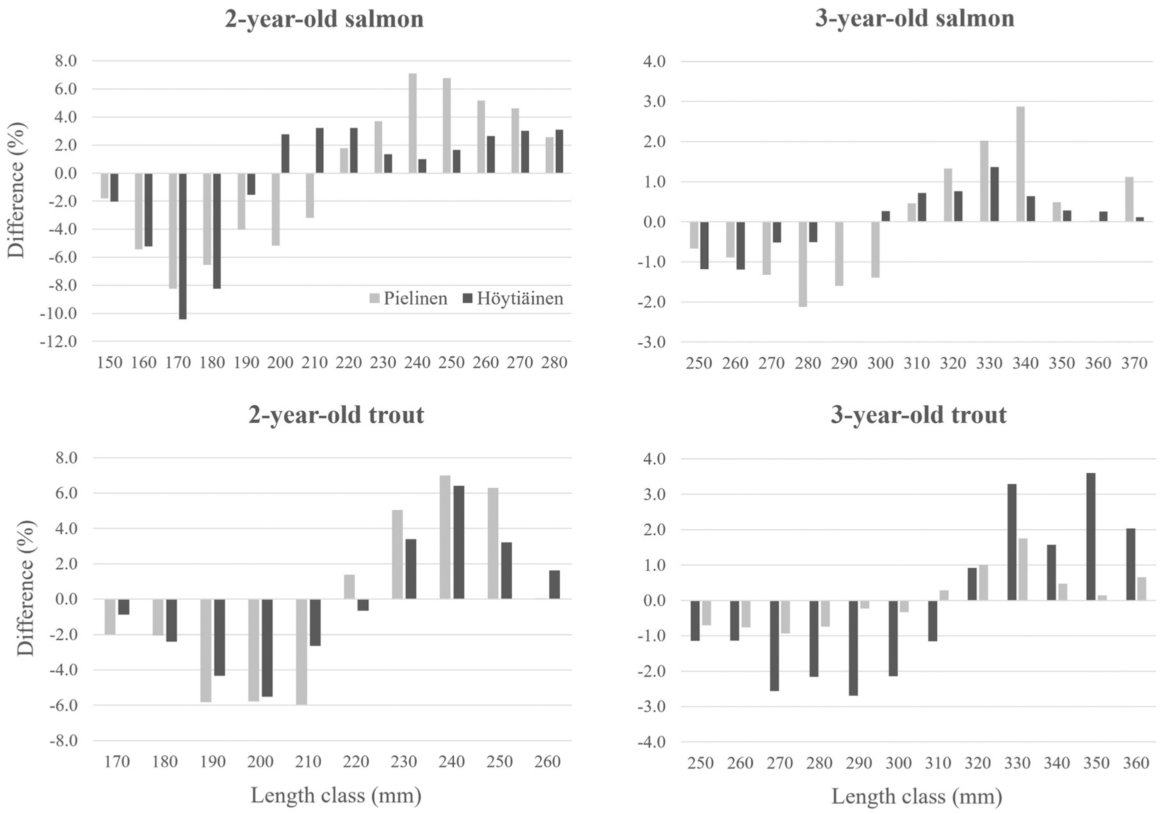

Fig. 4. Difference of relative proportions (in %-units) for stocked and captured landlocked salmon and brown trout in different stocking length classes. Separate age classes of both species are presented in different graphs and values are also partitioned for different lakes. Negative bar values depict that a relatively smaller proportion of individuals reported by fishermen belonged to a given length class compared to the proportion of stocked fish belonging to the same category; with positive values, the situation is the opposite. The length classes shown in the graphs cover more than 95 % of the stocked fish per lake.

/ 1000 released fish in Lake Höytiäinen (range 26–413 kg / 1000 released, $n = 15$ release groups), but only 16 kg / 1000 released fish in Lake Pielinen (0–53 kg / 1000 released, $n = 26$ release groups). For 3-yo salmon, the average minimum yield per release group was 444 kg / 1000 released fish in Höytiäinen (358–582 kg / 1000 released, $n = 7$ release groups) and 114 kg / 1000 released fish in Pielinen (34–169 kg / 1000 released, $n = 9$ release groups).

