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Interim report 2018–2019

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Summary

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Tornionjoki salmon and sea trout are closely monitored annually with multiple methods. Despite extensive data collection, some fundamental knowledge of the Tornionjoki salmon and sea trout relevant for modern adaptive salmon management is still lacking. Specifically, the in-river migratory behavior and survival of both pre- and post-spawning salmon and sea trout, as well as the distribution of spawning sites, are not well known.

In addition, recent observations of sick and dying salmon in the Tornionjoki system, and declining returns reported from many rivers in connection with these observations, are concerning. More knowledge about how the disease symptoms affect behavior and survival of the Tornionjoki salmon is therefore needed.

In-river migrations of Tonionjoki salmon and sea trout have been studied in cooperation between Luke and Swedish University of Agricultural Science (SLU) by means of radio telemetry in 2018–2019. Radiotagging of salmon was carried out at the estuary from June to July (n = 227) and in the river in spring (May-June, n = 10) and autumn (August-October, n = 38). Sea trout were tagged in the river in spring (May-June, n = 33) and autumn (August-October, n = 59). Samples for age and genetic analysis were taken from all tagged individual, and the visual condition of the fish was classified in conjunction with the tagging.

In both study years, a majority (61% in 2018; 83% in 2019) of the salmon tagged at the estuary returned to the sea by the end of July, i.e before spawning. Of the salmon that entered and stayed in the river until spawning, most of them were located below the Kattilakoski echo sounding place (c. 100 km from the sea) during spawning time. The salmon caught and tagged in the river showed a highly varying post-release behavior. In both study years, all salmon tagged in the spring moved downstream and descended to the sea or died during downstream movement. In contrast, all salmon tagged in autumn stayed in the river over the spawning time. Most of them stayed near the tagging site during the autumn, but some of them moved a long distance upstream after release.

The tagged sea trout can be divided into two groups based on their migration pattern: (1) immature trout which moved into the lowermost river for overwintering and returned back to the sea in next spring, and (2) mature trout which ascended the river for spawning. The second group can be further divided into trout which entered the lowermost river in autumn and overwinter there before continuing to the spawning areas next spring, and trout which entered the river in springtime and continued to the spawning areas within the same season. In spawning time, autumn 2019, tagged trout were located in the main stem Tornionjoki and Muonionjoki, as well as in the tributaries Naamijoki, Äkäsjoki, Parkajoki and Merasjoki.

Keywords: migration, salmon, sea trout, Tornionjoki, Torneälven, radiotelemetry

Summary in Finnish

Tornionjoen lohi- ja meritaimenkantoja seurataan vuosittain useilla menetelmillä. Huolimatta laajasta seurannasta modernille, adaptiiviselle kalastuksensäätelylle olennaista tietoa yhä puuttuu molempien lajien osalta. Tällaista puutteellista tietoa on erityisesti vaelluskäyttäytymisestä ja eloonjäännistä joessa ennen ja jälkeen kudun, sekä lisääntymisalueiden käytöstä.

Viime vuosina Tornionjoella on havaittu lohien sairastumista sekä lisääntynyttä kuolevuutta kesän aikana. Terveysongelmien aiheuttajasta ja sen vaikutuksesta lohien käyttäytymiseen tai selviytymiseen on vielä vähän tietoa, joten lisätietoa lohien käyttäytymisestä ja selviytymisestä nykytilanteessa tarvitaan myös tämän vuoksi.

Lohien ja meritaimenen vaelluskäyttäytymistä Tornionjoella on seurattu radiotelemetriatekniikkalla vuosina 2018–2019 Luken ja Ruotsin maataloustieteellisen yliopiston (SLU) yhteisessä hankkeessa. Lohia merkittiin radiolähettimellä joen edustan merialueella kesä-heinäkuun aikana (n= 227) ja joella touko-kesäkuun vaihteessa (n = 10) sekä elo-syyskuussa (n = 38). Meritaimenia merkittiin radiolähettimellä joella touko-kesäkuussa (n = 33) sekä syys-lokakuussa (n = 59). Kaikilta radiolähettimellä merkityiltä kaloilta kerättiin näytteet iänmääritystä ja geneettistä määritystä varten. Lisäksi merkittyjen kalojen ulkoista kuntoa arvioitiin ja luokiteltiin merkinnän yhteydessä.

Tornionjoen edustalla merkittyjen lohien käyttäytyminen poikkesi odotetusta, sillä suurin osa (61 % vuonna 2018 ja 83 % vuonna 2019) jokeen merkinnän jälkeen nousseista lohista palasi kesän aikana, ennen kutuaikaa, takaisin merelle. Jokeen jääneistä lohista suurin osa oli syksyllä kutuaikaan Kattilakosken kaikuluotainpaikan alapuolisella jokialueella. Joella keväisin merkityt lohet lähtivät merkinnän jälkeen liikkumaan alavirtaan, eikä yksikään keväällä merkitty lohi ollut elossa joella enää syksyn kutuaikana. Syyspuolella joella merkityt lohet sen sijaan pysyivät joella kutuajan yli, ja osa niistä vaelsi vielä huomattaviakin matkoja ylävirtaan merkinnän jälkeen.

Taimenien käyttäytymisessä havaittiin kahta käyttäytymismallia: (1) joen alajuoksulle talvehtimaan tulevat, ei-sukukypsät taimenet, jotka palaavat keväällä takaisin merelle, sekä (2) jokeen syksyllä tai keväällä tulevat yksilöt, jotka jatkavat vaellustaan kutualueille. Näistä syksyllä jokeen nousevat talvehtivat joen alajuoksulle ja jatkavat matkaansa lisääntymisalueille vasta seuraavana keväänä. Radiomerkittyjä taimenia havaittiin kutuaikana vesistön pääuomien (Tornionjoki, Muonionjoki) lisäksi Naamijoessa, Äkäsjoessa, Parkajoessa ja Merasjoessa.

Sammanfattning på svenska

Beståndsutvecklingen av lax och havsöring i Torneälven övervakas årligen noggrant med flera olika metoder. Trots denna relativt omfattande datainsamling saknas fortfarande grundläggande kunskap relevant för modern adaptiv laxförvaltning. Speciellt saknas information om migrationsbeteende och överlevnad hos lekvandrande fisk både före och efter leken, samt bättre kunskap om var arternas huvudsakliga lekområden är belägna.

Under senatre åren har också sjuk och döende lax observerats i Torneälven och flera andra älvar i Östersjön, och de potentiella konsekvenserna av detta är bekymmersamma. Mer kunskap om hur dessa sjukdomssymtom påverkar beteendet och överlevnaden hos Tornälvslaxen behövs.

Vandringsbeteende och överlevnad hos lax och havsöring i Torneälven har studerats med hjälp av radiotelemetri under åren 2018–2019 i ett samarbetsprojekt mellan finska Luke och sveska SLU. Radiomärkning av lax utfördes i Torneälvens mynning i juni och juli (n = 227), och i älven under våren (maj-juni, n = 10) samt hösten (augusti-oktober, n = 38). Havsöring radiomärktes i älven under våren (maj-juni, n = 33) samt hösten (augusti-oktober, n = 59). Prover för åldersbestämning och genetisk analys togs från alla märkta individer och det yttre hälsotillståndet hos fisken noterades via visuell inspektion i samband med märkningen.

Under båda studieåren återvände en majoritet (61% 2018; 83% 2019) av laxen märkt vid mynningen tillbaka till havet i slutet av juli, dvs före leken. För den lax som stannade i älven, uppehöll sig en majoritet nedströms ekolodsräknaren i Kattilakoski (ca 100 km från havet) vid lekperioden. Laxen som fångats och märkts uppe i älven uppvisade varierande beteende efter utsättningen. Under båda studieåren rörde sig all lax märkt på våren nedströms, antingen tillbaka till havet eller så dog den under nedströmsvandringen. Däremot stannade all lax märkt på hösten i älven fram till lekperioden. De flesta av dessa laxar stannade nära märkningsplatsen, men några rörde sig långt uppströms efter frisläppandet. Under lektiden befann sig dock de flesta av de märkta laxarna nedströms Kattilakoski.

Den radiomärkta havsöringen kan indelas i två grupper baserat på deras migrationsmönster: (1) ej könsmogna unga öringar som vandrade upp i älvens nedersta del för övervintring, varpå de återvänder till havet påföljande vår, och (2) könsmogen öring som vandrade upp i älven för att leka. Den senare gruppen kunde vidare indelas i öring som vandrade upp i älvens nedersta del av älven på hösten och övervintrade där, innan den på våren fortsatte till lekområdena på våren, och öring som vandrade upp i älven på våren och fortsatte till lekområdena samma vandringssäsong. Under hösten 2019 uppehöll sig märkt öring i huvudfårorna (Torneälven och Muonioälven) samt i biflödena Naamijoki, Äkäsjoki, Parkajoki och Merasjoki.

