Spring salmon on the River South Esk, Scotland

Scottish Marine and Freshwater Science Vol 7 No 10

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This report presents the results of marine and freshwater scientific work carried out by Marine Scotland Science.

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Executive Summary

Throughout the text, “spring salmon” and “spring fish” are used interchangeably to refer to an Atlantic salmon *Salmo salar* (L.) that either enters a river and / or is caught in either net or rod fisheries before the end of May in any given year.

Background and aims

There has been a decline in the abundance of Atlantic salmon at sea across much of its geographical range over the last four decades. This rate of decline has varied among individual stock components as indicated by reported rod catches across months of the year. Thus, although rod catch as a whole has shown an increase over the last 50 years, the numbers of spring salmon in the catch have declined markedly. The decline in rod catches of spring salmon has abated in recent years in many Scottish rivers. However, catches of spring fish in the River South Esk have continued to decline.

The decline in spring salmon catches in the River South Esk has stimulated extensive debate about the potential for management interventions. In 2010, the Esk District Salmon Fishery Board applied to the Scottish Government for measures that were designed to reduce overall exploitation on the spring component of the salmon stock and also the sea trout stock in the River South Esk. Marine Scotland Science advised that application of their Rod Catch Tool confirmed a significant decline. They further advised investigation of possible causes to establish the need and potential for mitigating actions. Scottish Ministers acknowledged that there may be issues with these stocks raising particular concerns in view of the status of the River South Esk as a Special Area of Conservation for salmon. In view of the shortage of information available locally, Ministers instructed Marine Scotland to carry out a project to investigate the spring component of the River South Esk salmon stock.

The ensuing three-year investigation addressed the following questions:

- In which geographic region of the River South Esk do spring salmon spawn?
- How does the status of the juvenile salmon stock vary within the River South Esk and how does this relate to spawning regions used by spring fish?

- Is it possible to assess to what extent changes in rod fishing effort have accounted for the declining trend in rod catches of spring salmon?

- What proportion of the catch from the coastal net fishery adjacent to the River South Esk was destined to spawn in the River South Esk?

The outcome of this investigation is summarised in this report.

Spawning locations of spring fish

Between 2012 and 2014, 245 spring salmon were sourced from either the coastal net fishery adjacent to the River South Esk (in 2012 and 2013), or the lower reaches of the river itself (in 2013 and 2014). A miniature radio transmitter was inserted into each fish so that they could be tracked to their spawning locations. Genetic samples were taken from each of these fish, and many other salmon from the nets, with the aim of relating genetic variation to geographic population structuring within the South Esk catchment.

Altogether, 24 spring salmon were tracked successfully until spawning time over three years. Of this sample, 20 fish (83.3 %) spawned in the upper catchment in either Glen Clova (16 fish) or Glen Prosen (4 fish). The other 4 fish (16.7 %) spawned in the middle reaches of the river.

It was not possible to use genetic tools (single nucleotide polymorphisms - SNPs) to identify geographic origins within the catchment due to relatively low levels of genetic differentiation between the geographic areas investigated.

The status of the juvenile salmon stock

Multiple-pass electrofishing was conducted in the River South Esk in 2013 and 2014 in sites from both the upper and lower catchment. These data were supplemented with historical data gathered in 2004, 2005 and 2011. The observed density of salmon fry at each site was compared with a national average abundance associated with broadly similar conditions. Model residuals (observed - expected) were examined to see whether sites were performing better or worse than expected in comparison with the national level.

Nine out of the thirteen sites surveyed in the upper South Esk during 2014 remained above expectation, providing reasonable evidence that the upper catchment as a whole was well populated by salmon fry relative to the average national expectation. Furthermore, sites in the upper catchment were generally more productive for salmon relative to expectations than those in the lower catchment. In the upper catchment, sites in Glen Clova were generally better than those in Glen Prosen. In the lower catchment, sites in the Pow Burn and the Lemno Burn were notably poor for salmon fry, whereas high densities of salmon fry relative to expectation were present in the Noran Water.

Spring rod fishing effort

The six rod fisheries that contribute most to the spring salmon rod catch on the River South Esk were contacted and information on fishing effort was requested. Effort data, in the form of bookings from 2002 to 2012, were received from one fishery proprietor. “Low definition” data for 2002 to 2006 indicated whether or not a given beat was let on a given day. “High definition” data for 2007 to 2012 also included information on the number of rods booked on each beat day let.

Trends in catch per unit of effort (CPUE) varied from trends in reported catch. It was also possible to identify trends in the high definition data which were not apparent in the low definition data. It is concluded that while measuring fishing effort may increase the reliability of fishery data as a proxy for stock abundance, such data need to be of a sufficiently high quality.

Geographic exploitation of the coastal net fishery

Radio tagged spring salmon sourced from the coastal net fishery in 2012 and 2013 were used to estimate the proportion of the catch destined to spawn in the River South Esk.

Tagged fish were detected in several major rivers in the northeast and east of Scotland including the Spey, Don, Dee (Aberdeenshire), North Esk, South Esk and Tay. The proportion of the catch destined to spawn in the River South Esk was estimated at 8 % to 25 % in 2012, and at 11 % to 29 % in 2013.

Genetic methods (SNPs) could not be used to determine the representation of different rivers stocks in the nets. This was because there is not enough differentiation detectable among the large east coast rivers.

Conclusions

In conclusion, considering the early running component of the River South Esk salmon stock, the majority of fish spawn in the upper catchment, and it is encouraging that densities of salmon fry in this area are generally as good as or better than expected. The limited available rod fishing effort data suggest a decline in angling effort for spring fish coinciding with a reduction in CPUE in recent years. Between 8 % and 29 % of the spring salmon catch from the coastal net fishery adjacent to the River South Esk was estimated to be destined to spawn in the River South Esk.

Acknowledgements

We are grateful to colleagues from Marine Scotland involved in the project, anglers (for donating fish for tagging), an anonymous fishery proprietor (for supplying rod effort data), Charlie Gow (for permitting the in-river net), HJS Helicopters Ltd. and PDG Helicopters (for aerial surveying), riparian landowners and fishery proprietors (for permitting access to their land), the River Dee Trust, the Spey Foundation and the Tweed Foundation (for deploying receiver stations), and Usan Salmon Fisheries Ltd. (for supplying fish for tagging).

Part 1: Introduction

1.1 THE PROBLEM

The abundance of Atlantic salmon at sea has declined across much of its geographical range over the last four decades (ICES, 2015). In Scotland, a reduction in coastal net fisheries has compensated to a large extent for this decline so that until recent years rod catches have tended to increase and spawning populations have been largely maintained (Gurney *et al*., 2015). However, rod catches have declined for the component of the salmon stock that returns to rivers early in the year – “spring fish”. This decline may reflect a change in strength of the sub-stock and run timing such that salmon may tend to arrive later in the year.

Salmon tend to home to their natal stream and this has resulted in genetic structuring with salmon from specific areas of the catchment leaving and returning at particular times of the year (Laughton & Smith, 1992; Youngson *et al*., 1994; Stewart *et al*., 2002; 2006). Direct counts of salmon in two tributaries in the Aberdeenshire River Dee known to be used by spring salmon have identified a trend in numbers of spawning fish that mirrors rod catches more generally. Across most rivers in Scotland, the decline in rod catches of spring salmon has abated over the last decade (Anon., 2015*a*). However, this has not been the case in the River South Esk, where catches of spring salmon have continued to decline (Figure 1.1.1).

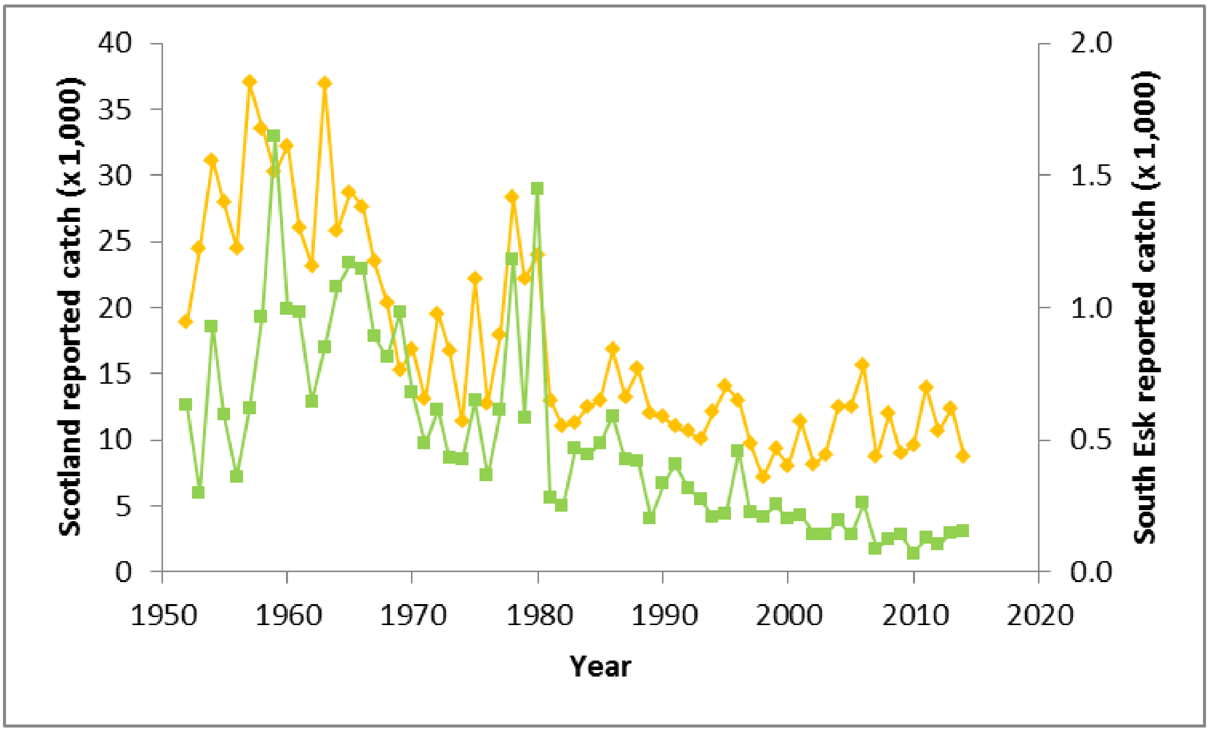


Figure 1.1.1: The total reported rod catch of Atlantic salmon for Scotland (—) and for the South Esk District (—), 1952 to 2014, spring data (February to May inclusive).

Concern over the decline in spring salmon in the River South Esk has stimulated extensive debate about the potential for management interventions. In 2010, the Esk District Salmon Fishery Board applied to the Scottish Government for measures that were designed to reduce overall exploitation on the early running component of the salmon stock and also sea trout stock in the River South Esk. Scottish Ministers responded by acknowledging that there may be issues with these stocks, noted the shortage of relevant information obtained locally, and instructed Marine Scotland to carry out a three-year demonstration project to investigate the reasons for decline in spring salmon rod catches on the River South Esk. The ensuing investigation addressed the following questions:

- In which geographic region of the River South Esk do spring salmon spawn?
- How does the status of the juvenile salmon stock vary within the River South Esk and how does this relate to spawning regions used by spring fish?
- Is it possible to assess to what extent changes in rod fishing effort have accounted for the declining trend in rod catches of spring salmon?
- What proportion of the catch from the coastal net fishery adjacent to the River South Esk was destined to spawn in the River South Esk?

The outcome of this investigation is summarised in this report.

1.2 THE RIVER

The River South Esk catchment is situated in Angus on the east coast of Scotland and drains an area of approximately 564 km^2 (Figure 1.2.1). The river is approximately 79 km long and rises at an altitude of approximately 975 m on the slopes of Cairn Bannoch (1012 m) in the Eastern Cairngorms (River South Esk Catchment Partnership, 2009; SNIFFER, 2011*a*). In its upper reaches, the River South Esk comprises two distinct stems: the main river initially draining Glen Clova; and the Prosen Water (Figure 1.2.2). These stems join just downstream of Cortachy and the river then flows across fertile agricultural land, passing through the town of Brechin before entering the tidal Montrose Basin and ultimately the North Sea at Montrose (Figure 1.2.2).

For the purposes of this study, the upper catchment was defined as anywhere upstream of the junction of the Quharity Burn with the main stem of the River South Esk (Figure 1.2.3). There is a noticeable change in geography here: downstream of this point is characterised by the relatively flat lowlands; upstream of this point, the Prosen Water and the main stem of the River South Esk drain their respective glens in an upland environment.

The river plays a significant role in the local economy, supporting farming, forestry, fisheries, leisure and tourism. The river is ecologically important, providing home to internationally significant populations of Atlantic salmon and freshwater pearl mussels. For these species, the River South Esk is designated a Special Area of Conservation (SAC) under the European Union (EU) Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora, commonly known as the Habitats Directive (River South Esk Catchment Partnership, 2009; SNIFFER, 2011*a*).

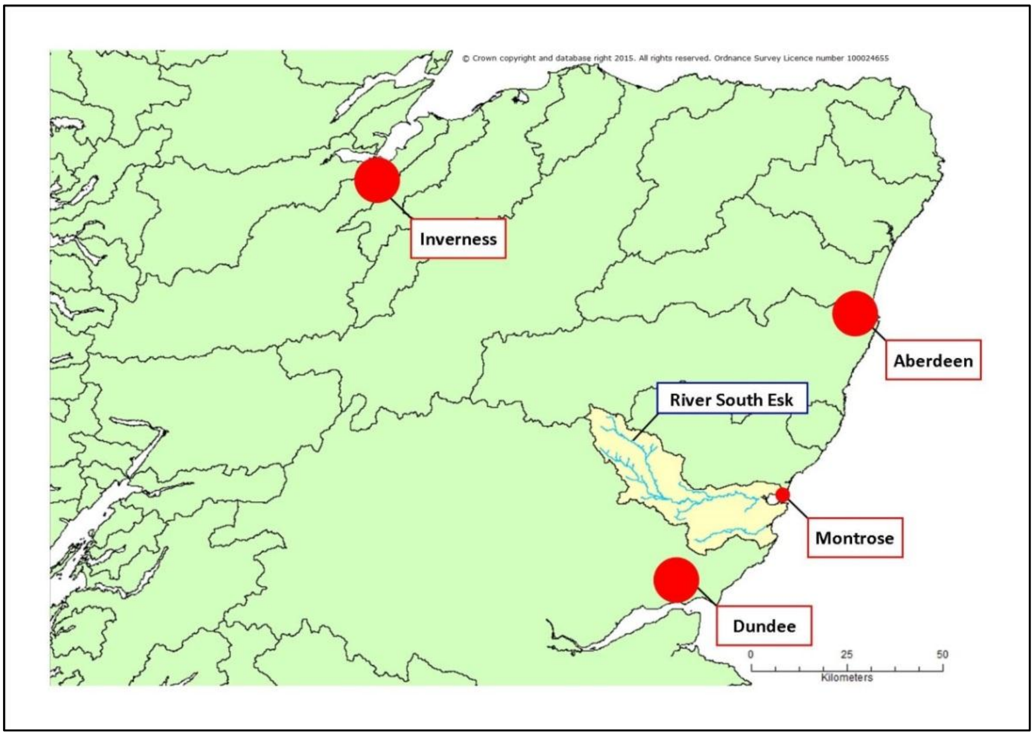


Figure 1.2.1: Location of the South Esk catchment in northeast Scotland. The river enters the sea at Montrose.

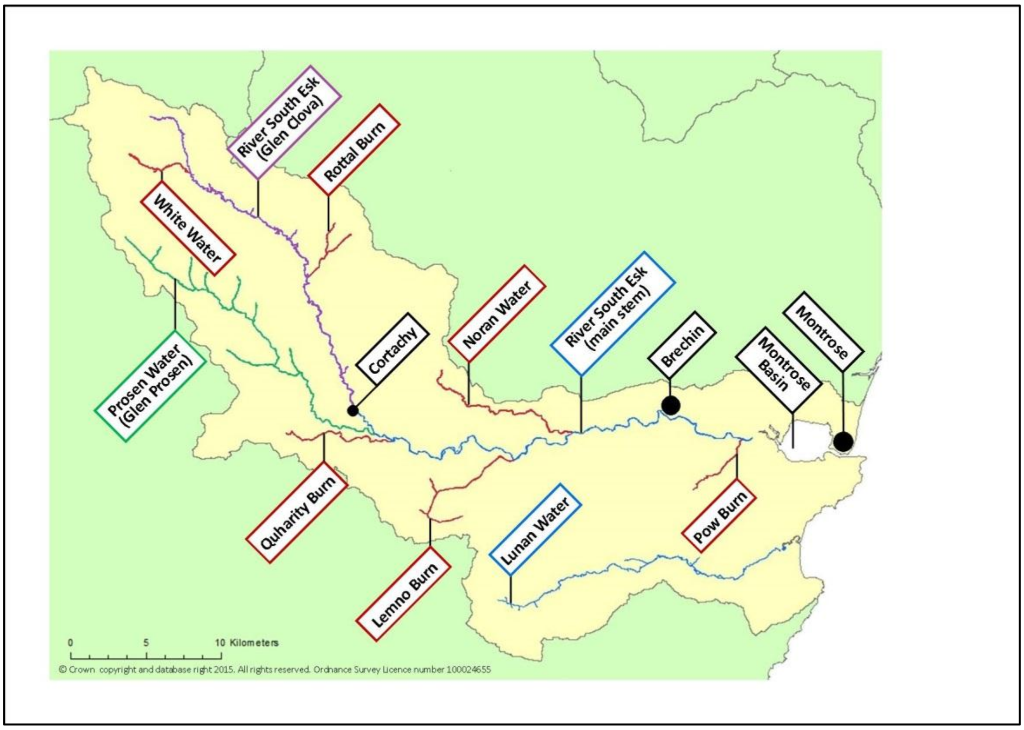


Figure 1.2.2: The South Esk catchment showing the positions of major features including the River South Esk in Glen Clova and the Prosen Water in Glen Prosen, the main stem of the River South Esk, major tributaries, significant settlements and Montrose Basin. Montrose and Brechin, the largest towns in the catchment, are shown by large black dots. Cortachy, a small settlement near the bottom of Glen Clova, is indicated by a small black dot.

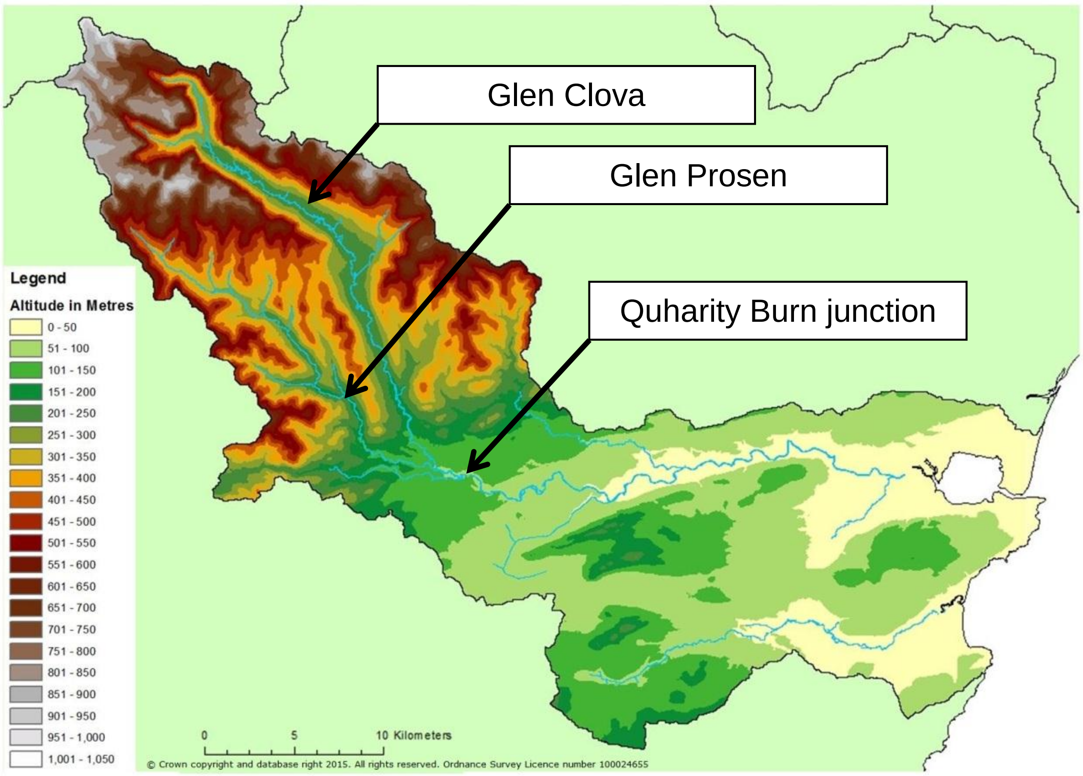


Figure 1.2.3: Relief map of the South Esk catchment showing the obvious change from the upper catchment to the lower catchment at approximately the junction of the Quharity Burn with the main stem of the River South Esk.

1.3 SALMON FISHERIES IN THE SOUTH ESK DISTRICT

There are three main types of gear used to fish for salmon in Scotland - fixed engines, net and coble, and rod and line. All three types of gear have been deployed in the South Esk District for at least part of the period from 1952 (when records began) to 2014.

Effort

Fixed engine fisheries are restricted to the coast and must be set outside estuary limits. Fixed engines have operated in the South Esk District every year from 1952 to 2014. Reported annual netting effort in the fixed engine fishery in the South Esk District peaked in 1972 and has declined over much of the period since (Figure 1.3.1*a*). In 2014, annual netting effort was the ninth lowest since records began in 1952. Reported spring netting effort (for the months of February, March, April and May) in the fixed engine fishery in the South Esk District also peaked in 1972 and has declined over much of the period since (Figure 1.3.1*b*). In 2014, spring netting effort was the second lowest since 1952.

Net and coble fisheries operate in estuaries and the lower reaches of rivers. A net and coble fishery operated in the South Esk District from 1952 until 1998. Reported annual netting effort in the net and coble fishery in the South Esk District peaked in 1972 and declined over much of the period since, until netting operations ceased in

1998 (Figure 1.3.1*a*). Reported spring netting effort in the net and coble fishery in the South Esk District peaked in 1974 and declined over much of the period since, until netting operations stopped in 1998 (Figure 1.3.1*b*). No net and coble fishery has operated in the South Esk District since 1998.

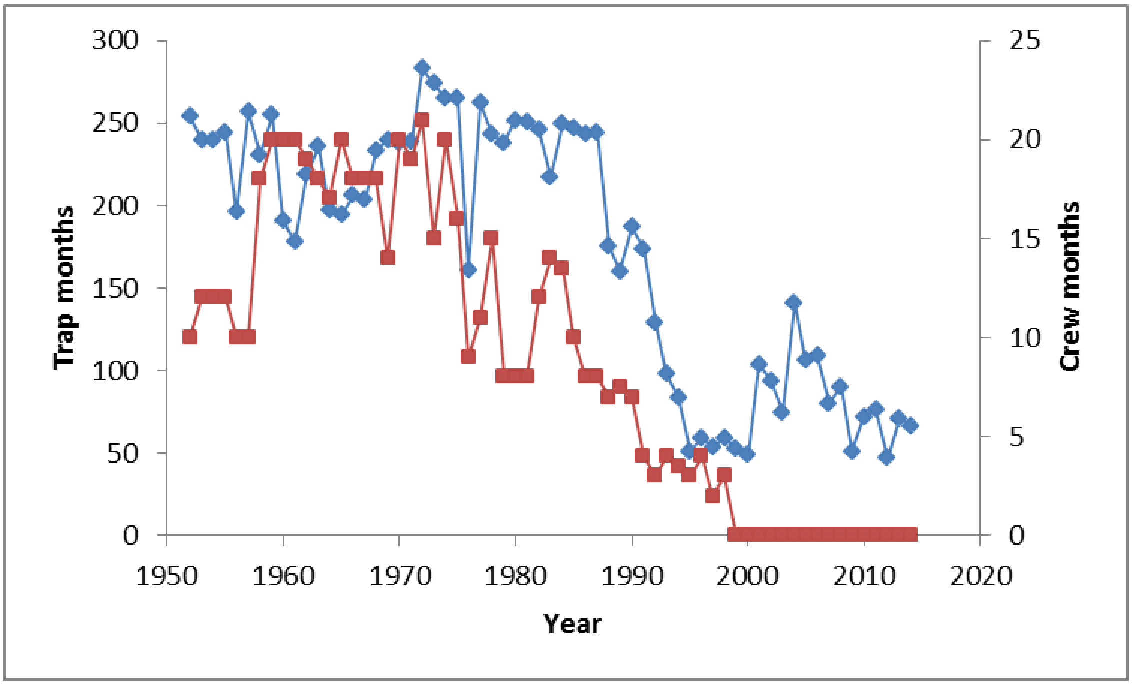


Figure 1.3.1*a*: Reported net fisheries effort in the South Esk District, 1952 to 2014, annual data. Data for the fixed engine fishery (—) and the net and coble fishery (—) are expressed as trap months and crew months respectively.

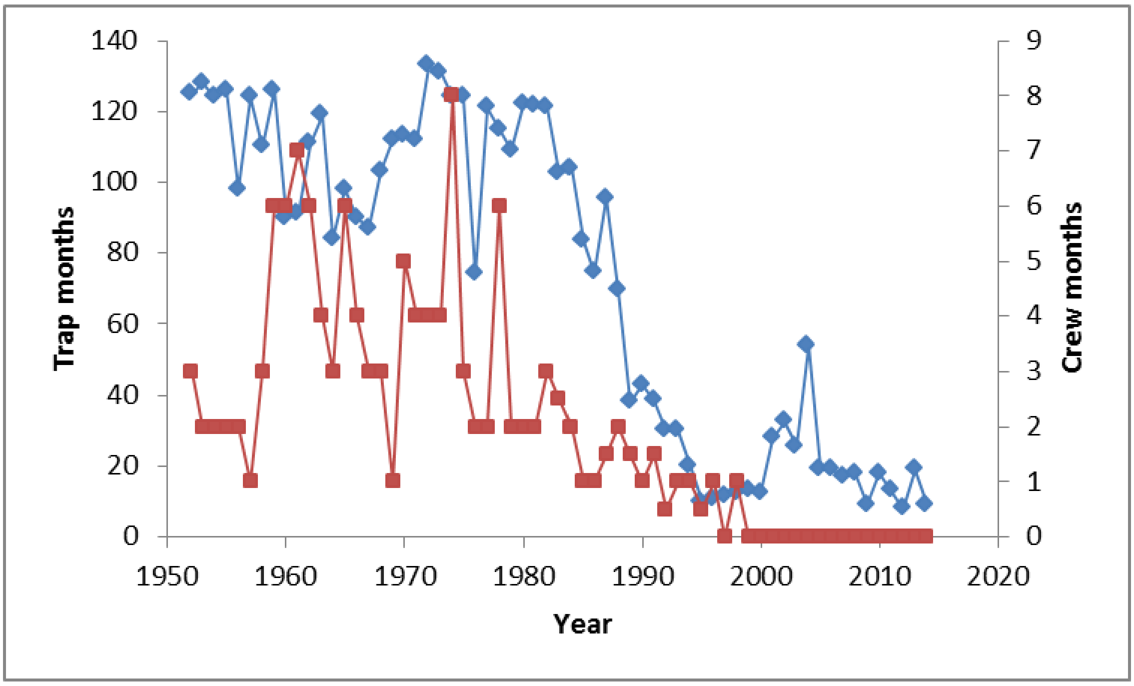


Figure 1.3.1*b*: Reported net fisheries effort in the South Esk District, 1952 to 2014, spring data (February to May inclusive). Data for the fixed engine fishery (—) and the net and coble fishery (—) are expressed as trap months and crew months respectively.

Rod and line is deployed extensively as a method for catching salmon on the River South Esk. There is no time series of fishing effort information associated with the rod and line fishery for the South Esk District.

Catch

The total annual and spring (February to May inclusive) reported nominal catches (i.e. the reported catch of retained salmon) in the South Esk District have declined over the period of recording (1952 to 2014) in all fisheries (Figures 1.3.2*a*, 1.3.2*b*, 1.3.3*a* and 1.3.3*b*). This is due to the combination of declining net catches throughout much of the period, the recent drop in reported rod catch and increasing incidence of catch and release in the rod and line fishery. The fixed engine fishery generally dominated both the annual (1.3.3*a*) and spring (1.3.3*b*) reported nominal catch over the time series. Nominal catch in the spring is comprised almost exclusively of multi-sea-winter (MSW) fish in all fisheries (1.3.2*b*).