Although increasing average size (age) of stocked salmon groups increased total catch in kilograms, the mean stocking length was negatively associated with minimum net yield (estimate ± SE = −1209.14 ± 179.64, $F_{1,\ 14} = 4.91$, $p = 0.044$). However, a clear negative relationship between mean fish size and yield only occurred in Lake Pielinen (lake × length interaction: $F_{1,\ 14} = 51.75$, $p < 0.001$), where all net yields were negative (Fig. 6). Neither the average condition factor nor

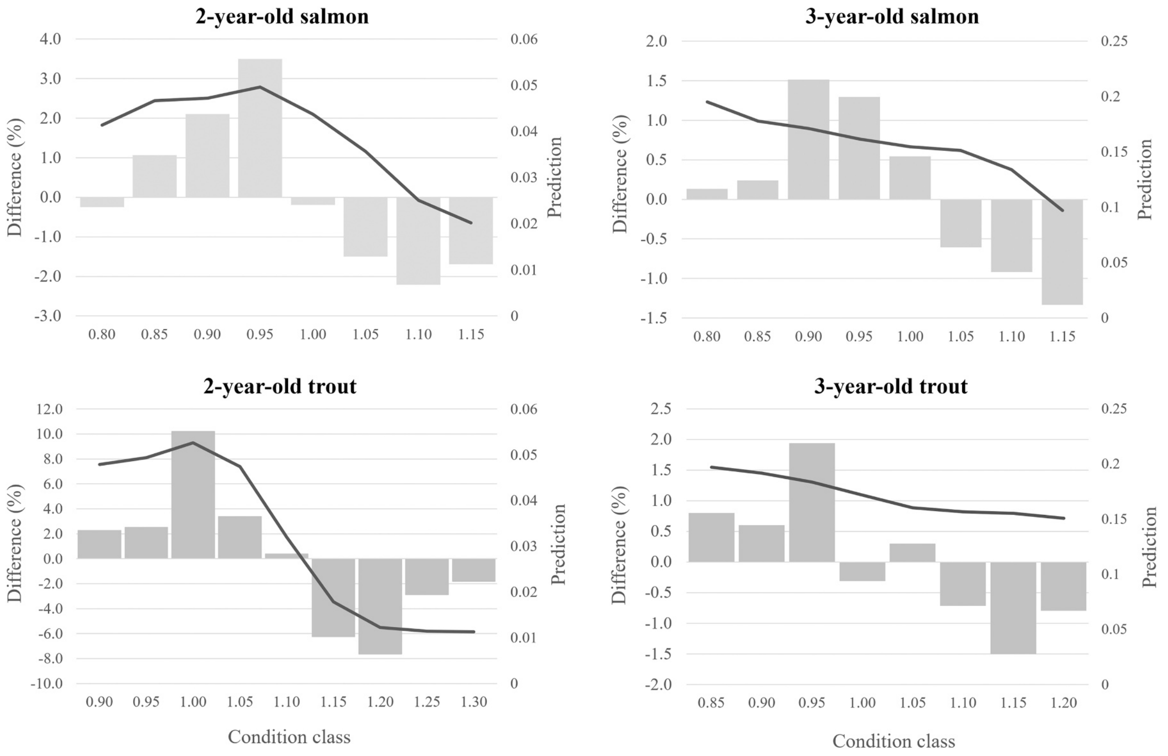

Fig. 5. Difference of relative proportions (in %-units) for stocked and captured landlocked salmon and brown trout in different condition factor classes shown with bars, and mean linear predictions of capture probability for different condition classes shown with lines (values depicted on the right y-axis). Separate age classes of both species are presented in different graphs. Negative bar values depict that a relatively smaller proportion of individuals reported by fishers belonged to a given condition class compared to the proportion of stocked fish belonging to the same category; with positive values, the situation is the opposite. The condition classes shown in the graphs cover at least 95 % of the stocked fish per lake.

