Fisheries Management
and Ecology

Fisheries Management and Ecology, 2017, 24, 73–81

Road culvert restoration expands the habitat connectivity and production area of juvenile Atlantic salmon in a large subarctic river system

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Abstract The effects of restoration of impassable road culverts on the distribution of juvenile Atlantic salmon, *Salmo salar* L., were evaluated in seven small tributaries of the subarctic River Teno system, northernmost Finland/Norway. Restoration enabled the passage of juvenile salmon through the culverts and increased the distribution area of salmon parr in the seven streams by tens or hundreds of metres, depending on the natural slope of the tributary with a total of ≈1 km new area for ascending juveniles. Areas upstream of the culverts were colonised after varying number of years, mostly 2–3, following restoration. Age-1 and age-2 parr were the first salmon age groups entering the new territory after removal of the migration barrier. Although the restoration measures were conducted at the downstream outlet area of the culverts only, the connectivity was improved and increased the production area accessible to juvenile salmon. Such removal of migration barriers and securing habitat connectivity by passable culverts should be taken into account in environmental management strategies of river systems safeguarding the essential habitats of salmonid fish.

KEYWORDS: Atlantic salmon, culvert, migration barrier, rearing habitat, restoration.

Introduction

Habitat connectivity has increasingly become a topic of interest in freshwater ecology, because of the need to understand the complex ecological interactions between habitat landscapes, population dynamics and dispersal patterns (Jungwirth *et al.* 2000; Neville *et al.* 2006; Tetzlaff *et al.* 2007; Olden *et al.* 2010), but especially because of negative anthropogenic impacts on catchments with vulnerable stream habitat networks (Warren & Pardew 1998; Gibson *et al.* 2005; Wheeler *et al.* 2005). Movement and migration are among the most important behavioural traits of animals, enabling behavioural responses to changes in environmental conditions. Therefore, impeding migration routes across fluvial freshwater habitats leads to restricted range size and most likely affects the community composition, survival, reproductive success, genetic diversity and fitness of fluvial fishes (e.g. Spens *et al.* 2007; Nislow *et al.* 2011; Torterotot *et al.* 2014). In line with this, a review of effectiveness of habitat rehabilitation techniques ranked the connection of isolated habitats by improving passage among the most successful ones (Roni *et al.* 2008).

Small streams are important habitats for various fish species. In many salmonid species, dispersal, movements or habitat shifts across various freshwater habitats of the catchment area are relatively common (see, e.g., reviews by Jonsson & Jonsson 1993; Gowan *et al.* 1994; Erkinaro 1997; McCormick *et al.* 1998). Small streams are often used only during some life stages, either as a migration route (Näslund *et al.* 1993), or for nursery habitat seasonally or temporally (Levings *et al.* 1995; Erkinaro *et al.* 1998a). Changes in habitat use by fish within the catchments are considered to be a response to poor habitat conditions, for example discharge, temperature, predation or food availability (Erkinaro & Niemelä 1995; Kahler *et al.* 2001; Johansen *et al.* 2005a and references therein). Moreover, habitat shifts are typically partial in a population (Jonsson & Jonsson 1993; Erkinaro 1995; Erkinaro *et al.* 1997); most individuals stay in their natal habitat, but others may actively search for more favourable conditions elsewhere.

Construction of roads is a major form of human modification of natural landscape that affects both terrestrial and aquatic ecosystems in many ways, including altering the behaviour and physical environment of

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animals (Trombulak & Frissell 2000). A number of recent inventories and studies, mostly carried out in North America, have shown that a great proportion of road crossings over streams have created conditions that are inadequate for fish passage, if not total obstructions (e.g. Gibson *et al.* 2005; Hoffman & Dunham 2007; Roni *et al.* 2008; Poplar-Jeffers *et al.* 2009; Price *et al.* 2010). Culverts have typically been used at stream crossings instead of more environmentally benign, but more expensive bridges. There are several conditions at culverts, due to poor design or installation, that often cause problems to fish passage, including excess drop at the outlet, high water velocity or inadequate water depth in the culvert barrel. In addition, excessive scour below the culvert is often adding to the barrier effect of the high drop at the culvert outlet (Warren & Pardew 1998; Gibson *et al.* 2005). However, assessing the passability and optimising and prioritising the restoration efforts is not a simple task, despite rapidly developing methodologies (e.g. Spens *et al.* 2007; Bourne *et al.* 2011; Beechie *et al.* 2012; O'Hanley *et al.* 2013), and often requires tailored solutions for different cases and areas.