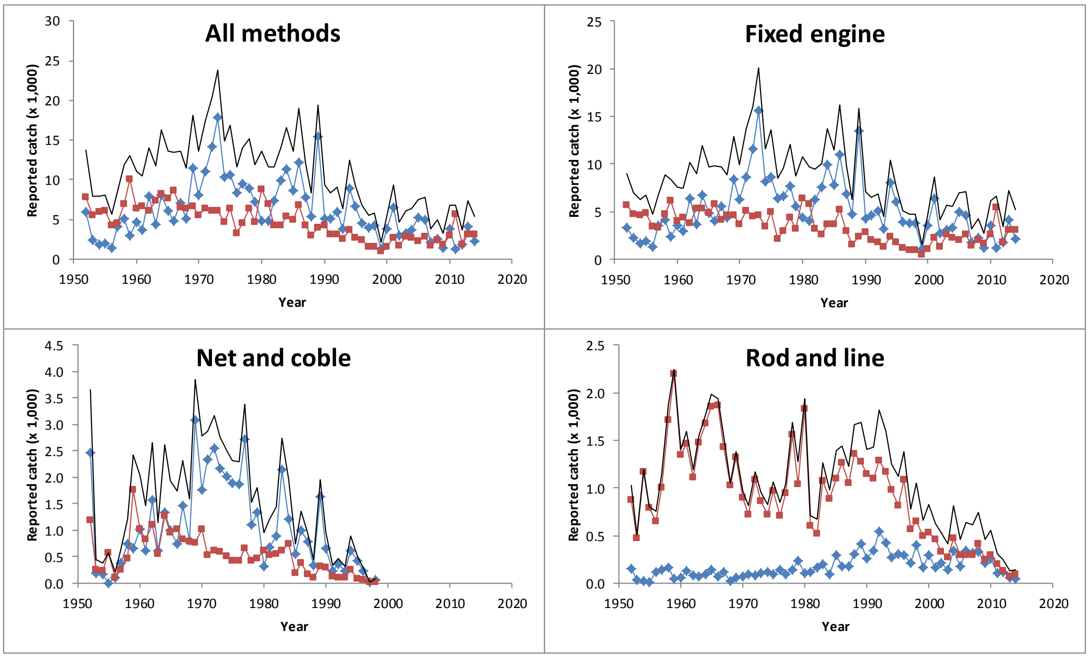


Figure 1.3.2*a*: Reported nominal catches of Atlantic salmon by fishing method and reported sea age in the South Esk District, 1952 to 2014, annual data. Data are shown for one-sea-winter (1SW) fish (—), MSW fish (—), and total catch (—). The net and coble fishery ceased operations in 1998.

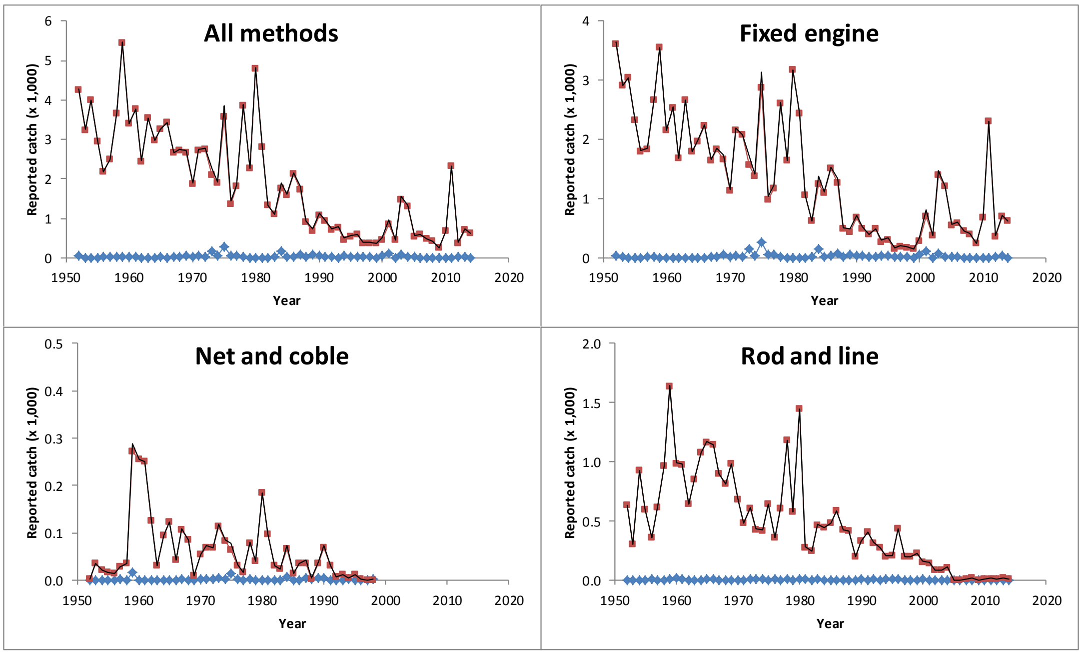


Figure 1.3.2*b*: Reported nominal catches of Atlantic salmon by fishing method and reported sea age in the South Esk District, 1952 to 2014, spring data (February to May inclusive). Data are shown for 1SW fish (—), MSW fish (—), and total catch (—). The net and coble fishery ceased operations in 1998.

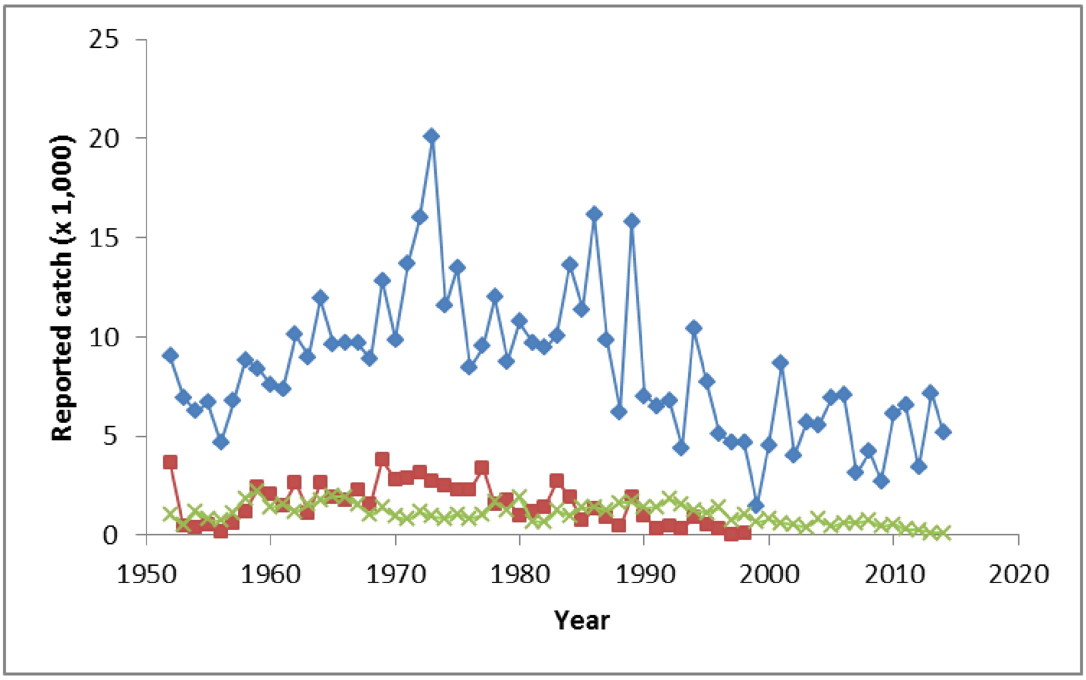


Figure 1.3.3*a*: Reported nominal catches of Atlantic salmon by fishing method in the South Esk District, 1952 to 2014, annual data. All reported sea ages have been combined. Data are shown for the fixed engine fishery (—), the net and coble fishery (—), and the rod and line fishery (—).The net and coble fishery ceased operations in 1998.

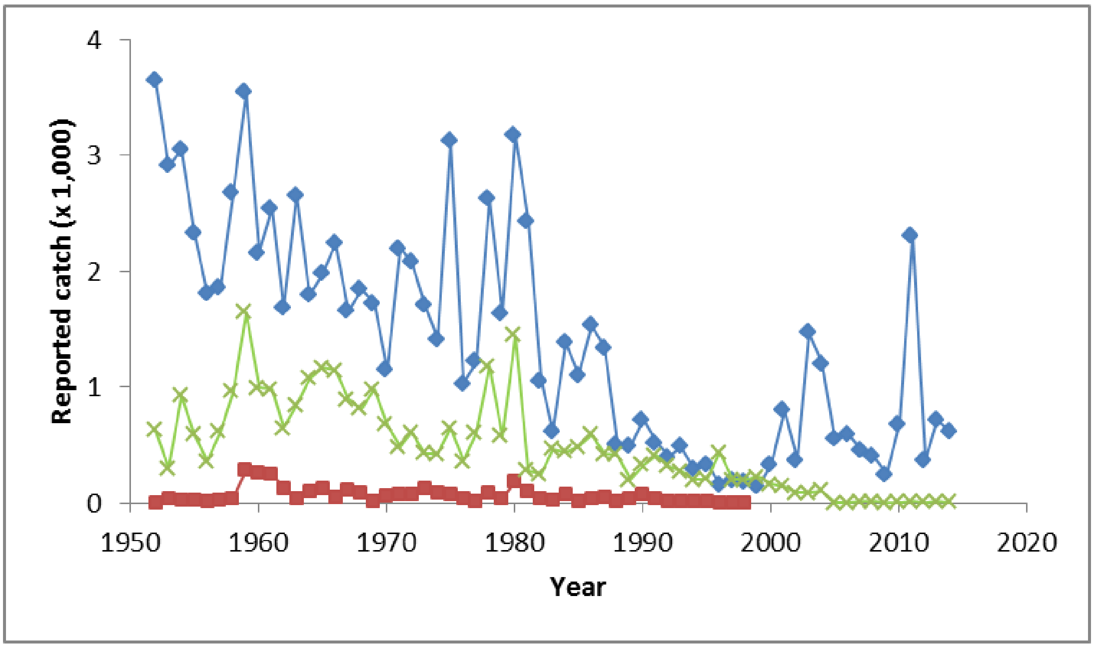


Figure 1.3.3*b*: Reported nominal catches of Atlantic salmon by fishing method in the South Esk District, 1952 to 2014, spring data (February to May inclusive). All reported sea ages have been combined. Data are shown for the fixed engine fishery (—), the net and coble fishery (—), and the rod and line fishery (—).The net and coble fishery ceased operations in 1998.

Catch and release in the rod and line fishery

The practice of catch and release in the rod and line fishery has been increasingly common since the early 1990s in Scotland, and reliable statistics have been collected since 1994. In the South Esk District, total annual reported rod catch of salmon and grilse has generally declined over the period 1994 to 2014 (Figure 1.3.4*a*). The proportion of the total annual reported rod catch accounted for by catch and release has generally increased over the same period, from 7.1 % in 1994 to 77.6 % in 2014 (Figure 1.3.4*a*). In the spring (February to May inclusive), total reported rod catch of salmon and grilse has shown a pronounced downward trend over the period 1994 to 2014 (Figure 1.3.4*b*). The proportion of the total spring reported rod catch of salmon and grilse accounted for by catch and release has generally increased over the same period, from 1.5 % in 1994 to 96.8 % in 2014 (Figure 1.3.4*b*). Thus, there has been an increasing tendency to release fish in the rod and line fishery over the period 1994 to 2014 such that in the early part of the time series, retained fish accounted for the majority of the reported rod catch. In recent years, however, released fish account for the majority of the reported rod catch, and this is particularly so in spring.

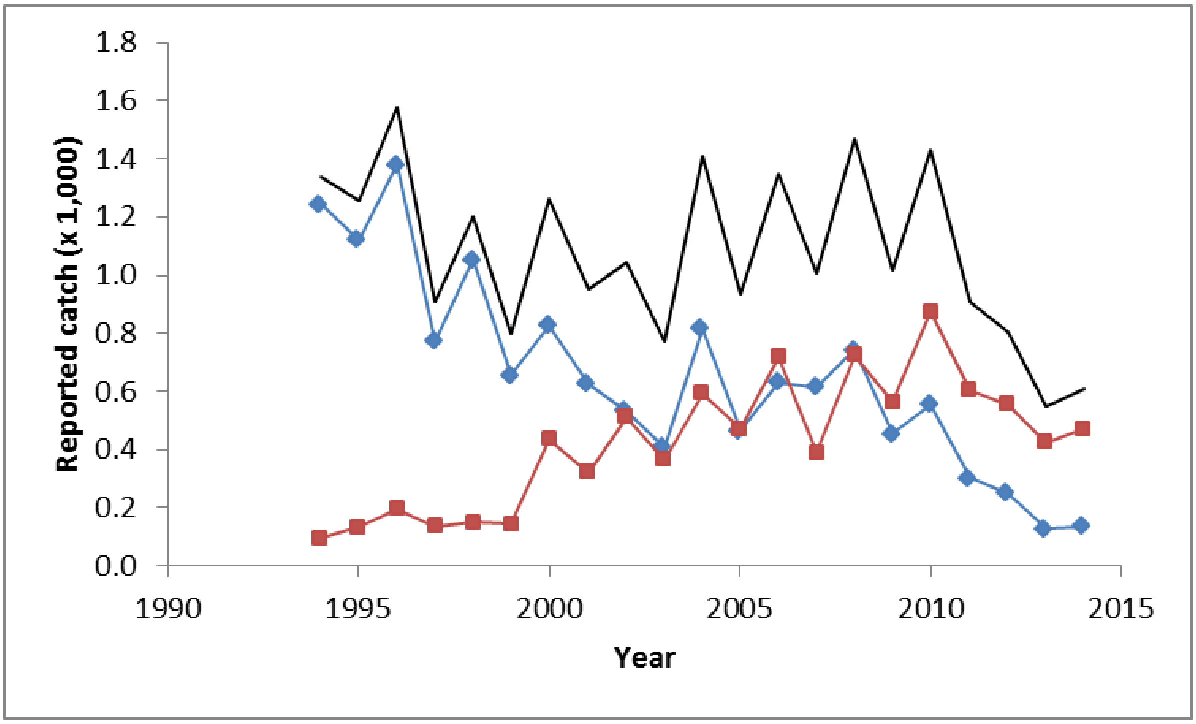


Figure 1.3.4*a*: The reported numbers of Atlantic salmon retained (—) and released (—) in the rod and line fishery in the South Esk District, 1994-2014, annual data (all sea ages combined). Total catch over the time series is shown (—).

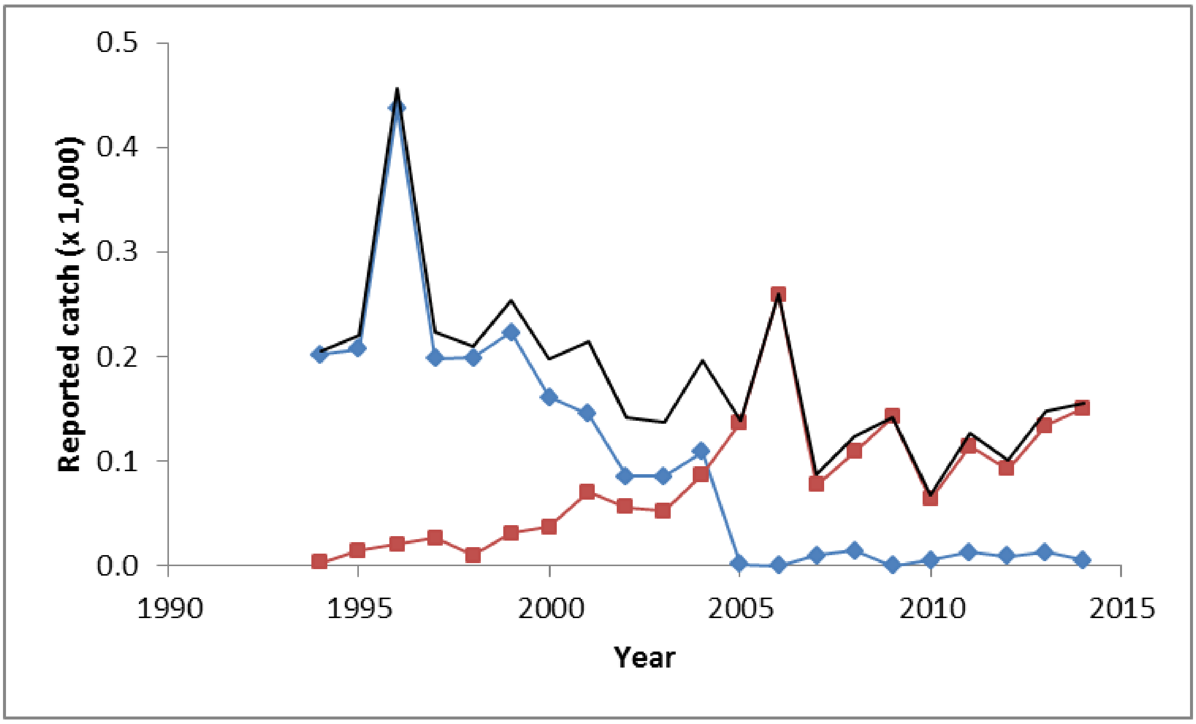


Figure 1.3.4*b*: The reported numbers of Atlantic salmon retained (—) and released (—) in the rod and line fishery in the South Esk District, 1994-2014, spring data (February to May inclusive, all sea ages combined). Total catch over the time series is shown (—).

Conservation measures in the spring

In the South Esk District, a compulsory restriction on all net fishing was first introduced in 2005. Under these restrictions, netting was prohibited in the Esk District Salmon Fishery Board area until the 01 May. At the same time, mandatory catch and release for rod fisheries was introduced from the beginning of the season (16 February) until the 31 May. These restrictions covered the 5-year period from 2005 to 2009 after which time a similar voluntary agreement was reached which covered the period 2010 to 2014.

Following consultation in 2014, regulations came into effect in January 2015 which sought to underpin existing voluntary and statutory measures. Under these regulations, the start of the net fishing season is delayed in most areas until 01 April while fishing by rod and line in any given district is restricted to catch and release from the season start date until 31 March. For the Esk District, the previous measures are carried forward - i.e. no net fishing until 01 May. These measures will be reviewed annually.

Part 2: Spawning locations of spring fish

Objective: *In which geographic region of the River South Esk do spring salmon spawn?*

2.1 INTRODUCTION

Salmon returning in spring to the Rivers Spey, Dee and Tay tend to originate from and return to upper catchment tributaries, whereas those returning in the autumn tend to originate from and return to lower catchment tributaries and the river main stem (Laughton & Smith, 1992). However, while this pattern appears to hold true where the relationship between distance upstream and spawning area is relatively simple, it is not universal. In more complex systems, the relationship between distance upstream and spawning areas is less clear, for example in the River Tweed (Campbell, 1998). Our knowledge of the factors affecting where spring fish are likely to spawn in a given catchment is not currently sufficient to predict spawning areas for spring fish for a specific river, and there is no information regarding the locations of spring salmon spawning areas in the River South Esk. It is necessary to identify such areas to establish whether there are low numbers of juveniles associated with an apparent lack of spring returns, and for identifying whether there is local habitat degradation that may have resulted in reduced smolt production.

This issue was approached using two methods. Firstly, spring salmon sourced from either the coastal net fishery adjacent to the River South Esk, or the lower reaches of the River South Esk itself, were radio tagged and tracked to their spawning locations. There is a long history of using radio transmitters placed in the stomach to track in-river migration of salmon (e.g. Hawkins & Smith, 1986; Laughton, 1989; 1991). However, despite being a tried-and-tested method, radio tracking is relatively expensive and relies on fish being subsequently detected post-tagging. Therefore, the potential to identify the natal origin of Atlantic salmon within the River South Esk using genetic analysis was also assessed. Genetic techniques potentially allow returning adults to be assigned to river of origin and / or region of origin within river (i.e. upper catchment *vs*. lower catchment or individual tributaries). If possible, this technique presents a number of advantages over more traditional techniques such as radio tracking. The sample size is larger using genetic techniques, as all captured fish have the potential to be assigned at relatively low cost. This approach is also not affected by post-tagging losses (e.g. predation, tag regurgitation, fish entering rivers not being monitored for tags), and any variation in these factors among fish destined for different rivers. As long as a comprehensive baseline survey is carried out, this approach is also unaffected by surveying biases, such as differences in tracking effort afforded to different rivers. The genetics approach relies only on samples being collected from returning adults and comparing the genetic signature of these samples to baseline data from the potential rivers of origin. However, a requirement of the genetics approach is that baseline data is sufficiently differentiated to allow separation among areas of interest, and the results of the present study will demonstrate whether such differentiation exists.

2.2 METHODS

2.2.1 Radio tracking

Source of fish

In the first year of this three-year investigation (2012), spring salmon were captured from the coastal net fishery near the mouth of the River South Esk (Figure 2.2.1.1*a*) and radio tagged. In the second year of the investigation (2013), radio tagging of fish sourced from the coastal nets continued. Tagging of spring salmon within the River South Esk itself was also initiated in 2013 by establishing a net in the lower reaches of the river (Figure 2.2.1.1*b*). In the third and final year of the investigation (2014), coastal netting was discontinued and fish for tagging were sourced from the in-river net as well as from a rod fishery adjacent to the in-river netting site. A fixed engine net of the type used in the coastal net fishery is shown in Figure 2.2.1.2*a*, while the in-river net used is shown in Figure 2.2.1.2*b*.

Figure 2.2.1.1*a*: Map showing the location of the coastal net fishery. The extent of the fishery used in the project is delimited by triangles (▲), and the release point is indicated by a red circle (●).

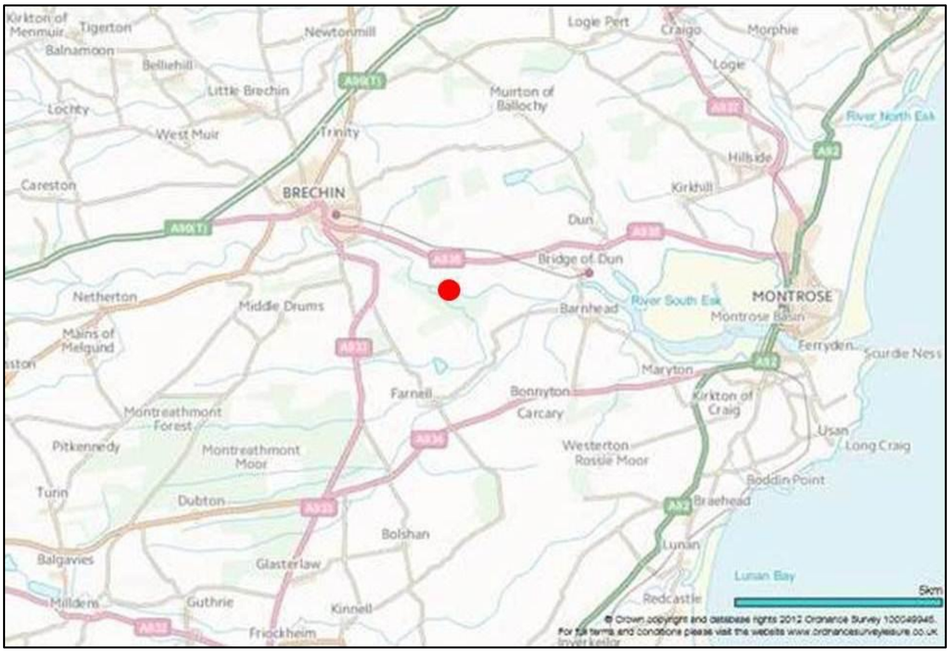


Figure 2.2.1.1*b*: Map showing the location of the in-river net on the River South Esk, indicated by a red circle (●).


Figure 2.2.1.2*a*: A fixed engine net of the type used in the coastal net fishery.


Figure 2.2.1.2*b*: The in-river net.

All nets were operated by personnel from Usan Salmon Fisheries Ltd. Weather permitting, coastal nets were operated from Monday to Friday inclusive between the dates specified in Table 2.2.1.1. River level permitting, the in-river net was operated from Monday to Sunday inclusive between the dates specified in Table 2.2.1.1. The numbers of fish tagged by capture method are indicated in Figures 2.2.1.3*a* to 2.2.1.3*c*.

Table 2.2.1.1: Summary of the tagging regime and resulting numbers of spring salmon tagged from each source during the three years of the investigation.

		Number of fish tagged from each source		
Year	**Tagging period**	**Coastal nets**	**In-river net**	**Rods**
2012	20 February to 31 May	153	N/A	N/A
2013	04 March to 26 April	38	22	N/A
2014	17 February to 27 April	N/A	20	12

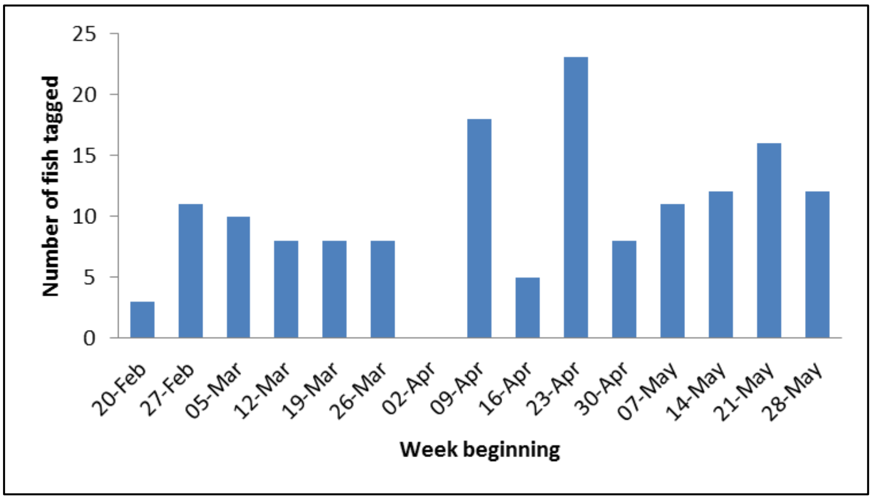


Figure 2.2.1.3*a*: Number of fish tagged per week during 2012 sourced from the coastal nets.

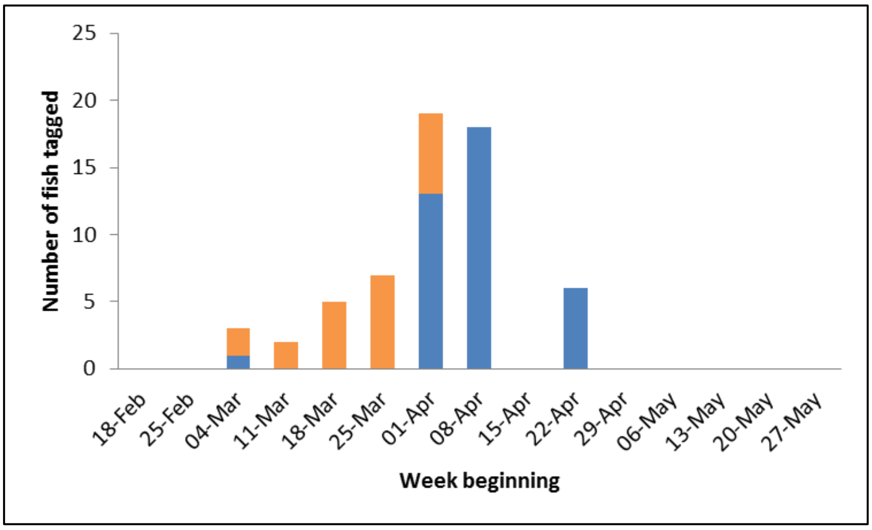


Figure 2.2.1.3*b*: Number of fish tagged per week during 2013 sourced from the coastal nets (■) and the in-river net (■).

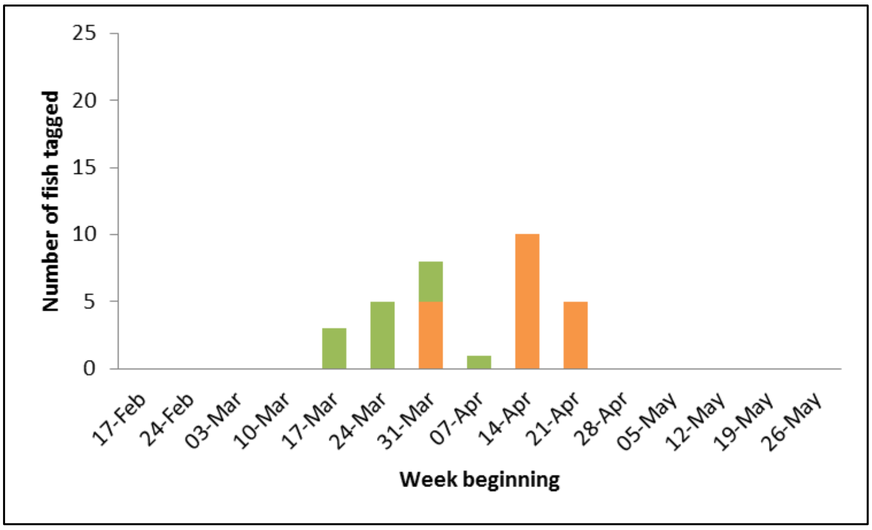


Figure 2.2.1.3*c*: Number of fish tagged per week during 2014 sourced from the in-river net (■) and rods (■).

Fish sampling and tagging

In the coastal net fishery, salmon were removed from the net in which they were captured and placed into a holding tank filled with approximately 150 - 200 L of sea water. Fish were then removed from the holding tank one at a time and placed in a bath containing 75 L of anaesthetic solution (23 mg / L eugenol in sea water). Fish caught in the in-river net were transferred directly from the net in which they were captured to the anaesthetic solution one at a time. Once anaesthetised, fitness for tagging was assessed (fish with signs of physical damage were not tagged), the sex of the fish was assigned using external physical characteristics, five scales were removed for later age determination, fork length was measured (to the nearest cm), and a small sample of fin tissue was removed and retained in ethanol for subsequent genetic analysis.

Sex assignment was carried out using a method described by Shearer (1972) based on head shape. These assessments are subjective, and were, given the time of year, carried out on fish before the secondary sexual characteristics had developed. As it was not possible to determine the age of the fish at the time of tagging, criteria were developed to ensure that fish selected for tagging were likely to be MSW salmon. Analysis of sample data from the nearby River North Esk suggested that at the time of year in which fish were being tagged, 1SW salmon were rare and were generally smaller than 60 cm, and thus only fish with a fork length of 60 cm (to the nearest whole cm) or greater were selected for tagging. The ages of tagged fish were subsequently determined by scale reading.

