Scottish Marine and Freshwater Science Report

Volume 6 Number 5

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Published by Marine Scotland Science

ISSN: 2043-7722
DOI: 10.7489/1610-1

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Ranching to the rod: an evaluation of adult returns from hatchery-reared Atlantic salmon smolts released in Scottish rivers

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Summary

The introduction of hatchery-reared Atlantic salmon smolts to rivers in support of local salmon fisheries (termed ranching) is a controversial subject with little information available to fishery managers on the value of the method in a Scottish context. Here we present recapture data from monitored smolt releases on four Scottish rivers and compare return rates of hatchery and wild-reared salmon smolts originating from a common stock on two of these rivers. Rod recapture rates from stocked hatchery smolts ranged from 0-0.23%. In comparative tests return rates for wild-reared fish were on average ten times greater than those for stocked fish (range 6 to 13-fold where at least one reared fish returned). Given the relatively poor returns and associated production costs any benefit to fisheries of stocking with hatchery-reared smolts is unlikely to be sustainable in the Scottish context. Furthermore, risks of adverse genetic effects should be considered.

Introduction

Atlantic salmon (*Salmo salar* L.), are fish of great cultural importance, which for many years have supported substantial fisheries in countries bordering the North Atlantic Ocean. In most regions salmon live in fresh water for 1-4 years before smolting and migrating to sea. The fish then grow rapidly at sea before returning after one winter, as grilse (1SW), or longer, as multi-sea-winter (MSW) salmon. The species is currently in decline in many parts of its range, probably due in large part to reduced survival at sea (ICES, 2014). This pattern of decline has focussed attention on the need to maximise the output of high quality smolts from rivers to mitigate, where possible, reductions in numbers of returning adults.

The numbers of smolts produced in river systems are limited by the availability of suitable habitat, which varies with fish size, and the presence of competitors and predators (Armstrong and Nislow, 2006). Stocking of early life stages is therefore likely to invoke competition with wild-reared fish (Metcalfe et al., 2003). A potential option for increasing production of smolts beyond the capacity of the river is to rear salmon in aquaculture facilities and stock them into the river only when they are ready to migrate to sea. This process is termed “ranching”. Salmon are believed to imprint on specific odour cues during their out-migration and to use these to locate home reaches on their return to fresh water (e.g. Hasler and Sholz, 1983). Hence, ranched fish are stocked in rivers above the site to which they are required to return.

Although the technique of ranching salmon has been advocated by some fishery managers in Scotland, there appears to have been little formal analysis of the method in the Scottish context. Such information is important for evaluating the economies of potential fisheries based on ranching, and for assessing aspects of the value of the method for conservation purposes. Although there has been some review of a range of studies of survival of either wild or hatchery-reared smolts in the UK and Ireland (Aprahamian et al., 2003), only the studies of marine survival in the River Bush (Crozier and Kennedy, 1993) and the Burrishoole system (Piggins and Mills, 1985) have directly compared the two categories of fish during the same years within the same river system.

To investigate the effectiveness of smolt ranching as a tool to enhance local salmon fisheries, we examine first, the range of recapture rates from monitored smolt releases in Scottish rivers and second, we compare returns from hatchery and wild-reared smolts originating from the same stocks released concurrently at the same river sites. We then consider a range of practical issues associated with operating a smolt ranching scheme on a Scottish river, both for conservation and fishery enhancement purposes, and then, using best available information, assess the likely financial implications.

Materials and methods

Rod-caught recaptures from hatchery-reared smolts

Hatchery-reared smolts were released in four Scottish river catchments (Figure 1, Table 1) in the period 1987-2000. In all cases stocked smolts were the progeny of local-caught adult fish. On the Rivers Dionard, Conon and Tay, brood stock was collected annually, close to spawning, in late autumn. Crosses of mature fish were made randomly within

groups, and the resultant offspring were reared in tanks. On the River Lochy, smolts were derived from brood stock of Lochy origin that had been bred in captivity for several generations (number unknown) by a commercial fish farm operator and were cage-reared. In all cases hatchery-reared smolts were fed a diet of commercial pelleted fish food.