In the large, subarctic River Teno system in northernmost Europe, several salmonid species, for example brown trout *Salmo trutta* L. and Arctic charr *Salvelinus alpinus* (L.), typically inhabit small tributaries. They have also been shown to be important rearing areas for juvenile Atlantic salmon *Salmo salar* L., although returning adult salmon do not reproduce in these streams (Erkinaro 1995, 1997; Johansen *et al.* 2005a). Juvenile salmon enter the streams from the spawning habitats in the main stems and stay for one or more years before the next phase in the life cycle, smolt migration to the sea (Erkinaro *et al.* 1998a). In some cases, residence in these small tributaries is predominantly seasonal and most individuals descend to the main stem during the autumn, but in other cases, the streams serve as important overwintering habitats too (Erkinaro 1995). Stream-dwelling salmon juveniles are typically larger compared with their counterparts of the same age living in the main rivers (Erkinaro & Niemelä 1995; Erkinaro *et al.* 1997). The enhanced growth of juveniles has been attributed at least partly to more abundant food resources available in the streams (Erkinaro & Niemelä 1995; Erkinaro & Erkinaro 1998; Johansen *et al.* 2005b).

Despite the remote and mostly pristine nature of the Teno River catchment, road construction and stream crossings pose obstacles for free fish movements to some extent. Early investigations of salmon parr production in the River Teno system have identified the problems that culverts often pose to habitat connectivity (Rikstad 1981; Aarseth 1982; Erkinaro 1988). Several culverts on larger streams were replaced by bridges in the 1970s and early 1980s, and this has opened up long distances, up to >10 km per stream, of new nursery habitat for juvenile salmon in many small tributaries of the Teno catchment (Erkinaro 1995, 1997). However, a large number of road crossings at smaller streams, equipped with culverts with high vertical drops at the pipe outlet, have remained unsatisfactory for fish passage (Erkinaro 1988, 1997). The still-remaining potential restoration needs have been reviewed (Lundvall *et al.* 2001; Jørgensen 2004), and regional environment authorities conducted the work by diminishing or eliminating the thresholds between the culvert outlets and the water surface level of the downstream channels (Sivonen 2006).

The aim of this study was to evaluate the effects of the culvert restorations on juvenile Atlantic salmon distribution in the small tributaries of the River Teno system. Specifically, the study investigated whether juvenile salmon expanded their range following the barrier removal, and if so, how enduring their occupation was. In addition, the age structure of salmon parr colonising the newly available areas was investigated to determine whether this was consistent with the pattern documented in open-access streams, where most ascending fish represent the young age groups, ages 1 and 2 (Erkinaro *et al.* 1998a).

Materials and methods

Study area

The subarctic River Teno system (Tana in Norwegian, Deatnu in Sami) forms the border between northernmost Norway and Finland (70° N, 28° E), and the river drains a catchment area of 16 386 km^2. More than 1100 km of the different branches of the system is accessible to anadromous salmon, including the main stem and more than 30 tributaries that support distinct subpopulations (Vähä *et al.* 2007, 2016). The Atlantic salmon population of the River Teno is among the largest within the distribution range of the species, producing 100–200 t (20–50 000 individuals) of annual freshwater catch (Niemelä *et al.* 2005) and showing an extremely wide range of life histories (Niemelä *et al.* 2006). Salmon populations of the Teno system are based on natural reproduction only; stocking of fish or eggs is strictly prohibited.