Each fish selected for tagging had a radio tag (Lotek individually coded MCFT2-16-CE tag with integrated antenna, 46 mm in length with a diameter of 16 mm and weighing 16 g in air) gently introduced into the stomach. This was achieved by inserting an acrylic tube containing a radio tag into the oesophagus. A plunger was then used to place the radio tag into the stomach. The tube and plunger were then removed, and the fish was placed in a tank of sea water (coastal) or river water (in-river) and allowed to recover fully. Those fish that were too small and / or were not in prime condition were placed in a tank of sea water (coastal) or a keepnet positioned adjacent to the river bank (in-river) and allowed to recover before being released. Fish captured in the coastal nets were transported to and released at a specific point approximately 0.5 km from the nearest net to reduce the likelihood of recapture (Figure 2.2.1.1*a*). Similarly, all fish captured by the in-river net were released, approximately 200 m upstream of the netting site.

Salmon sourced from rods during the final year of the project were processed in exactly the same way as fish captured using the in-river net. A number of keepnets were positioned at strategic locations in the area around the in-river netting site for use by anglers to allow time for the tagging team to arrive on site. These fish were tagged and released at the site of capture. All procedures carried out on the fish were performed under Home Office licence.

Tracking locations

It was possible to detect radio tagged spring salmon only in fresh water as radio signals are quickly attenuated in salt and brackish water. A combination of fixed and mobile radio receivers was used to track tagged fish in fresh water in three ways - fixed receiver stations, aerial surveys and manual tracking. Fixed receiver stations were deployed on the River South Esk and a number of other rivers in the east of Scotland (Figure 2.2.1.4). Mobile receivers were deployed, either during helicopter surveys, or by manual tracking, either on foot or by vehicle. A summary of the extent of aerial survey coverage on each river during the three years of the investigation is shown in Table 2.2.1.2. A summary of the tracking methods employed on each river during the three years of the investigation and the numbers of tags detected in rivers by fixed receiver stations (where they existed) and aerial surveys (where they were carried out) is shown in Table 2.2.1.3.

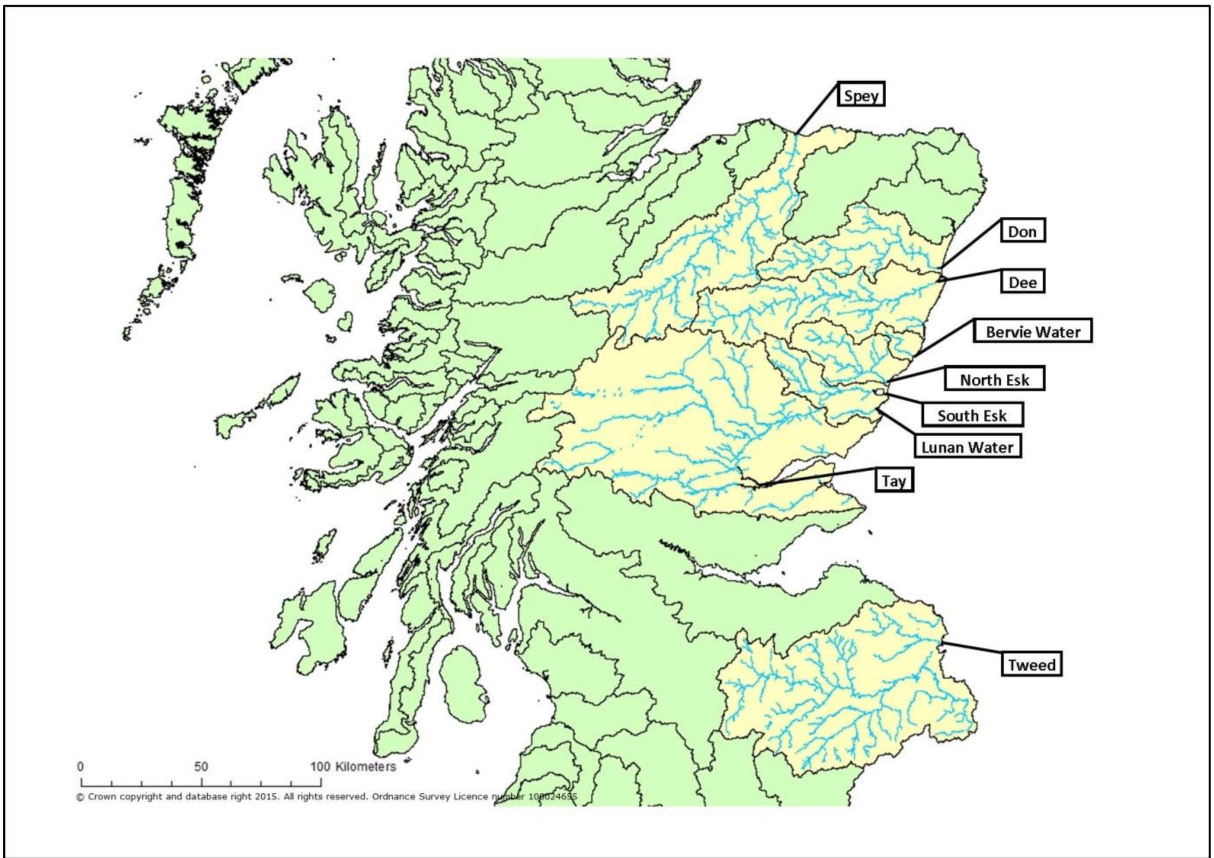


Figure 2.2.1.4: Rivers in the east of Scotland on which fixed receiver stations were deployed.

Table 2.2.1.2: Summary of the extent of aerial survey coverage on each river during the three years of the investigation. For clarity of presentation, rivers which were either not monitored and / or where no aerial survey was carried out in a given year have been excluded.

(*a*) Summary of aerial survey coverage in 2012

					Downstream limit of aerial survey			Upstream limit of aerial survey		
Catchment	Date surveyed	Survey number	River name	Description	Easting	Northing	Description	Easting	Northing	Description
Don	15/11/2012	1 (of 1)	River Don	Mainstem of the River Don	393600	809025	Weir upstream of A956 roadbridge, Aberdeen	322200	808800	Torran Deallaig
			River Urie	Tributary of the River Don	378325	820050	Confluence of the River Urie with the mainstem of the River Don	364850	831000	Mill Croft
			Lochter Burn	Tributary of the River Urie (itself a tributary of the River Don)	377325	823000	Confluence of the Lochter Burn with the River Urie	377000	824500	Lethenty Mill
Dee	02/11/2012	1 (of 3)	River Dee	Mainstem of the River Dee	392500	803050	Upstream of Bridge of Dee, Aberdeen	307100	789650	Confluence of the Lui Water with the mainstem of the River Dee
			Water of Tanar	Tributary of the River Dee	351350	797550	Confluence of the Water of Tanar with the mainstem of the River Dee	346825	794250	In forest, Glen Tanar
			River Muick	Tributary of the River Dee	336700	794900	Confluence of the River Muick with the mainstem of the River Dee	329950	784150	Outflow from Loch Muick
			River Gairn	Tributary of the River Dee	335300	796600	Confluence of the River Gairn with the mainstem of the River Dee	328500	800625	Balnaan
	06/11/2012	2 (of 3)	River Dee	Mainstem of the River Dee	314900	792400	Confluence of the Clunie Water with the mainstem of the River Dee	299550	790800	Glen Dee, approximately 3.5 km upstream of White Bridge
			Clunie Water	Tributary of the River Dee	314900	792400	Confluence of the Clunie Water with the mainstem of the River Dee	313700	783350	Confluence of the Baddoch Burn with the Clunie Water
			Geldie Burn	Tributary of the River Dee	302150	788450	Confluence of the Geldie Burn with the mainstem of the River Dee	297750	787500	Open hillside
	15/11/2012	3 (of 3)	River Dee	Mainstem of the River Dee	314900	792400	Confluence of the Clunie Water with the mainstem of the River Dee	298100	793750	Confluence of the Geusachan Burn with the mainstem of the River Dee
			Ey Burn	Tributary of the River Dee	308700	789700	Confluence of the Ey Burn with the mainstem of the River Dee	310050	784950	Track bridge over the Ey Burn
			Lui Water	Tributary of the River Dee	307100	789700	Confluence of the Lui Water with the mainstem of the River Dee	304000	793300	Confluence of the Luibeg Burn with the Lui Water at Derry Lodge

Bervie Water	30/10/2012	1 (of 1)	Bervie Water	Mainstem of the Bervie Water	383600	772500	Sea at Bervie Bay	376825	780300	Glenbervie
North Esk	16/11/2012	1 (of 2)	Survey unsuccessful for operational reasons							
	21/11/2012	2 (of 2)	River North Esk	Mainstem of the River North Esk	374000	762550	Estuary, Montrose Bay	344900	780250	Confluence of the Water of Lee and the Water of Mark with the mainstem of the River North Esk
			Luther Water	Tributary of the River North Esk	365975	766325	Confluence of the Luther Water with the mainstem of the River North Esk	368075	769400	Wakefield
			Cruick Water	Tributary of the River North Esk	362750	765850	Confluence of the Cruick Water with the mainstem of the River North Esk	351200	762550	Milton of Balhall
			West Water	Tributary of the River North Esk	362400	766000	Confluence of the West Water with the mainstem of the River North Esk	341350	774800	Open hillside
			Water of Tarf	Tributary of the River North Esk	349450	779075	Confluence of the Water of Tarf with the mainstem of the River North Esk	348900	782150	Footbridge
			Water of Lee	Tributary of the River North Esk	344900	780250	Confluence of the Water of Lee with the mainstem of the River North Esk	340000	779775	Upstream of Loch Lee
			Water of Mark	Tributary of the River North Esk	344900	780250	Confluence of the River Mark with the mainstem of the River North Esk	340325	783600	Upstream of confluence with the Burn of Doune
South Esk	30/10/2012	1 (of 2)	River South Esk	Mainstem of the River South Esk	373225	757000	Sea at Scurdie Ness	328600	775600	Braedownie
			White Water	Tributary of the River South Esk	328575	775625	Confluence of the White Water with the mainstem of the River South Esk	328100	775950	Acharn
			Prosen Water	Tributary of the River South Esk	340850	758300	Confluence of the Prosen Water with the mainstem of the River South Esk	324900	770700	Kilbo
			Quharity Burn	Tributary of the River South Esk	342150	757925	Confluence of the Quharity Burn with the mainstem of the River South Esk	335375	758425	Bridgend of Balloch
	15/11/2012	2 (of 2)	Rottal Burn	Tributary of the River South Esk	336450	768750	Confluence of the Rottal Burn with the mainstem of the River South Esk	337625	770150	Confluence of the Burn of Heughs and the Kennel Burn with the Rottal Burn
Lunan Water	30/10/2012	1 (of 1)	Lunan Water	Mainstem of the Lunan Water	369000	751075	Sea at Lunan Bay	359150	749850	Friockheim
Tay	23/11/2012	1 (of 1)	River Tay	Mainstem of the River Tay	310400	726550	Scone Park, Perth	277150	745550	Kenmore
			River Tummel	Tributary of the River Tay	297800	751100	Confluence of the River Tummel with the mainstem of the River Tay	293550	757800	Pitlochry Dam

(*b*) Summary of aerial survey coverage in 2013

Catchment	Date surveyed	Survey number	River name	Description	Downstream limit of aerial survey: Easting	Downstream limit of aerial survey: Northing	Downstream limit of aerial survey: Description	Upstream limit of aerial survey: Easting	Upstream limit of aerial survey: Northing	Upstream limit of aerial survey: Description
Dee	04/11/2013	1 (of 2)	River Dee	Mainstem of the River Dee	392500	803050	Upstream of Bridge of Dee, Aberdeen	326200	794900	B976 road bridge at Crathie, just downstream of Balmoral Castle [1]
			Water of Tanar	Tributary of the River Dee	351350	797550	Confluence of the Water of Tanar with the mainstem of the River Dee	346825	794250	In forest, Glen Tanar
	07/11/2013	2 (of 2)	River Dee	Mainstem of the River Dee	324800	794650	Just upstream of Balmoral Castle [1]	298100	793650	Confluence of the Geusachan Burn with the mainstem of the River Dee
			River Muick	Tributary of the River Dee	336700	794900	Confluence of the River Muick with the mainstem of the River Dee	329950	784150	Outflow from Loch Muick
			Girnock Burn	Tributary of the River Dee	333150	796300	Confluence of the Girnock Burn with the mainstem of the River Dee	331850	793250	Edge of forest, Glen Girnock
			Clunie Water	Tributary of the River Dee	314900	792400	Confluence of the Clunie Water with the mainstem of the River Dee	313700	783350	Confluence of the Baddoch Burn with the Clunie Water
			Ey Burn	Tributary of the River Dee	308700	789700	Confluence of the Ey Burn with the mainstem of the River Dee	310050	784950	Track bridge over the Ey Burn
			Luibeg Burn	Tributary of the Lui Water (itself a tributary of the River Dee)	304000	793300	Confluence of the Luibeg Burn with the Lui Water at Derry Lodge	301550	793875	Glen Luibeg
			Lui Water	Tributary of the River Dee	307100	789700	Confluence of the Lui Water with the mainstem of the River Dee	304000	793300	Confluence of the Luibeg Burn with the Lui Water at Derry Lodge
			River Gairn	Tributary of the River Dee	335300	796600	Confluence of the River Gairn with the mainstem of the River Dee	328500	800625	Balnaan
South Esk	04/11/2013	1 (of 1)	River South Esk	Mainstem of the River South Esk	373225	757000	Sea at Scurdie Ness	328500	776000	Upstream of Braedownie
			White Water	Tributary of the River South Esk	328575	775625	Confluence of the White Water with the mainstem of the River South Esk	327000	776000	In forest, Glen Doll
			Prosen Water	Tributary of the River South Esk	340850	758300	Confluence of the Prosen Water with the mainstem of the River South Esk	324900	770700	Kilbo
			Quharity Burn	Tributary of the River South Esk	342150	757925	Confluence of the Quharity Burn with the mainstem of the River South Esk	335375	758425	Bridgend of Balloch

[1] Aerial surveying of a short (< 2 km) stretch of the River Dee immediately adjacent to Balmoral Castle was not permitted for security reasons.

(*c*) Summary of aerial survey coverage in 2014

					Downstream limit of aerial survey			Upstream limit of aerial survey		
Catchment	**Date surveyed**	**Survey number**	**River name**	**Description**	**Easting**	**Northing**	**Description**	**Easting**	**Northing**	**Description**
South Esk	04/11/2014	1 (of 1)	River South Esk	Mainstem of the River South Esk	373225	757000	Sea at Scurdie Ness	328100	777575	Moulzie
			White Water	Tributary of the River South Esk	328575	775625	Confluence of the White Water with the mainstem of the River South Esk	326450	775850	Spot height 325 m, Glen Doll
			Prosen Water	Tributary of the River South Esk	340850	758300	Confluence of the Prosen Water with the mainstem of the River South Esk	325950	769675	Confluence of the Burn of Louie with the Prosen Water
			Quharity Burn	Tributary of the River South Esk	342150	757925	Confluence of the Quharity Burn with the mainstem of the River South Esk	335375	758425	Bridgend of Balloch
			Rottal Burn	Tributary of the River South Esk	336450	768750	Confluence of the Rottal Burn with the mainstem of the River South Esk	337625	770150	Confluence of the Burn of Heughs and the Kennel Burn with the Rottal Burn

Table 2.2.1.3: Summary of the tracking methods employed on rivers in the east of Scotland during the three years of the investigation and the numbers of tags detected in rivers by fixed receiver stations (where they existed) and aerial surveys (where they were carried out) according to year of study and source of tagged fish.

(*a*) 2012 (Tagged fish sourced from coastal nets)

		Fixed receiver stations			Aerial surveys			
River	**Total no. of tags detected in-river**	**No. deployed**	**No. of tags available for detection**	**No. of tags detected (% of no. of tags available for detection)**	**Date(s)**	**No. of tags in-river at the time**	**No. of tags detected (% of no. of tags in-river at the time)**	**Manual tracking?**
Spey	Not monitored							
Don	2	0	N/A	N/A	15/11/2012	2	2 (100 %)	Yes
Dee	7	2	7	0[b] (0 %)	02/11/2012, 06/11/2012 & 15/11/2012	7	7 (100 %)	Yes
Bervie Water	0	0	N/A	N/A	30/10/2012	0	N/A	No
North Esk	17[a]	2	17	14[c] (82 %)	16/11/2012 & 21/11/2012	6[d]	6 (100 %)	Yes
South Esk	18[a]	15	18	18 (100 %)	30/10/2012 & 15/11/2012	11[e]	11 (100 %)	Yes
Lunan Water	0	0	N/A	N/A	30/10/2012	0	N/A	No
Tay	5	1	5	5 (100 %)	23/11/2012	5	1[f] (20 %)	No
Tweed	Not monitored							

[a] Includes 1 which was detected initially in the North Esk which subsequently returned to sea and entered the South Esk.
[b] Due to operational reasons.
[c] The 3 not detected include 2 which were caught by the in-river net and coble fishery and 1 which was detected only by a mobile box.
[d] Of the 17 detected in the North Esk, 7 returned to sea and 4 were caught by the in-river net and coble fishery prior to aerial surveys taking place.
[e] Of the 18 detected in the South Esk, 6 returned to sea and 1 regurgitated tag was recovered prior to aerial surveys taking place.
[f] Thought to be due to a relatively small proportion of the Tay catchment being surveyed.

(*b*) 2013 (Tagged fish sourced from coastal nets)

		Fixed receiver stations			Aerial surveys			
River	Total no. of tags detected in-river	No. deployed	No. of tags available for detection	No. of tags detected (% of no. of tags available for detection)	Date(s)	No. of tags in-river at the time	No. of tags detected (% of no. of tags in-river at the time)	Manual tracking?
Spey	2	1	2	2 (100 %)	No aerial survey carried out			No
Don	0	1	0	N/A	No aerial survey carried out			No
Dee	0	1	0	N/A	04/11/2013 & 07/11/2013	0	N/A	No
Bervie Water	Not monitored							
North Esk	7[a,b]	1	7	7 (100 %)	No aerial survey carried out			No
South Esk	5[b]	18	5	5 (100 %)	04/11/2013	3[c]	3 (100 %)	Yes
Lunan Water	0	1	0	N/A	No aerial survey carried out			No
Tay	2[a]	1	2	2 (100 %)	No aerial survey carried out			No
Tweed	0	1	0	N/A	No aerial survey carried out			No

[a] Includes 1 which was detected initially in the North Esk which subsequently returned to sea and entered the Tay.

[b] Includes 1 which was detected initially in the South Esk which subsequently returned to sea and entered the North Esk. This fish returned to sea again and re-entered the South Esk, before returning to sea again (ultimate fate unknown).

[c] Of the 5 detected in the South Esk, 1 returned to sea and 1 regurgitated tag was recovered prior to aerial surveys taking place.

(*c*) 2013 (Tagged fish sourced from in-river net)*

* Since none of the tagged fish sourced from the in-river net in 2013 were detected in any other river, the following table has been collapsed significantly for clarity of presentation.

		Fixed receiver stations			Aerial surveys			
River	**Total no. of tags detected in-river**	**No. deployed**	**No. of tags available for detection**	**No. of tags detected (% of no. of tags available for detection)**	**Date(s)**	**No. of tags in-river at the time**	**No. of tags detected (% of no. of tags in-river at the time)**	**Manual tracking?**
South Esk	22	18	22	19[a] (86 %)	04/11/2013	10[b]	9[c] (90 %)	Yes

[a] The 3 not detected include 2 regurgitated tags which were confirmed as being no longer associated with live fish close to the in-river tagging site and 1 which was lost (suspected removal by an angler).

[b] Of the 22 fish tagged in the South Esk, 6 returned to sea and 6 regurgitated tags were recovered prior to aerial surveys taking place.

[c] The 1 not detected was lost (suspected removal by an angler).

(*d*) 2014 (Tagged fish sourced from in-river net and rods)

		Fixed receiver stations			Aerial surveys			
River	Total no. of tags detected in-river	No. deployed	No. of tags available for detection	No. of tags detected (% of no. of tags available for detection)	Date(s)	No. of tags in-river at the time	No. of tags detected (% of no. of tags in-river at the time)	Manual tracking?
Spey	Not monitored							
Don	Not monitored							
Dee	Not monitored							
Bervie Water	Not monitored							
North Esk	1[a]	1	1	1 (100 %)	No aerial survey carried out			No
South Esk	32[a]	18	32	30[b] (94 %)	04/11/2014	23[c]	18[d] (78 %)	Yes
Lunan Water	Not monitored							
Tay	Not monitored							
Tweed	Not monitored							

[a] Includes 1 which was tagged and detected initially in the South Esk which subsequently returned to sea and entered the North Esk. This fish returned to sea again and re-entered the South Esk.

[b] The 2 not detected include 1 which was never detected again after tagging (suspected tag malfunction) and 1 regurgitated tag (confirmed as being no longer associated with a live fish between the fixed receiver stations upstream and downstream of the in-river tagging site).

[c] Of the 32 fish tagged in the South Esk, 6 returned to sea, 2 regurgitated tags were recovered and 1 was caught by the in-river rod fishery prior to aerial surveys taking place.

[d] The 5 not detected include 2 which were subsequently confirmed as live fish, 1 regurgitated tag (confirmed as being no longer associated with a live fish between the fixed receiver stations upstream and downstream of the in-river tagging site), 1 which was lost (suspected removal by an angler) and 1 which was never detected again after tagging (suspected tag malfunction).

Fixed receiver stations detected, decoded and logged (with date and time stamp) the identity of any tagged fish that moved within range. Each fixed receiver station consisted of a watertight metal container which housed a rechargeable battery (Yuasa M26-80 Marine Battery, 12 V, 80 Ah, 450 A) connected to a combined radio receiver / data logger box (Lotek SRX-DL), in turn connected to an external radio antenna (Lotek rigid 3-element Yagi) (Figure 2.2.1.5). Deployment locations were chosen based on the need to maximise spatial resolution of the resulting data (for example by not having long stretches of river that were without coverage) while also providing coverage for specific points of interest (for example points of entry into major tributaries on the River South Esk). Practicalities were also considered including positioning boxes as high above the river as feasibly possible to reduce the risk of flooding while also maximising antenna "line of sight". To this end, when *in-situ* on the river bank, antennae were attached securely to a suitable fixed point (e.g. a tree or stake) which also maximised stability.

Figure 2.2.1.5: A typical fixed receiver station *in situ*. Note the watertight metal container which housed a rechargeable battery connected to a combined radio receiver / data logger box, in turn connected to an external radio antenna. This particular fixed receiver station was located at Shielhill Bridge (see Figure 2.2.1.6), a disused road bridge across the River South Esk. The installation is positioned high and directly above the river with the antenna pointing directly downstream, reducing the risk of flooding while maximising antenna "line of sight". The antenna was attached securely to the bridge railings to maximise stability.

A network of fixed receiver stations was used to monitor the movements of tagged salmon in the River South Esk in each of the three years of the study (Figure 2.2.1.6). In 2012, a total of 15 fixed receiver stations were deployed around the South Esk catchment. An additional 3 fixed receiver stations (at Brechin Castle, Gella Bridge and Lednathie, giving a total of 18) were added to the network in 2013 and 2014 in order to break up some relatively long stretches of river that were without coverage in 2012 (Figure 2.2.1.6).

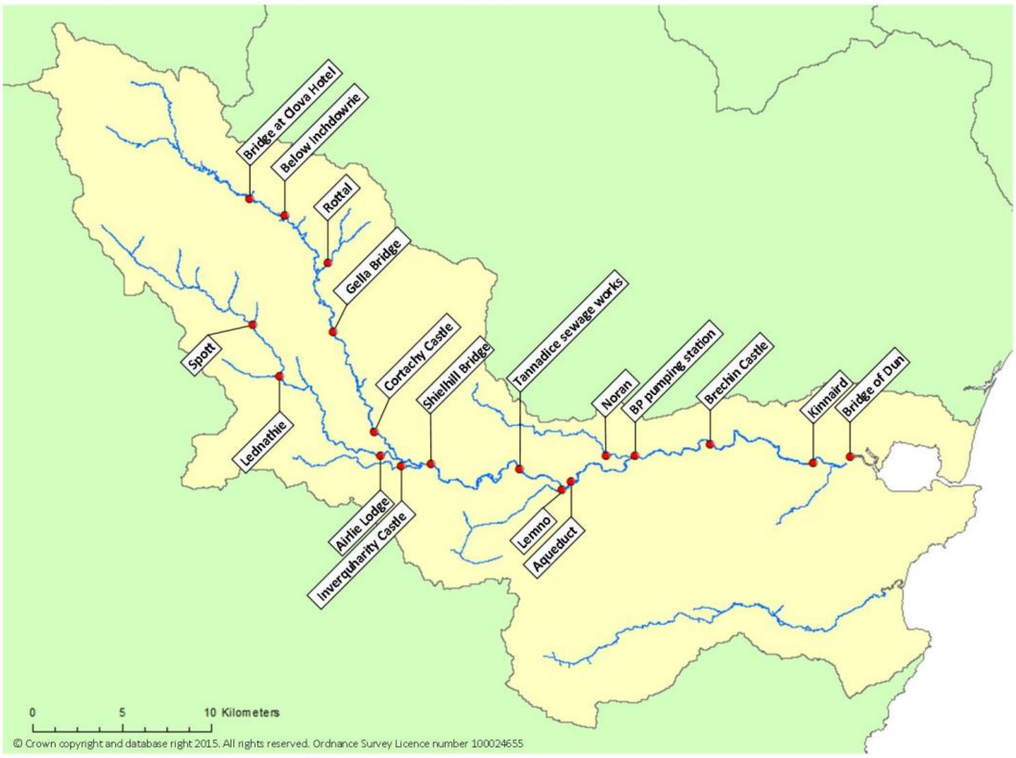


Figure 2.2.1.6: Map showing the locations of the 18 fixed receiver stations deployed around the South Esk catchment. Note that those at Brechin Castle, Gella Bridge and Lednathie were not deployed in the first year of the study (2012).

Aerial surveys were carried out from a helicopter employing a combined mobile radio receiver / data logger box (Lotek SRX-600) with a skid mounted antenna (Lotek rigid 4-element Yagi) and dashboard mounted GPS antenna. The helicopter was flown at low air speed (up to 60 knots) at an altitude of approximately 150 m over the survey area and the receiver was monitored for the identity of any tagged fish. The positions of tag transmissions and the limits of the survey carried out on each river were also recorded on Ordnance Survey 1:25,000 scale paper maps. Aerial surveys meant that large areas could be covered rapidly, although the topography of each river meant that not all areas, particularly small tributaries, could be accessed. Throughout the study, aerial surveys were generally carried out around the period when spawning activity was expected, in practice from 30 October to 23 November. In particular, aerial surveys of the River South Esk were carried out on 30 October and 15 November in 2012, and on 04 November in both 2013 and 2014.

Manual tracking of tagged fish was carried out on foot or by vehicle using a combined mobile radio receiver / data logger box (Lotek SRX-600) with a hand-held antenna (Lotek rigid 3-element Yagi). Manual tracking was carried out on an *ad-hoc* basis around the South Esk catchment throughout the year in all three years of the investigation (Table 2.2.1.3). Additional, and more intensive, manual tracking was carried out after aerial surveys had located the positions of the tags in order to verify whether or not a given tag was still associated with a live fish. This was done for all tags in the River South Esk in all three years of the investigation (except those tags which were still actively moving into and out of range of the fixed receiver stations). Additionally, this process was carried out in the Rivers North Esk, Dee and Don in 2012 (Table 2.2.1.3).

Manual tracking was, in most cases, used successfully to determine the fate of the associated salmon (e.g. alive, dead, tag regurgitated). The verification process was carried out by first locating the tag to within a few metres, either in the water, or on the bank. Tags located on the bank were retrieved when possible. A tag in an active fish would move when approached. Those tags that did not move were retrieved when possible. Manual tracking was very labour intensive, and did not allow large stretches of river to be covered quickly. This method was used in conjunction with fixed receiver stations and aerial surveys, to determine the fate of tagged fish.

2.2.2 Genetic stock assignment

Obtaining baseline samples for genetic analysis

Fin clips were taken from juvenile Atlantic salmon obtained by electrofishing from 14 sites within the River South Esk (n = 333 fish) and from 12 sites within the River North Esk (n = 232 fish) (Figure 2.2.2.1).

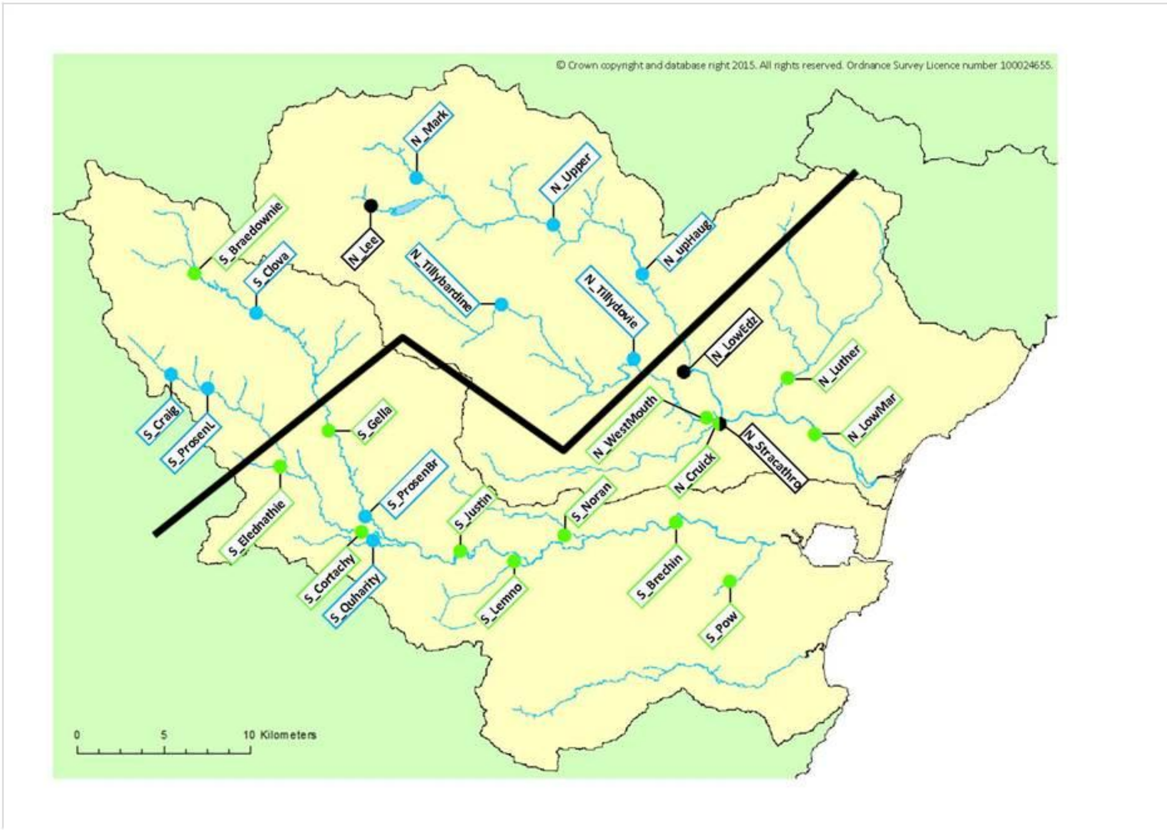


Figure 2.2.2.1: Sampling sites in the Rivers South and North Esk from which juvenile Atlantic salmon were obtained. Colour codes are according to clusters identified by multidimensional scaling analysis based on pairwise D_A (see Figure 2.3.2.1). The three outliers (see text) are shown in black. The line represents the upper and lower regions defined for subsequent assignment analysis.