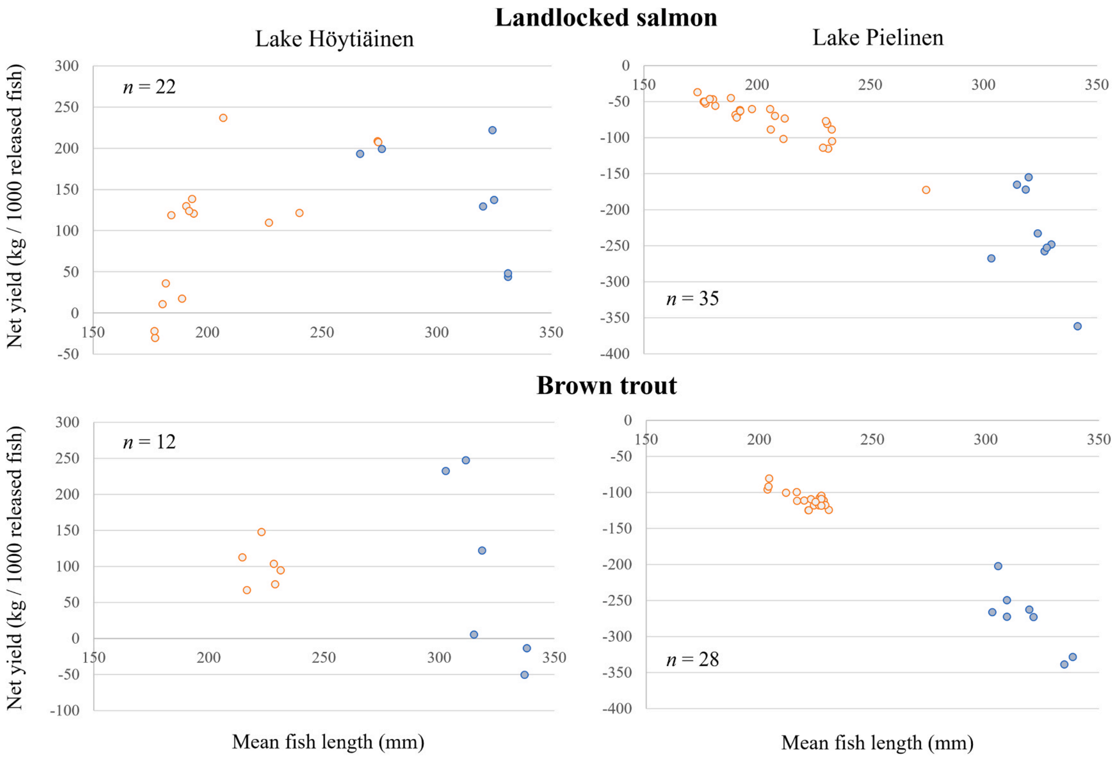

Fig. 6. Relationship between mean stocking length (mm) and relative catch biomass (yield, kg / 1000 released fish) among release groups of landlocked salmon and brown trout. For both species, results from different lakes (Pielinen and Höytiäinen) are presented in separate graphs. Within each graph, light circles denote 2-year-old release groups and darker circles 3-year-old groups.

the average condition of fins significantly affected salmon yields.

3.2.2. *Brown trout*

Fish tagging length showed a significant positive relationship with the recapture probability of trout at both stocking ages (Table 5, Fig. 4). The 2-yo trout longer than 210–220 mm produced proportionally higher yields, relative to all stocked fish. Correspondingly, 3-yo fish produced positive yields in both lakes when their stocking size was at least 320 mm (Fig. 4). Like in landlocked salmon, however, the size effect on recapture probability was not very clear among 3-yo trout.

Sexual maturity and pectoral fin erosion significantly decreased the capture probability of trout stocked at age 3 (Table 5). The overall proportion of mature fish was 12.8 % in 3-yo trout but only 1.5 % in 2-yo trout. On the contrary, condition factor had a significant positive effect on recapture probability among 2-yo trout. In this case, the relationship between condition factor and recapture probability also differed between the lakes (lake × condition: $F_{1,\ 30833} = 4.35$, $p = 0.037$). Due to low number of captured trout within each condition factor class (max. 35 fish) in Lake Pielinen, however, interpretation of the optimal range was based on all 2-yo fish together. Thus, the group level average condition factor seems ideal at values 0.90–1.05 (optimum at 1.00) (Fig. 5).

The average mimimum catch of 2-yo release groups was 217 kg / 1000 released fish in Lake Höytiäinen (range 173–265 kg / 1000 released, $n = 6$ release groups), but only 9 kg / 1000 released fish in Lake Pielinen (3–23 kg / 1000 released, $n = 20$). For 3-yo trout, the average minimum catch per release group was 451 kg / 1000 released fish in Höytiäinen (334–582 kg / 1000 released, $n = 6$ release groups) and 78 kg / 1000 released fish in Pielinen (22–118 kg / 1000 released, $n = 8$).

The mean fish length of release group was negatively associated with minimum net yield (estimate ± SE = -1891.00 ± 253.49, $F_{1,\ 11} = 23.87$, $p = 0.001$), and similar to salmon, such relationship only concerned the trout stocked to Lake Pielinen (lake × length interaction: $F_{1,\ 11} = 16.10$, $p = 0.002$), where all net yields were negative (Fig. 6). Average condition factor or condition of fins did not predict the obtained trout yields.

4. Discussion

Although effective fisheries management requires continuous, locally or regionally scaled monitoring of the outcomes of management actions, including stockings, many evaluations of stocking programs are still based on academic research (Masuda and Tsukamoto, 1998; Hunt and Jones, 2018; Claussen and Philipp, 2022). In this study, we documented both successful and unsuccessful stocking results in two adjacent lakes that differ both in ecological conditions and intensity of fishing; tag returns accumulated fast in heavily modified, clear-water Lake Höytiäinen compared to more humic Lake Pielinen that, however, represents an unregulated native environment for both landlocked Atlantic salmon and brown trout. In Lake Höytiäinen, the average yields obtained from 3-yo fish were more than doubled compared to 2-yo fish, and in Lake Pielinen, the corresponding difference was more than sevenfold. Manifesting the difference between the lakes, the uncorrected net yields (calculated directly from the raw tag recovery data) were negative for all release groups and also decreased by the increasing size and age of fish in Pielinen. In both lakes and species, the estimated total mortality rates of fish recruited to fishing were very high and much beyond the mortality rates that are expected to be ecologically sustainable together with the applied measures to adjust the size-based recruitment to fishing (Syrjänen et al., 2017), and observed in other fisheries (He et al., 2022).