Contents

1. Introduction

The River Tornionjoki (Finnish name; the Swedish name is Torneälven) is currently the most productive Atlantic salmon river in the world. The river system produces half of all the wild salmon in the Baltic Sea (ICES 2019), and efficient and sustainable management of the salmon stock in the Tornionjoki is hence of utmost importance.

Tornionjoki salmon is closely monitored. Upstream migrating fish are counted by echo sounders in Kattilakoski (rapid area about 100 km from the river mouth). Salmon catches in the river are estimated by annual surveys with catch samples collected for monitoring of the stock demography. Moreover, salmon juvenile production is annually monitored by electrofishing and smolt trapping. Despite the relatively extensive data collection, some fundamental knowledge of the Tornionjoki salmon of relevance for modern adaptive salmon management is still lacking. Specifically, the in-river migratory behavior and survival of both pre- and post-spawning salmon, as well as the distribution of spawning sites, are not well known. This information needs to be collected and evaluated against life-history characteristics of the spawners (e.g. sex, virgin/repeat spawner, sea age).

Recent observations of sick and dying salmon in many Baltic rivers, including the Tornionjoki system, and declining returns reported in connection with such observations, are concerning. Hence, knowledge about how disease symptoms affect the behavior and survival of the Tornionjoki salmon is needed.

The status of sea trout populations in the Gulf of Bothnian rivers has been a concern for decades. In Tornionjoki, the situation has been deemed so weak that sea trout has been fully protected from harvest since 2013. Much about Tornionjoki sea trout is less well known than for salmon, because of its more complex life history and scattered spawning areas, and there are considerable knowledge gaps of importance for effective management of sea trout in the system. In order to understand effects of implemented fishing regulations, as well as further improve the management and conservation of the Tornionjoki sea trout, basic information is needed about the migration behavior, spawning sites and survival of the population. For the protection of sea trout, the very poorly understood back and forth movements of non-mature (sub-adult) individuals between the sea and the river pose a specific problem. Targeted research on the behavior and migration of sea-run individuals is an effective way of collecting information about this severely threatened component of the Tornionjoki trout stock.

1.1. Main objectives

The overall objective of this ongoing project is to obtain more knowledge about in-river migrations of salmon and sea trout by the means of radiotelemetry. More specifically, the aims of the project are to:

1. study the effects of river origin (according to DNA), age, sex, and run time on salmon and sea trout migration and spawning area selection
2. better understand upstream migration behavior (migration speed, rate of continuity, back and forth movements, holding sites, entrance into tributaries) of salmon and sea trout;
3. map the distribution of salmon and sea trout spawning areas in the Tornionjoki system (above/below Kattilakoski counting site, main stem/tributaries, in-tributary locations);
4. better understand migration behavior of non-mature (sub-adult) sea trout;
5. investigate if radio tagged individuals may be indentified in the echo sounder data from the Kattilakoski counting site;

6. study how catch-and-release recreational fishing (C&R) affects post release behavior and survival of salmon and sea trout;

7. better understand and quantify pre-spawning migration, pre- and post-spawning survival, overwintering and post-spawning downstream migration of salmon and sea trout.

The project will continue in coming years, and if successful, the study will provide key information for improving salmon and sea trout management in river Tornionjoki, including supporting information for the development of assessment and monitoring plans for the Tornionjoki catchment. The study will also provide much needed information on consequences of the recent disease outbreaks among salmon spawners. This report includes activities and results from the years 2018-2019.

2. Material and methods

2.1. Study area

The River Tornionjoki is 520 km long with a mean annual flow of 400 m^3/s. It has a catchment area of 40 157 km^2 and drains into the Bothnian Bay, the northernmost rim of the Baltic Sea (Figure 1). The Tornionjoki supports a large wild Atlantic salmon stock, which utilizes the main stem of the river and the largest tributaries for reproduction (Romakkaniemi *et al.* 2003). In contrast, the Tornionjoki sea trout primarily spawns in several smaller tributaries and streams, most of which locate in the middle part of the catchment (Figure 1).

Normally the highest spring flood occurs between mid-May to mid-June (Figure 2), caused by melting waters of snow and ice. After spring flood, river flow decreases and typically stays below 600 m^3/s during the summer. Water temperature increases concurrent with the decreasing flow and is usually highest in the end of July (Figure 2). Flow conditions are more variable in the autumn, and often contain a second flow peak following autumn rains. Water temperature decreases relatively fast during August, and the ice cover usually forms in October. During winter, river flow and temperature are usually low and steady because of the water being contained below the ice cover.

In years 2018 and 2019, the river flow and water temperature summer conditions were exceptional, with the flow being considerably lower than normal and the water temperature well above normal, with >20°C in July (Figure 2).

Figure 1. The River Tornionjoki locate in the northernmost part of the Baltic Sea. Colours mark the known distribution of salmon (black) and the known/assumed distribution of sea trout (red) in the river system.

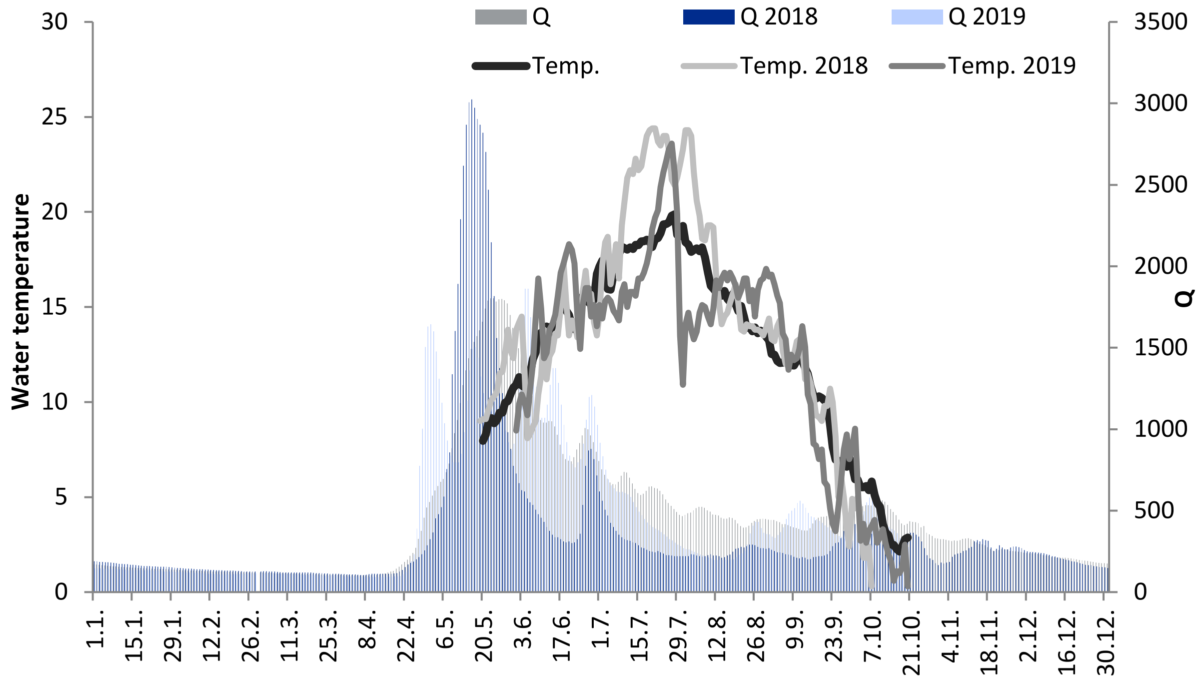

Figure 2. Average river flow (m^3/s, observation point in Karunki near the city of Tornio, years 2010–2019) and average water temperature (°C, observation point in Kukkolankoski near the city of Tornio, years 2010–2019) in the River Tornionjoki. The values of the study years 2018 and 2019 are also shown separately. Data from SYKE open data base, syke.fi/avoindata

2.2. Catching of fish

Salmon and sea trout for tagging were caught both in the sea, at the Tornionjoki estuary using trap-nets, and along the lower and middle reach of the main river using angling. The estuarine trapnet catches consisted almost entirely of salmon. Therefore, angling in the river was mostly arranged to target sea trout, while only a relatively small number of salmon were caught by angling and tagged in the river.

2.2.1. Fishing at the estuary

A Swedish commercial fisherman collaborating with the project deployed his trapnets at the estuary close to the river mouth (65°46.0759'; 24°07.4725') during the first days of June 2018 and 2019. Due to harsh environmental conditions (spring flood, strong wind), the coastal trap could not be set up until the second week of June in both study years. Therefore, no salmon from the very earliest run (i.e. salmon that had passed Kattilakoski counting site by the mid-June) were tagged at the estuary.