SNP screening

Genomic DNA was extracted using a Blood and Tissue DNeasy purification kit (Qiagen) following the manufacturers' protocols. Extracted DNA was quantified by fluorometry (Qubit, Life Technologies) and diluted to a concentration of 50 ng / µl in a 10 mM Tris-HCl (pH 8.0), 1 mM EDTA buffer.

To avoid potential bias in the analysis due to family effects, relatedness analysis was carried out within each site to determine the presence of full siblings, based on a pedigree likelihood approach in the programme COLONY (Jones & Wang, 2010). This was done based on SNP data from a panel from Karlsson *et al*. (2011) and 36 random SNPs selected from GenBank (Benson *et al*., 2005), obtained using a 96 x 96 Fluidigm EP1 SNP genotyping platform (Fluidigm Europe b.v., Netherlands) following the manufacturers' protocols and workflow. For each identified full sib family, all but one individual from that family was removed from the data set.

Following removal of full sibs, each sample was genotyped at 5,568 SNPs, using a modified version of a custom-designed Illumina® iSelect SNP-array (Lien *et al*., 2011; Bourret *et al*., 2013; Johnston *et al*., 2013) at the Centre for Integrative Genetics (CIGENE), Norway. The procedures are outlined in Johnston *et al*. (2013). Only normal diploid polymorphic SNPs and SNPs existing on a single paralogue (MSV3) were retained in the analysis - other variants (Gidskehaug *et al*., 2011) were removed. SNPs with an overall scoring percentage of less than 95 % were removed.

Genetic structuring analysis

Genetic structuring was examined by calculating pairwise F_{ST} and D_A (Nei, 1972) in GENALEX (Peakall & Smouse, 2012). Pairwise D_A values were used as a basis for multidimensional scaling (MDS) analysis in R (R Core Team, 2013). A neighbour - joining tree (NJ) was produced with the programme MEGA6 (Tamura *et al*., 2013), again based on pairwise D_A. Assignment regions were defined by an examination of the genetic structuring, together with the geographic position of the sites.

Individual assignment analysis

Genetic assignment regions were defined as described above, and accuracy of assignments to these regions was then examined using individual assignment (IA) analysis. To avoid ascertainment bias when assessing assignment accuracy to region (Anderson, 2010; Waples, 2010), four training sets (TSs) were created whereby one different site from each identified region was removed in both rivers. The removed sites were then classified as blind sites and formed the hold-out set (HOS). Each TS was used to rank the SNPs according to their ability to separate between the regions and assignment accuracy tested using the TS as the genetic baseline and assigning the HOS to this baseline. Ranking of the SNPs was carried out by estimating hierarchical F_{ST} for each SNP using HIERFSTAT (Goudet, 2005).

Individual assignment of the HOS was carried out in GENECLASS (Piry *et al*., 2004), using a Monte-Carlo resampling approach (Rannala & Mountain, 1997). Assignments were performed using the top 12, 24, 48, 96, 192, 288 and 480 ranked SNPs and a likelihood cut-off of 80 was applied. The likelihood score reflects the best match of the individual fish to a baseline assignment unit. The most likely site of origin for a fish from the available baseline sites is thus the one with the highest likelihood score. Some fish were difficult to assign in the simulations and have low scores for all baseline sites and so a likelihood cut-off is applied that classifies fish as assigned only if they have a score above this value. This exclusion method is similar to that used by Ikediashi *et al*. (2012). The value of 80 was chosen to give an acceptable balance between the number of fish assigned and the accuracy of assignment. Fish with an assignment likelihood score below this value were considered to be unassigned.

Where the assignment regions were observed to span across both rivers, further IA analysis was carried out to separate the two rivers within each of these identified assignment regions. Within each assignment region, SNPs were again ranked according to their ability to separate between the two rivers, and again assignment accuracy assessed using an increasing number of SNPs. Accuracy was determined based on the same TS / HOSs as used for the regional assignments.

Finally, a hierarchical assignment analysis was performed, by which fish were first assigned to region and then to river of origin within each region. Accuracy across both levels of assignment was then examined (i.e. assignment to regions within each river), as well as overall estimates of the proportion of fish assigned.

2.3 RESULTS

2.3.1 Radio tracking

Radio tagged fish

Characteristics of tagged fish are summarised in Table 2.3.1.1. In total, 245 Atlantic salmon were radio tagged, 160 of which (65 %) were assigned as females according to the criteria of Shearer (1972). Age determination by scale reading was possible for 242 of the 245 fish that were tagged (99 %). Of these, 178 were two-sea-winter (2SW) fish (72.7 %), 63 were three-sea-winter (3SW) fish (25.7 %) and 1 was a four-sea-winter (4SW) fish (0.4 %). No age determination was possible for 3 of the fish that were tagged (1 %). The fork lengths of fish tagged ranged from 59.5 cm to 100.5 cm.

Spawning locations in the River South Esk

Of the 153 salmon tagged in the coastal net fishery during 2012, 51 fish (33.3 %) were subsequently detected. During 2013, 38 salmon were tagged in the coastal net fishery, of which 14 fish (36.8 %) were subsequently detected.

Tracking was not undertaken sufficiently intensively to test whether tagged fish had spawned successfully (e.g. Webb & Hawkins, 1989). Spawning location in this sense is taken to mean the highest upstream location that tagged fish were detected during the period over which spawning activity would be expected to have occurred (i.e. from the end of October to the end of December for the upper part of the South Esk catchment). For this assessment, identification of spawning location is restricted to fish migrating within the River South Esk, where sufficient location information is available. A manual verification was carried out on each tag within the River South Esk to determine whether or not the tag was still associated with a live fish at spawning time, either by manual tracking or by observing extensive downstream movement after spawning time (see “Tracking locations” section above).

In 2012, four tags were still associated with live fish at spawning time. Three of these fish were located within Glen Clova, including one which was detected within the Rottal Burn, and one was located within the main stem of the River South Esk at Tannadice (Figure 2.3.1.1*a*). In 2013, six tags were still associated with live fish at spawning time. Of these six fish, two were sourced from the coastal net fishery and four were sourced from the in-river net. Three of these fish were located within Glen Clova, two were located within Glen Prosen, and one was located on the main stem of the River South Esk at Tannadice (Figure 2.3.1.1*b*). In 2014, fourteen tags were still associated with live fish at spawning time. Of these fourteen fish, eight were sourced from the in-river net and six were sourced from the rods. Seven of these fish were located in the upper reaches of Glen Clova, three were located in the lower reaches of Glen Clova, and two were located within Glen Prosen. Two fish were located on the main stem of the River South Esk, one at Tannadice and one downstream of the Aqueduct (Figure 2.3.1.1*c*).

Thus, over the course of the three-year investigation, a total of 24 spring salmon were tracked to spawning in the River South Esk (Figure 2.3.1.1*d*). The majority (20 fish, 83.3 %) spawned in the upper reaches of the River South Esk (Figure 2.3.1.1*d*), with 16 fish (66.7 %) spawning in Glen Clova and 4 fish (16.7 %) spawning in Glen Prosen. The remaining 4 fish (16.7 %) spawned in the middle reaches of the River South Esk (Figure 2.3.1.1*d*), with 3 of these fish (12.5 %) spawning in the main stem of the river at Tannadice and 1 of these fish (4.2 %) spawning in the main stem of the river downstream of the Aqueduct. These data are summarised in Table 2.3.1.2.

Table 2.3.1.1: Biological characteristics of spring salmon tagged according to year of the investigation and method of capture.

(*a*) 2012 coastal nets							
Sex	**Category**	**Male**			**Female** [1]		
	Number (%)	54 (35.3)			99 (64.7)		
Age	**Category**	**2SW**	**3SW**	**4SW**	**2SW**	**3SW**	**4SW**
	Number (%)	40 (74.1)	14 (25.9)	0 (0.0)	67 (67.7)	30 (30.3)	1 (1.0)
Fork length (cm)	**Minimum**	60.5	76.0		59.5	60.5	
	Mean	70.7	84.1	N/A	67.8	79.0	86.5
	Maximum	82.0	100.5		83.0	88.5	
(*b*) 2013 coastal nets							
Sex	**Category**	**Male**			**Female**		
	Number (%)	7 (18.4)			31 (81.6)		
Age	**Category**	**2SW**	**3SW**	**4SW**	**2SW**	**3SW**	**4SW**
	Number (%)	6 (85.7)	1 (14.3)	0 (0.0)	25 (80.6)	6 (19.4)	0 (0.0)
Fork length (cm)	**Minimum**	66.0			64.5	75.0	
	Mean	72.9	81.5	N/A	70.5	79.1	N/A
	Maximum	79.5			77.0	88.5	
(*c*) 2013 in-river net							
Sex	**Category**	**Male**			**Female** [2]		
	Number (%)	8 (36.4)			14 (63.6)		
Age	**Category**	**2SW**	**3SW**	**4SW**	**2SW**	**3SW**	**4SW**
	Number (%)	6 (75.0)	2 (25.0)	0 (0.0)	13 (92.9)	0 (0.0)	0 (0.0)
Fork length (cm)	**Minimum**	63.0	81.5		62.0		
	Mean	68.6	82.8	N/A	66.3	N/A	N/A
	Maximum	76.5	84.0		72.0		
(*d*) 2014 in-river net							
Sex	**Category**	**Male**			**Female** [3]		
	Number (%)	12 (60.0)			8 (40.0)		

Age	**Category**	**2SW**	**3SW**	**4SW**	**2SW**	**3SW**	**4SW**
	Number (%)	8 (66.7)	4 (33.3)	0 (0.0)	6 (75.0)	1 (12.5)	0 (0.0)
Fork length (cm)	**Minimum**	60.5	75.5		66.5		
	Mean	68.9	79.8	N/A	69.3	77.5	N/A
	Maximum	82.0	84.0		74.0		
(*e*) 2014 Rods							
Sex	**Category**	**Male**			**Female**		
	Number (%)	4 (33.3)			8 (66.7)		
Age	**Category**	**2SW**	**3SW**	**4SW**	**2SW**	**3SW**	**4SW**
	Number (%)	2 (50.0)	2 (50.0)	0 (0.0)	5 (62.5)	3 (37.5)	0 (0.0)
Fork length (cm)	**Minimum**	64.0	73.0		60.0	66.3	
	Mean	67.5	73.8	N/A	67.1	73.1	N/A
	Maximum	71.0	74.5		74.0	79.0	

[1, 2, 3] Age determination by scale reading was not possible for 1 fish in each of these 3 categories.

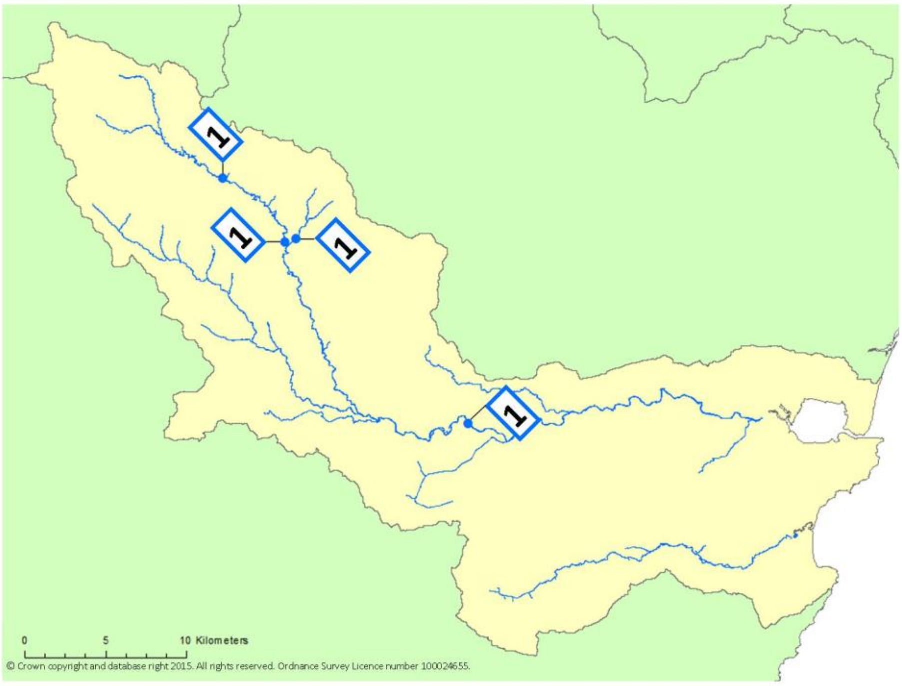


Figure 2.3.1.1*a*: Assumed spawning locations of tagged fish sourced from the coastal net fishery (●) in 2012, expressed as the furthest position a given tagged fish was detected upstream at spawning time in the River South Esk. Numbers in boxes denote the number of fish assumed to spawn in that location.

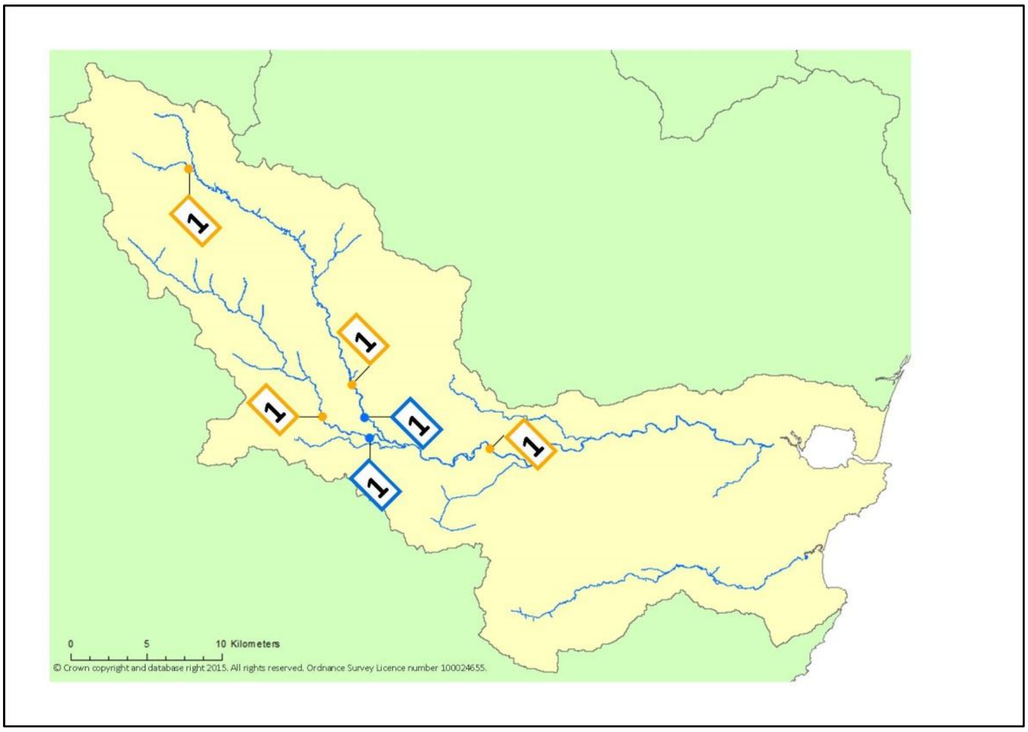


Figure 2.3.1.1*b*: Assumed spawning locations of tagged fish sourced from the coastal net fishery (●) and the in-river net (●) in 2013, expressed as the furthest position a given tagged fish was detected upstream at spawning time in the River South Esk. Numbers in boxes denote the number of fish assumed to spawn in that location.

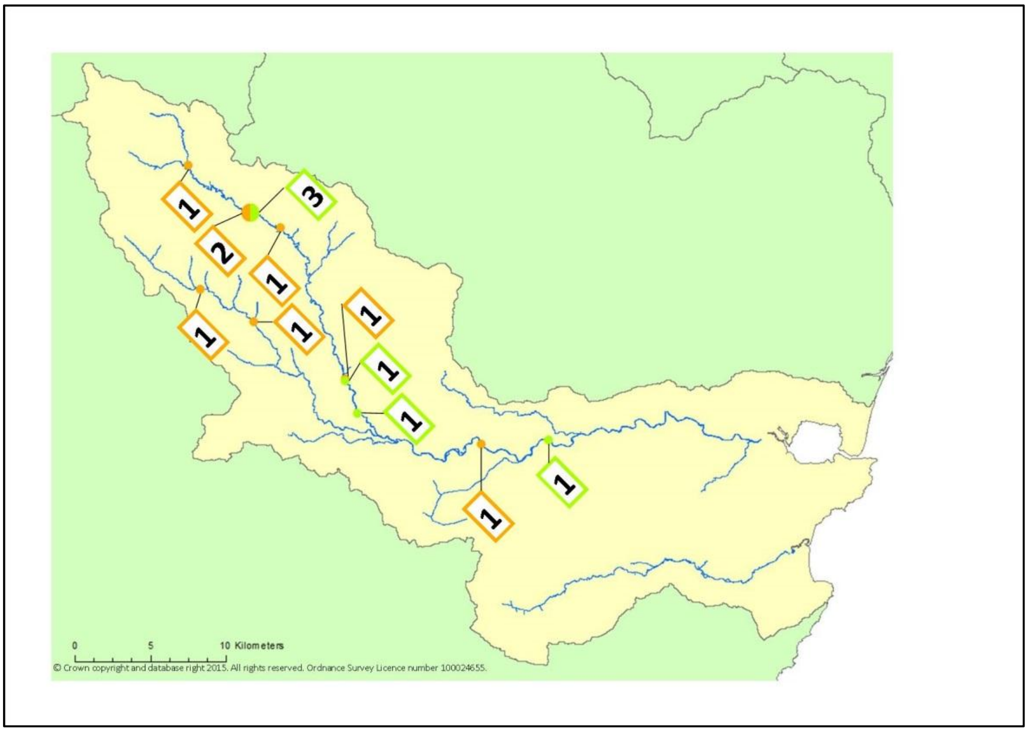


Figure 2.3.1.1*c*: Assumed spawning locations of tagged fish sourced from the in-river net (●) and rods (●) in 2014, expressed as the furthest position a given tagged fish was detected upstream at spawning time in the River South Esk. Numbers in boxes denote the number of fish assumed to spawn in that location.

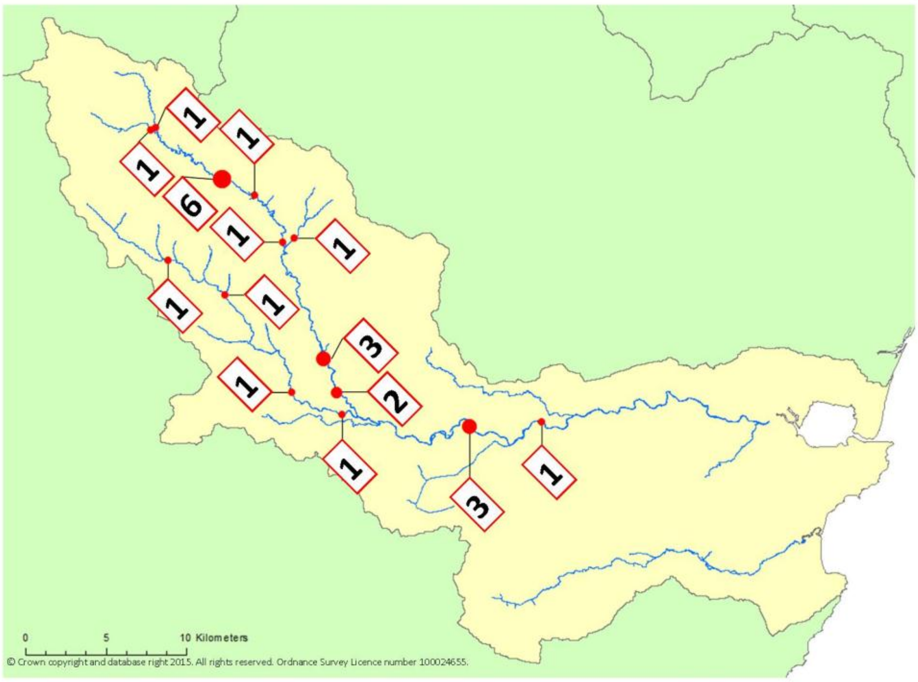


Figure 2.3.1.1*d*: Assumed spawning locations of all tagged fish (●) in all three years of the investigation, expressed as the furthest position a given tagged fish was detected upstream at spawning time in the River South Esk. Numbers in boxes denote the number of fish assumed to spawn in that location.

Table 2.3.1.2: Summary of assumed spawning locations for tagged fish within the River South Esk during the three years of the investigation.

		Upper catchment			**Lower catchment**	
Year	**Number of tagged fish tracked to spawning**	**Number of fish in Glen Clova (%)**	**Number of fish in Glen Prosen (%)**	**Total (%)**	**Number of fish in the main stem (%)**	**Total (%)**
	4	3 (75.0)	0 (0.0)	**3 (75.0)**	1 (25.0)	**1 (25.0)**
	6	3 (50.0)	2 (33.3)	**5 (83.3)**	1 (16.7)	**1 (16.7)**
	14	10 (71.4)	2 (14.3)	**12 (85.7)**	2 (14.3)	**2 (14.3)**
	24	16 (66.7)	4 (16.7)	**20 (83.3)**	4 (16.7)	**4 (16.7)**

2.3.2 Genetic stock assignment

Four full sib families were identified, the largest consisting of three individuals. As such, five fish were removed from further analysis, reducing the total number of fish from 565 to 560.

From the 5,568 SNPs screened, 1,143 were removed as they were not classed as a SNP or MSV3. Furthermore, for 22 SNPs, scoring percentage was lower than 95 %. This resulted in a final panel of 4,403 SNPs for use in subsequent analysis.

Genetic structuring

The pairwise F_{ST} values ranged from 0.011 (S_Pow Burn and S_Prosen_Br) to 0.027 (N_LowEdz and N_Lee), with a mean (± S.D.) of 0.015 ± 0.003. Similar values were observed for D_A (mean ± S.D. = 0.015 ± 0.003), with a minimum of 0.010 between S_Pow Burn and S_Prosen_Br and a maximum value of 0.026 between N_LowEdz and N_Lee.

The MDS analysis showed three outlier sites (N_Stracathro, N_Lee and N_LowEdz) and a central cluster (Figure 2.3.2.1). When examining this central cluster in more detail, a split into two groups could be seen, which, with the exception of three sites (S_Braedownie, S_Cortachy and S_Quharity), corresponded to upper and lower regions in both rivers (Figure 2.3.2.1). Similarly, the NJ tree also showed a split, with the majority of sites from the upper reaches of the rivers clustered into one branch of the tree, with the exception of N_Westmouth, whilst all the lower sites formed the other branches, apart from S_Prosen_L (Figure 2.3.2.2). Based on a combination of both analyses, two assignment regions (upper and lower) were defined, and all sites classed as belonging to one of them, according to a dividing line shown in Figure 2.2.2.1.

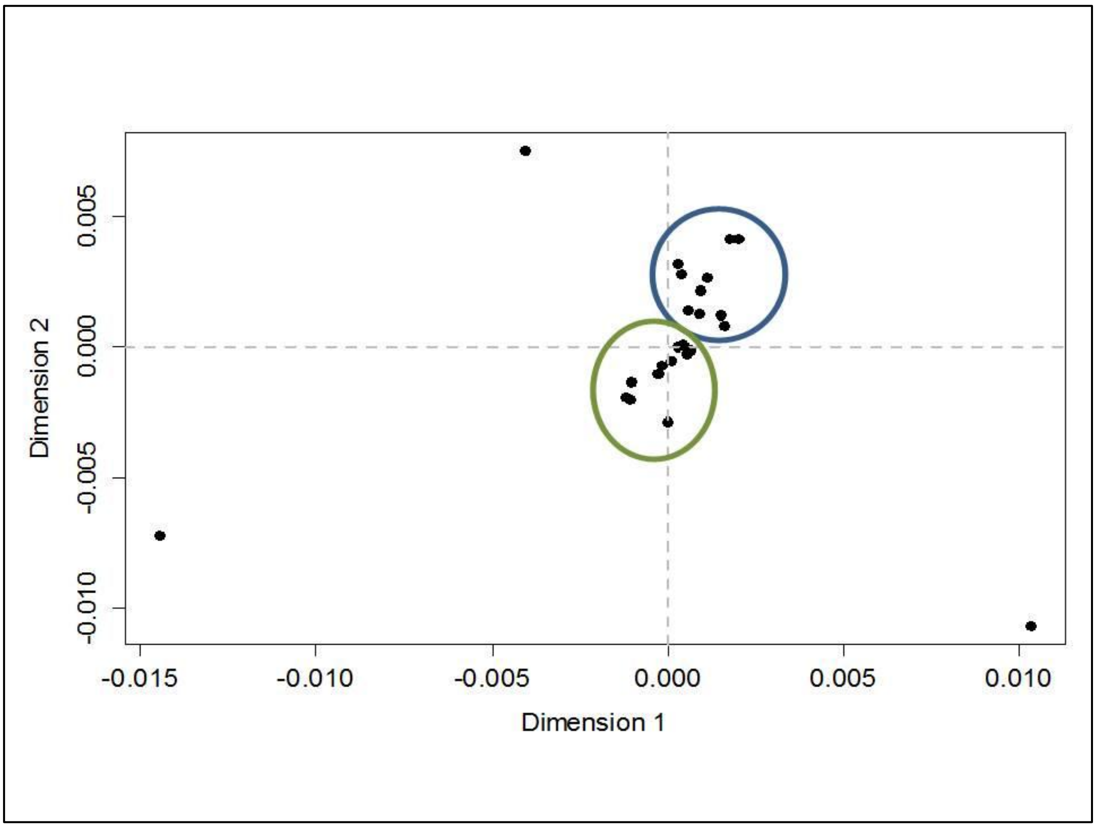


Figure 2.3.2.1: MDS plot of sample sites from the rivers North and South Esk. Circles represent the two identified regions, upper (blue) and lower (green).

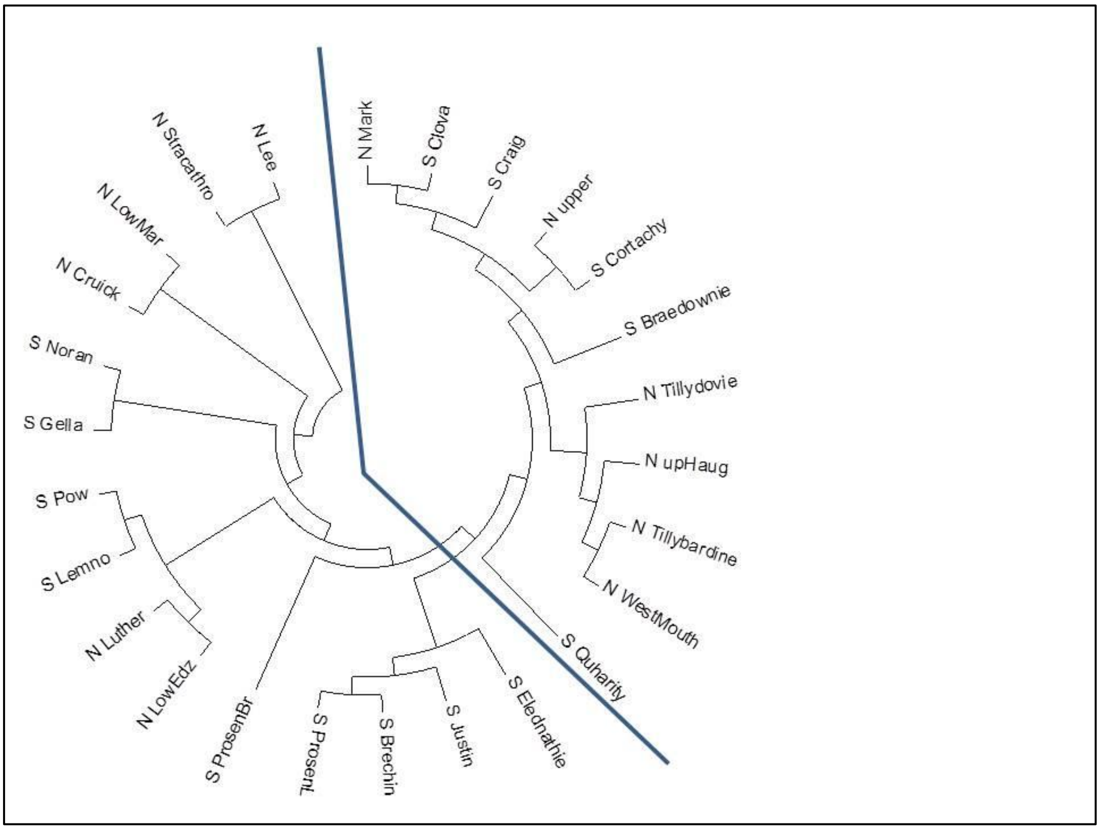


Figure 2.3.2.2: Neighbour - Joining Tree of sample sites. The line indicates a separation between mostly upper and lower sites.