4.1. *Tag returns: survival and recruitment to fishing*

In general, tag recoveries are assumed to reflect variation in survival of fish prior to their capture (Vainikka et al., 2021). As such, the effects of fish size (age) and other traits on stocking results can be considered from the conservation point of view (Lundqvist et al., 1994; Hyvärinen and Vehanen, 2004a). On the other hand, the accumulation of tag returns and catch curves estimated based on the tag returns by age provide information on how sustainably fisheries is managed in relation to the objectives of stockings (He et al., 2023).

In this study, the growth potential of fish was similar between the studied lakes (see Fig. A.1 in Appendix A), regardless of species and stocking age (see also Huusko et al., 2017). Yet, the number of tag returns (both absolute and proportional) and the estimated mortality rates were remarkably larger in Höytiäinen than in Pielinen. The recaptures of salmon were also influenced by the minimum size limit, which was 500 mm in Höytiäinen and 600 mm in Pielinen during most of the study period (currently 600 mm in both lakes). Consequently, salmon reached the permitted size clearly faster in Höytiäinen (in 5–12 months) and were therefore caught as younger/smaller fish, on average, than in Pielinen. This was particularly evident in the accumulation of recoveries from the fish released at age 3: due to stronger fishing pressure in Höytiäinen, a vast majority of fish became captured during their first autumn and winter. Correspondingly, there were relatively few salmon that reached 600 mm in tag return data for Höytiäinen: approx. 22 % of returns in fish released at age 2 and 15 % of returns in fish released at age 3. In Pielinen, the proportion of salmon of at least 600 mm was 45 % in the returns of fish released at age 2 and 40 % in the returns of fish released at age 3, indicating a better but still not sustainable fishing in Lake Pielinen that is a native environment for the landlocked salmon and target for intensive restoration attempts in the breeding habitats (c.f. Siemer and Brown, 1994).

4.2. *Tag returns by species and fishing gear*

Landlocked Atlantic salmon is a predominantly pelagic piscivore and the fastest-growing fish in boreal inland waters (Hutchings et al., 2019), while adfluvial brown trout is more attached to its feeding grounds in shallow waters close to shorelines particularly during cold-water seasons. This makes them differentially vulnerable to certain types of fishing gears and particular types of natural predators. As such, it was not a surprise that most brown trout tag returns came from gillnets applied particularly from mid-summer to early winter (Syrjänen and Valkeajärvi, 2010). This likely also explained the higher total mortality rates of brown trout in Lake Höytiäinen in comparison to Lake Pielinen.

Tag returns reflected both differences and similarities in the fishing methods used to catch salmonids in the study lakes. In Lake Höytiäinen, most salmon from both stocking age groups were caught with gillnets and relatively evenly from the end of summer until the end of year, whereas the smaller share of salmon caught with rod methods, mainly by motorized trolling, was highest in October in both lakes. Correspondingly, a larger proportion of salmon stocked in Lake Pielinen was caught with rods than with stationary gears, and more tag recoveries were obtained in May-July compared to Lake Höytiäinen. The observed difference between the lakes likely reflects the highly intensive gillnet fisheries targeted at pikeperch in Lake Höytiäinen (Huuskonen et al., 2019), whereas larger Lake Pielinen is a popular destination for mobile fishers using motorized trolling gear. Unfortunately, no data were available on the fishing effort on these lakes making it impossible to assess catchabilities of various gears in salmonid fisheries.

4.3. *Relationship between fish age, size and condition, and recaptures*

Irrespective of the species and age, fish length at tagging was the strongest phenotypic determinant of susceptibility of capture. This generally reflects the positive association of stocking size with survival in migratory salmonids (e.g. Hyvärinen and Vehanen, 2004a; Kallio-Nyberg et al., 2004, 2007, 2009; Saloniemi et al., 2004; Tsuboi et al., 2016) but also points that fishing may pose negative selection differentials on fish length-at-age (Vainikka et al., 2021). In both species, the importance of size for recapture rates was particularly notable in 2-yo fish, whose body length of 200 mm or more provided a survival benefit. In Lake Pielinen, the favorable length at stocking appears to be rather 220–230 mm for both salmon and trout, potentially due to higher pike predation pressure (according to authors' personal experience of angling in both lakes, pike is much more abundant in Lake Pielinen than in Lake Höytiäinen). Unfortunately, there is no such monitoring data that could confirm this claim with a published reference.