The tributaries selected for road culvert restoration in the present study (Fig. 1) were chosen based on earlier inventories and the recommendations by Erkinaro (1988) and Lundvall *et al.* (2001) and prioritised by their potential in expanding habitat connectivity for juvenile

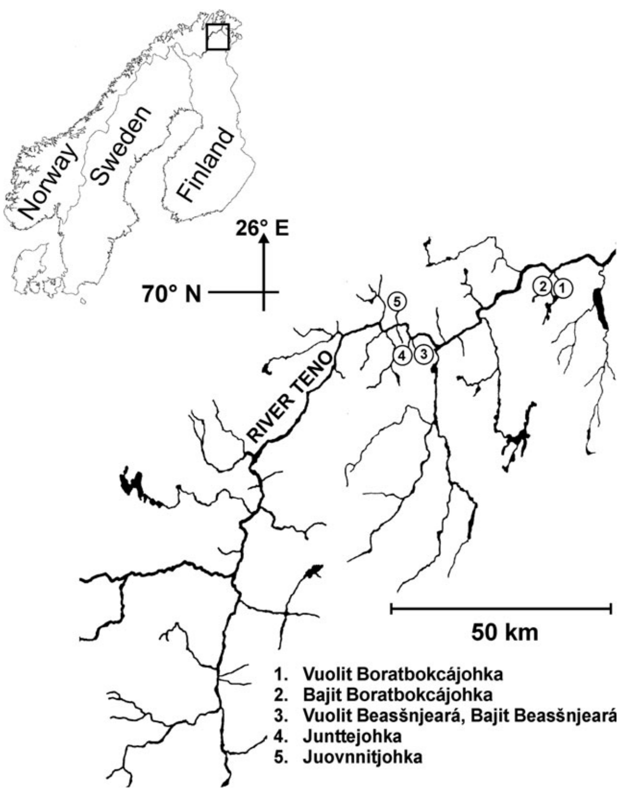

Figure 1. Location of the streams in the River Teno system where road culverts have been restored during the study.

Atlantic salmon. Culverts of seven small tributaries of the River Teno were restored between 2000 and 2004 (five subcatchments with seven separate outlet streams; Fig. 1). Seven other stream crossings were also modified, but in those cases the aim was to improve the already-existing salmon passage or increase connectivity for resident salmonid fishes in streams where the culverts were upstream of natural obstacles for salmon (Erkinaro & Erkinaro 2006). Thus, these streams are not included in the present study.

Culvert restoration and fish surveys

The culverts in all streams were round pipes made of concrete with no baffles or other structures inside the culvert barrel. The culvert outlet areas were restored by placing rocks to create a distinct new pool downstream of the culvert or increase its size and raise the water level of the existing pool, to decrease or eliminate the artificial waterfall, that is the vertical drop at the culvert entrance. Heights of the vertical drops before restoration varied between 20 and 105 cm in the streams (Table 1), and restoration actions were tailored for each stream depending on the local conditions. In some cases, sampling was not possible to undertake before the culvert restoration was carried out, and therefore, historical information (1980s–1990s) on occurrence of juvenile salmon in streams, downstream and upstream of the road crossing, was used. The number of years in the 'before' period ranged between 1 and 5, whereas those in the 'after' period varied between 3 and 5. This unbalanced sampling was not optimal for a real 'before–after' design, and no control sites with unchanged connectivity were included in sample. Therefore, the data were not rigorously analysed with statistical methods (before–after, or before–after–control designs; see Underwood 1994).

In each stream, one or two sampling areas were electrofished at both sides of the culvert (Table 1). Depending on the tributary, the lowermost sampling areas were typically 30–50 m upstream of the tributary outlet, and the sites on both sides of the road crossing were usually close to the culvert, immediately downstream and

Table 1. Characteristics of the sampling areas in tributaries of the River Teno. Distances downstream from the road culverts are indicated as negative values. In most cases, one of the sites is located right at the culvert outlet (distance = 0)