Individual assignment analysis

Four TS / HOSs were created whereby two upper and two lower sites were removed, one from each river (i.e. blind sites) (Table 2.3.2.1).

Table 2.3.2.1: Sites removed from the four training sets (TS1 - TS4), including one site from each region within each river.

Training set	Upper North Esk	Lower North Esk	Upper South Esk	Lower South Esk
TS1	N_upper	N_Cruick	S_Clova	S_Brechin
TS2	N_Tillybardine	N_LowMar	S_ProsenL	S_Justin
TS3	N_Mark	N_LowEdz	S_Braedownie	S_Pow
TS4	N_Lee	N_Stracathro	S_Craig	S_Cortachy

Assignment of fish from the HOS to region was assessed. Figure 2.3.2.3 shows the accuracy of the assignments to either upper or lower region in the four HOSs, for an increasing number of SNPs, as well as the number of fish assigned at a cut-off of 80 %. With the exception of the accuracy of the blind sites to the lower region (dashed green line in Figure 2.3.2.3), accuracy and numbers of fish plateaued at the top ranked 192 SNPs and remained relatively stable for higher numbers of SNPs. At 192 SNPs, on average 79.2 % of fish could be assigned to the lower region with 57.2 % accuracy, whilst 79.1 % of fish could be correctly assigned (with an accuracy of 74.4%) to the upper region.

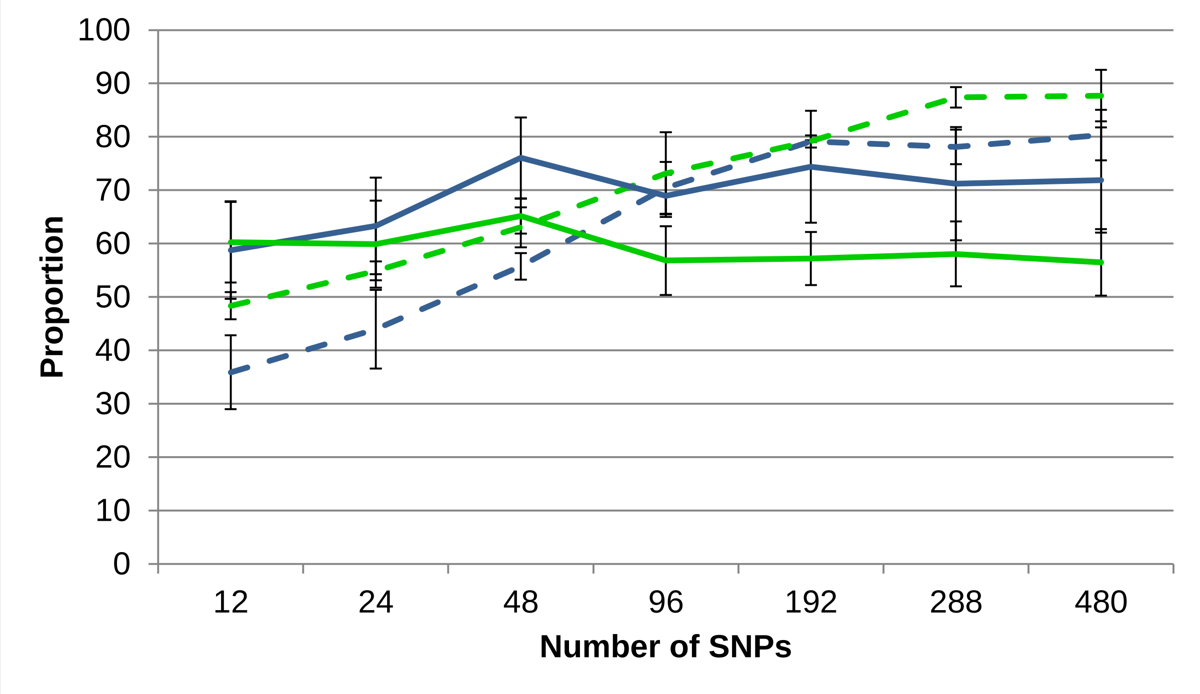


Figure 2.3.2.3: Average assignment accuracies (solid lines) to the upper (blue) or lower (green) region and average proportion of fish assigned (dashed lines) for an increasing number of SNPs, after a cut-off of 80 % was applied. Bars represent standard errors calculated over all replicate TS / HOS sets.

Between river differentiation

Within the upper region

Assignment success to the different rivers within the upper region is detailed in Figure 2.3.2.4. Average accuracy was highest for the top 12 SNPs and then gradually decreased with increasing number of SNPs, though it plateaued at the top 192 SNPs. The proportion of fish assigned increased gradually and started to plateau at the top 288 SNPs. Based on the top 12 SNPs, 55.9 % of fish were assigned to the South Esk with an accuracy of 76.3 %.

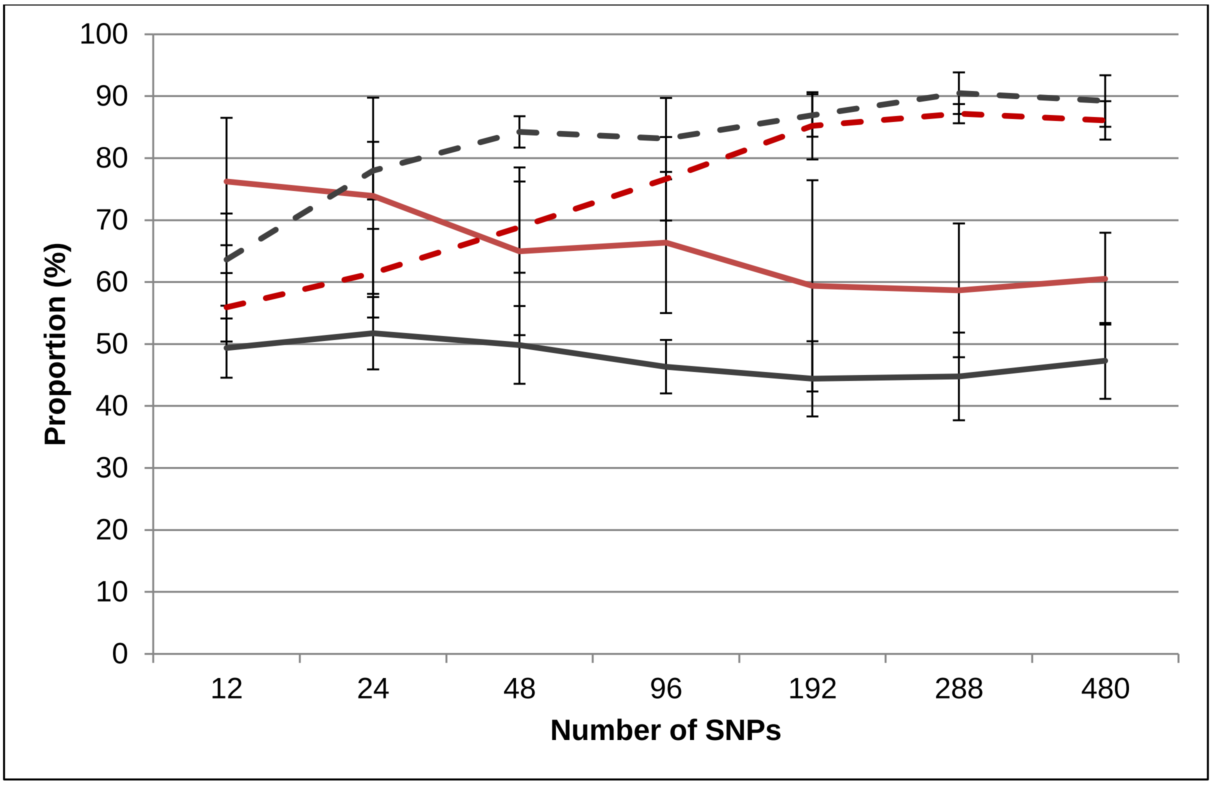


Figure 2.3.2.4: Average assignment accuracies (solid lines) to the River North Esk (grey) or River South Esk (red), and average proportion of fish assigned (dashed lines), for an increasing number of SNPs, after a cut-off of 80 % was applied. Bars represent standard errors calculated over all replicate TS / HOS sets.

Within the lower region

The assignment accuracy to river of origin within the lower region increased with increasing number of SNPs, and levelled off at the top 192 SNPs, with the exception of the accuracy to the River North Esk based on the top 480 SNPs (Figure 2.3.2.5). The proportion of fish assigned increased gradually and stabilised after the top 192 SNPs. Using the top 480 SNPs, 83.1 % of fish could be assigned to the River South Esk with an accuracy of 65.5 %.

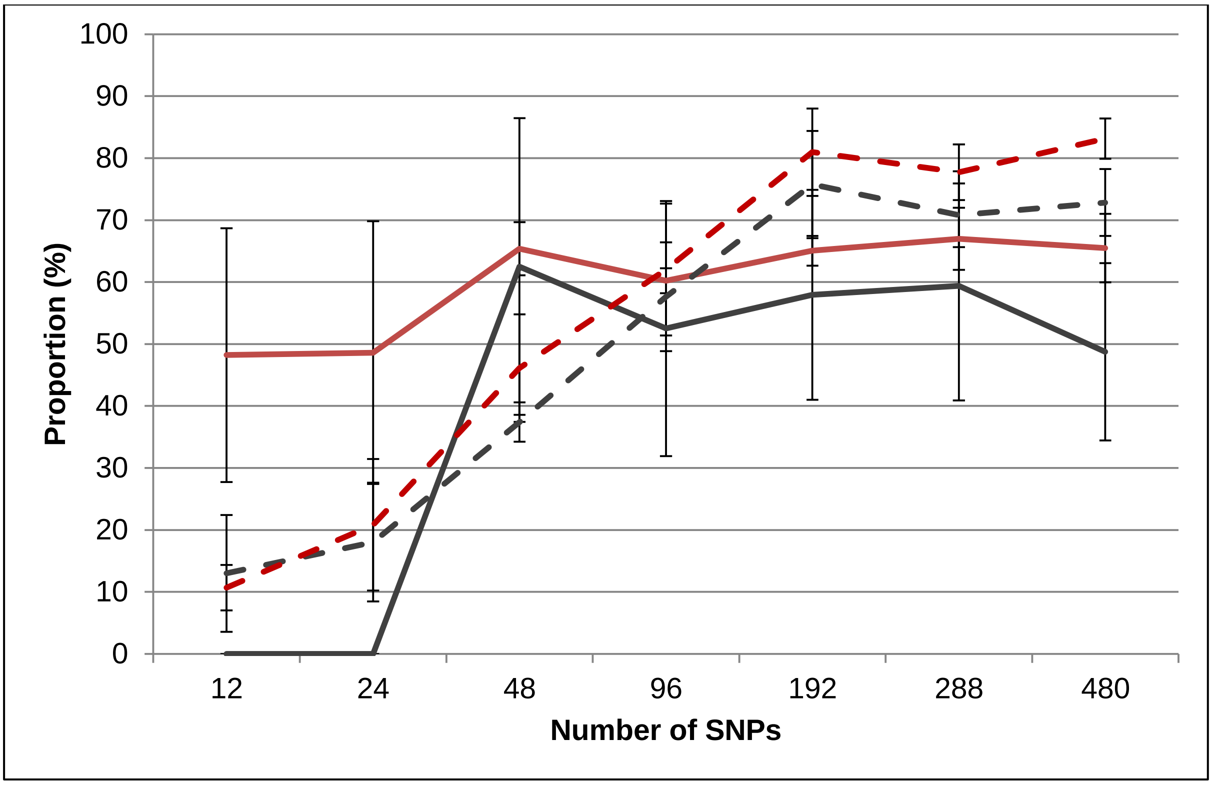


Figure 2.3.2.5: Average assignment accuracies (solid lines) to the River North Esk (grey) or River South Esk (red), and average proportion of fish assigned (dashed lines) for an increasing number of SNPs, after a cut-off of 80 % was applied. Bars represent standard errors calculated over all replicate TS / HOS sets.

Hierarchical assignment

Fish from the blind sites were firstly assigned to region of origin (upper / lower) using the top 192 SNPs identified in the upper / lower analysis, and subsequently to river of origin within each region, based on the top 12 SNPs and top 480 SNPs identified within the upper and lower region analysis, respectively. After applying an assignment likelihood cut-off of 80, accuracy to the upper and lower South Esk was 22.7 % and 44.9 %, respectively, and an average of 15.7 % of fish were assigned (Table 2.3.2.2).

Table 2.3.2.2: Summary of the hierarchical assignment analysis (cut-off of 80 applied), where fish were first assigned to region and then to river of origin within the upper and lower region, resulting in three assignment classes. Proportion assigned (%) to original sample size (*n* = 329) and accuracy (%) to each of the three classes are shown in italics. Figures in bold are correctly assigned fish on which the accuracy calculation is based.

	Assigned region / river			
Fish origin	**Upper South Esk**	**Lower South Esk**	**North Esk**	**Proportion assigned (%)**
Upper South Esk	**5**	7	34	*14.0*
Lower South Esk	10	**31**	16	*17.3*
North Esk	7	31	**44**	*24.9*
Accuracy (%)	*22.7*	*44.9*	*46.8*	
Average accuracy (%) to South Esk regions	*39.6*			

2.4 DISCUSSION

Levels of genetic differentiation between sites and areas (upper / lower, main stem / tributaries) were examined, as well as assignment success to site and / or areas of the system. Levels of differentiation between sites and areas were found to be relatively low within the system, and accurate assignments to site / area were thus not possible. The genetic approach employed was therefore not a useful approach in this situation and interpretation of spawning locations is based exclusively on the results of radio tracking work.

Spawning locations in the River South Esk

Over the course of the three-year investigation, a total of 24 spring salmon were tracked to spawning in the River South Esk. The majority (83.3 %) spawned in the upper reaches of the River South Esk, with 66.7 % spawning in Glen Clova and 16.7 % spawning in Glen Prosen. It is therefore concluded that River South Esk spring salmon spawn predominantly in the upper reaches of the catchment. This finding concurs with that observed previously on the Rivers Dee (Hawkins & Smith, 1986; Laughton & Smith, 1992) and Spey (Laughton, 1989; 1991; Laughton & Smith, 1992). It was interesting to note, however, that as on the River Tweed (Campbell, 1998), spring salmon in the present study did not spawn exclusively in the upper catchment, as defined by changes in geography (see Section 1.2). Indeed, 16.7 % spawned in the middle reaches of the River South Esk on the main stem. Therefore, distance upstream is unlikely to be the only feature defining the spawning location of spring fish, and other factors such as the relative availability of spawning habitat, are also likely to be important.

Of the tagged fish that stayed in the River South Esk, the proportions of fish surviving and retaining their tags until spawning time ranged from 25.0 % to 75.0 % among years and sources of tagged fish. These proportions are broadly similar to the range seen in previous in-river tagging studies. In a radio tracking study of 10 Atlantic salmon tagged near the mouth of the Aberdeenshire Dee, 2 fish (20 %) were monitored for most of the time they spent in fresh water (Hawkins & Smith, 1986). In a similar study carried out on the River Spey over two consecutive years (1988 and 1989), Laughton (1991) reported that 20 % and 29 % of tagged fish were subsequently tracked through to spawning in 1988 and 1989 respectively. In another study (Laughton, 1989), 10 fish out of a total of 24 that were tagged (42 %) were successfully tracked to spawning. The fish in that study (a mixture of salmon and grilse) were tagged between April and August, and it appears that the higher rate of successful tracking to spawning than in the present study reflects the shorter time period between tagging and spawning experienced by fish tagged later in the study period. Of the three seasonal groups of fish considered in the study by Laughton (1989), only the first group consisting of 10 salmon released in late April and early May are directly comparable with the present study. Of these, just 1 fish (10 %) was successfully tracked to spawning. In the second seasonal group of fish (three salmon and one grilse released during low water in June), 2 fish (50 %) were successfully tracked to spawning (Laughton, 1989). In the third seasonal group of fish (ten grilse released in August), 7 fish (70 %) were successfully tracked to spawning (Laughton, 1989). Webb (1989) reported that of 44 salmon radio tagged in the River Tay estuary during June and July, 5 tags (11.4 %) were detected during an aerial survey carried out at the end of September. Tag retention could be improved by surgically implanting tags into the body cavities of salmon. However, there is no information with which to assess how such intervention would itself affect mortality risk. It was decided in this study to minimise risk to the fish by using intragastric tagging and accept a possible higher cost due to regurgitation of tags.

Detection rates of fish post-tagging

In the present study, approximately one third of the radio tagged salmon sourced from the coastal net fishery were detected again after tagging (51 out of 153 tagged in 2012, 33.3 %; 14 out of 38 tagged in 2013, 36.8 %). Of the 153 fish tagged in 2012, 3 fish (2.0 %) were re-caught by the coastal net fishery. Of the 48 fish that were detected in the monitored rivers, 4 fish (2.6 % of all fish tagged) were caught by the net and coble fishery in the River North Esk. No tagged fish were reported as being taken by the rod and line fishery in 2012, while in 2013, no tagged fish sourced from the coastal net fishery were recaptured at sea or taken by fisheries.

The overall detection rate of tagged fish sourced from the coastal net fishery after release is at the lower end of the ranges reported by previous studies. In a study of Atlantic salmon radio tagged at sea south of the Aberdeenshire Dee between May and August, Smith & Johnstone (1996) detected 51 % of the tagged fish after release. Monthly detection rates varied from 30 % to 67 %. However, in contrast to the current study, the proportion of detections made by fisheries in Smith & Johnstone (1996) was greater; 4.9 % were caught by coastal fisheries and 11.5 % were caught by rod and line (1.6 % returned). In the first two years of the present study, no external marking of tagged fish to indicate the presence of an internal radio tag was carried out. Thus, only tags extracted from killed, gutted fish are likely to be reported by anglers. The lack of reported tags from rod caught fish in the current study compared to Smith & Johnstone (1996) may be due to the increased rates of catch and release in the rod fishery. In 2014, just one tag was returned by an angler. Given the high incidence of catch and release for salmon in Scotland [80.0 % in 2013 (ICES, 2014)], detection rates for tagged fish sourced from the coastal net fishery by anglers is likely to have been low in the present study.

A further difference between the present study and previous studies which may have affected the detection rate of tagged fish after release is the time of year at which fish were tagged. Those fish tagged in the present study were spring fish, tagged at sea between February and May. In the study by Smith *et al*. (1994), the tagging period was longer, running from February to August, while those tagged by Smith & Johnstone (1996) were tagged later in the year (May: 52.46 %; June: 14.75 %; and August: 32.79%). Differences in fish behaviour and angling practices among different stock components (spring salmon, summer salmon and grilse) and varying environmental factors in the period following release may have affected the detection rate of tagged fish after release.

The fate of radio tagged fish

For the study as a whole, 24 fish out of 245 that were tagged (9.8 %) were tracked to spawning. For tagged fish sourced from the coastal net fishery, 6 fish out of 191 that were tagged over two years (3.1 %) were tracked to spawning. In contrast, for tagged fish sourced from within the River South Esk itself, 18 fish out of 54 that were tagged over two years (33.3 %) were tracked to spawning. Thus, the coastal net fishery accounted for one quarter of all tagged fish that were tracked to spawning, with the remaining three quarters all sourced in-river. Furthermore, “survival” rates from tagging to spawning were an order of magnitude greater for fish tagged in-river than for fish sourced from the coastal nets as significant numbers of tagged fish were either lost in the marine phase after tagging or returned to rivers that were not monitored with receivers.

There are several reasons for failing to subsequently detect fish tagged and released from coastal fisheries. Firstly, it is likely that a proportion of the tagged fish would have regurgitated their tag. In a study of Atlantic salmon radio tagged in the River Tweed estuary between April and September, Smith *et al*. (1998) recorded an in-river regurgitation rate (where fish are not expected to be feeding) ranging from 12.5 % to 16.7 %. At sea, where the fish in the present study were tagged, regurgitation rate is likely to be higher as feeding may still be occurring to some extent. Support for this comes from the observation that one of the tagged fish caught in nets during the present study showed evidence of post-tagging feeding in the gut. Furthermore, Mills (1989) cites data from Grey & Tosh (1894) which shows that the proportion of salmon caught in the estuary of the River Tweed with food in their stomachs is highest during spring (February: 14.3 %; March: 43.5 %; April: 39.8 %; May: 16.7 %; June: 13.1 %; July: 1.8 %; August: 3.8 %; and September: 1.9 %). Thus, Grey & Tosh (1894) showed that the greatest proportion of fish with food in their stomachs occurred in the months during which tagging was carried out in the present study.

Secondly, it is likely that predation accounted for the loss of some tagged fish sourced from the coastal net fishery. Middlemas *et al*. (2003) assessed the influence of marine mammal predators on salmon. Four species known to be predators of Atlantic salmon inhabit the waters off the east coast of Scotland - grey seals (*Halichoerus grypus*), harbour seals (*Phoca vitulina*), harbour porpoises (*Phocoena phocoena*) and bottlenose dolphins (*Tursiops truncatus*). All four species are present in the area in which the present study was carried out. Harbour seals are regularly seen in the Montrose Basin, and grey seals are occasionally seen (Scottish Wildlife Trust, 2011). Bottlenose dolphins have also been observed foraging in the Montrose Bay area (Dempsey, 2009), as have harbour porpoises (Marine Life Angus, 2013).

Thirdly, it is possible that some of the salmon tagged in the coastal net fishery were destined for other rivers that were not being monitored for tags. Fisheries operating along migration routes of salmon as they return through coastal waters to spawn may exploit fish from a number of different rivers (Gilbey *et al*., 2012). Therefore, salmon caught and tagged at a particular coastal location may be returning to a variety of rivers, possibly a considerable distance from the point of tagging (e.g. Shearer, 1986; 1992; Smith & Johnstone, 1996; Malcolm *et al*., 2010). In the present study, a proportion of the tagged fish sourced from the coastal net fishery were detected in rivers other than the South Esk that were also being monitored for tags (see Section 5), and it is possible that some tagged fish returned to rivers elsewhere.

Efficacy of radio tracking

Due to operational reasons, the fixed receiver stations deployed on the River Dee in 2012 did not detect any tags, although 7 tags were subsequently detected during aerial surveys. Elsewhere, and in other years, fixed receiver stations had a high tag detection efficacy, ranging from 82 % to 100 %. When fixed receiver station efficacy was less than 100 %, there were plausible explanations as to why some tags were seemingly not detected, and these are discussed briefly below. In light of this additional information, efficacy figures presented should be viewed as minimum estimates.

On the River North Esk in 2012, 14 of the 17 tags available for detection (82 %) were detected by the fixed receiver stations. The 3 tags not detected include 2 tags in fish which were caught and removed by the in-river net and coble fishery. It is entirely possible that these fish were not “missed” by the fixed receiver stations as the net and coble fishery is located in the estuary, downstream of the downstream-most fixed receiver station. It seems likely that these 2 fish may have been intercepted shortly after entering the River North Esk and before they had moved sufficiently far upstream to be detected by the downstream-most fixed receiver station. However, it is also possible that these 2 fish were “missed” by the fixed receiver stations and were intercepted by the net and coble fishery as they returned to sea, having initially progressed some distance up-river beyond the fixed receiver stations. Although we have no way of verifying which scenario is correct, it is worth noting that a further 2 fish caught and removed by the net and coble fishery in the River North Esk in 2012 were detected successfully by a fixed receiver station, and were subsequently captured by the net and coble fishery, presumably whilst attempting to return to sea. The other tag that was not detected by a fixed receiver station in the River North Esk in 2012 was detected only by a mobile receiver, and is not thought to have progressed sufficiently far up-river to have reached the downstream-most fixed receiver station. The efficacy figure of 82 % on the River North Esk in 2012 should therefore be seen as a minimum estimate as it is entirely plausible that all fish progressing sufficiently far up-river to be detected by at least one of the two fixed receiver stations were infact detected.

On the River South Esk in 2013, for those tagged fish sourced from the in-river net, 19 of the 22 tags available for detection (86 %) were detected by the fixed receiver stations. This efficacy figure should also be viewed as a minimum estimate as the 3 tags not detected are thought not to have passed any fixed receiver stations. The 3 tags not detected include 2 regurgitated tags which were confirmed as being no longer associated with live fish and which were located close to the in-river tagging site. It seems likely that these tags were regurgitated soon after the fish in question were tagged, and did not therefore have the opportunity to be detected by fixed receiver stations situated either upstream or downstream of the netting site. The other tag that was not detected by a fixed receiver station is thought to have been in a fish removed by an angler in the vicinity of the in-river tagging site.

On the River South Esk in 2014, 30 of the 32 tags available for detection (94 %) were detected by the fixed receiver stations. Similar reasons to those noted above were suspected for these “missed” tags. 1 tag that was not detected by a fixed receiver station was never detected again after tagging, and tag malfunction was suspected. 1 regurgitated tag was confirmed as being no longer associated with a live fish between the fixed receiver stations upstream and downstream of the in-river tagging site.

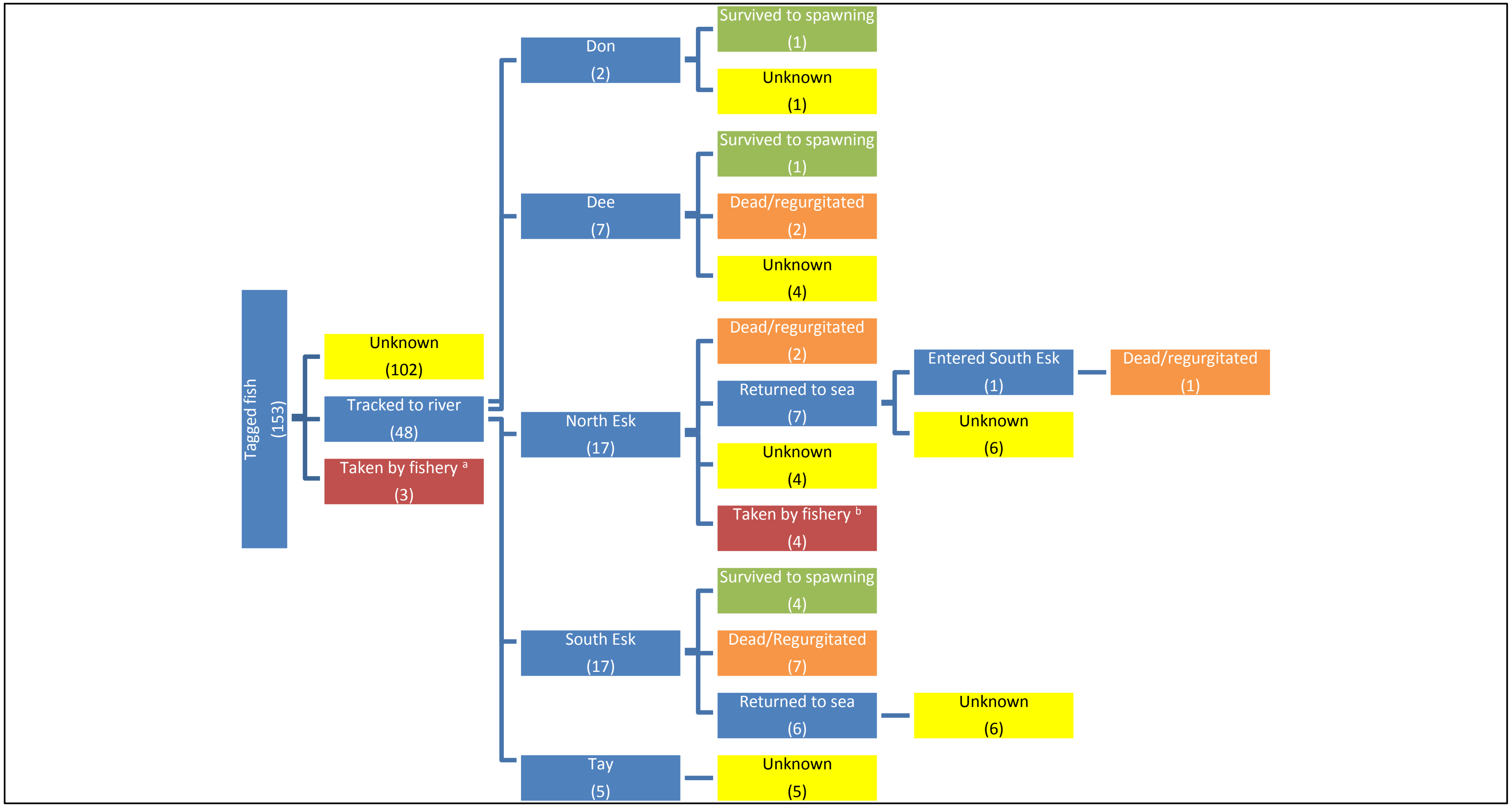
Aerial surveys were also generally highly efficient at detecting tags known to be in a given river at the time of the survey, i.e. after taking into account tags no longer available for detection such as those in fish known to have returned to sea, or regurgitated tags recovered from a river prior to aerial surveys taking place. The exception to this was on the River Tay in 2012, when only 1 of the 5 tags thought to be in the river at the time (20 %) were detected by the aerial survey. It is thought this was due to the relatively small proportion of the Tay catchment that was surveyed. On the River South Esk in 2013, for those tagged fish sourced from the in-river net, 9 of the 10 tags available for detection (90 %) were detected by the aerial survey. The 1 tag that was not detected was lost, and it was suspected that this tag was in a fish removed by an angler. On the River South Esk in 2014, 18 of the 23 tags available for detection (78 %) were detected by the aerial survey. Of the 5 tags that were “missed” by the aerial survey, 1 tag was lost (suspected removal by an angler) and 1 tag was never detected again after tagging (suspected tag malfunction). However, the other 3 tags were genuinely “missed” by the aerial survey, and included 1 regurgitated tag (confirmed as being no longer associated with a live fish between the fixed receiver stations upstream and downstream of the in-river tagging site) which was subsequently found (lodged deeply in the river bed) by manual tracking, and 2 tags in fish confirmed as being alive at spawning time, having proceeded upstream of the upstream-most fixed receiver station in Glen Prosen. These 2 tags were presumably outside the area covered by the aerial survey in the very highest reaches of Glen Prosen, although it is also possible that the aerial survey passed over them, but failed to detect them. (One of these fish was subsequently detected moving downstream by fixed receiver stations after the aerial survey took place).