Stocked smolts were selected on size (>100 mm) and evidence of smolting (silvering, blackening of fins). Using standard procedures, each fish was anaesthetised, tagged with a coded wire microtag (CWT) and adipose fin-clipped to aid recognition. The tagging process took place up to several weeks before the fish were stocked and stocking took place in spring (i.e. mid. April to mid. May). On the Rivers Lochy and Conon, smolts were released as one-year-olds (S1s), whereas those released on the Dionard and Tay comprised both S1 and two-year-old (S2) fish. As there were no significant differences in the recapture rates of S1s and S2s stocked in the Tay in the same years (Fishers exact test; p=0.404) the two categories have been combined. In years when S1s and S2s were both released in the Dionard , the recaptures generated were insufficient to allow comparisons (Table 1). Tagged fish were transported and released at sites within or upstream of the main fishing beats, generally in the lower sections of the rivers ca. 5-15 km above the head of tide. In most cases, stocked smolts were released directly into rivers. The exceptions were those stocked in the River Dionard when in three of four years a proportion (unknown) of the stocked fish was held in release pens for a period prior to release.

Comparative smolt releases

Comparisons were made of wild and hatchery-reared smolts from the River Conon (2 years) and the River Tay (1 year). Hatchery smolts were batch-stocked as S1s on the Conon and as S2s on the Tay. Several days prior to release, stocked smolts were tagged with Passive Integrated Transponders (PITs, Conon) or with CWTs (Tay). Wild-reared smolts were trapped as downstream migrants in a fixed trap (Conon) or in a modified Fyke net (Tay) and were tagged and released on the day of capture. Two release sites were used on the Conon: Conon Bridge (NH542560), close to the head of tide, and Torrachilty (NH448544), ca. 10 km upstream from the sea (Table 2). The Tay release site was in the middle reaches of the River Braan tributary (NN939384) ca. 45 km from the sea (Table 2). In both rivers the release of hatchery smolts was timed to coincide with the period of peak smolt migration for wild fish in April. Returns of tagged fish to the Conon were detected using an automatic PIT detection system located in a fish pass at Torrachilty Dam, below the point where the fish were reared. Returns to the

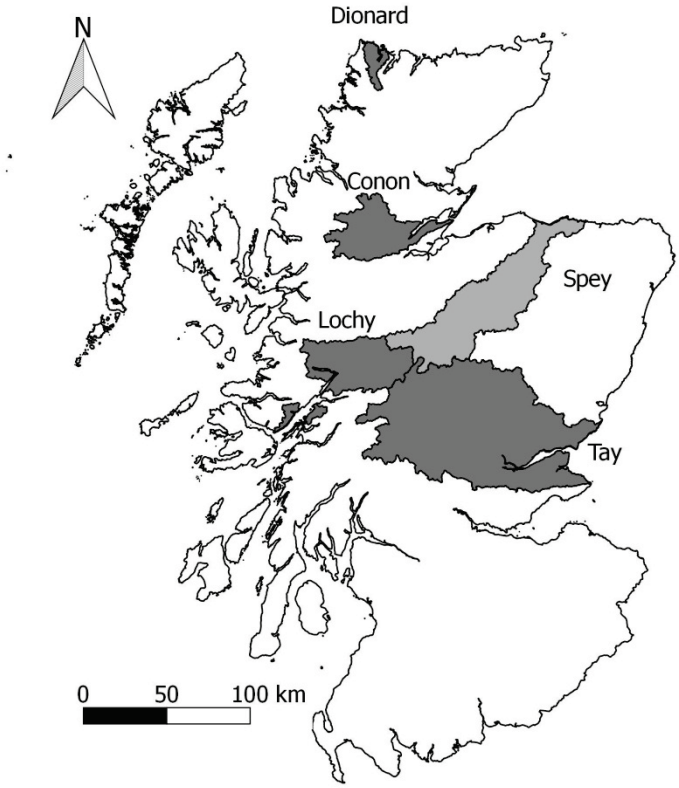
Tay were from recaptures of tagged adult fish reported from commercial net and rod fisheries.