	Site	Distance from main stem, m	Area m^2	Distance from road culvert, m	Vertical drop at culvert outlet before/ after restoration (cm)
Vuolit Boratbokcájohka	1	110	51	−50	
lower branch	2	160	20	0	
	3	230	50	70	105/30–45
Vuolit Boratbokcájohka	1	80	81	0	
upper branch	2	110	85	30	40/0
	3	530	137	450	
Bajit Boratbokcájohka	1	60	69	−10	
	2	70	52	0	
	3	190	104	120	80–90/20
	4	240	64	170	
Vuolit Beasšnjeará	1	50	33	−30	
	2	80	26	0	
	3	140	48	60	30/0
	4	220	48	140	
Bajit Beasšnjeará	1	30	24	−40	
	2	70	32	0	
	3	90	8	20	20/0
	4	120	44	50	
Junttejohka	1	30	30	−40	
	2	70	48	0	
	3	110	78	30	40/0
	4	130	33	60	
Juovnnitjohka	1	20	55	−80	
	2	100	80	10	40/20

upstream of it. The sites furthest upstream were, depending on the landscape and natural slope of the stream, some tens or hundreds of metres upstream from the site at the culvert inlet (Table 1) The threshold height or vertical drop of the culverts was measured in each stream, in most cases both during the 'before' and 'after' periods.

A single-pass electrofishing employing standard field methods (Niemelä *et al.* 2001) was used to derive estimates of abundance (fish per 100 m^2; Table 2). Fish ages were determined from scale samples. Electrofishing was carried out in late August to early September each year to minimise seasonal variation in water level and temperature conditions (cf. Niemelä *et al.* 2001).

Results

Improved connectivity at road crossings

Following the culvert restoration, passage through the culverts was established and the distribution area of salmon parr increased in all brooks by tens or hundreds of metres, depending on the stream (Tables 1 and 2). In four streams, restoration has totally eliminated the threshold below the culvert, and in the other three, the decreased vertical drop below culverts enabled habitat connectivity (Table 1).

In most cases, the first electrofishing survey was carried out 2 or 3 years after the restoration; only in the

Table 2. Abundance (individuals per 100 m^2 caught by single-pass electrofishing) of juvenile Atlantic salmon in small tributaries of the River Teno (– = no sampling). Horizontal lines denote the location of the road crossing and the culvert between the sampling sites (1 = lowermost site). Shaded areas denote years after the culvert restoration. The year of culvert restoration is indicated

Vuolit Boratbokcájohka lower branch (restored 2003)

Site	1988	1991	1995	2003	2004	2005	2007	2010
1	27	-	-	53	29	31	43	38
2	-	-	22	35	-	-	-	-
3	0	-	-	0	0	4	5	8

Vuolit Boratbokcájohka upper branch (restored 2001)

Site	1988	1991	1995	2003	2004	2005	2007	2010
1	35	42	27	41	33	40	26	28
2	5	3	5	8	2	4	4	8
3	-	-	-	0	0	0	3	3

Bajit Boratbokcájohka (restored 2004)

Site	1988	1991	1995	2003	2004	2005	2007	2010
1	36	40	39	50	44	42	52	66
2	-	-	-	74	53	41	64	43
3	0	0	0	1	0	0	1	4
4	-	0	0	0	0	0	0	0

Vuolit Beasšnjeará (restored 2000)

Site	1987	2003	2004	2005	2010
1	45	34	36	20	36
2	27	43	-	-	40
3	0	13	19	21	15
4	-	0	0	0	6

Bajit Beasšnjeará (restored 2000)

Site	1988	2003	2004	2005	2010
1	36	48	39	48	42
2	-	31	45	46	35
3	0	87	262	87	87
4	-	0	0	0	0

Junttejohka (restored 2000)

Site	1988	1991	2003	2004	2005	2010
1	41	50	53	39	42	51
2	-	-	52	-	-	-
3	1	0	14	11	21	7
4	-	0	0	0	0	0

Juovnnitjohka (restored 2002)

Site	1991	2004	2005	2007	2010
1	13	20	9	15	7
2	0	0	1	1	4

Vuolit Boratbokcájohka (lower) and in the Bajit Boratbokcájohka did the first sampling take place the following year (Table 2). However, even in these streams, the first salmon detected entering the newly opened area upstream of the culverts were 2 or 3 years after the restoration. Furthermore, in two streams, the first salmon parr detected were at sites furthest upstream 6 or 10 years after removing the barrier (Table 2).