Fixed receiver stations and aerial surveys were generally highly efficient at detecting tags. In combination, and supplemented by manual tracking, the radio tracking methodology was sufficiently robust to enable conclusions regarding the fate of individual fish to be made in the vast majority of cases for the River South Esk. This was particularly the case when dealing with fish that were tagged in-river as there was a known number of fish within the river to start with. Two fixed receiver stations were situated downstream of the in-river tagging site on the River South Esk, enabling all fish returning to sea to be identified successfully. Efficacy values for both fixed receiver stations and aerial surveys were high for tagged fish sourced in-river, being at least 86 % and 94 % for fixed receiver stations on the River South Esk in 2013 and 2014 respectively, and at least 90 % and 78 % for aerial surveys on the River South Esk in 2013 and 2014 respectively.

In the case of tagged fish sourced from the coastal net fishery, the number of fish *actually* entering each river was ultimately unknown, since fish tagged at sea may have regurgitated their tags prior to entering a river. It is not therefore possible to truly validate the efficacy of fixed receiver stations versus aerial surveys since the number of tags available to be detected by either method was only known from the other method. Nonetheless, there was a high degree of congruence between the number of tags detected by both methods, suggesting that the numbers detected by the two methods were infact representative of the numbers of tagged fish entering the different rivers. It is also worth considering that the mechanism of detecting tags by the two methods differs somewhat. Fixed receiver stations detect fish that are actively moving whereas aerial surveying detects *tags* (not necessarily associated with live fish). Manual tracking is required in combination with these approaches to provide an overall picture of fish movements over time.

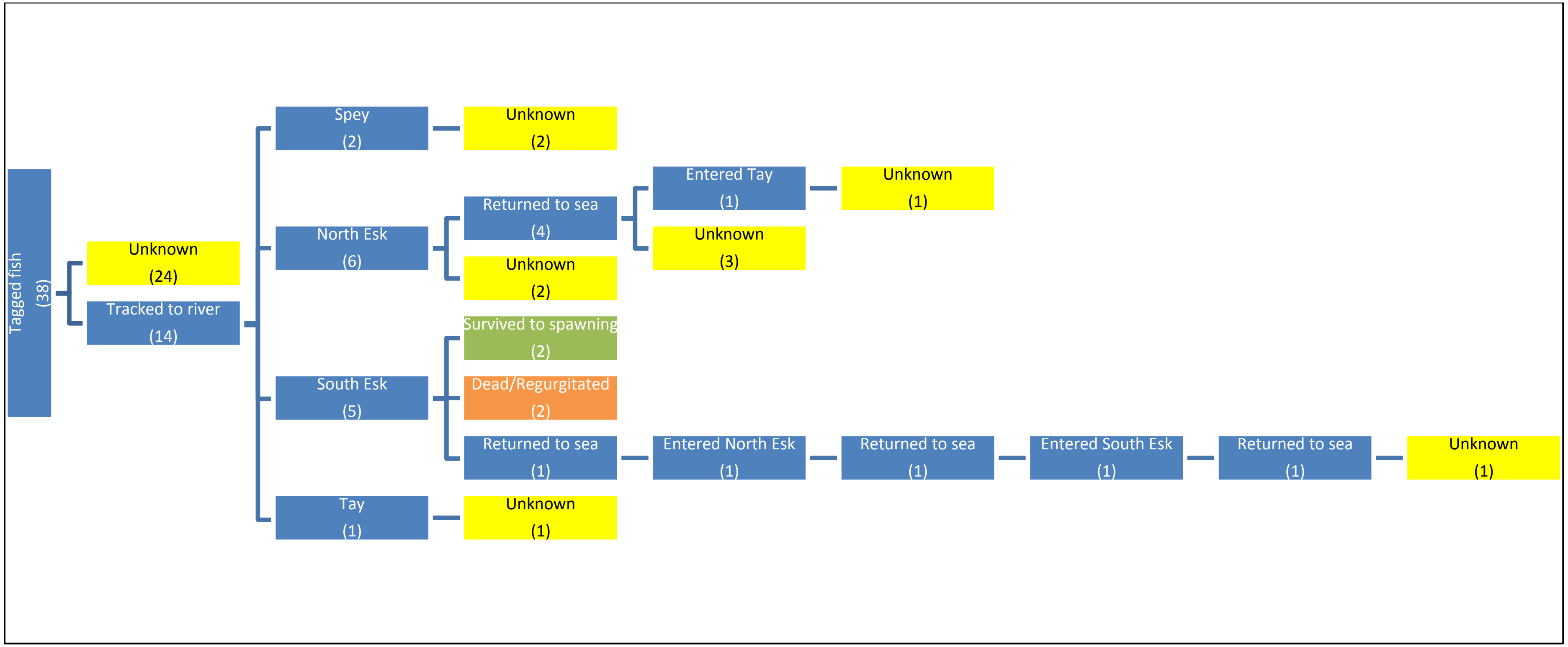
2.5 APPENDICES

Appendix 2.5*a*: The fate of all tagged fish sourced from the coastal net fishery in 2012.

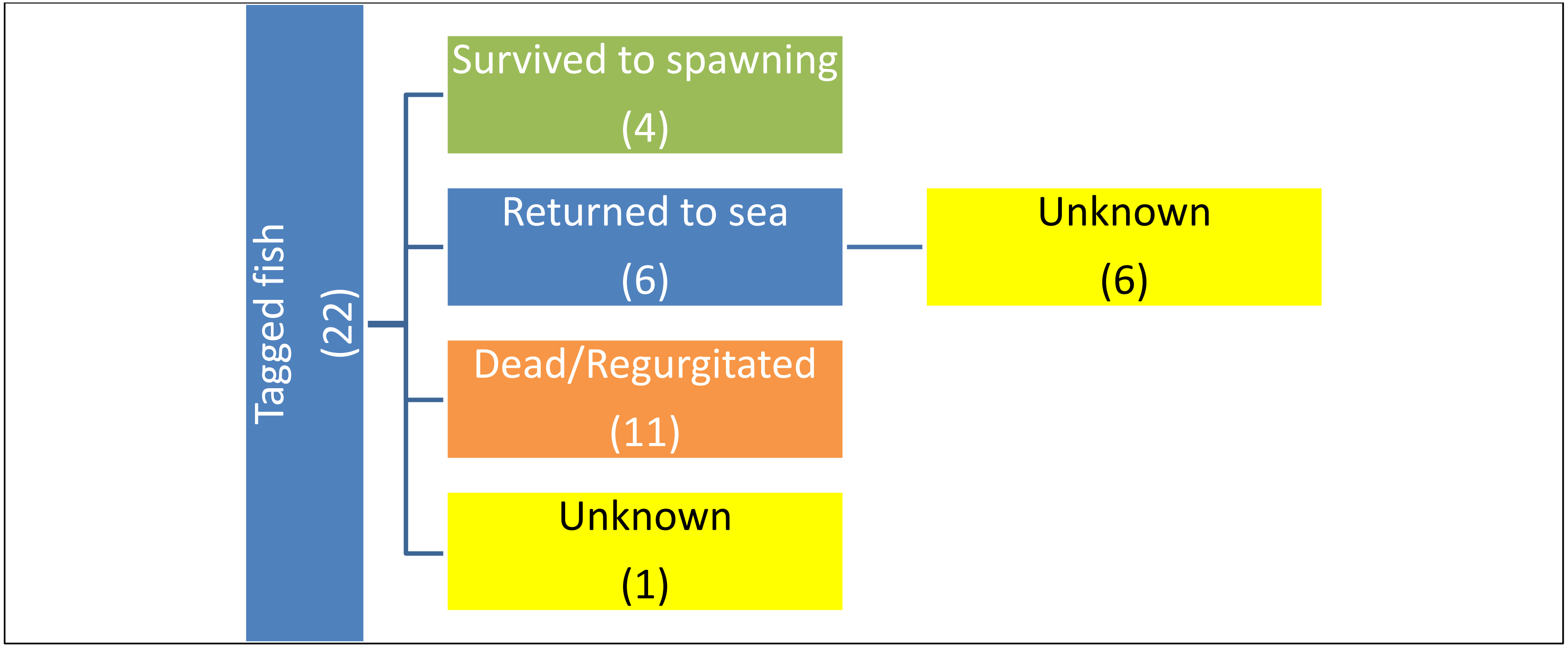


[a] Coastal net fishery; [b] In-river net and coble fishery.

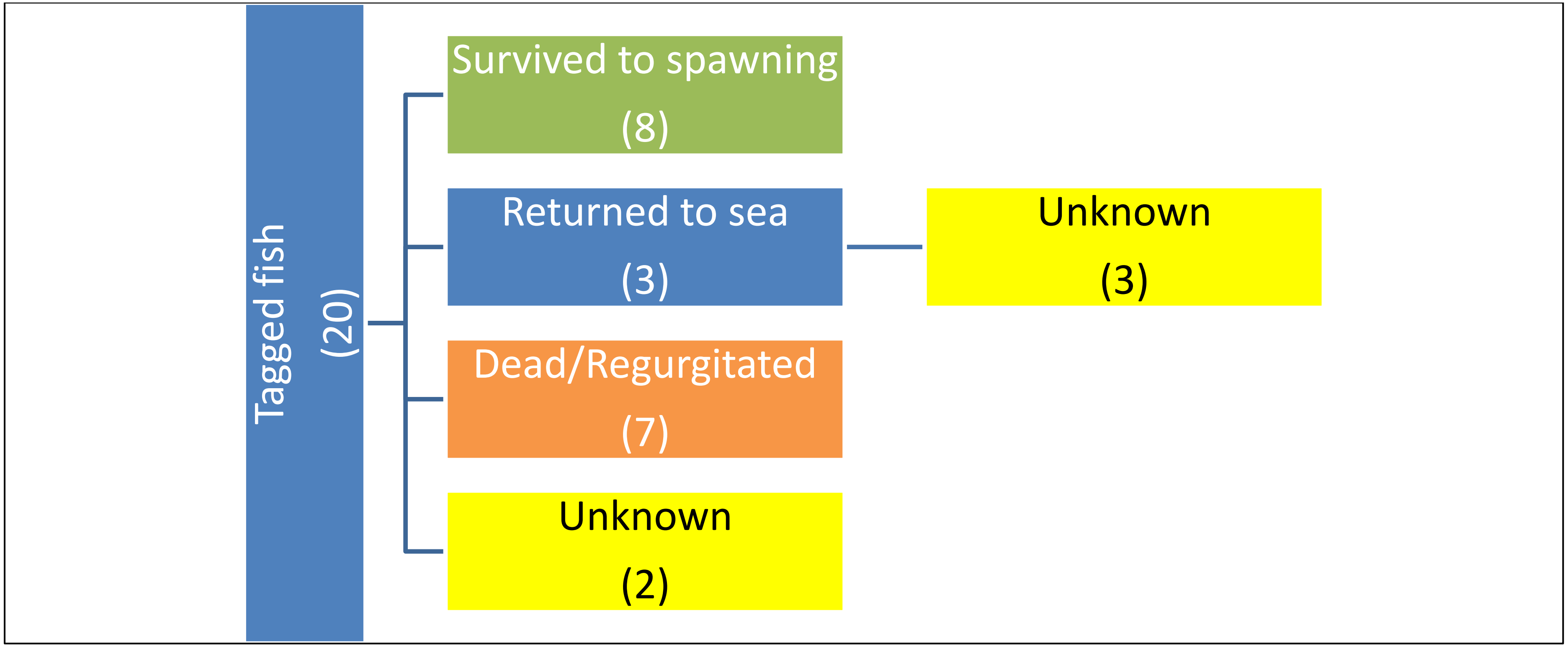
Appendix 2.5*b*: The fate of all tagged fish sourced from the coastal net fishery in 2013.



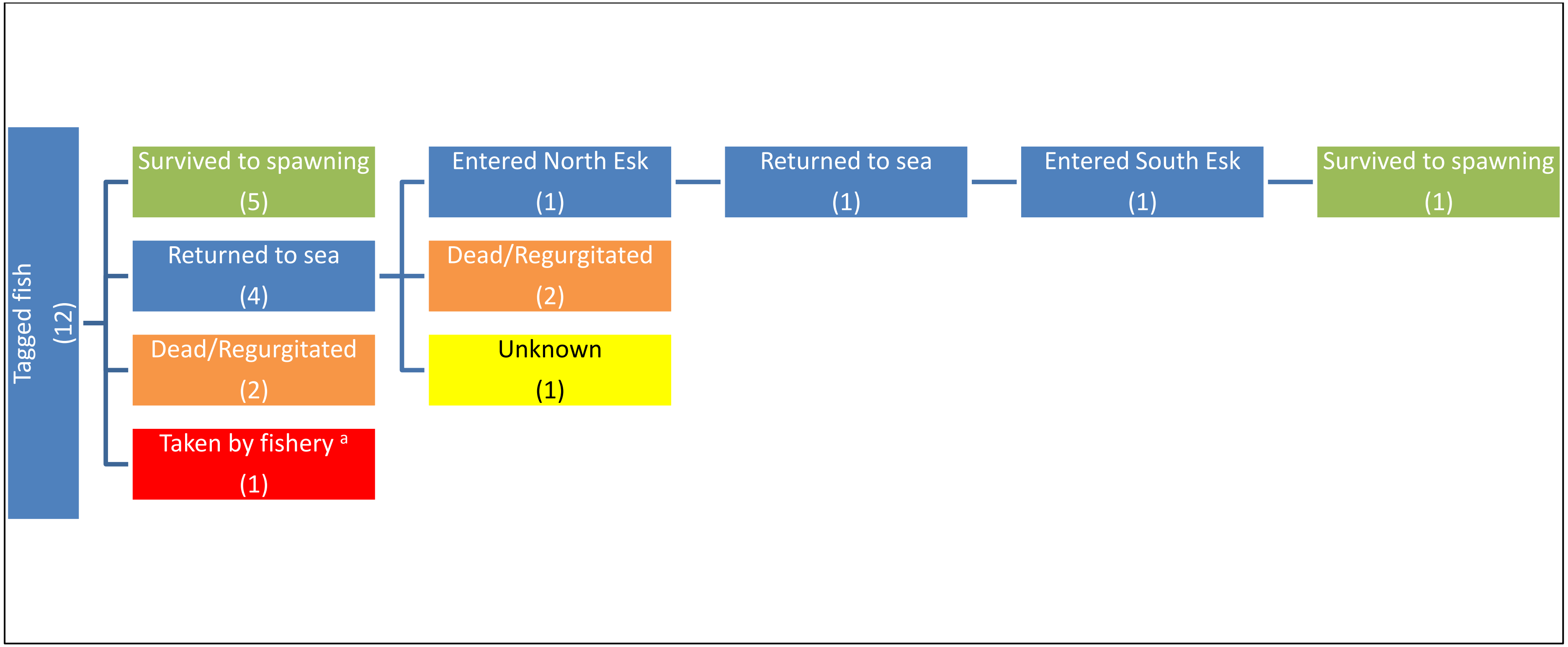
Appendix 2.5*c*: The fate of all tagged fish sourced from the in-river net in 2013.



Appendix 2.5*d*: The fate of all tagged fish sourced from the in-river net in 2014.



Appendix 2.5*e*: The fate of all tagged fish sourced from the rods in 2014.



[a] In-river rod fishery.

Part 3: The status of the juvenile salmon stock

Objective: *How does the status of the juvenile salmon stock vary within the River South Esk and how does this relate to spawning regions used by spring fish?*

3.1 INTRODUCTION

Juvenile assessments are often used to determine the health of fish populations and contribute towards status assessments under the Water Framework Directive (SNIFFER, 2011*b*) and EU Habitats Directive (Godfrey, 2005). Due to density dependent processes, juvenile assessments are potentially less sensitive than other metrics of fish population health, at least at relatively high densities, but can still be a useful indicator where spawner numbers drop below saturation levels or where there are problems with local habitat quality that prevent successful recruitment.

Electrofishing is the most commonly applied sampling approach for juvenile salmonids. Where quantitative multi-pass electrofishing is performed, estimates of capture probability can be obtained. Given estimates of capture probability, it is possible to scale the observed fish numbers, to the total numbers of fish estimated to occur at a site (Millar *et al*., 2015).

One of the greatest challenges in juvenile salmon assessment relates to the interpretation of data obtained by electrofishing. To determine whether observed salmon numbers are adequate, it is first necessary to determine the expected numbers under natural environmental conditions. Juvenile salmon densities vary in response to a wide range of biotic and abiotic habitat variables including water quality, depth, velocity, substrate, cover and food availability (Armstrong *et al*., 2003). Although it is not possible to measure all these variables at the large spatial and temporal scales required for salmon assessment, it is possible to model salmon densities in relation to habitat proxies, often obtained from a Geographical Information System (GIS). Such an approach was recently described by Millar *et al.* (2015) for Scotland and provides the basis for interpreting electrofishing data in this report. Specifically, observed densities from electrofishing on the River South Esk were compared with the national fish density model described by Millar *et al*. (2015) to assess whether sites are performing better or worse than expected given the habitat characteristics of the river. Due to the potential for status to change over time, data are presented for each year of the study (2013 and 2014) and compared with historical data (2004, 2005 and 2011), to determine if there is any obvious temporal variation in numbers of salmon fry across sites.

In the context of the current investigation, radio tracking has shown that early running spring salmon spawn predominantly in the upper South Esk (see Section 2). Therefore, it seems reasonable to assume that the status of electrofishing sites in the upper catchment are broadly indicative of the health of spring salmon stocks and it is on this basis that that the electrofishing data are interpreted.

3.2 METHODS

Electrofishing data

Only quantitative electrofishing data containing more than two passes was included in this report. Historical electrofishing data were obtained from Scottish Natural Heritage (SNH) for the years 2004 and 2005 (Godfrey, 2005), and from the Scottish Fisheries Co-ordination Centre (SFCC) database for 2011. Additionally, Marine Scotland Science undertook programmes of electrofishing in 2013 and 2014 in support of this project. A summary of available data is provided in Table 3.2.1.

Table 3.2.1: Summary of available electrofishing data.

Year	Date	Easting	Northing	Number of passes	Data Source	Area fished (m^2)
2004	01/09/2004	330489	774254	3	SNH	372
2004	01/09/2004	336311	769818	3	SNH	136
2004	01/09/2004	336353	768610	3	SNH	355
2004	02/09/2004	340149	759445	3	SNH	155
2004	02/09/2004	349945	756805	3	SNH	152
2004	02/09/2004	325779	769888	3	SNH	228
2004	05/08/2004	364147	758240	3	SNH	592
2004	31/08/2004	328095	778108	3	SNH	337
2004	31/08/2004	328043	776048	3	SNH	220
2005	08/07/2005	325779	769888	3	SNH	136
2005	08/08/2005	328095	778108	3	SNH	241
2005	22/09/2005	334178	762769	3	SNH	46
2005	22/09/2005	329253	767866	3	SNH	77
2005	27/09/2005	352457	758502	3	SNH	53
2005	27/09/2005	338751	762338	3	SNH	48
2011	01/08/2011	328095	778108	3	SFCC	96
2011	06/10/2011	325779	769888	3	SFCC	125
2011	23/08/2011	334173	762925	3	SFCC	37
2011	23/08/2011	329253	767866	3	SFCC	77
2011	29/07/2011	352457	758502	3	SFCC	98
2011	29/09/2011	338751	762338	3	SFCC	73
2011	31/07/2011	340090	758522	3	SFCC	80
2013	11/09/2013	332177	773323	3	MSS	56
2013	11/09/2013	333988	762936	3	MSS	83
2013	18/09/2013	335398	771511	3	MSS	41
2013	18/09/2013	337218	769781	4	MSS	85
2013	24/09/2013	364178	756374	3	MSS	47
2013	25/09/2013	354159	758510	3	MSS	31
2013	25/09/2013	352456	758508	3	MSS	50
2013	27/09/2013	328813	768113	3	MSS	71
2014	02/09/2014	335343	758440	3	MSS	86
2014	02/09/2014	338566	758327	3	MSS	115
2014	03/09/2014	348402	760161	3	MSS	90
2014	04/09/2014	329693	768000	3	MSS	77
2014	04/09/2014	331455	766776	3	MSS	144

2014	05/09/2014	332767	765773	3	MSS	65
2014	05/09/2014	332618	762968	3	MSS	76
2014	08/09/2014	363075	755529	3	MSS	65
2014	08/09/2014	363400	755634	3	MSS	81
2014	09/09/2014	335418	771535	3	MSS	66
2014	09/09/2014	337293	769889	3	MSS	78
2014	10/09/2014	328167	777375	3	MSS	110
2014	10/09/2014	326674	775757	3	MSS	105
2014	11/09/2014	352457	758502	3	MSS	58
2014	11/09/2014	353096	758438	3	MSS	51
2014	12/09/2014	345010	754416	3	MSS	67
2014	12/09/2014	345952	754667	3	MSS	49
2014	15/09/2014	364170	756362	3	MSS	57
2014	15/09/2014	364882	756968	3	MSS	74
2014	15/09/2014	365071	757618	3	MSS	79
2014	16/09/2014	332697	773054	3	MSS	55
2014	16/09/2014	334178	762769	3	MSS	50
2014	17/09/2014	335291	763673	3	MSS	45
2014	17/09/2014	335305	763600	3	MSS	115
2014	18/09/2014	347362	755222	3	MSS	65
2014	24/09/2014	349187	756818	3	MSS	74

During 2004 and 2005, 15 electrofishing sites were fished. Sites were chosen to maximise the value of historical data consistent with a reasonable geographical spread of sites throughout the SAC (Godfrey, 2005). During 2013, eight sites were selected to provide data on salmon abundance in the upper and lower South Esk catchment. The sites were subsequently micro-sited to include only areas where local physical habitat appeared suitable for salmon. This is likely to be broadly consistent with historical site selection approaches. During 2014, 26 sites were regularly distributed across the catchment, within the geographical range occupied by Atlantic salmon, subject to a number of logistical constraints. These constraints were that the site had to be accessible with respect to access permission or stalking activity, and that the site had to be of fishable dimensions in terms of wet width (generally < 8 m) and water depth (suitable for safe and comfortable wading). This approach removed surveyor bias towards “good” salmon fry and parr habitat, increased the range of habitat types surveyed, and provided good overall spatial coverage.

Estimating salmon densities

Salmon were separated into fry (age 0+) and parr (age 1+ and older) using site specific length breakpoints. Densities were subsequently estimated for salmon fry. Full details of the methods used to estimate salmon fry densities are described by Millar *et al*. (2015). However, in brief, capture probabilities were modelled from multiple-pass (depletion) electrofishing data as a function of the organisation carrying out the electrofishing, the year, day of the year, geographical location, distance to sea, channel width, channel gradient, catchment area and altitude. The modelled capture probabilities were then used to raise observed fry counts to provide an estimate of the total number of fish occurring at a site.

Assessing the performance of electrofishing sites

The salmon fry densities that would be expected for each electrofishing location under natural environmental conditions were modelled in relation to local habitat characteristics using a national fry density model. For full details of the model see Millar *et al*. (2015). The resulting predictions from the model were specified such that they represent an average national expectation for salmon fry in a good year, given the local habitat characteristics of the site but excluding the effect of the negative anthropogenic impacts including “urban area” and “conifer forest”.

Expected (modelled) salmon densities were compared with observed densities to determine the relative fry numbers at each electrofishing site, and the resulting differences in densities (model residuals, observed - predicted values) were plotted using a simple colour coded system where sites close to average national expectation were coded green, those exceeding expectation were coloured shades of blue and those below expectation were coded shades of red.

3.3 RESULTS

Expected salmon fry densities

Figure 3.3.1 shows the expected densities of salmon fry for monitoring locations in the River South Esk. Spatial differences in expected densities reflect the spatial variability of habitat variables. The greatest spatial variability was driven by altitude, with lower densities expected at higher altitudes. The next greatest effects were associated with distance to sea (densities increase with increasing distance) and upstream catchment area (densities increase with increasing catchment area up to *ca*. 50 km^2). Expectations are also reduced at a local level by the presence of mixed forestry. In general, higher densities are expected at the bottom of larger tributaries in the lower catchment which are associated with low altitudes, moderate upstream catchment areas and a moderate distance to sea. Very low density expectations are predicted for higher altitude sites in the upper catchment that also have relatively small upstream catchment areas.

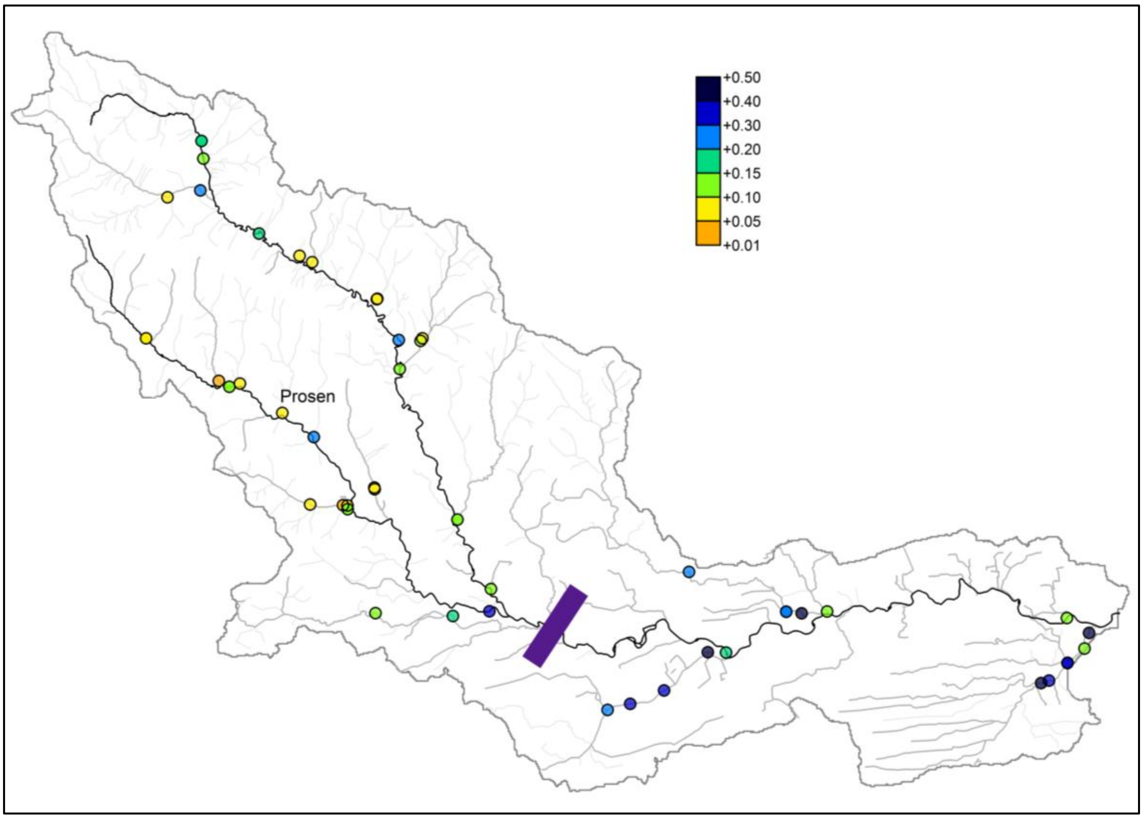


Figure 3.3.1: Predicted (expected) densities of salmon fry for monitoring locations on the River South Esk. The expectations are derived from a national salmon fry abundance model described by Millar *et al.* (2015). The predictions were made for a good year (2003) and time of year (day of the year 150) when the highest densities are expected. The effect of negative anthropogenic impacts "urban area" and "conifer forest" have been excluded from predictions. The predictions can be considered a mean national expectation under good conditions and in the absence of anthropogenic pressures. Scale represents number of salmon fry expected m^{-2}. Solid purple bar indicates an approximate delineation between the upper catchment where spring fish predominate and the lower catchment.

Observed salmon fry densities

Across all years, fry densities ranged from 0 - 3.9 fish m^{-2} (Figure 3.3.2). Observed fry densities were more variable during later years (2011 to 2014) than earlier years (2004 and 2005), although the numbers and distribution of sites and sampling strategies also varied between years. Fry were found at all sites in 2004, 2005 and 2011, although these surveys contained few sites in the lower catchment. Fry were absent from 38 % and 46 % of sites in 2013 and 2014 respectively. Given the lack of a consistent sampling methodology, sample locations and sample numbers across years it was not possible to identify any clear temporal trends in fry densities. However, a qualitative assessment of the data suggests that densities may have been lower in the upper catchment in recent survey years (2013 and 2014). Unfortunately there were very few sampling locations in the lower catchment prior to 2013.