Recaptures of tagged fish

The tagging programmes were publicised widely within the river catchments used for smolt releases. As an incentive, a reward together with tagging information was offered to captors of tagged fish and posters with contact details were displayed in fishing huts and local tackle shops. In addition, on the Rivers Lochy, Dionard and Conon, daily inspections of catches were undertaken by trained ghillies on the main angling beats. Heads of fin-clipped fish were retained and tags later excised and decoded at the Freshwater Fisheries Laboratory, Pitlochry.

Recaptures were also reported from commercial coastal and river/estuary nets and reductions in coastal netting occurred over the course of the study. The Tay releases are therefore represented by two distinct periods. In the earlier period (1991-1994) nets accounted for the majority of reported recaptures (overall 41 compared with 5 rod-caught fish). From 1996-1998 declines in coastal netting and the cessation of a net and coble fishery that operated within the river in 1995, led to an increase in the percentage of rod-caught fish reported from the Tay (Fishers exact test; $p < 0.001$). A seasonal net and coble fishery also operated in the Conon estuary but reported no recaptured fish. There was no commercial netting in the lower reaches or estuaries of the Rivers Lochy and Dionard during the course of the study.

Figure 1. Map of Scotland showing salmon fishery districts with rivers used for smolt stocking experiments (dark shading). Also shown is the Spey salmon fishery district (light shading) where a study on the economic impact of salmon rod fisheries to the local economy was conducted in 2003 (Butler et. al. 2009).



Results

Rod-caught recaptures from hatchery-reared smolts

The release of 90,073 tagged smolts into four river catchments over a twelve year period resulted in 48 tagged adult fish reported caught by anglers in the river of release (Table 1). Most recaptures (42) were caught as 1SW fish with the remainder (6) caught as two-sea-winter (2SW) fish (Table 1).

There was considerable variation between rivers and years with the best returns recorded from releases on the Dionard (1992) and Tay (1997), when each rod-caught

salmon was generated by the release of c. 450 smolts. In contrast, zero returns were recorded on five occasions on three different rivers (Table 1). Overall, combining both sites and years, each rod-caught fish that was reported required the release of c. 1800 hatchery-reared smolts.

Table 1. Rod-caught recaptures from tagged hatchery-reared smolts released in four Scottish rivers between 1987 and 2000. Recaptures from the Tay are represented by two periods: before (1991-94) and after (1996-98) commercial netting in the river ceased.

River	smolt year	number stocked	recaptures		percentage
			1SW	2SW	
Lochy	1987	5140	3	0	0.06
Lochy	1988	5184	1	0	0.02
Lochy	1989	4841	0	0	0
	1987-89	**15165**	**4**	**0**	**0.03**
Dionard	1991	8043	10	1	0.14
Dionard	1992	6462	13	2	0.23
Dionard	1993	5660	0	0	0
Dionard	1994	5743	0	0	0
	1991-94	**25908**	**23**	**3**	**0.10**
Tay	1991	10460	1	1	0.03
Tay	1992	3140	1	0	0.06
Tay	1993	2120	2	0	0
Tay	1994	2067	0	0	0
	1991-94	**17787**	**4**	**1**	**0.03**
Tay	1996	3459	4	1	0.17
Tay	1997	1304	3	0	0.23
Tay	1998	3174	2	1	0.13
	1996-98	**7937**	**9**	**2**	**0.16**
Conon	1999	14145	1	0	0.01
Conon	2000	9131	1	0	0.01
	1999-2000	**23276**	**2**	**0**	**0.01**

Return rates from comparative releases

The percentage return rates of both wild and ranched salmon smolts differed between years and release sites and therefore are considered as within-year, within-site

comparisons (Table 2). In all paired tests wild-reared smolts gave higher return rates than hatchery-reared smolts. In cases where there was at least one returning hatchery-reared fish, the average elevation in survival of wild compared with reared salmon was ten-fold (range 6 to 13-fold).

Table 2. Adult returns from comparative releases of wild and hatchery-reared smolts. Returns on the River Conon were derived from automatic data loggers. Returns on the River Tay were from captures reported from net and rod fisheries. P values were determined using Fishers Exact test.