Abundance indices of juvenile salmon in the lower parts of the small tributaries ranged mostly between 40 and 100 individuals per 100 m^2 and mostly decreased towards sampling sites further upstream (Table 2).

Culvert restoration in the seven small tributaries of the River Teno opened up at least 1 km (≈ 0.5 ha) of stream habitat for salmon parr ascending from the main stem, although the extent of the new habitat area is likely larger as the new uppermost limit for salmon parr distribution is not known for all the streams.

Age distribution of salmon parr

There was a significant difference in age distribution of juvenile salmon between the sampling sites below and above the road crossings (all streams combined; Pearson chi-square $P < 0.05$). The youngest year classes, underyearlings (0+) and 1+ parr, were generally the most abundant groups in the lower parts of the streams, followed by relatively high proportions of 2+ parr (Fig. 2). At sites upstream of the culverts, 1+ and 2+ parr dominated the age distribution of juvenile salmon, whereas single individuals of 0+ fish were detected in only two streams (Fig. 2).

After opening the access to sites upstream of the stream crossing, the first electrofishing survey, 1–3 years after restoration, revealed that the ascending salmon parr were mostly from age groups 1+ and 2+ (mean 46 and 42%, respectively). In later years, the age composition was more variable and the proportions of age-2 and age-3 parr increased (mean 60 and 21%, respectively) with some 4+ parr detected (Fig. 2).

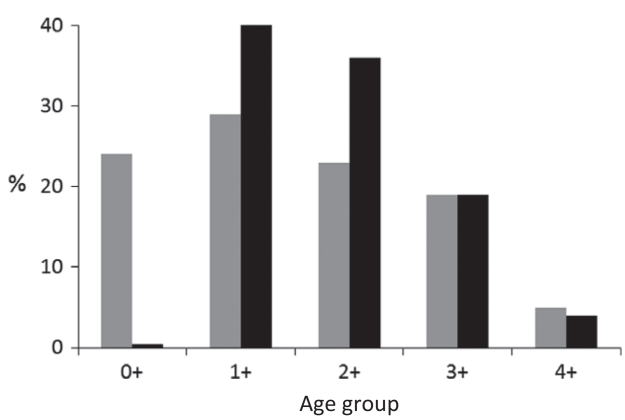

Figure 2. Age distribution (%) of juvenile Atlantic salmon in five small tributaries of the River Teno. Grey bars: below the road culvert; black bars: above the culvert.

Discussion

Improved connectivity in streams

The results of the present study showed that the culvert restorations carried out in the River Teno system were successful in improving the connectivity and expanding the distribution area of juvenile Atlantic salmon in small tributaries. Improved passage opened up stretches of the streams, varying between tens and hundreds of metres, although natural obstacles and steep gradient upstream of the culvert were limiting factors for further expansion of the distribution in some cases. However, even short stretches of new habitat are important additions to the production area of juvenile salmon.

In addition to juvenile Atlantic salmon, the small tributaries of the River Teno are inhabited by other fish species, mostly brown trout and Arctic charr (Erkinaro 1988, 1995; Johansen *et al.* 2005a). Although the non-migratory morphs (resident trout and charr) may have less needs for movement compared with migratory fish, the improved longitudinal connectivity also increases the habitat range in response to seasonal changes in temperature, flow and food availability for resident fish (e.g. Näslund *et al.* 1993; Petty *et al.* 2012). In addition, many of the small tributaries in the Teno system are important spawning habitats for anadromous brown trout (sea trout), and improved passage also facilitates their spawning migration (Orell *et al.* in press).