On the other hand, the positive association between stocking length and recaptures also conforms to the general conception that size selectivity of gears (particularly gillnets), together with increasing food intake needs and movement activity, make larger fish more vulnerable to fishing (Hyvärinen and Vehanen, 2004b; Alós et al., 2012; Lennox et al., 2017; Watz, 2019). Based on their recapture data on released brown trout, Vainikka et al. (2021) concluded that positively size-selective fishing can also counteract the natural survival benefit provided by large body size. Considering that a major proportion of 3-year-old salmon and trout were indeed captured soon after release in our study, perception of the importance of fish size for fish survival may be biased. That is, although stockings made with older and large fish seem to produce a better catch (gross biomass), the net yield (biomass difference between stocked and captured fish) may remain lower than in stockings made with smaller, younger, and economically less expensive fish (see also Hyvärinen and Vehanen, 2004b). This was an apparent result in Lake Pielinen, where the use of large-sized 2-yo fish appears as the recommended option for salmon and trout stockings. In Lake Höytiäinen, on the contrary, the variation of net yields did not involve clear divergence between stocking age groups. Thus, despite stronger fishing mortality in Höytiäinen, large mean size at stocking did not necessarily reduce the possibility for older fish to utilize the natural food resources of the waterbody and produce added value with their growth, relative to younger release groups.

Similar to fish length at stocking the influence of body condition on the likelihood of tag recovery was more pronounced among fish stocked at age 2 than at age 3. Being positively correlated with body lipid reserves, condition factor provides indicative information about the nutritional status of fish (Herbinger and Friars, 1991; Sutton et al., 2000). A previous stocking-recapture study on brown trout in a small-scale and predator-free lake suggested that good body condition promotes starvation-resistance and thus tolerance of difficult conditions (Vainikka et al., 2021). Even though condition factor showed a positive relationship (slope coefficient) with recapture probability of salmon and trout also in our study, the relationship cannot be considered linear. That is, condition factor seems to involve relatively narrow optimum ranges, and neither its low nor high values promote the post-stocking survival of fish. When feeding with modern industrial aquafeeds, excessive deposition of lipid reserves and high condition factor are commonplace. In addition to the energy content of feeds, the nutritional status of stocked fish is affected by hatchery-specific feeding practices. Proper dietary restriction during winter and spring prior to outmigration may significantly increase the readiness of Atlantic salmon and brown trout to migrate (Vainikka et al., 2012; Jones et al., 2015). Consequently, the level of condition factor and its development during the months before stocking should be examined in more detail under rearing conditions, especially for the landlocked salmon and 2-year-old trout.

Our present results also conform to previous findings that preciously mature males have a lower probability of being captured in both species, compared to immature fish (Vehanen et al., 1993; Kallio-Nyberg et al., 2009; Petersson et al., 2013). This is probably explained by the weaker readiness of previously matured males to pelagic conditions; that is, they mostly show a non-migratory behavior (Fängstam et al., 1993), and by staying close to the release site become less vulnerable to fishing and more vulnerable to predation (Lundqvist et al., 1988, 1994).

4.4. Relationship between fin condition and recaptures

Based on the tag recovery data, it is advisable to pay particular attention to the condition of paired (pectoral) fins, as their condition explained the tag return proportions in landlocked salmon at both stocking ages (Fig. 7), and also in brown trout at age 3. Pectoral fins are known to provide Atlantic salmon parr a superior adaptation to fast-flowing water (Arnold et al., 1991), but these paired fins also play a major role in the diverse locomotor repertoire needed in the pelagic habitat (Drucker and Lauder, 2003). The present results support the findings of Petersson et al. (2013), where fin erosions determined at the time of tagging were found to reduce the likelihood of Atlantic salmon and brown trout to be captured as spawners in the River Dal, Sweden. Earlier observations on the association between fin condition and tag recovery result have been variable, which may partly be due to different ways of classifying fin damages. Slight fin erosions are assumed to be repaired quickly after release, in which case their effect on recovery rates is not necessarily an issue (e.g. Vehanen et al., 1993). In our study, fin erosions were generally at a low level, and only the dorsal fin of salmon showed notable variation in condition. Along with our study, dorsal fin erosions did not predict survival of stocked salmon during their migration phase in the Baltic Sea (Kallio-Nyberg et al., 2009). The possible effect of fin condition on post-smolt survival has also been analyzed in connection with the stock assessment of the ICES salmon and sea trout working group (WGBAST) (ICES, 2009). Neither in this analysis were dorsal fins erosions related to survival, but damage to other fins did have a significant negative effect.