River	smolt year	release site	origin	total	mean length in mm (SD)	adult returns	%	P value
Conon	2002	Conon Bridge	wild	491	120 (9.6)	6	1.22	
		Conon Bridge	reared	497	115 (4.0)	0	0.00	0.015
		Torrachilty	wild	688	120 (9.7)	19	2.76	
		Torrachilty	reared	485	114 (4.2)	1	0.21	<0.001
	2006	Torrachilty	wild	998	122 (9.0)	43	4.31	
		Torrachilty	reared	1028	119 (8.3)	7	0.68	<0.001
Tay	1992	River Braan	wild	253	127 (9.6)	15	5.93	
		River Braan	reared	3140	142 (11.1)	17	0.54	<0.001

Discussion

The study revealed that rod capture rates of hatchery-reared salmon smolts returning to Scottish rivers ranged between 0 and 0.23% of fish stocked, with the majority (87.5%) of recaptures caught as 1SW fish. Capture rates are the product of number of returning fish and exploitation rate. On the River Spey (Scotland), recapture rates were 2-25%, with the highest rates occurring in fish tagged in spring and lowest rates in those tagged in summer and autumn (Thorley et al, 2007). It appears that in general, MSW salmon are more vulnerable to capture by angling than 1SW fish (Gee and Milner 1980; Erkinaro et al. 1999; Thorley at al. 2007). Rod exploitation rates are known to vary among regions, river catchments, and component stocks. For example, on Icelandic rivers exploitation rates may be 36-85% (Johannsson et al. 1996). On the Tana River (Norway) Erkinaro et al. (1999) report rates of 29% for 1SW salmon and 51% for MSW fish. By contrast, more southerly rivers appear to have exploitation rates more similar to

those on the Spey. On the River Bush (Ireland), Crozier and Kennedy (2001) found that rod exploitation rates of mainly 1SW fish were 10.9% for wild fish and 11.1% for ranched salmon. Whereas on the River Burrishole (Ireland) exploitation of ranched fish, again predominantly 1SW, was 10.8% (Mills and Piggins, 1983).

The recapture rates of rod-caught fish from CWT tagged smolts reported must be considered minimum values, as it was not possible to account for any non-reporting of tags or tag loss that may have occurred. However, this is not a consideration concerning the PIT tagging experiments on the River Conon in which returning fish were detected automatically. Accounting for expected angler exploitation rates, the low returns of hatchery-reared fish on the Conon are of the same order as those from coded wire tagging experiments.

In comparative tests the magnitude of difference in favour of wild-reared smolts found on Scottish rivers was approximately 10-fold and therefore of similar order but in some cases higher than in other regions. For example, 3-fold on the River Imsa (Norway) (Jonsson et al. 2003) and 4.5-fold on the Simojoki river (northern Finland) (Saloniemi et al., 2004). In Ireland, survival of wild compared to hatchery-reared smolts on the River Bush (Crozier and Kennedy, 1993) was 4 to 8-fold, whereas on the Burrishoole system, return rates of wild smolts were on average 5-fold greater (Piggins and Mills, 1985). On Iceland's Ellioaár River, Isaksson (1979) reports survival of microtagged wild smolts approximately 7-fold higher than directly planted hatchery-reared smolts.

It is well established (Einum and Fleming, 2001; Weber and Fausch, 2003; Jonsson and Jonsson, 2006) that artificial rearing of salmonid fishes affects their subsequent biology. In captivity they are held at high densities relative to wild-reared fish, feed primarily on artificial food and may lack the abilities to recognise and catch wild prey effectively. Compared with wild-reared fish, hatchery-reared salmon are a different shape, have lower swimming capabilities, reduced social awareness, and poorer predator recognition and escape behaviours. Indeed, the overall brain mass is smaller in hatchery than in wild-reared salmonids, probably reflecting the simpler environment in which they grow (Lema et al*.,* 2005; Kihslinger et al*.,* 2006). It appears that the longer fish are kept in artificial rearing facilities before they are released, the less well adapted they are to survival in the wild (Milot et al. 2013; Young, 2013). Therefore, poor survival of hatchery-reared smolts is to be expected. Despite extensive periods of stocking on the Rivers Tyne and Thames (England) with both hatchery-reared parr and smolts as part of a rehabilitation programme, both Milner et al. (2004) and Griffiths et al. (2011)