Age distribution of Atlantic salmon parr in streams

Young-of-the-year salmon were captured in the streams to a larger extent than in earlier investigations in corresponding streams (Erkinaro 1988, 1995; Johansen *et al.* 2005a). The present set of streams included more small streams with low-gradient outlets than some of the earlier studies, and these outlet areas provide suitable and easily reachable habitat for underyearlings that have recently emerged in nearby spawning sites in the main stem. However, the dispersal potential of underyearling salmon is typically not very strong (e.g. Gibson 1993 and references therein), and their active movements upstream into small tributaries do not seem to be common (e.g. Erkinaro 1995; Johansen *et al.* 2005a): only two individual underyearling salmon were detected upstream of any culvert during the present study.

The first juvenile salmon colonising the newly opened areas upstream of the road crossings were age-1 or age-2 fish as expected based on earlier studies at some open-access tributaries in the River Teno system (Erkinaro *et al.* 1998a). In addition, a similar age pattern in salmon parr shifting their rearing habitat from fluvial to lacustrine habitat has been documented (Hutchings 1986; Erkinaro & Gibson 1997; Erkinaro *et al.* 1998b). Although the age distribution in many of the small streams shows notable proportions of old, age-2–4, parr, the age-1 and age-2 parr are probably the most active groups searching for new opportunities for successful rearing in habitats with good feeding and overwintering conditions (Erkinaro 1995; Erkinaro *et al.* 1998a). In contrast to an explanation based on simple territorial behaviour, it has been suggested that often the individuals with highest growth rates may face the limitations of their original habitat and shift to a secondary habitat (Hutchings 1986; Jonsson & Jonsson 1993; Erkinaro & Niemelä 1995; Erkinaro *et al.* 1998b). However, no comparison between growth rates of parr from the tributaries and the Teno main stem was conducted in this study.

Success and importance of habitat restoration activities

In a review on the effects of road construction, management and restoration, Trombulak and Frissell (2000) called for more experimental research to supplement the traditional *post hoc* correlative approaches in assessing the effects of such anthropogenic impacts on biota. In addition, corresponding recommendations for assessing the characteristics of the habitat and fish community before mitigation and conducting before–after monitoring have been frequently stated (e.g. Kiffney *et al.* 2009; Franklin & Bartels 2012). Studies rigorously evaluating the biological effects of retrofitted, modified and restored stream crossings and their culverts are not abundant, at least not in the primary literature (Roni *et al.* 2008), although some exceptions can be found (e.g. Macdonald & Davies 2007; Franklin & Bartels 2012). In the present study, information on occurrence of juvenile salmon and their age composition was available before the culvert restoration for each stream. However, because of practical and financial reasons, a regularly spaced, annual before–after study design was not possible, although information had been collected over several years. In addition, the number of individual fish caught was often low, and one may argue that the observations of fish presence upstream of the culverts could not be attributable to restoration. However, in all seven tributaries studied, juvenile salmon were captured further upstream and/or in higher abundances in later years than in earlier years, which suggests an effect of improved passage through culverts.

In the present study, the only restoration action was to increase the water level below the culvert and thus decrease the vertical drop. In some studies assessing the effects of culvert restoration, improvement of fish passage has also been achieved through installation of baffles that provide rest areas for ascending fish and also continuous low-velocity areas of water. Examples include restoration of passage for galaxiids in Australia (Macdonald & Davies 2007) and salmonids in North America (Hoffman & Dunham 2007 and references therein). In addition, Franklin and Bartels (2012) showed that installation of a ramp and spoiler baffles in a stream in New Zealand increased species richness and total fish density upstream of the culvert by improving passage through the stream crossing. Moreover, corrugated metal culverts have been reported to allow better passage of juvenile salmonids than pipes with a smooth surface (Goerig *et al.* 2016). Such corrugated pipes with minimal or no vertical drops exist in some tributaries of the Teno system, and they seem to allow satisfactory fish passage (Erkinaro 1988; Lundvall *et al.* 2001).