Altogether, 93 salmon were tagged in 2018 (7th June – 13th July) whereas 134 salmon were tagged in 2019 (7th June – 10th August; Table 1). In addition, two trout were caught and tagged in 2018: 29th June (620 mm, 3.3 kg) and 9th July (540 mm, 1.8 kg). Fishing outside the regular fishing season was conducted using a permit from the Swedish Agency for Marine and Water Management (HaV).

Table 1. Number of salmon tagged at the Tornionjoki river estuary per week during the fishing periods in 2018 and 2019, with associated average sea-age (years, from scale reading), average weight (kg) and average total length (TL, cm). Ranges (min–max) of the measured quantities are shown in parentheses.

	2018				**2019**			
Catching time	n	Sea Age	Weight	TL	n	Sea Age	Weight	TL
Week 23 4.–10.6.2018 3.–9.6.2019	2	4 (3–4)	14.8 (14.3–15.3)	117 (116–118)	9	3 (2–4)	10.6 (5.0–14.2)	98 (81–108)
Week 24 11.–17.6.2018 10.–16.6.2019	34	3 (2–5)	10.1 (5.8–17.3)	97 (80–115)	25	3 (2–4)	9.7 (5.0–19.0)	95 (80–114)
Week 25 18.–24.6.2018 17.–23.6.2019	21	3 (2–4)	8.9 (5.3–14.5)	92 (75–107)	20	3 (2–4)	9.6 (5.5–17.2)	95 (79–113)
Week 26 25.6.–1.7.2018 24.–30.6.2019	15	2 (2–4)	8.5 (6.0–12.4)	91 (82–107)	25	2 (2–3)	7.8 (4.0–13.0)	91 (73–110)
Week 27 2.–8.7.2018 1.–7.7.2019	10	2 (1–2)	5.2 (1.7–10.1)	76 (57–97)	16	2 (1–2)	6.7 (2.4–8.9)	87 (62–95)
Week 28 9.–15.7.2018 8.–14.7.2019	11	2 (1–3)	4.2 (1.2–8.8)	71 (53–94)	29	2 (1–3)	6.5 (1.3–14.8)	84 (52–109)
Week 32 6.–12.8.2018 5.–11.8.2019					10	1 (1–2)	2.2 (1.6–2.4)	62 (56–69)
Total	93	2 (1–5)	8.5 (1.2–17.3)	90 (53–118)	134	2 (1–4)	7.8 (1.3–19.0)	89 (52–114)

2.2.2. Fishing in the river

Fish from the river were caught mainly by local collaborating anglers. Most of the fish were caught by trolling using a rowing boat (most common type of rod fishing in Tornionjoki), but salmon in early summer 2018 were also caught using flyfishing from the riverbank. Altogether, 17 salmon and 17 trout in 2018 and 31 salmon and 75 trout in 2019 were caught at seven places along the river between early summer and autumn (Tables 2–3).

Table 2. Number of river caught and tagged salmon in both research years (2018–2019) per catching site and time, with average sea-age (years, from scale reading), average weight (kg) and average total length (TL, cm). Ranges (min–max) of the measured quantities are shown in parentheses.

		2018				2019			
Catching site	**Catching time**	**n**	**Sea Age**	**Weight**	**TL**	**n**	**Sea Age**	**Weight**	**TL**
Vojakkala	Septem-ber					14	2 (1–2)	5.1 (2.4–9.0)	78 (64–95)
	October	6	2 (1–2)	5.1 (2.5–8.9)	82 (65–98)	1	2	6.2	82
Matkakoski	May					4	3 (2–4)	10.2 (6.9–15.1)	100 (91–112)
	June					1	2	5.5	84
Naamisu-vanto	August	3	1 (1–2)	4.0 (2.8–6.8)	73 (61–89)	2	2	8.0 (7.9–8.0)	93 (92–94)
	Septem-ber	2	1	1.6 (1.4–1.8)	59 (55–62)				
Kengis/Pa-jala	June	5	3 (2–4)	9.5 (5.3–13.3)	98 (80–113)				
	August	1		6.6	86				
Lappea	August					9	2 (1–2)	5.1 (1.8–11.4)	77 (58–103)
Total		17	2 (1–4)	5.9 (1.4–13.3)	83 (55–113)	31	2 (1–4)	6.0 (1.8–15.1)	82 (58–112)

Table 3. Number of caught and tagged trout in the Tornionjoki in both research years (2018–2019) per catching site and month, with average weight (kg) and average total length (TL, cm). Ranges (min–max) of the measured quantities are shown in parentheses.

		2018			2019		
Catching site	**Catching time**	**n**	**Weight**	**TL**	**n**	**Weight**	**TL**
Vojakkala	May				24	2.2 (1.2–5.7)	59 (48–82)
	August	1	2.1	55			
	September				21	2.7 (1.1–5.5)	61 (50–74)
	October	13	2.0 (1.1–4.7)	56 (48–74)	23	2.3 (1.2–4.0)	60 (52–68)
Matkakoski	May				1	2.3	62
	June				1	2.0	59
Naamisu-vanto	June	3	3.5 (1.5–5.2)	68 (54–79)			
	August				1	3.1	65
Äkäsjokisuu	June				4	3.5 (1.9–6.5)	70 (62–85)
Total		17	2.3 (1.1–5.2)	58 (48–79)	75	2.5 (1.1–6.5)	60 (48–85)

2.3. Tagging and release

All fish were tagged with an individually coded radio transmitter (model MCFT2-3A, Lotek Wireless Inc., Canada). Before tagging, individuals were anaesthetised with buffered MS-222 solution (100 mg/l), one fish at a time. During anesthesia, scale and finclip samples were taken for later ageing and genetic analysis, and the fish was photographed to determine and document health status and body condition. The fish was moved into a custom-made tagging cradle filled with water, which allowed fish to ventilate during the entire surgical procedure. The transmitter was placed into the body cavity via a 30 mm longitudinal incision made on the ventral skin posterior to the pectoral fins (Figure 3). The antenna wire was run through skin with a hypodermic needle (1.5x50 mm/17Gx2´´) pricked caudally from the incision. Finally, the incision was closed with two stiches using monofilament sutures (Ethilon 1671H, Ehticon, USA). Tagging took on average 2 min 56 sek per fish. After the operation, the total lenght (TL, cm) and mass (kg) of the fish was measured, after which it was moved to a recovery cage. All fish were released following visual inspection to ensure that they had fully recovered from anesthesia and tagging.

Figure 3. Surgical tagging. During the tagging fish was placed in a custom-made tagging cradle. Photo: Mikko Jaukkuri, Luke.

2.4. Tracking of fish

Radiotagged fish were tracked continuously with 20 automatic listening stations (ALS) installed along the main river branches and in main tributaries along the catchment. ALS were also placed in the river mouths of the neighboring rivers Kalixälven and Kemijoki (Figure 4). Each ALS consisted of an automatic radio receiver (SRX-DL or SRX800, Lotek Wireless Inc.) connected to a four-, six-, or nine-elements Yagi-antenna. The detection area of each ALS covered the whole river width.

Manual tracking of radiotagged fish was done weekly by car during the summer and autumn and once per month in winter, using a mobile receiver (SRX-400, Lotek Wireless Inc.). The manual tracking from car could only cover areas where roads follow alongside riverbanks. In addition, manual tracking by boat was done twice in the autumn 2018 and once in the autumn 2019. In both years, boat tracking covered the lowermost 15 km of river and the estuarine area from the lowermost ALS to the tagging place, were the low salinity allowed radio tags to be detected. In 2018, tracking by boat also covered a section of the river around Pello; this tracking was focused on sites where fish had been observed earlier by manual tracking from car. Finally, fish were tracked once by airplane in autumn 2018, covering the main rivers from the river mouth to the village Karesuando (Muonionjoki branch) and to the village Junosuando (Swedish Torneälven branch).