In many cases, fins erosions may be linked to the general condition and health status of the fish, which might be the actual factor explaining survival. Since fin erosions can be caused by multiple factors, it is difficult to prevent their occurrence in conventional hatchery condition yet certain low-intensity or environmental enrichment measures could prevent them (reviewed by Latremouille, 2003). These measures include, among other things, lower fish densities in rearing tanks, adjustments of water flow, feeding frequency and amount, and minimized fish handling. Structural enrichment with in-tank shelter was shown to reduce dorsal fin damages in Atlantic salmon juveniles, in relation to rearing in plain tanks, but such a positive effect only occurred at a high fish density (Rosengren et al., 2017). In another study on landlocked Atlantic salmon, various enrichments in rearing tanks (a combination of shelters and changes in water flow and depths) in turn increased the level of erosion in dorsal fin, compared to standard-reared fish (Janhunen et al., 2021). However, in Janhunen et al. (2021), the higher incidence of dorsal fin erosions in enriched-reared fish was suspected to arise from their better survival during the first summer, which led to higher density than in standard-reared fish.

4.5. Sustainability of the assessed stocking programs

Salmonid fisheries management should target spawning stock sizes that ensure maximal sustainable yields (Potter et al., 2003). Both landlocked salmon and brown trout become sexually mature at sizes above 500 mm – the landlocked salmon always at a length of more than 600 mm (Huusko et al., 2017; Hutchings et al., 2019). As such, both species recruited to fishing even 1–3 years before their potential first spawning. Particularly, the fish stocked at age 3 recruited to fishing already during their first year in lake while the fish stocked at age 2 likely suffered from stronger natural mortality as indicated by their lower tag return proportions in both lakes yet comparable total mortality rates at sizes recruited to fishing. We can further assume that the reporting rate of undersized fish was lower than their actual proportion among captured fish (see Kallio-Nyberg et al., 2007). Despite the later capture of stocked salmon in Lake Pielinen, the numbers of fish captured for brood stock renewal below the lowermost dam in the only spawning river Lieksanjoki were very low during the period of the study (years 2008–2016: 6–25 salmon and 3–9 trout spawners per year).

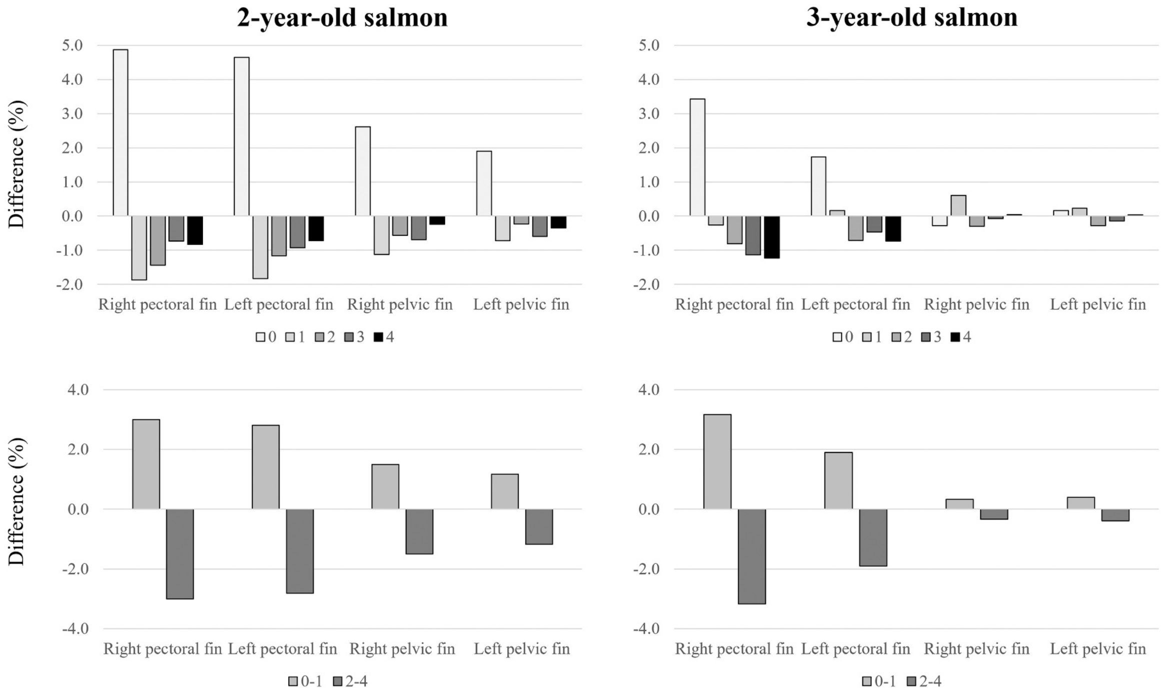

Fig. 7. The difference in the relative shares (in percentage units) of released and captured landlocked salmon in paired fin condition classes 0–4. The lower graphs show the erosion level of the fins only in two categories: less than and more than 25 %. Negative values indicate that a relatively smaller proportion of individuals reported to be captured belonged to a particular fin class compared to the proportion of stocked fish belonging to the same class; with positive numbers, the situation is the opposite.