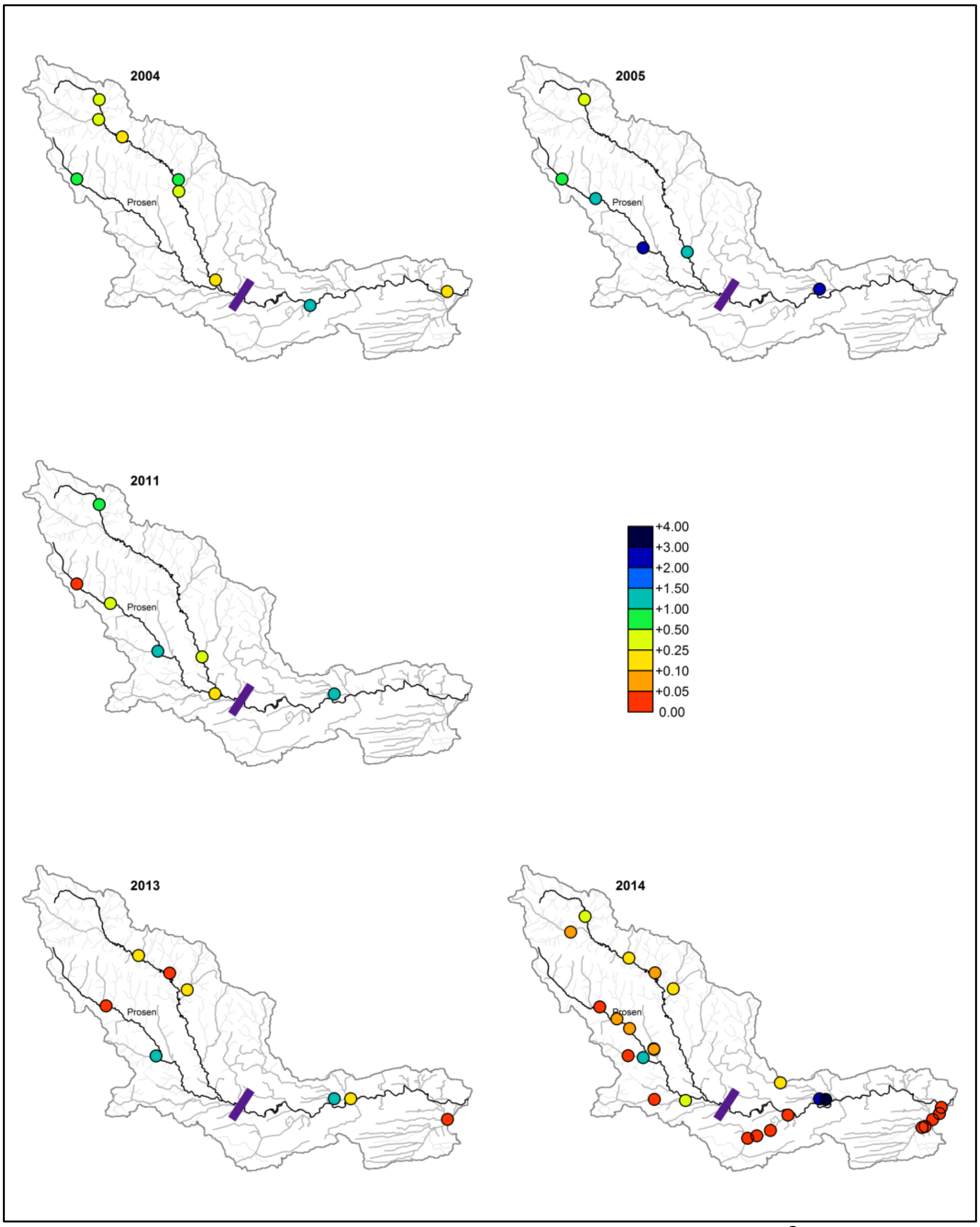


Figure 3.3.2: Observed densities of salmon fry (fish m^{-2}) calculated by raising fry counts observed during electrofishing by an estimate of capture probability derived from a national fry capture probability model (Millar *et al*., 2015). Electrofishing data are presented for each year where > 2 electrofishing sites were available.

Performance of electrofishing sites relative to average national expectation

The percentage of sites meeting or exceeding the national expectation for fry densities was 100 %, 100 %, 83 %, 80 % and 69 % in 2004, 2005, 2011, 2013 and 2014 respectively (Figure 3.3.3). There were few electrofishing sites in the lower catchment prior to 2013 and substantial numbers of sites were only fished in 2014. Of the sites fished in the lower catchment in 2014, only 17 % exceeded the average national expectation for fry numbers, although these sites greatly exceeded expectation.

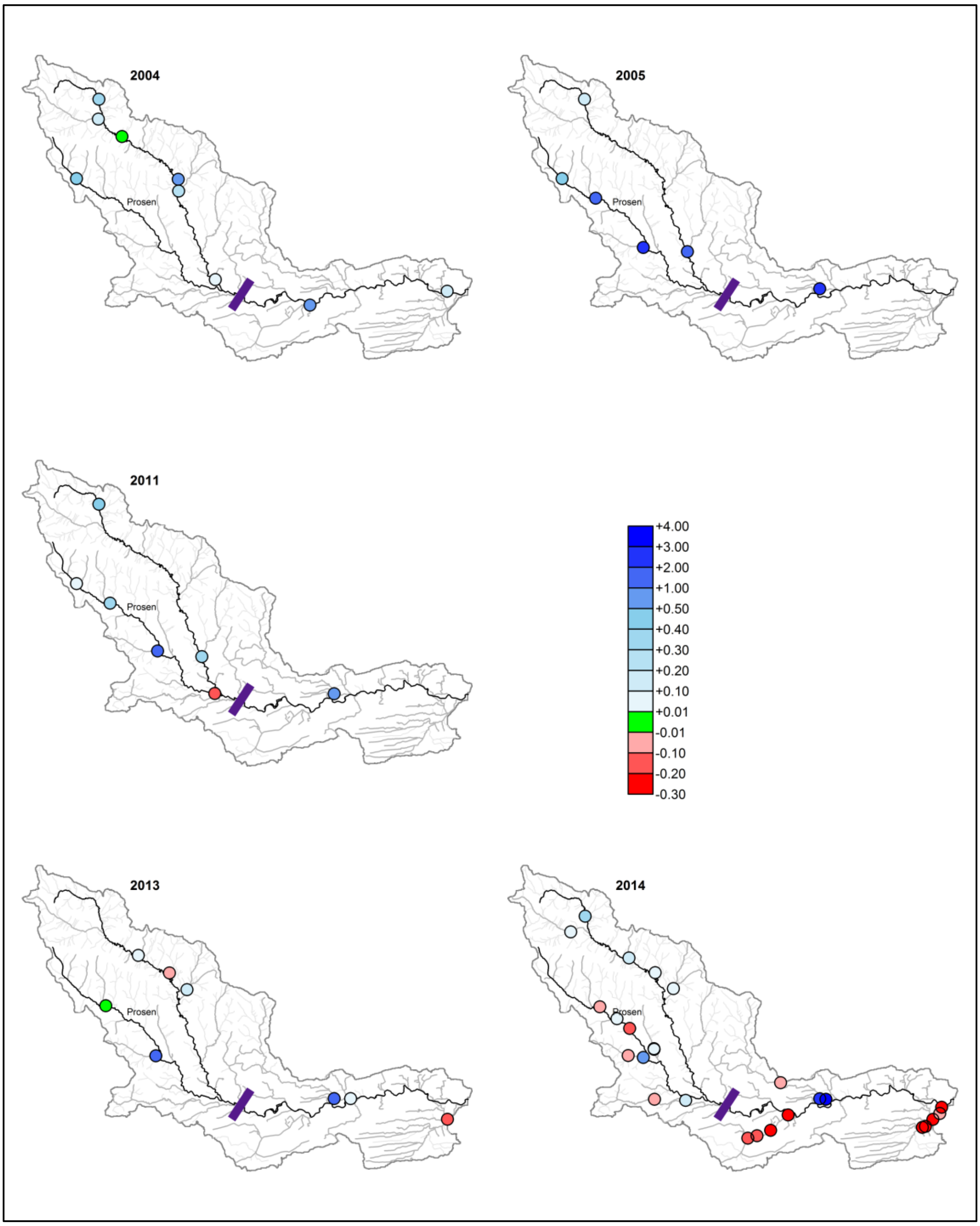


Figure 3.3.3: Differences (model residuals) between expected fry densities obtained from a national fry density model (Millar *et al.*, 2015) and observed densities estimated from electrofishing data. Positive residuals (blue) indicate that sites have done better than expected based on a national expectation; negative residuals (red) indicate that sites have done worse than expected. All values are fish m^{-2}.

3.4 DISCUSSION

Given the lack of consistent experimental design, spatial coverage and site selection across years and the fact that density expectations vary by location, it was not possible to provide a quantitative assessment of any changes in fry density over time. However, it was possible to assess the performance of individual electrofishing sites relative to a recently published national expectation model (Millar *et al*., 2015). Based on the available radio tracking data it was also possible to broadly delineate the upper South Esk, which is considered to reflect the status of spring fish populations.

For the upper South Esk, a qualitative consideration of the data suggests an increase in the number of sites failing to meet the national expectation in 2014, relative to previous years. However, some care is required in the interpretation of these data. In contrast to previous years, there was no attempt to electrofish sites that were assessed as suitable for salmon during 2014. This would have the benefit of providing an unbiased assessment of fry densities across the upper catchment, but would inevitably increase the chances of fishing sites where salmon fry would be scarce due to local habitat characteristics. Setting aside the issue of survey design, nine out of the thirteen sites surveyed in the upper South Esk during 2014 remained above expectation, providing reasonable evidence that the upper catchment as a whole continues to perform adequately relative to the average national expectation.

There were relatively few data available for the lower South Esk. However, for the sites that were sampled, it is evident that there were substantial deviations from expected densities. Sites on the Noran Water, a northern tributary of the lower South Esk, performed considerably above expectation, whereas sites on two southern tributaries, the Pow Burn and Lemno Burn, performed particularly badly suggesting local anthropogenic impacts that prevent expected levels of salmon production across substantial areas of the lower catchment or differentially poorer adult returns to these areas.

Part 4: Spring rod fishing effort

<u>Objective:</u> *Is it possible to assess to what extent changes in rod fishing effort have accounted for the declining trend in rod catches of spring salmon?*

4.1 INTRODUCTION

Rod catch data for salmon is frequently used to infer stock level in a given river. To do this, it is necessary to know, or be able to estimate, exploitation rate, such that:

Catch = Total number of fish available to the fishery x Exploitation rate

Exploitation rate by the rod fishery will depend on the number of days on which anglers fish, and how effective that effort is, such that:

Exploitation rate = Number of angler days x Mean effectiveness

Effectiveness of anglers will be influenced by many factors (Smith *et al*., 1996) including the amount of time they spend fishing on any given day, their skill level, the quality of their tackle and the catchability of the fish, such that:

Effectiveness = Time on water x Skill level x Quality of tackle x Catchability of fish

There is rarely, if ever, a good account of inter-annual variations in these factors, and in practical terms, exploitation rate is usually assessed only by comparing catches and counts. Nevertheless, it is evident that the number of angler days on its own will be a major determinant of exploitation rate (Smith *et al*., 1996). It is widely recognised that effort data would be useful for increasing inferences from rod catches. However, such information is difficult to source.

Despite the national spring salmon rod catch stabilising in recent years, rod catch on the River South Esk has continued to decline during spring. The overall aim of this project is to assess the causes underlying the continuing decline. One consideration is rod fishing effort (hereafter referred to as "effort") and whether there are any trends in effort over recent years. Namely, do declining catches of spring salmon on the River South Esk reflect a declining trend in effort? Or, has effort remained relatively stable against a backdrop of declining catches? Data is therefore required on rod fishing effort. While it is acknowledged that other factors affecting the number of fish caught by the rod fishery may also have changed (i.e. the total number of fish available to the fishery, exploitation rate, angler effectiveness), rod effort is the factor we have the best chance of quantifying in the context of the present study.

In this context, effort can be thought of as the amount of use that anglers are making of a fishery. This might be measured in several ways, for example bookings, the number of anglers fishing a beat per day or per week, or the number of rods fishing over a specified time period. Such data may therefore occur in a diverse range of formats, particularly given the disparate sources from which they are likely to be sourced. The physical format of the data (e.g. whether in the form of paper records or in an electronic form such as a spreadsheet), the consistency of the data over time, and the consistency of the data among different providers are all important considerations. Furthermore, it is necessary to identify who might have such data and then request any of sufficient quality to be informative. In the context of the present study, Marine Scotland is interested only in effort data for the spring months (February to May inclusive) in relation to rod catches of early running spring salmon. An analysis of effort data during spring (February to May inclusive) on the River South Esk over the period 2002 to 2012 inclusive is presented here.

4.2 METHODS

Data requesting process

Using the annual catch returns submitted to Marine Scotland, rod fisheries accounting for the greatest proportion of the spring salmon catch on the River South Esk were identified. For all catch return forms, the data considered were the reported rod catch (retained & released) for MSW salmon caught between February and the end of May inclusive over the period 1997 to 2013 inclusive for the South Esk river. The mean annual catch was calculated for each form and the forms were ranked from 1 to 26 in terms of their overall contribution to the spring catch (1 = greatest contribution). Using data from 10 out of the 26 forms accounted for 2,308 out of 2,713 fish (85.1 %). The proprietors of the 6 fisheries associated with these 10 forms were identified and contacted *via* letters (Appendix 4.5), phone calls and face-to-face meetings.

Data treatment

Effort data were received from one fishery proprietor. These data were used in conjunction with the associated official catch statistics for that fishery in the following analyses.

The effort data took the form of bookings for the period 2002 to 2012 inclusive. The data for the first five years of the time series (2002 to 2006 inclusive) identified whether or not a given beat was let on a given day. The data for the last six years of the time series (2007 to 2012 inclusive) provided equivalent information, but also included information on the number of rods booked per beat day let.

The data for the first five years of the time series were considered “low definition” data since they did not include information regarding the number of rods booked per beat for those days on which a given beat was let. The data for the last six years of the time series were considered “high definition” data since they included information regarding the number of rods booked per beat for those days on which a given beat was let. It was possible to simplify the high definition data into a format analogous to the low definition data, thus harmonising data in a consistent format for the entire time series (2002 to 2012 inclusive).

Low definition data were used to calculate the number of beat days let as a percentage of the number of beat days available in the spring of each year from 2002 to 2012 inclusive. The number of beat days let was calculated as the number of days on which any of the available beats were let in the spring of that year. The number of beat days available was calculated as the number of beats available multiplied by the number of angling days available in the spring of that year.

To determine if there was a temporal trend in effort, a random walk model was fitted to the data on the percentage of beat days let annually between 2002 and 2012. A bootstrap procedure was used to generate confidence intervals to determine if there was a significant difference at the 5 % level between 2002 and subsequent years.

Catch data for the fishery were used to investigate whether there was a relationship between catch and effort (calculated as described above) for the period 2002 to 2012 inclusive. Catch was taken as the total spring rod catch (reported rod catch (retained & released) for MSW salmon caught between February and the end of May inclusive) for the fishery for each year between 2002 and 2012 inclusive. “Standardised catch”, expressed as the catch for each year as a percentage of the highest value in the time series, was used as the *y*-variable so as not to show absolute catch figures. Effort was expressed as the percentage of beat days let per year. Catch per Unit of Effort (CPUE) was expressed as the absolute catch divided by the percentage of beat days let per year. A smoother was fitted to the CPUE time series. CPUE values were assumed to follow a gamma distribution (constant coefficient of variation) with the smoother fitted on the log-link. A test of trend was performed by comparing the smoother fit to a fit with only an intercept term. Given the small sample size, a bootstrapped F-test was used to assess significance.

High definition data were used to examine whether there were any trends in the number of rods booked per beat day let for the period 2007 to 2012.

4.3 RESULTS

Percentage of beat days let per year, 2002 to 2012

Figure 4.3.1 shows that the number of beat days let in 2003 was not significantly different from 2002, and that 2004 was significantly different, though the difference was small. However, there is evidence of a substantial decline in 2005, with all the years from 2005 to 2012 characterised by a significantly lower percentage of beat days let than in 2002.

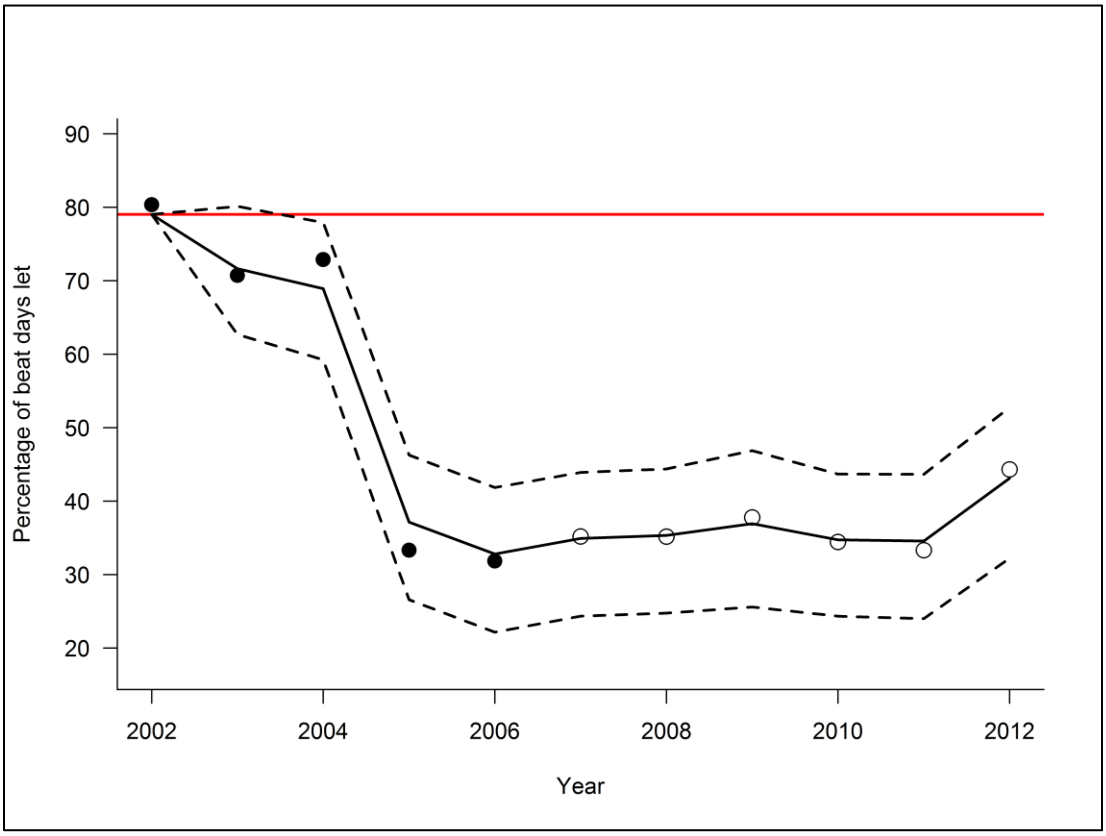


Figure 4.3.1: Observed and modelled temporal variability in the percentage of beat days that were let annually between 2002 and 2012. The solid line shows the model fit, with the dashed lines indicating pointwise 95 % confidence intervals for the difference between the fit and the 2002 estimate. The red line shows the 2002 estimate for reference: when the dashed lines fall below the red line, the fitted trend is significantly different from the 2002 estimate.

CPUE, 2002 to 2012

There was no evidence of a significant linear trend between effort and standardised catch for the period 2002 to 2012 inclusive (correlation: $r = 0.113$, $P = 0.740$; Figure 4.3.2). However, this appeared to be driven largely by an obvious outlier with a large standardised catch (Figure 4.3.2). This data point was from 2006 when a particularly large catch (in the context of the time series under consideration) was reported, being 195 % of the next largest value in the time series (Figure 4.3.2).

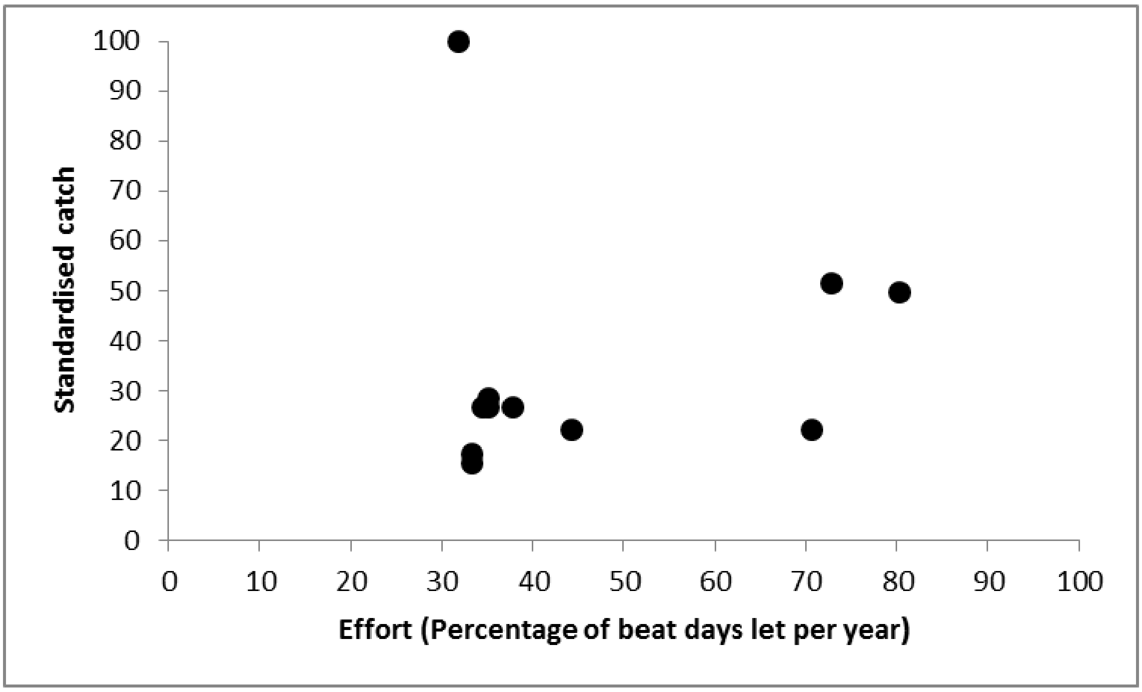


Figure 4.3.2: Plot of effort (expressed as the percentage of beat days let per year) against standardised catch (expressed as the catch for each year as a percentage of the highest value in the time series) for the period 2002 to 2012 inclusive.

Similarly, there was no evidence of a significant linear trend in CPUE (expressed as the absolute catch divided by the percentage of beat days let per year) over the time series 2002 to 2012 inclusive (correlation: r = - 0.055, P = 0.873; Figure 4.3.3). However, the same outlier as mentioned above appeared to be affecting this result (Figure 4.3.3).

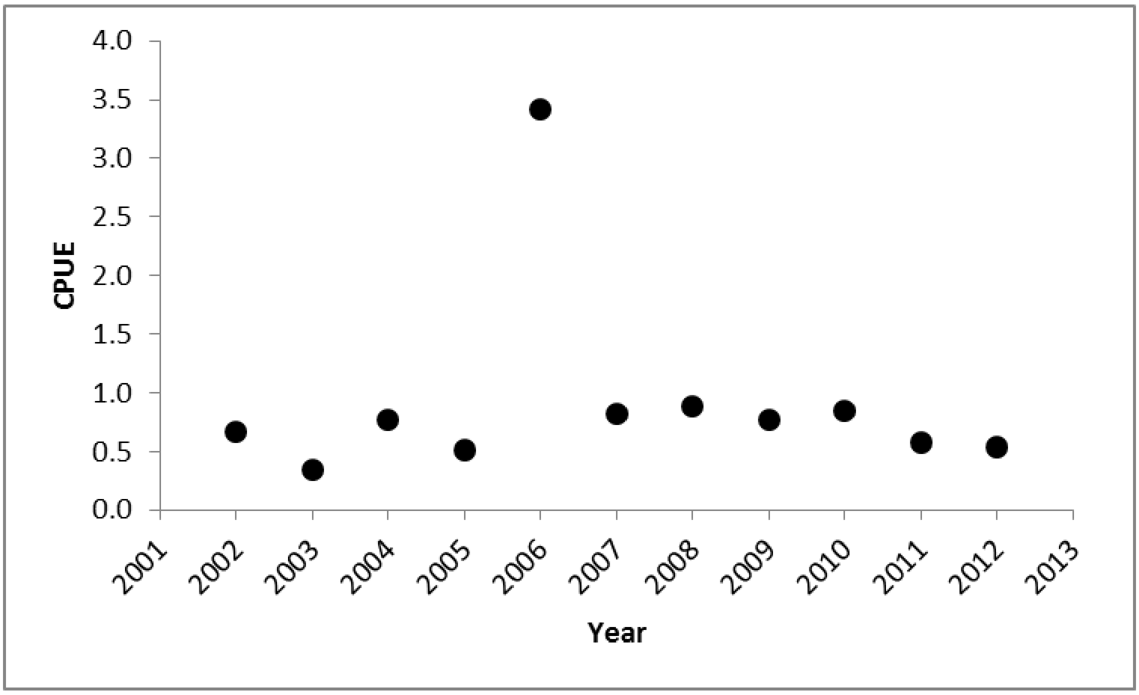


Figure 4.3.3: CPUE (expressed as the absolute catch divided by the percentage of beat days let per year) over the time series 2002 to 2012 inclusive.

Removing 2006 from the time series revealed a significant positive linear relationship between effort and standardised catch (regression: r^2 = 54.8 %, $F_{1, 8}$ = 9.69, P = 0.014; Figure 4.3.4). Thus, years associated with a relatively high standardised catch tended to be those in which effort was also relatively high (Figure 4.3.4).

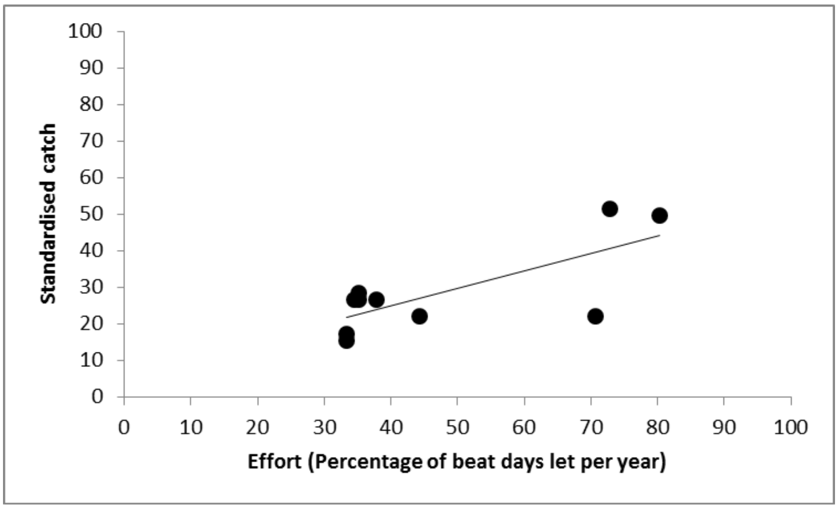


Figure 4.3.4: Plot of effort (expressed as the percentage of beat days let per year) against standardised catch (expressed as the catch for each year as a percentage of the highest value in the time series) for the period 2002 to 2012 inclusive, excluding 2006. A line of best fit is shown to illustrate the significant linear trend between standardised catch and effort over the period 2002 to 2012 inclusive, excluding 2006.

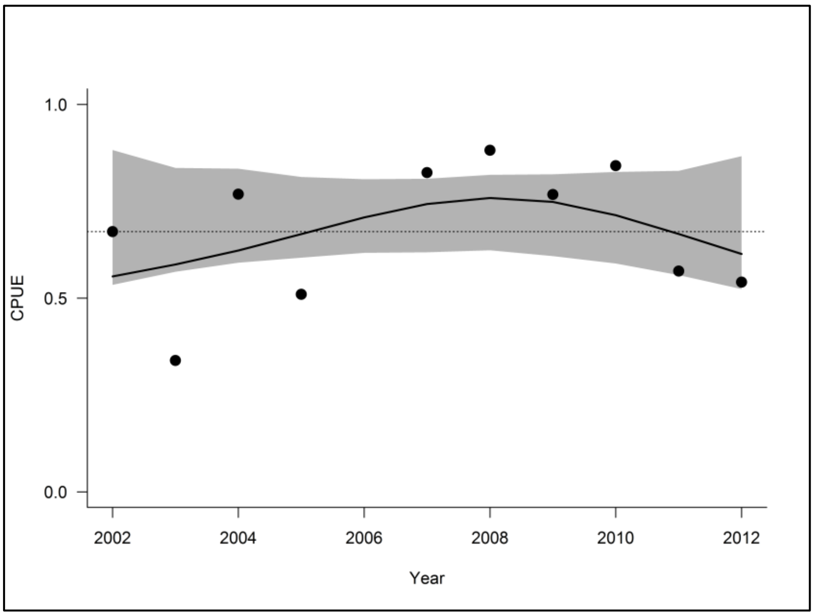


Figure 4.3.5: CPUE (expressed as the absolute catch divided by the percentage of beat days let per year) over the time series 2002 to 2012 inclusive, excluding 2006. The solid line shows the fitted smoother, with the shaded region indicating the reference bands for the difference between the smoother and an intercept only model. As the smoothed fit is always inside the reference bands the trend is not significantly different from a straight line (indicated by the dashed line).