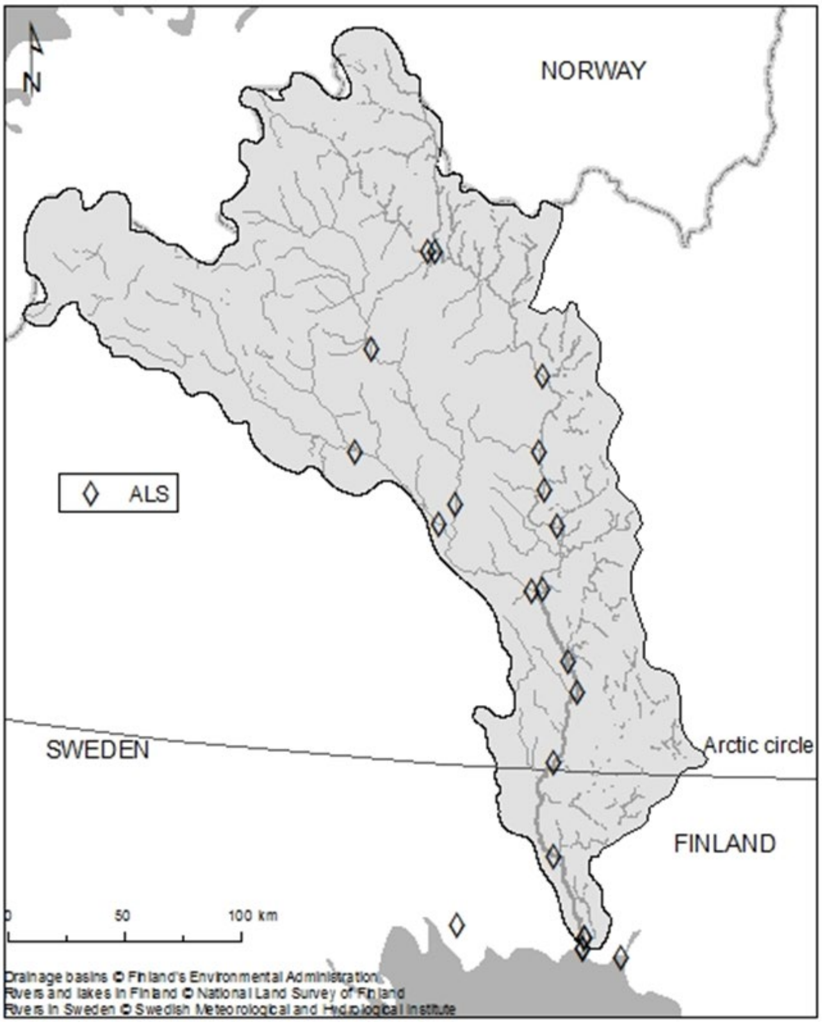

Figure 4. Locations of the automatic listening stations in the River Tornionjoki and on the mouths of neighboring rivers Kemijoki (Finland) and Kalixälven (Sweden). The catchment area of River Tornionjoki is highlighted with grey.

2.5. Genetic analysis of origin

Analysis of DNA-variation was used to assess most likely origin (place/area of birth) for tagged salmon and sea trout, which allowed comparisons with tagging results and identification of putative strayers from other rivers. For salmon, the same panel of 18 microsatellite markers was utilized as in Miettinen *et al.* (manuscript in revision) in their genetic study of salmon in the Torne-Kalix river system. Out of these markers, 17 are common to the "pan-Baltic genetic baseline" used for mixed-stock-analyses (MSA) of offshore and coastal catches of Baltic salmon that includes a total of 39 Baltic salmon stocks from six countries (Whitlock *et al.* 2018, ICES 2020).

For trout, a panel with 10 microsatellites analysed for parr samples (and partly smolt) from various parts of the Tornionjoki river system was used (Palm *et al.* 2019). Data for these markers exist for a relatively large number of Swedish wild and hatchery reared sea trout populations previously analyzed at SLU Aqua. However, the geographic "coverage" for trout is not as comprehensive as for salmon, since only two samples exist from neighboring Kalix river (tributary Ängesån), many smaller Swedish tributaries and rivers are missing, no Finnish wild or reared (e.g. Iijoki) stocks are included, etc.

Following DNA-analysis, four salmon-trout hybrids (one presumed salmon and three presumed trout at the moment of tagging) were identified. These four species hybrids were removed before further statistical analyses. In total, the origin of 273 salmon and 91 trout radiotagged within the present project was identified using genetic data. In parallel and in close cooperation with Luke, Swedish SLU in 2018 performed a smaller radiotagging study of post-release behavior and mortality of salmon released from push-up traps close to the Torne river mouth. The present analyses of salmon included data from both above projects, as a larger sample size gives expectedly higher statistical precision and accuracy for individual results.

The ONCOR software (Kalinowski et al. 2008) was employed for statistical estimation of population origin by means of individual assignment (IA). Salmon were assigned probabilistically to 16 sampling sites (i.e. groups of neighboring electrofishing sites from main rivers and tributaries) in the Torne-Kalix river system. To reduce statistical uncertainties associated with assignment to weakly differentiated sites, the sampling areas were combined into two reporting groups (‘upper’ and ‘lower’) encompassing 6 and 10 sampling areas, respectively. The division of the 16 sites into two reporting groups was based on genetic results revealing a main division among parr samples from upper and lower sites regardless of river (Miettinen et al., in revision). The upper reporting group for salmon consisted of headwater sites, whereas the lower one included sites located further downstream (in Tornionjoki with sites from the Border and Muonio and lowermost Lainio rivers). Trout genotypes were similarly assigned to 28 electrofishing sites in the Tornionjoki river system, grouped into 17 reporting groups representing separate tributaries known or presumed to produce sea trout (Palm et al. 2019).

2.6. Definitions and data analysis

Visual inspections of salmon to document health status and outer body conditions were based on the photographs for the fish tagged at the estuary. Salmon were classified based on presense and magnitude of skin damages, including haemorrhage (“redness”) in the skin of the belly. In 2019, all salmon had photographs, but in 2018, only 71 salmon (out of 93) were photographed. Visual classification of skin damages was based on three categorical levels: (1) no fresh damage; (2) a small damage (e.g. small scale loss, splitted fin); and (3) several small damages or one/several notable damages (e.g. many splitted fins or/and scale loss). Salmon was also classified based on the degree of haemorrhage (“redness”) based on three levels: (1) no redness; (2) small amount of redness (e.g. redness in the base of fin or small patch); and (3) one or several large red areas in the belly.

Migration distance in the river (km; starting point was the lowermost ALS) was manually measured for each fish, based on a map and data from ALS and manual tracking observations. Time spent in the river (h) was calculated using the first and last observations from the lowermost ALS.

Migration speed (MS; km/day) was calculated between each automatic listening station using the time of detection with the highest signal power of each fish at each station. The migration speed was calculated for all fish which had been observed by the passing between two separate listening stations. In case many detections with the same signal power were present, the first detection time was selected.

3. Results

3.1. Salmon tagged at the estuary

Altogether, 227 salmon were tagged at the estuary of the Tornionjoki during the years 2018–2019 (Table 1). The average size of salmon decreased during the tagging period in both research years (Table 1). In both years, the first one-sea-winter (1SW) male salmon, grilse, was caught in beginning of July. Multi-sea-winter (MSW) females and males were most common during the early part of the tagging period, but MSW salmon were still caught and tagged during July in both years. The proportion of female salmon was largest in the early season and decreased during the summer so that after the end of June most of the tagged salmon were males.

According to the DNA-analyses all tagged salmon most likely originated from the Torne-Kalix river system (no strayers from other rivers). Furthermore, most of the salmon radiotagged at the estuary (n = 202) most likely originated from the 'lower' reporting group with about half of those individuals (n = 90) being assigned to genetic sampling areas located below the Kattilakoski counting site. Only 24 of the tagged salmon were genetically assigned to the 'upper' reporting group, including sampling areas located upstream in the Tornionjoki headwaters (Lätäseno, Lainio, and Swedish Torne rivers). About half (n = 11) in the latter group were tagged in mid June, which indicated that the amount of the 'upper' group salmon seemed to decrease as the migration season progressed (Figure 5).

In 2018, altogether 61 salmon (66% of the tagged salmon in the trapnet fishery at the estuary in that year) were detected by the lowermost ALS (Figure 4) which is located at the river mouth of Tornionjoki. In 2019, the same ALS detected 114 salmon (85%). In 2018, a larger proportion of tagged females (71%) than male salmon (57%) was detected at the river mouth. No similar difference between the sexes was observed in 2019 (females 84% and males 88%).