concluded that natural processes (recolonisation, improved water quality, better access) were more important to recovery than initial pump-priming with hatchery-reared fish. Similarly, on the River Sundalslagen, western Norway, extensive stocking with hatchery-reared parr and smolts over a ten year period was estimated to have produced between 0.003 (one for c. 33,000 stocked fish) and 0.028% (one for c. 3,570 stocked fish) rod recaptures to the river, and it was concluded that in most years the number of wild fish taken for brood stock exceeded the number of adult fish recaptured from their offspring (Saltveit, 2006).

From a fisheries enhancement perspective, any hatchery programme is usually required to be economically viable. The production of approximately 250 hatchery-reared S1s was required to generate each returning adult to the River Conon. At an assumed exploitation rate by the rods of 10% (similar to rates found in Irish rivers, Mills and Piggins, 1983; Crozier and Kennedy, 2001, and within the range found on the nearby River Spey, Thorley et al*.,* 2007), it would have required the production of 2500 smolts for each rod-caught adult. At an estimated £1.50 $smolt^{-1}$ (S. McKelvey, unpublished data) the cost of each rod-caught fish would have been £3750. This cost needs to be weighed against the economic benefits brought to the fishery which, according to Aprahamian et al*.* (2003), can be calculated from the additional number of fish caught multiplied by their capital value. Using a capital value for 1995 of £5925 (Postle and Moore, 1996), it is evident that the proposed capital gain of each ranched fish exceeds the costs of producing it, even before adjusting for inflation. However, it is questionable whether such an approach is robust because the value of the fishery might be maintained only by continual, annual investment. Hence, any capital gain would be outweighed by smolt rearing costs after only two years. An alternative approach is to consider the benefit to households from fishing revenue. Butler et al*.* (2009) calculated that each salmon caught on the River Spey in 2003 was worth £970 to annual household incomes. Using this approach, the annual benefit of each hatchery-reared rod-caught salmon (£970) is far less than the cost of producing it (£3750).

In reality, such simple calculations are unlikely to capture the essence of the values of rearing fish to the economies that they support. For example, there is no account taken of season caught, method of capture or size of fish. All of which may act to influence value. Also, it is unlikely that there is a simple linear relationship between rod catches and expenditure by anglers. In some cases, the fact that fish are being stocked may itself stimulate increased expenditure associated with a fishery, regardless of the actual survival of the fish. However, an understanding of the survival and production costs of

hatchery-reared smolts is useful for enabling well-founded decisions on allocation of resources to options for restoring, maintaining and enhancing fisheries.

If ranching salmon is to be employed as a tool for enhancing fisheries in Scotland, then it is probably important to consider what measures can be taken to enhance smolt quality and hence marine survival, and at what additional cost. There are further considerations beyond finance. For example, there is a potential for hatchery-rearing to increase levels of unfit genes in wild populations (Araki et al. 2009; McGinnity et al., 2009; Christie et al. 2012). There may also be potential for large numbers of stocked smolts to attract predators that then deplete numbers of wild-reared salmon. However, the general extent and likelihood of such hazards remains to be evaluated.

Acknowledgements

We thank Scottish and Southern Energy for financing aspects of the study. We also thank our colleagues Bob Morgan, Gordon Struthers and Alisdair MacDonald for helping to organise and for assisting with the earlier tagging programmes, and Stuart Middlemas for assistance with reporting. The work was carried out with the support of landowners and local fishery managers to whom we are grateful.

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St Andrew's House
Edinburgh
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ISBN: 978-1-78544-330-5 (web only)

Published by The Scottish Government, May 2015

Produced for The Scottish Government by APS Group Scotland, 21 Tennant Street, Edinburgh EH6 5NA
PPDAS49140 (05/15)