While we could not directly assess the natural mortality rates of the released fish, our results suggest that mortality prior to recruitment to fishing must have been considerable. According to a standard age-based yield-per-recruit calculation (Beverton and Holt, 1957; Gulland, 1969) on brown trout with published von Bertalanffy's growth parameters for Saimaa watercourse (Huusko et al., 2017) and an assumption of natural mortality rate of 0.2^{-yr} on all ages and here observed total Z rate of 1.5^{-yr} for the fish > 500 mm in length, 1000 stocked brown trout (3-yo) should produce a catch of over 650 fish (65 % return rate) and 1300 kg (calculations not shown), while the observed return rate was 7 %. The observed tag return rate could be obtained, for example, with a combination of natural mortality rate of 1.07^{-yr} and fishing mortality rate 0.43^{-yr}. Due to the uncertainties in growth, predation and tag recovery rates, these results call for further research on the partitioning of the total mortality to natural and fishing mortality at different ages but robustly suggest that the stocked fish face very strong natural mortality soon after stocking and strong total mortality also after recruitment to fishing (c.f. Hansen et al., 2010). Supporting the possibility of natural mortality driving the low tag recovery proportions particularly in fish stocked as 2-yo, there was a positive association between the length of an individual fish and its likelihood of becoming captured. However, according to our results, also fishing mortality rates should be decreased in both study lakes to reach both spawning population and yield targets.

Biological and economic feasibility of fish releases have been widely questioned, regardless of whether their objective is to support natural stocks (i.e. high survival of fish to adulthood) or sustain recreational fisheries (Naish et al., 2007; Araki and Schmid, 2010; Fraser, 2008; Bacon et al., 2015). Modern development (intensification) of aquaculture production together with unintended domestication under captive breeding involve aspects that may detrimentally impact the performance of released fish (Hutchings and Fraser, 2008) or the natural stocks that are susceptible to the ecological and genetic effects of the stocked fish. As such, the current stocking paradigms require critical evaluation (Aas et al., 2018). Based on our results, the stocking program and related management of salmonid fisheries in Lake Pielinen appears inefficient in supporting the conservation and recovery of these salmonid populations in this large lake with accessible native riverine breeding habitats.

4.6. *Concluding remarks*

This study underlines the importance of phenotypic attributes of stocked salmonids in determining their survival and susceptibility to fishing in lake environments. Although the assessed stocking programs were primarily aimed at maintaining fishable stocks, our findings entail a practical conservation aspect. A statutory maintenance program of landlocked salmon is primarily based on annual releases of 2-yo smolts in rivers Lieksanjoki and Pielisjoki in Vuoksi watercourse. These fish are fully protected by the current fishing law (since 2016), and their adipose fin is left uncut to distinguish them from individuals stocked for fishing. Production of salmon for population maintenance is implemented through so called "contract rearing" where the state (Natural Resources Institute Finland) provides eggs for on-growing in private aquaculture companies. However, companies interested in producing landlocked salmon smolts are currently rare, because the strain is highly susceptible to *Saprolegnia*-induced mortality. One way to increase the attractiveness of landlocked salmon aquaculture could be suitable price incentives, when the production is controlled by bonuses paid for smolts that meet certain fitness indicators. Based on the results presented here, fish size, condition factor and the condition of paired fins can be considered such relevant metrics that could be included in commercial rearing contracts. Moreover, such quality assessment criteria would be simple enough to be verified reliably and fast from a representative number of sampled fish before the redemption.

The rapid accumulation of tag returns reflected early recruitment to fishing after stocking without sufficient time for the stocked fish to utilize natural food resources for additional growth and net yield benefits. The problem of early recruitment seemed to be accentuated by heavy gillnetting (Lake Höytiäinen) and large stocking size (i.e. fish stocked at age 3). The results thus emphasize the responsibility of fisheries management in balancing the conservation of wild salmonid stocks and fisheries-related needs to support economically sustainable stocking-based fishing activities. In this respect, benefits from stockings can also be significantly improved by rationalizing applied fisheries management measures such as minimum size limits, gillnet mesh sizes and depth zone regulations, closed seasons and daily bag limits, rather than focusing on the phenotypic qualities of the stocked fish only (see also Janhunen et al., 2021).

Funding

This work was supported by the Ministry of Agriculture and Forestry (423.30.40.51), North Carelia T&E Centre (regional fisheries funds), Kemijoki Oy, Pielisen-Karjalan Kehittämiskeskus Oy, fisheries areas of Höytiäinen and Pielinen, Finnish Game and Fisheries Research Institute, and Natural Resources Institute Finland (Luke; project: 41007-00287101).