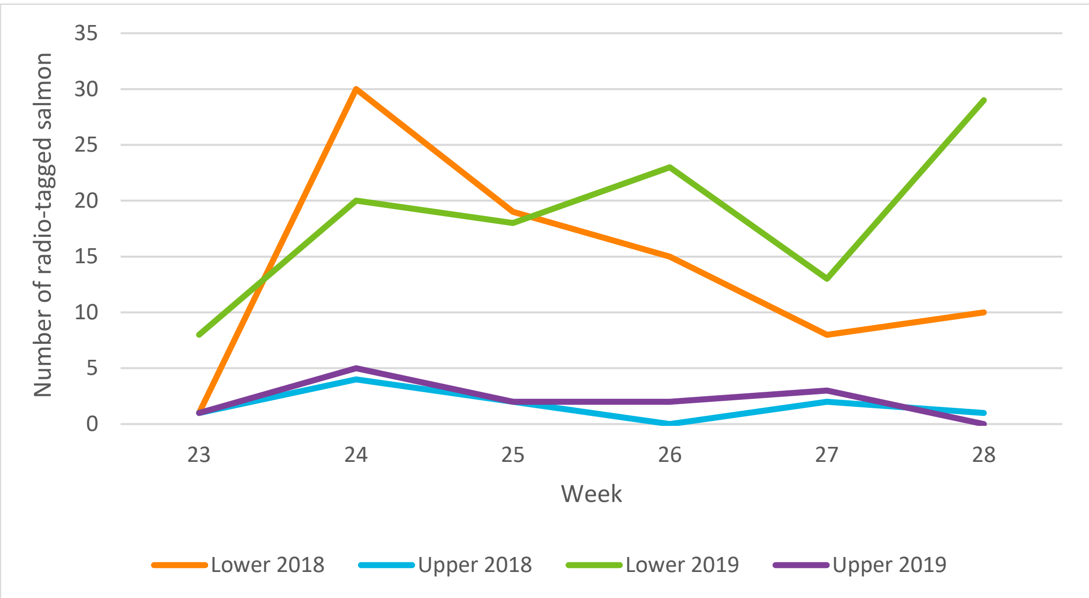

Figure 5. Number of salmon divided to different genetic reporting groups ('lower'/'upper') at estuary taggings in 2018 and 2019.

3.1.1. Visual condition

In 2019, for which a complete set of individual photographs existed, 41% of tagged salmon had no visual skin damages or redness. 40% of the tagged salmon had visual damages and 37% had visible redness in the photos (Figure 6). 19% of tagged salmon had both visual damages and redness. In 2018, 56% of the tagged salmon had visual damages, 33% had visible redness, and 18% had both visual damages and redness. 29% of tagged salmon in 2018 had no visual damages or redness. However, in year 2018 only 76% of all salmon were photographed. Because of this reason, the result from 2018 does not necessarily give an unbiased information about the health status of the tagged fish.

Figure 6. Examples of visual damages: above a minor scale loss and fin damages (class 2), and below redness in the fins (class 2). Photos: Riina Huusko, Luke.

3.1.2. Migration behaviour and speed

In both study years, most of the tagged salmon, which were detected at the lower most ALS (61% in 2018; 83% in 2019), returned to the sea by the end of July, i.e before spawning. In 2018, the salmon which eventually left the river before spawning stayed longer and migrated further upstream, compared to in 2019 (Table 5). In both years, a majority of the returning pre-spawning salmon were females (Table 5). Of the grilse tagged at the eastury, only one returned in 2018, and five in 2019. There was no difference in behavior between salmon assigned to the ‘lower’ and ‘upper’ genetic reporting groups.

Table 4. Average migration distance (km) and average time (h) in the river (before returning to the sea) of radiotagged salmon in 2018 and 2019 by sex. Ranges (min–max) of the measured quantities are shown in parentheses.

	2018			2019		
	n	**Time, h**	**Distance, km**	**n**	**Time, h**	**Distance, km**
Female, MSW	28	181 (1–438)	34 (1–140)	64	92 (10–525)	10 (1–100)
Male, MSW	6	171 (71–264)	20 (5–50)	28	87 (9–219)	13 (1–100)
Grilse, 1SW	1	82	5	5	81 (24–189)	4 (1–5)
Total	34	176 (1–438)	30 (1–140)	92	90 (9–525)	11 (1–100)

After entering the river, salmon not leaving the river usually migrated actively to the area where they also stayed during the spawning period. The migration from the river mouth to Kattilakoski (99 km) took about 11 days (median, range 4–90 days) in 2018. In 2018, most of the migrating salmon were MSW males (n = 6) with a median migration time of 11 days (range 5–90 days) and median migration speed 10 km/day (range 1–19 km/day). The large variation in migration times and speeds of MSW males were due to two males, which stayed on the lowermost part of the river over summer and finally migrated relatively fast upstream during August–September. In addition to the MSW males, two MSW females and one grilse migrated upstream of Kattilakoski in 2018. The migration speed of grilse was higher than that of MSW salmon, being on average 26 km/day (time from the river mouth to the Kattilakoski took only 4 days). The average migration time and speed of MSW females (11–17 days; 6–9 km/day) were slightly slower than those of MSW males. In 2019, only three grilse migrated from river mouth above Kattilakoski and their average migration speed was 5 km/day (range 3–7 km/day, time from the river mouth to the Kattilakoski took 14–36 days).

Of those salmon, that migrated upstream Kattilakoski, the majority stayed below Lappea. No salmon were observed to enter Swedish Torne or the Lainio branches (either in 2018 or 2019), and all the fish which passed Lappea choose to enter the Muonionjoki branch.

3.1.3. Spawning areas and behaviour after spawning

At autumn time, there were 18 estuary-tagged salmon remaining in the river in 2018 and 13 salmon in 2019. In 2018, 10 of these fish had migrated over 100 km (above the Kattilakoski counting site) whereas 8 salmon stayed below Kattilakoski. In 2019, only 3 salmon migrated above Kattilakoski and all the rest (10 salmon) stayed in the lowermost 50 km of the River Tornionjoki (Figure 7).

Altogether, 19% of the salmon migrated back to the sea after the spawning. After spawning season most of the salmon started to move slowly downstream, but only 9.5% of them migrated back to the sea by the end of the spawning year. All these fish had stayed near the river mouth during the spawning period. Next springafter the spawning, 9.5% of the overwintering salmon migrated back to the sea. The rest of salmon did not migrate back to the sea and presumably died in the river.

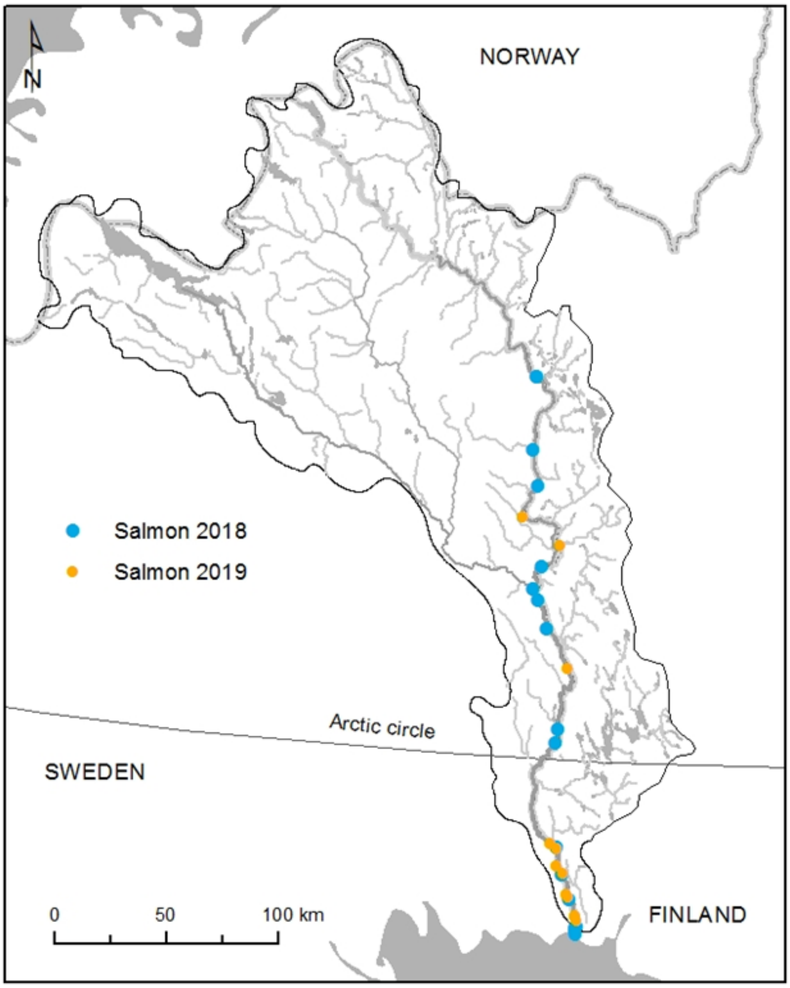

Figure 7. Locations of radiotagged salmon during the spawning time in 2018 (blue circles) and 2019 (orange circles).

3.1.4. Tag returns

Altogether, 18 tagged salmon had been recaptured by fishermen and their tags were returned by the end of 2019. 11 of them were caught in the coastal trapnet fishery (2018: n = 6, 2019: n = 5) and the rest (n = 7) of the tag returns were caught in the river (2018: n = 5, 2019: n = 2). The majority (n = 6) of the tag returns from the river were from fishing below the Kattilakoski counting site.