Although the results may suggest a slightly better success in salmon parr colonising the areas above the restored culverts when the vertical drop at the culvert outlet was totally eliminated (e.g. Junttejohka, both branches of Beassňjeará), compared with streams where some residual head difference remained post-restoration, one should be cautious in making direct conclusions. Seasonal variation in migration activity of fish together with seasonal patterns in flow and water levels in streams (e.g. Erkinaro *et al.* 1998a) has likely a strong influence on the colonisation success. Head differences in restored culvert outlets should be studied at different times of the open water season and in connection with information on movement activity of salmon parr before concluding guidelines on critical vertical drops can be established.

Roni *et al.* (2008) concluded that failure of many aquatic habitat restoration projects to achieve their objectives is ‘attributable to inadequate assessment of historic conditions and factors limiting biotic production, poor understanding of watershed-scale processes that influence localised projects, and monitoring at inappropriate spatial and temporal scales’. More specifically, Kiffney *et al.* (2009) suggested that three factors contribute to a rapid and successful natural colonisation after a barrier removal: a sufficient source population below the barrier, high-quality habitat above the barrier and relatively low densities of resident fish upstream of the barrier. All these criteria were met in the tributaries of the River Teno, where the production and abundance of juvenile salmon in the main stem is high (Niemelä *et al.* 2005), the streams provide pristine habitat, and the abundance of resident fish upstream the culverts is not especially high (Erkinaro 1995, unpublished data). In addition, reasonable temporal and spatial extents were covered in monitoring of restoration success in the present study.

Given the widespread spatial extent of migrations of juvenile salmon into small streams of the River Teno system (Erkinaro 1997; Johansen *et al.* 2005a) and the estimated smolt production of these habitats (>1 smolt per 100 m^2; Erkinaro *et al.* 1998a), the importance of the small, non-spawning tributaries for the area over which juvenile salmon are produced within the catchment should not be underestimated. Current management practices are often based on the view that juvenile salmon undertake only restricted movements during the freshwater stage, and rearing habitats beyond the classic, primary fluvial habitats may not even be identified. The evidence for widespread use of small tributaries by juvenile salmon, both in the River Teno system and also in northern salmon rivers in other areas with low fish species diversity (Erkinaro 1997; Erkinaro & Gibson 1997; Crabbe 2000), highlights the need to identify all habitats used by different life stages of salmon and include them in management strategies for species and habitat conservation (see also Johansen *et al.* 2005a). Some of the secondary habitats, if unidentified, may be lost to river systems through poor development practices.

To conclude, the before–after study demonstrated an improvement of culvert passage following restoration, and the successful colonisation of juvenile Atlantic salmon in previously impassable areas in small streams of the River Teno system. In the seven small streams studied, a minimum of 1 km (≈0.5 ha) of stream habitat was opened for ascending juvenile Atlantic salmon. In addition, the restoration likely improved connectivity for other salmonid species. The experience gained in the present study on restoration of stream connectivity could be used as an example in future road management practices, both in the River Teno system and elsewhere. As part of conservation efforts for safeguarding valuable, native and endangered fluvial fish species, re-establishment of longitudinal connectivity, for example by overcoming small-scale obstructions such as culverts, enables protection and enhancement of all available high-quality natural habitats (cf. Trombulak & Frissell 2000; Franklin & Bartels 2012).

Acknowledgments

A number of people contributed to the fieldwork over the years, including Jorma Kuusela, Matti Kylmäaho, Jorma Ollila, Arto Koskinen and Arttu Erkinaro. The project 'Preservation of the River Tenojoki as a salmon river in its natural state', coordinated by the Lapland Regional Environment Centre, the Norwegian Water Resources and Energy Directorate, and the County Governor's Office of Finnmark, made the culvert restoration and part of the 'after' surveys possible. Funding was provided by the EU/Interreg III A North programme, the Finnish Ministry of Labour and Employment, the Ministry of the Environment, the Lapland Regional Environment Centre, Finnish Game and Fisheries Research Institute, the municipalities of Utsjoki, Inari, Tana and Karasjok and the Government of Norway. Our deep gratitude is extended to late Dr. R. John Gibson for his comments and encouragement at early stages of this study and on an earlier version of the manuscript.

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