CRediT authorship contribution statement

Anssi Vainikka: Writing – review & editing. **Jorma Piironen:** Writing – review & editing, Resources, Methodology, Funding acquisition, Data curation. **Matti Janhunen:** Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank all the stakeholders, particularly the fisheries areas and fish farms, who were involved in planning and implementation of this project. A large group of FGFRI staff participated in fish tagging, and Lili Porspakka and Soili Timperi were responsible for managing the tag recovery database in fish tagging office. The study was financially supported by the Ministry of Agriculture and Forestry, North Carelia T&E Centre (regional fisheries funds), Kemijoki Oy, Pielisen-Karjalan Kehittämiskeskus Oy, fisheries areas of Höytiäinen and Pielinen, Finnish Game and Fisheries Research Institute, and Natural Resources Institute Finland.

Appendix A

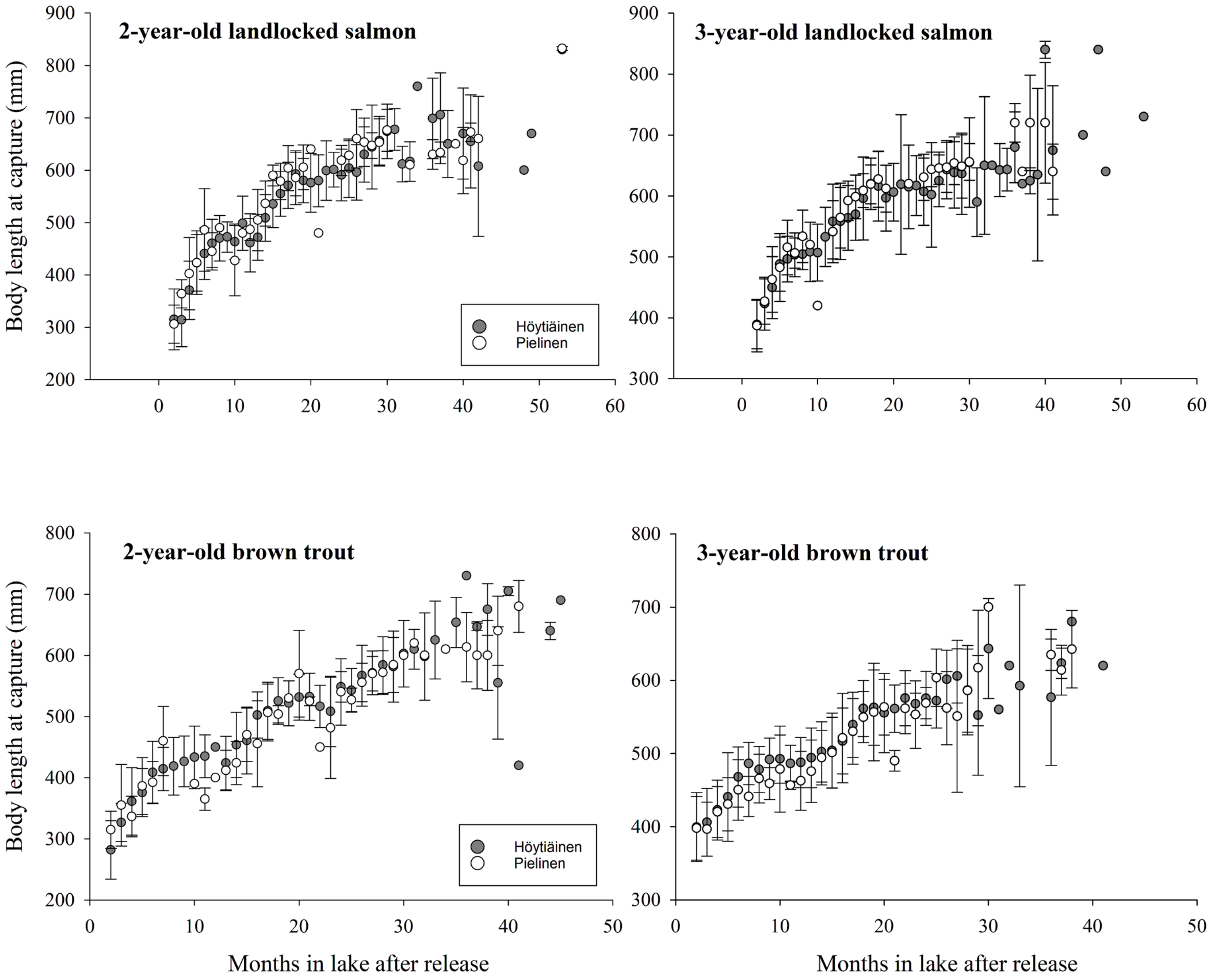

Fig. A.1. Means (±SD) of the reported body lengths in landlocked Atlantic salmon and brown trout in relation to months spent in lakes Höytiäinen and Pielinen before capture. For both species, separate graphs are presented for the fish stocked at 2 and 3 years of age

Data availability

Data will be made available on request.

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