3.2. Salmon tagged in river

Altogether, 48 salmon were caught and tagged in the river during 2018–2019 (Table 2). Most of the salmon were caught in the autumn (August–October). In both study years, five salmon were caught and tagged in spring (Table 2), but the tagging locations differ between years: in 2018 spring tagging was done about 200 km upstream from the river mouth, while in 2019 tagging was done about just 40 km upstream from the river mouth. Autumn tagging was carried out both near the river mouth (c. 15 km) and higher up in the river (c. 155–200 km from the river mouth).

The salmon tagged in the spring were 2–4SW fish. Most of the salmon tagged in autumn were 2SW fish, but also grilse (1SW) were tagged in autumn in both study years (Table 5). According to DNA-analysis most of the radiotagged salmon from the river were assigned to the 'lower' reporting group (n = 32). Four salmon, genetically assigned to the 'upper' reporting group were tagged in springtime (3 tagged in Kengis and 1 tagged in Matkakoski) and only one ‘upper’ river salmon was tagged in autumn (caught in Naamisuvanto).

Table 5. The number, average sea-age (year, based on scale samples), average weight (kg) and average total length (TL, cm) of salmon tagged in river in spring and autumn during both study years (2018–2019), divided by sex. Ranges (min–max) of the measured quantities are shown in parentheses.

	Female				Male			
Catching time	**n**	**Sea-age**	**Weight**	**TL**	**n**	**Sea-age**	**Weight**	**TL**
Spring 2018	3	3 (2–4)	7.1 (5.3–8.5)	90 (80–96)	2	4 (3–4)	13.2 (13.0–13.3)	111 (109–113)
Spring 2019	1	2	5.5	84	4	3 (2–4)	10.2 (6.9–15.1)	101 (91–112)
Autumn 2018	4	2	6.1 (4.1–6.8)	86 (78–92)	8	1 (1–2)	3.6 (1.4–8.9)	71 (55–98)
Autumn 2019	13	2 (1–2)	6.5 (2.5–9.0)	85 (66–95)	13	2 (1–2)	4.3 (1.8–11.4)	74 (58–103)
Total	21	2 (1–4)	6.4 (2.5–9.0)	86 (66–96)	26	2 (1–4)	5.6 (1.4–15.1)	80 (55–113)

3.2.1. Behavior patterns, spawning areas and behaviour after spawning

The salmon caught and tagged in the river showed highly varying post-release behavior. In both study years, all salmon tagged in the early summer (May–June; Table 2 and 5) moved downstream and descended to the sea (n = 7) or died (n = 3) during the downstream movement. The behavior was similar in both years, even though the tagging locations in the river were different. In addition, behaviour in spring was similar regardless of sex. Of the dead salmon, one was found along the riverbank about the 12 km upstream from the river mouth (tagged 2018), whereas the two others were presumed dead based on the manual tracking observation (both tagged 2018).

All salmon tagged in autumn (Table 2 and 5) stayed in the river over the spawning time. Most of them stayed near the tagging site during the autumn, but some of them moved up- or downstream after release (Figure 8).

Altogether, 36% of the river tagged salmon migrated back to the sea after the spawning season. After spawning season most of the salmon started to move slowly downstream and 22% of them migrated back to the sea by the end of the spawning year. All these fish had stayed near the river mouth during the spawning period. The rest of salmon did not migrate back to the sea and they presumably died in the river.

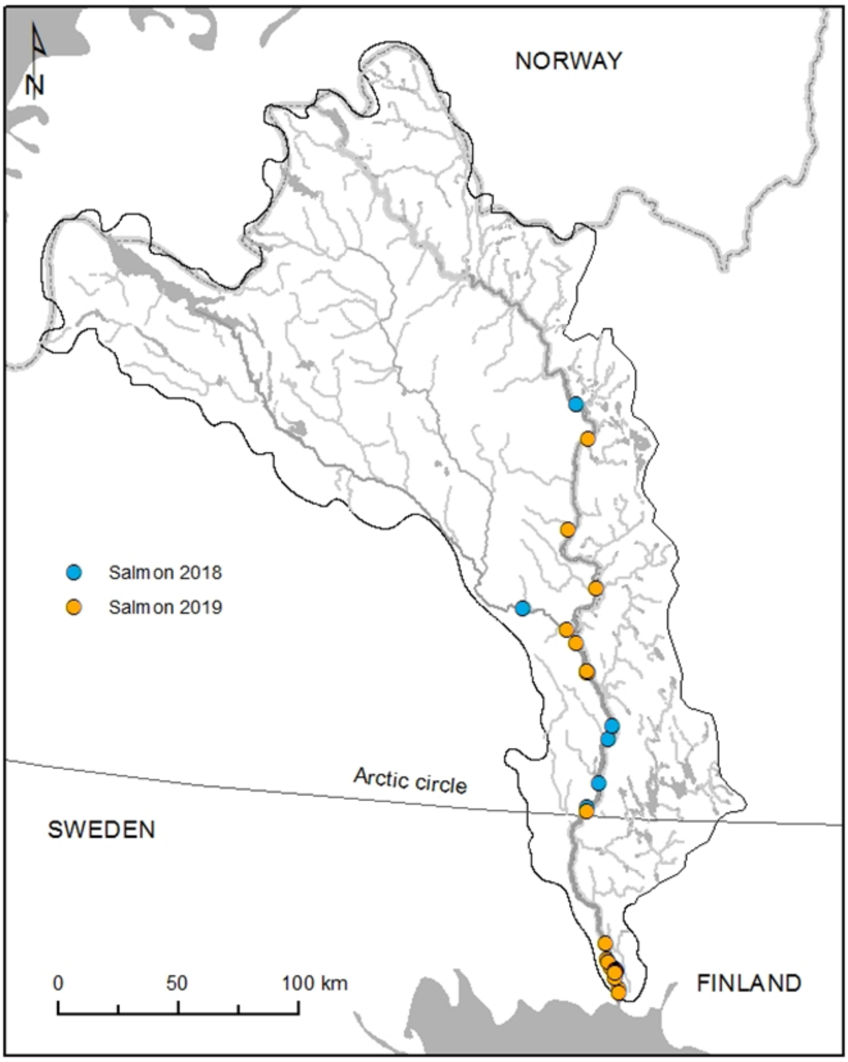

Figure 8. Locations of the autumn-tagged salmon during the spawning time in 2018 (blue circles) and 2019 (orange circles).

3.3. Trout

Altogether, 92 trout were caught and tagged in the river during 2018–2019 (Table 3). Most of the trout were caught in autumn (August–October). The autumn-tagging was mostly carried out near the river mouth (12–41 km upstream). Based on scale samples, most of the trout tagged near the river mouth were young (79% of them had spent only one or two years at sea) and therefore probably non-mature trout. In contrast, trout tagged further up in the river were older fish and most of them (63%) had spawed earlier.

The DNA-analyses indicated that most of the tagged trout originated from the Äkäsjoki (n = 39), Parkajoki (n = 21) or Naamijoki (n = 14) tributaries, all previously shown to be important areas for production of sea trout in the Tornionjoki system (Palm et al. 2019). In 2019, three individuals tagged near the river mouth were assigned to other Swedish rivers (two most likely from Piteälven, one from Dalälven).

3.3.1. Behavior patterns of trout tagged near the river mouth

Near the river mouth (12–41 km upstream), trout were tagged in the autumn of 2018 and 2019, and in spring 2019 (Table 3). These trout overwintered near the tagging site in both study years (Figure 9). Trout tagged in the autumn 2018 and spring 2019 moved either upstream or downstream in the end of May – beginning of June (Figure 9). There were no tagged trout left near the tagging area during the summer 2019. However, the six trout which had moved to the sea in spring 2019, migrated back to the river in autumn 2019 (August–October) and overwintered on the lowermost 50 km of the river (Figure 9). Tracking of these and all other tagged trout will continue during the next years.

Most of the tagged trout overwintered about 15–20 km from the river mouth below the Kukkolankoski rapid area. The trout moved to the overwintering area during October and movements during the winter were minor (max. a couple of kilometers up- or downstream). After overwintering, the trout that did not move upstream towards spawning time, migrated back to the sea from the end of May to middle of June (Figure 9).

45% of the tagged trout (n = 18) started their upstream migration the next spring after the tagging (Table 6). The upstream migrating trout were on average larger than individual that moved to the sea during the spring (Table 6). 50% of the upstream migrating trout were repeat spawners, while only two repeat spawners moved to the sea after overwintering (2018: 74 cm, 4.7 kg; 2019: 56 cm; 1.5 kg).

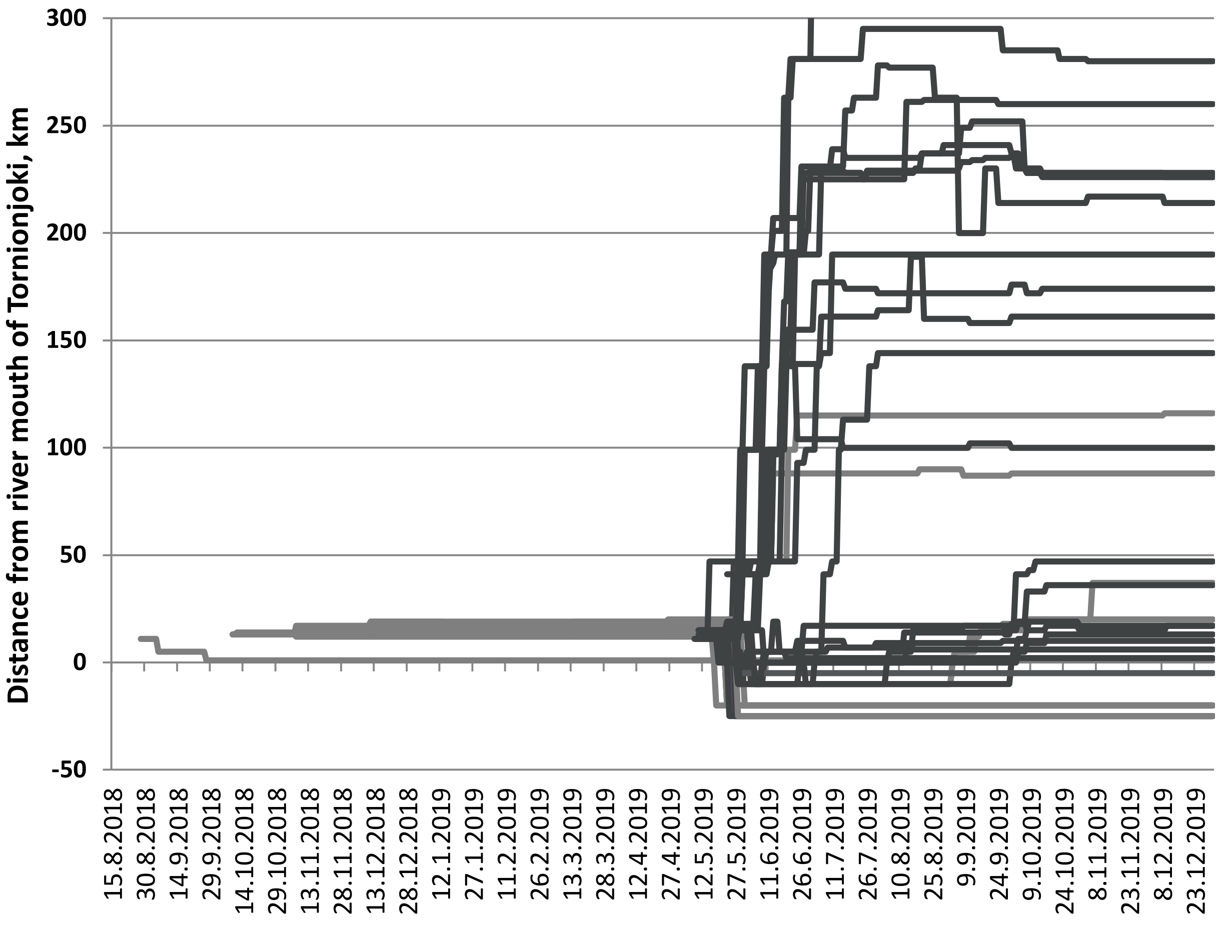

Figure 9. Up/downsream movements of trout tagged in the autumn 2018 (grey lines) and spring 2019 (black lines). Trout tagged in the autumn 2019 are not shown, but they overwintered in the same area in the winter 2019–2020 as the trout overwintering a year before.

Table 6. Number, average sea-age (year, from scale reading), average weight (kg) and average total length (TL, cm) of the trout tagged at lowermost tagging place in the river in autumn 2018 and spring 2019, by the migration pattern in spring 2019 (migrated either to the sea or upstreams). Ranges (min–max) of the measured quantities are shown in parentheses.

	to the sea				upstream			
Catching time	**n**	**Sea Age**	**Weight**	**TL**	**n**	**Sea Age**	**Weight**	**TL**
Autumn 2018	10	2 (1–3)	1.9 (1.1–4.7)	55 (48–74)	4	2 (1–2)	2.2 (1.7–3.0)	57 (52–64)
Spring 2019	12	2 (2–3)	1.8 (1.2–2.3)	56 (48–65)	14	3 (2–4)	2.6 (1.3–5.7)	62 (53–82)
Total	22	2 (1–3)	1.8 (1.1–4.7)	55 (48–74)	18	3 (1–4)	2.6 (1.3–5.7)	61 (52–82)

3.3.2. Behaviour patterns of trout tagged further upstream in the river

Most of the trout tagged higher up in the river were mature trout that migrated to the spawning areas within the same year. In the spring 2018, only three trout were tagged; all of them near the river mouth of Naamijoki tributary (about 150 km from the sea). One of these trout moved to the sea during the summer, one transmitter was found along the riverbank, and one trout moved to the Naamijoki tributary during the summer (Figure 10). The latter individual (79 cm, 5.2 kg) stayed in the Naamijoki tributary over the summer 2018 and overwintered after spawning in the main stem Tornionjoki, near the village of Pello. After overwintering the trout returned to the sea at the end of May 2019, migrated back into the river in the beginning of August 2019 and overwintered again in the Pello area (Figure 10).

In spring 2019, four trout were tagged in the river mouth of Äkäsjoki tributary (about 230 km from the river mouth of Tornionjoki). Three of these individuals migrated to the Äkäsjoki tributary during the summer. One trout moved upstream, migrated back to to the sea during June, migrated back to the river in August, and overwintered in Pello area (Figure 10).

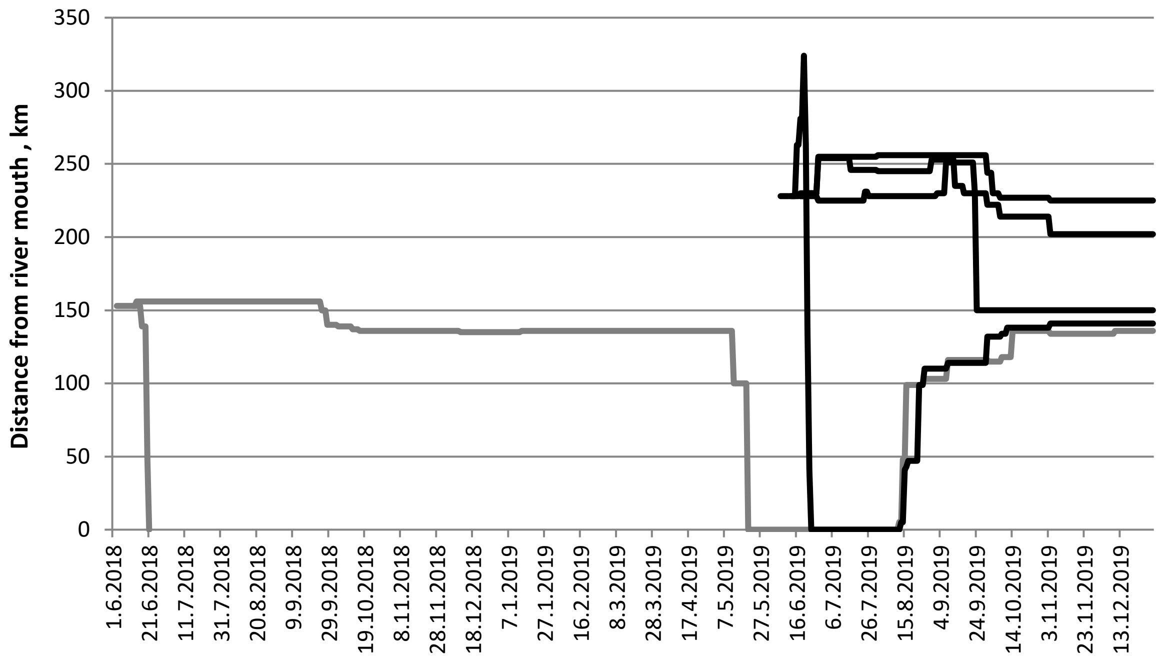

Figure 10. Migration patterns of trout tagged higher up in the river (tagged in 2018 with grey lines and tagged in 2019 with black lines). In 2019 trout were tagged in the river mouth of Äkäsjoki tributary beginning of June.

3.3.3. Spawning areas of tagged trout

During autumn 2019, trout were found in the main stem Tornionjoki and Muonionjoki, as well as in the tributaries Naamijoki, Äkäsjoki, Parkajoki and Merasjoki (Figure 11). There were five trout in the Äkäsjoki during the spawning season (middle August – middle September). The trout found in the main stem of Tornionjoki may continue their spawning migration in spring 2020, because they have likely entered the river around the spring – autumn 2019. These trout will be further tracked during 2020.

A comparison between observed spawing areas and genetic assignments of radio tagged trout showed that assigned origins and observed areas were not always same. Trout observed to spawn in Naamijoki and Parkajoki in autumn 2018 and 2019 were assigned those respective tributaries, whereas spawners in Äkäsjoki had been genetically assigned to that tributary and to the closely located (aand genetically similar; Palm *et al.* 2019) Parkajoki.

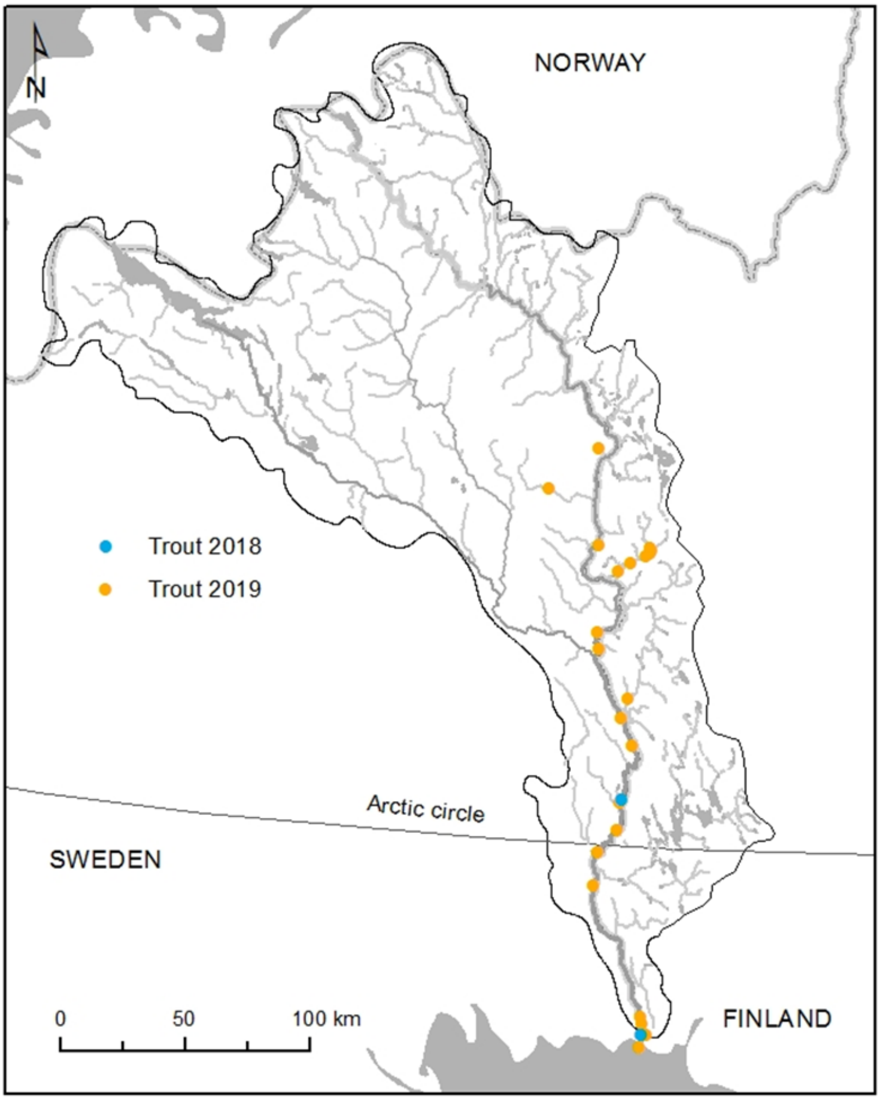

Figure 11. Locations of tagged trout in autumn 2018 (blue circles) and 2019 (orange circles).

3.4. Radiotagged fish vs. echo sounding at Kattilakoski

Observations from the ALS placed at Kattilakoski were compared with the echo sounder data (ARIS) from 2019. The aim was to see if the tagged fish was also detected by the echo sounder when they passed the sonar, swimming either upstream or downstream. If no fish is visible by the echo sounder but the ALS records a passing fish, this would be an indication of non-detection by the echo sounder.

None of the downstream migrated radiotagged fish (n = 13) were detected in the echo sounder data. This result indicates that echo sounding does not give information about the total amounts of downstream moving fish in the Kattilakoski.

In contrast, it was possible to link the observations of radiotagged fish and echo sounder recording for most of upstream migrated fish. However, it is not indisputable proof that the fish detected in the echo sounder data was indeed the tagged individual. The level of confidence for correct identification is higher when a lower number of fish is passing the site at the same time as a radiotagged individual. In the future, it could be possible to increase the confidence for correct identifications by using underwater ALS-antennas. This type of antennas would more precisely define the locations and times of passing of tagged fish swimming through the echo sounder beams.

4. Discussion

An unexpected high proportion of the salmon tagged at the river mouth that entered Tornionjoki, moved back to the sea during the same summer. The same surgical tagging method has been used for a long time for behavioural studies of fish (Summerfeld & Lynnwood 1990) and is considered a good method for tagging of fish in running waters (Bridger & Booth 2003). In this study, tagged salmon and trout recovered well and quickly after the tagging, and they did not exhibit any worrying immediate post-release behavior. A delay of some days in the continuation of migration is typical among freshly tagged salmon and trout, and this behaviour was observed also in this project (salmon stayed at the river estuary 1.4 day (median, range 0.2–35 days) before entering the river. Thus, the tagging itself likely did not cause any severe problems to the salmon that could explain the short in-river migration distances or movement back to the sea during the same summer.

Potential explanations for the short in-river migations and downstream migrations during the summer could be related to the observed health problems among Baltic salmon spawners during the last few years. It is possible that handling related to tagging was the ultimate event got the already weak salmon to abort their migration. In both study years, redness seen at the skin on the stomach, especially near the fins was common among the tagged Tornionjoki salmon. In several rivers along the Swedish coast, sick and weak salmon have also been reported in recent years, with visual damages like the ones reported in our study. These fish seem to tackle off once in the river, and many aborts their migration early on and eventually may die to the disease. For example, in the River Umeå the observation of migration success of tagged salmon from the estuary to the fishway has dropped dramatically during the last couple of years (Vikström et al. unpublish). Although possible reasons behind the symptoms have been investigated (SVA 2019), neither the root cause(s) of the problem nor the potential impacts of it on the Baltic salmon populations are yet known.

Observations by local fishermen from the River Tornionjoki support our findings that unusually high numbers of salmon stayed in the lowermost river during late summer –early autumn in both study years. Both summers were dry and created unique conditions for migrating salmon. River flow decreased rapidly after the spring flood and stayed low over the summer. In addition, the hot summer in 2018 caused the water temperature to rise fast to levels rarely observed in Tornionjoki. It is possible that high river temperature and low discharge may have inhibited the upstream migration of salmon. Data from the Kattilakoski counting site in 2018 support this interpretation. The daily counts of salmon unexpectedly increased at Kattilakoski in early autumn, indicating that unlike in normal years, some salmon tried to reach upper parts of the river system late in the season, when the water temperature had finally dropped and the discharge had become higher.

The tagged sea trout can be divided into two groups based on their migration pattern: (1) immature trout which move into the lowermost river for overwintering and leave back to the sea in next spring, and (2) mature trout which move to the river for spawning migration. This second group can be further subdivided into trout, which enter the lowermost river in autumn and overwinter there before continuing to the spawning areas next spring, and trout which enter the river in springtime and continue to the spawning areas within the same season. More information about the trout migration behavior will be obtained later, when individuals which have overwintered in the river start their migration in spring 2020. Also, the plan is to tag additional 30 trout during the year 2020.

Almost all trout tagged during springtime upstream Kattilakoski moved to tributaries during the summer. However, one trout in 2018 and one in 2019 moved to the sea during June after tagging. These trout could be post-spawners heading back to the sea at the tagging time. One indication supporting this possibility is that the one tagged in 2018 swam back to the river in the autumn 2019 and moved to overwinter upstream from Kattilakoski. This individual may have recovered by feeding one summer at the sea, and it may spawn again in 2020. Notably more information from trout migrations is expected to be received from 2020, when the high number of already tagged trout will start their active migrations again in spring.

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