CPUE across the time series (excluding 2006) varied by a factor of 2.6 from a minimum of 0.34 in 2003 to a maximum of 0.88 in 2008. A smoother fitted to the CPUE data revealed no overall significant trend across the time series (permutation F-test, P = 0.370; Figure 4.3.5). However, although the overall trend was non-significant, the distribution of data points around the fitted smoother suggested a tendency for CPUE to increase during the initial part of the time series (broadly coinciding with the step-change in effort noted previously) before peaking and, in later years, returning to values observed during the initial part of the time series (Figure 4.3.5).

Number of rods booked per beat day let, 2007 to 2012

Over the period 2007 to 2012 inclusive, the mean number of rods booked per beat day let during spring declined significantly over the period (regression: r^2 = 86.2 %, $F_{1, 4}$ = 25.01, P = 0.007; Figure 4.3.6). This trend was driven by a significant increase in the number of beat days let on which either 1 rod (correlation: r = 0.912, P = 0.011; Figure 4.3.7) or 2 rods (r = 0.873, P = 0.023; Figure 4.3.7) were booked, and a significant decrease in the number of beat days let on which 4 rods were booked (r = - 0.923, P = 0.009; Figure 4.3.7). The number of beat days let on which 3 rods were booked remained relatively constant (r = 0.798, P = 0.057; Figure 4.3.7).

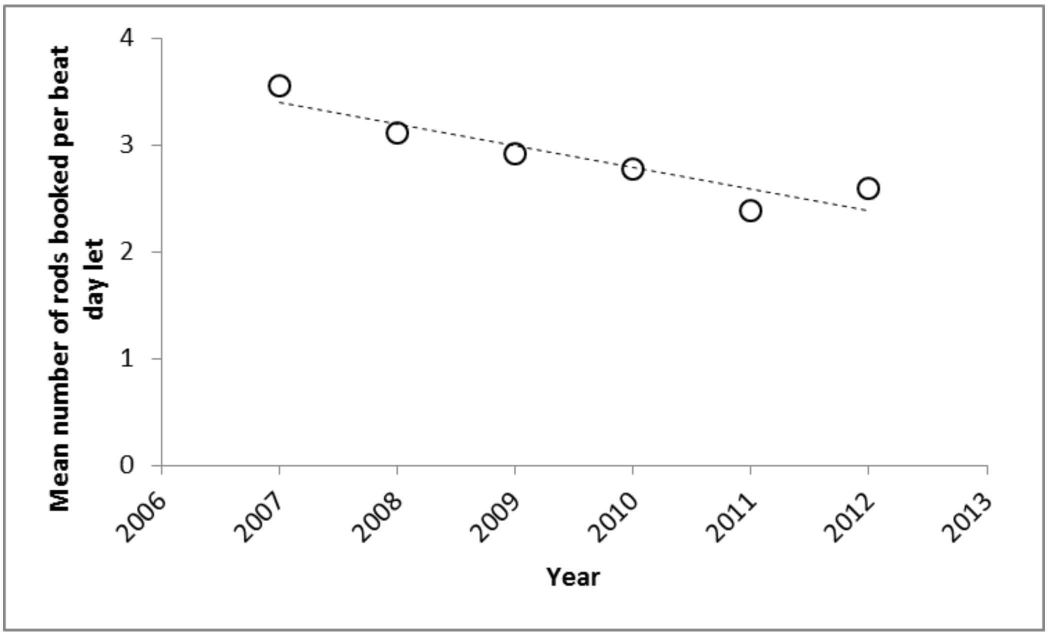


Figure 4.3.6: The mean number of rods booked per beat day let in the spring of each year between 2007 and 2012 (○). A line of best fit is shown to illustrate the significant linear decline in the mean number of rods booked per beat day let over the period 2007 to 2012 inclusive.

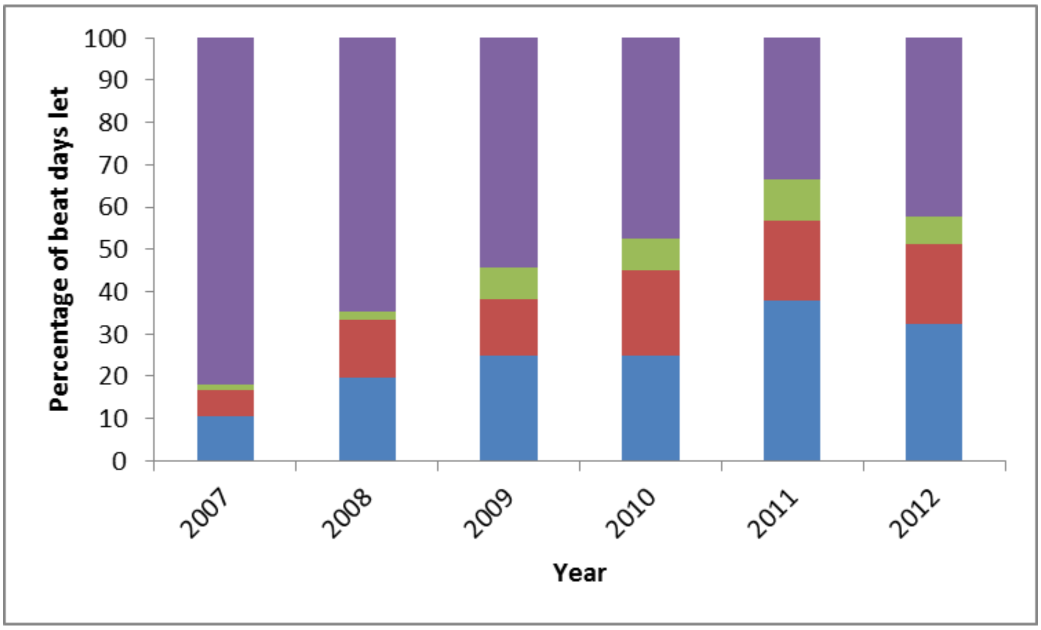


Figure 4.3.7: The percentage of beat days let during spring on which either 1 rod (■), 2 rods (■), 3 rods (■) or 4 rods (■) were booked over the period 2007 to 2012 inclusive.

CPUE, 2007 to 2012

Over the period 2007 to 2012 inclusive, there was a significant negative correlation between CPUE and year (r = - 0.833, P = 0.040, Figure 4.3.8).

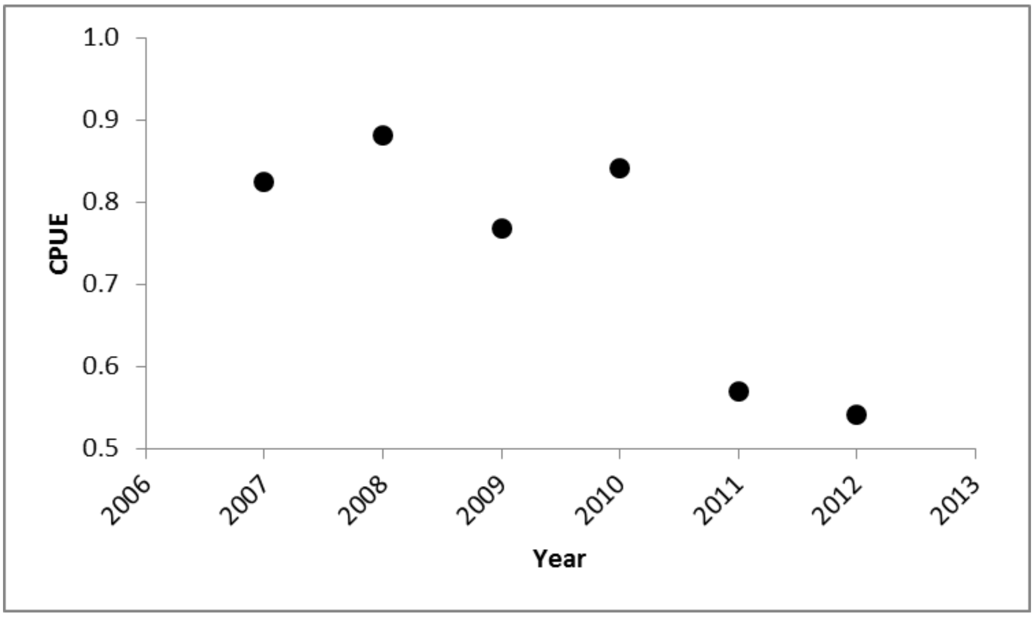


Figure 4.3.8: CPUE (expressed as the absolute catch divided by the percentage of beat days let per year) over the time series 2007 to 2012 inclusive.

4.4 DISCUSSION

Percentage of beat days let per year, 2002 to 2012

Between 2002 and 2004, the percentage of beat days let per year remained relatively constant. However, there was a substantial decline in 2005, with all years from 2005 to 2012 characterised by a significantly lower percentage of beat days let than in 2002.

CPUE, 2002 to 2012

When the outlying year of 2006 was removed from the data series, there was a significant positive linear relationship between effort and standardised catch. Those years associated with a relatively high standardised catch tended to be those in which effort was also relatively high. There was no evidence of a trend in CPUE across the time series as a whole, although there was some evidence of a decline in later years (2007 to 2012).

Number of rods booked per beat day let, 2007 to 2012

Between 2007 and 2012, the mean number of rods booked per beat day let during spring declined significantly. This trend was driven by a significant increase in the number of beat days let during which either 1 rod or 2 rods were booked, and a significant decrease in the number of beat days let during which 4 rods were booked. The number of beat days let during which 3 rods were booked remained relatively constant.

CPUE, 2007 to 2012

Between 2007 and 2012, CPUE declined significantly.

Low definition data for the period 2002 to 2012 provides evidence of a significant reduction in rod fishing effort on a rod fishery which contributes substantially to the overall reported spring salmon rod catch on the River South Esk. Additionally, the significant reduction in the mean number of rods booked per beat day let can be interpreted as a reduction in effort over the period 2007 to 2012, and this coincides with a significant reduction in CPUE over the same period.

It should also be noted that the period 2007 to 2012 occurs in the latter part of the time series under consideration, when effort is lower than in the early years of the time series. Furthermore, with the exception of a single outlying year (2006), there was a significant positive relationship identified between effort and catch. In other words, the more effort expended in the fishery, the higher the resultant catch. Although there was no overall trend in CPUE across the time series, the step-change reduction in effort between 2004 and 2005 coincided with relatively high CPUE values in the next few years. Thereafter, CPUE values tended to decline in the latter part of the time series, although spring rod catch appears to recover a little by 2010 onwards (Figure 1.3.4*b*). These data confirm that while, in the absence of other abundance indicators, rod catch may be used as a proxy for stock size, such a measure may be confounded by changes in rod effort.

Of particular note is the value of the high definition data in this study. Low definition data was successful in detecting a step-change in effort post-2004 and allowed a significant linear decline in CPUE to be identified between 2007 and 2012. However, it is only with the high definition data that the reduction in effort over the period 2007 to 2012 becomes apparent. Thus while it is recognised that measuring fishing effort may increase the reliability of fishery data as a proxy for stock abundance, such data needs to be of a sufficiently high quality.

When considering these results, it is necessary to consider the limitations of the data. For example, for the years in which the number of rods booked per beat day let was known, it is possible that not all booked rods turned up to fish on the day. Furthermore, individual rods may have fished for different periods of time (e.g. just a morning *vs*. all day), and angler skill is likely to vary among individuals. It is also necessary to consider whether these results for a single fishery apply to the River South Esk more generally. When seeking fishery proprietors for possible data supply, only those fisheries accounting for the greatest proportion of the reported spring salmon rod catch were contacted. We can therefore be confident that although the data presented here are from only one fishery, they do at least originate from a fishery contributing substantially to the overall spring salmon rod catch on the River South Esk. In this regard, it is disappointing that more data were not available for inclusion in the study. However, effort data in a consistent format collected over a reasonable time period and relating to a consistent fishery is notoriously difficult to source. Previous attempts by Marine Scotland to collate rod fishing effort data also resulted in very few positive returns. For studies such as this, rod effort data collected in a systematic and consistent fashion is required in order to draw any firm conclusions.

The value of the data, although undoubtedly useful, would have been strengthened further had it been available in a consistent format throughout. Low definition data were available for the entire time series and therefore allowed examination of effort across a reasonable time period (11 years). However, for six of these years, high definition data were available which meant that an additional level of detail in the data was being lost with respect to the actual number of rods booked per beat day let.

This study has demonstrated a reduction in rod fishing effort on a fishery contributing substantially to the spring salmon rod catch on the River South Esk. This reduction in effort could conceivably contribute to a reduction in the spring salmon rod catch. The question therefore arises as to why effort has declined. Firstly, it may be to do with perceived likelihood of success. For example, if an angler does not think they are going to catch a fish, they do not go fishing. By not going fishing, fewer fish get caught and so the perceived likelihood of success declines still further, continuing the cycle of declining effort. Secondly, the way people decide when to go fishing may have changed in recent years with advances in technology such as fishery websites, online reports and blogs, webcams and social media. Up-to-date information about current catches and river conditions (and therefore perceived likelihood of success) is very easy and quick to access compared with (say) 20 years ago. It may be that anglers are targeting their fishing effort at more specific times based on the wealth of information available, rather than booking several days of fishing a long time in advance of their proposed visit to the fishery. Thirdly, it may be that participation in salmon angling is declining more generally, perhaps as a result of population demographics. In relation to the last two suggestions, however, if these were correct, one might expect catches of salmon to be in decline more generally across Scotland. This is not the case, however, and it is difficult to envisage how the last two suggestions would apply only to the River South Esk, where catches of spring salmon continue to decline. It therefore seems most likely that effort has declined based on a lack of perceived likelihood of angling success, at least on the fishery from which these data were obtained.

4.5 APPENDICES

Appendix 4.5: Sample letter sent to selected fishery proprietors on the River South Esk requesting historical records of rod fishing effort for spring salmon. Personal details have been shaded out.

marinescotland

The Scottish Government

T: +44 (0)1674 677070 F: +44 (0)1674 672604
james.orpwood@scotland.gsi.gov.uk

[redacted]

Our Ref: [redacted]
19 June 2014

Dear [redacted]

Spring salmon on the River South Esk – Historical records of rod fishing effort

As you will no doubt be aware, Marine Scotland Science (MSS) are currently carrying out an investigation into spring salmon on the River South Esk. As part of this project, MSS are planning to look at historical records of rod fishing effort to see whether there are any trends in these data. I am therefore writing to you to ask whether you have data relating to rod fishing effort for your beats, and whether you would be willing to provide this data to MSS?

In this context, rod fishing effort can be thought of as the amount of use that anglers are making of the fishery. Data relating to this may take several forms, for example bookings data, the number of anglers fishing a beat per day or per week, or the number of rods fishing over a specified time period. Furthermore, as the investigation relates to spring fish, MSS is interested only in effort data for the spring months (February to May inclusive).

If you do have such data, and would be willing to provide it to MSS, it would be helpful if you could address the following questions:

- For what time period are data available? (Effort for all fisheries from 1997 to 2013 would be ideal, and earlier if available).
- What units are used to measure effort, and are these units consistent over the time period?
- What format do the data take?
- Can we make arrangements for me to obtain the data?

I will phone you after you have received this letter in order to talk through this request. However, in the meantime, please do not hesitate to contact me if you have any questions or if you require further information. I look forward to talking with you and hope that you will be able to assist with this request.

[redacted]

Dr James Orpwood

Freshwater Laboratory Field Station, Inchbraoch House, South Quay,
Ferryden, Montrose, Angus DD10 9SL
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INVESTOR IN PEOPLE

POSITIVE ABOUT DISABLED PEOPLE

Part 5: Geographic exploitation of the coastal net fishery

Objective: *What proportion of the catch from the coastal net fishery adjacent to the River South Esk was destined to spawn in the River South Esk?*

5.1 INTRODUCTION

Net fisheries operating along coastal migration routes of salmon returning to spawn may exploit fish from a number of different rivers (Gilbey *et al*., 2012). The management of such mixed stock fisheries [defined as those which exploit significant numbers of fish from several river stocks (Anon., 2015*b*)] requires a knowledge of the river of origin and the proportion of each river's stock being exploited (Shearer, 1986). Previous work using genetic techniques to investigate stock composition of the northeast English net fisheries (Gilbey *et al*., 2012) found that levels of genetic differentiation among stocks were sufficient to enable fish to be assigned to rivers within the northeast of England, and to distinguish fish from the northeast of England from fish of Scottish origin. However, the resolving power to assign fish to rivers within Scotland was insufficient to allow robust assignments (Gilbey *et al*., 2012). Subsequent genetics work using SNPs could also not be used to determine the representation of different rivers stocks in the nets in the present study because, again, there was not enough differentiation detectable among the large Scottish east coast rivers using the techniques that are currently available.

Numerous tagging studies have shown that salmon caught and tagged at a particular point along the coast may be returning to a variety of rivers (e.g. Shearer, 1986; 1992; Smith & Johnstone, 1996). The radio tracking data used to determine the spawning locations of spring salmon within the River South Esk (see Section 2) were used to estimate the proportion of the catch from the coastal net fishery that was destined to spawn in the River South Esk.

5.2 METHODS

This portion of the investigation concerns only those fish caught and radio tagged from the coastal net fishery in 2012 (n = 153) and 2013 (n = 38). These fish were processed in the manner described in Section 2.2. Radio tagged salmon sourced from the coastal net fishery in 2012 and 2013 were assigned to the River South Esk stock using a decision tree (Appendix 5.5).

5.3 RESULTS

Rivers in which tagged fish were detected

In 2012, tagged fish sourced from the coastal net fishery were detected in five of the seven rivers on the east coast of Scotland being monitored in that year (Rivers Don, Dee, North Esk, South Esk and Tay; Figure 5.3.1*a*). No tagged fish were detected in either the Bervie Water or the Lunan Water in 2012. A total of 3 fish were recaptured at sea having not been detected in a monitored river, and a further 4 fish were taken by the net and coble fishery in the River North Esk, having first been detected in that river (Figure 5.3.1*a*).

In 2013, tagged fish sourced from the coastal net fishery were detected in four of the eight rivers on the east coast of Scotland being monitored in that year (Rivers Spey, North Esk, South Esk and Tay; Figure 5.3.1*b*). No tagged fish were detected in the River Don, the River Dee, the Lunan Water or the River Tweed in 2013. The Bervie Water was not monitored in 2013. Fish were neither recaptured at sea nor taken by the net and coble fishery in the River North Esk in 2013 (Figure 5.3.1*b*).

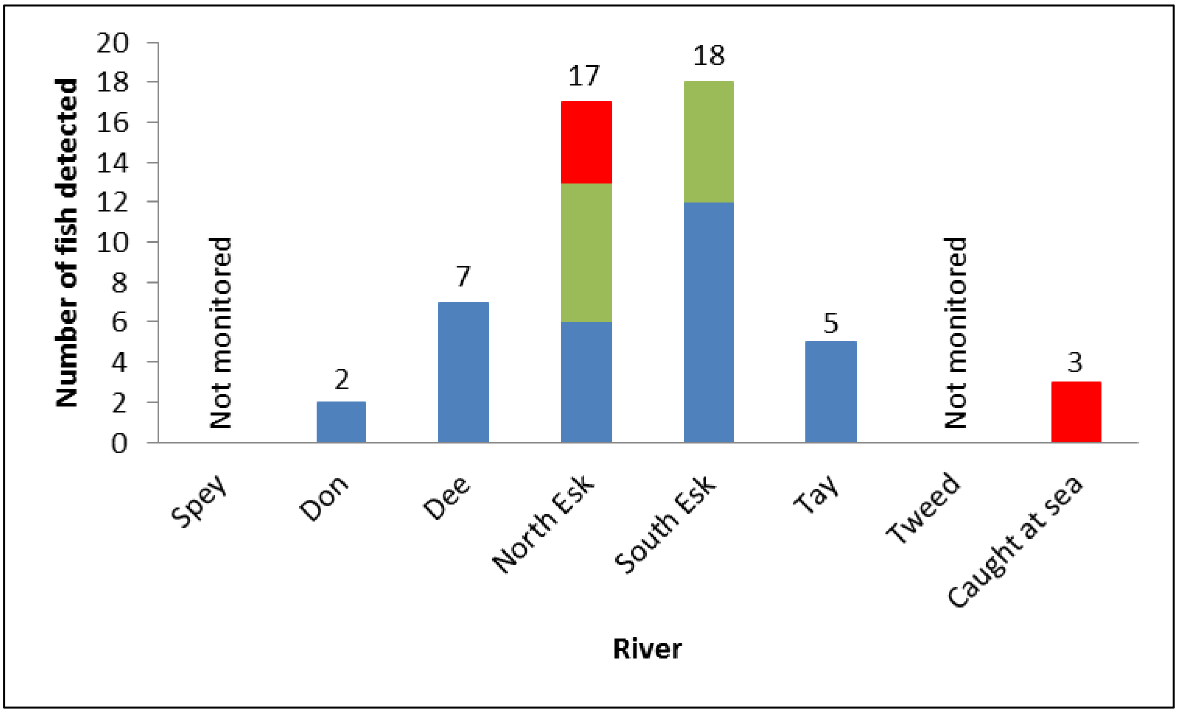


Figure 5.3.1*a*: The number of tagged fish sourced from the coastal net fishery detected in each of the monitored river systems in 2012, assigned as either: fish detected in-river and nowhere else (■); fish detected in-river which subsequently left the system (■); or fish recaptured at sea or taken by fisheries (■). For clarity of presentation, the Bervie Water and the Lunan Water are omitted. Note that the total number of tagged fish detected in-river adds up to 49, i.e. 1 more fish than the number of fish that were detected post-tagging. This is because 1 fish was detected in the River North Esk before returning to sea and being subsequently detected in the River South Esk.

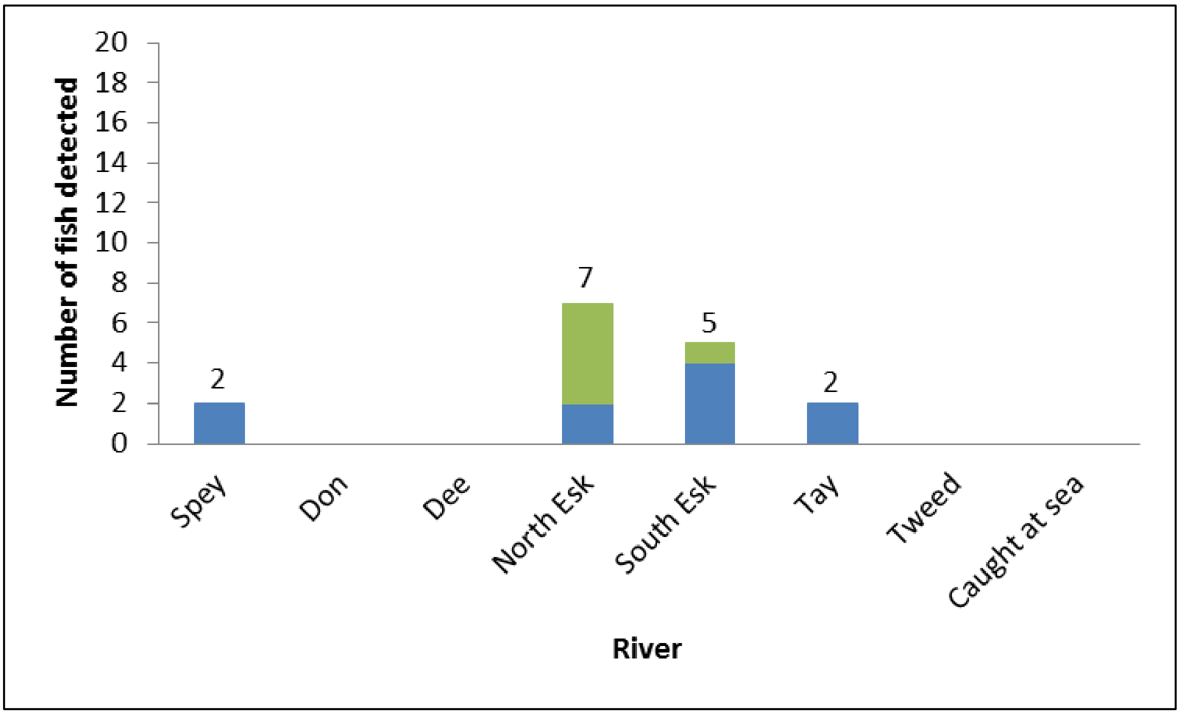


Figure 5.3.1*b*: The number of tagged fish sourced from the coastal net fishery detected in each of the monitored river systems in 2013, assigned as either: fish detected in-river and nowhere else (■); or fish detected in-river which subsequently left the system (■). No fish were recaptured at sea or taken by fisheries in 2013. For clarity of presentation, the Bervie Water and the Lunan Water are omitted. Note that the total number of tagged fish detected in-river adds up to 16, i.e. 2 more fish than the number of fish that were detected post-tagging. This is because: (1) 1 fish was detected in the River North Esk before returning to sea and being subsequently detected in the River Tay; and (2) 1 fish was detected in the River South Esk before returning to sea and being subsequently detected in the River North Esk. This fish then returned to sea again and re-entered the River South Esk before finally returning to sea. This fish was not detected again.

Estimation of the contribution of the River South Esk stock to the coastal net fishery

2012

In 2012, 12 tagged fish sourced from the coastal net fishery were assigned to the River South Esk stock. 153 fish were tagged in total, of which 3 fish were subsequently caught and killed, leaving 150 fish with the potential to be detected in fresh water. In practice, 48 tagged fish were detected in fresh water after tagging, of which, 12 fish were assigned to the River South Esk stock.

The maximum proportion of fish caught in the coastal net fishery which were South Esk stock assumes that the 48 fish detected in fresh water after tagging were the only ones to survive from tagging to river: 12 / 48 = 25 %.

The minimum proportion of fish caught in the coastal net fishery which were South Esk stock assumes that all 150 fish with the potential to be detected in fresh water survived from tagging to river: 12 / 150 = 8 %.

2013

In 2013, 4 tagged fish sourced from the coastal net fishery were assigned to the River South Esk stock. 38 fish were tagged in total, of which 0 fish were subsequently caught and killed, leaving 38 fish with the potential to be detected in fresh water. In practice, 14 tagged fish were detected in fresh water after tagging, of which, 4 fish were assigned to the River South Esk stock.

The maximum proportion of fish caught in the coastal net fishery which were South Esk stock assumes that the 14 fish detected in fresh water after tagging were the only ones to survive from tagging to river: 4 / 14 = 29 %.

The minimum proportion of fish caught in the coastal net fishery which were South Esk stock assumes that all 38 fish with the potential to be detected in fresh water survived from tagging to river: 4 / 38 = 11 %.

Movements of fish among rivers

For tagged fish sourced from the coastal net fishery, entry into a given monitored river and subsequent return to the sea, occasionally followed by entry into a different monitored river, was a feature in both 2012 and 2013.

Of the 48 tagged fish sourced from the coastal net fishery that were detected in fresh water in 2012, 13 fish (27.1 %) subsequently returned to sea. Of these, 1 fish (7.7 % of those fish that returned to sea having been detected in a monitored river) was subsequently detected in a different monitored river from that in which it was first detected - having initially entered the River North Esk, this fish returned to sea and entered the River South Esk where it remained. This tag was no longer associated with a live fish at spawning time. The fate of the remaining 12 fish that returned to sea having been detected in a monitored river was unknown.

Of the 14 tagged fish sourced from the coastal net fishery that were detected in fresh water in 2013, 5 fish (35.7 %) subsequently returned to sea. Of these, 2 fish (40.0 % of those fish that returned to sea having been detected in a monitored river) were subsequently detected in a different monitored river from that in which they were first detected - 1 fish was initially detected in the River North Esk before returning to sea and subsequently entering the River Tay; and 1 fish was initially detected in the River South Esk before returning to sea and entering the River North Esk. This fish then returned to sea again, entered the River South Esk and finally returned to sea, after which it was not detected again. The fate of the remaining 3 fish that returned to sea having been detected in a monitored river was unknown.

5.4 DISCUSSION

Tagged fish sourced from the coastal net fishery were detected in several major rivers in the northeast of Scotland: the Rivers Spey, Don, Dee, North Esk, South Esk and Tay. In addition, it is possible that fish destined for rivers other than those being monitored could have been intercepted by the coastal net fishery near the mouth of the River South Esk. Therefore, the number of rivers from which fish were intercepted should be viewed as a minimum estimate. The proportion of the catch from the coastal net fishery destined to spawn in the River South Esk was estimated at 8 % to 25 % in 2012 and at 11 % to 29 % in 2013.

Aerial surveys were also carried out on the Lunan Water and the Bervie Water and no tags were detected in these (relatively small) rivers. This is not surprising given the low numbers of salmon reported being caught in these rivers during the months up to and including May in recent years. Using a time series of total reported rod catch of wild salmon and wild grilse (retained and released) for the Lunan Water (1993 to 2012) and the Bervie Water (1960 to 2012) (Scottish Government, 2013) reveals that the months up to and including May account for just 8.9 % of the reported catch in the Lunan Water (4 fish out of a total of 45 reported for the time series as a whole) and just 2.5 % of the reported catch in the Bervie Water (11 fish out of a total of 441 reported for the time series as a whole). Furthermore, no tagged fish sourced from the coastal net fishery in 2013 were detected in the River Tweed.

The tracking data provide direct observations of the subsequent spawning migrations undertaken by spring fish tagged in the coastal net fishery. However, such tracking data has limitations which must be considered when using such data to estimate the composition of the coastal net fishery. Firstly, not all rivers that tagged salmon could possibly enter were monitored for tags. Secondly, there are no estimates of the losses of fish between tagging and subsequent river entry. Thirdly, using radio tracking data to assign fish to a specific river stock relies on the tagged fish being detected again after release, and only about one third of the tagged fish that were sourced from the coastal net fishery were detected again after tagging. Factors such as post-tagging mortality and other sources of post-sampling loss would also influence a mixed stock fishery assessment made from tracking data. Furthermore, the likelihood of tagging a fish from a particular river will be strongly influenced by the river stock size and perhaps differences in coastal migration patterns among river stocks.

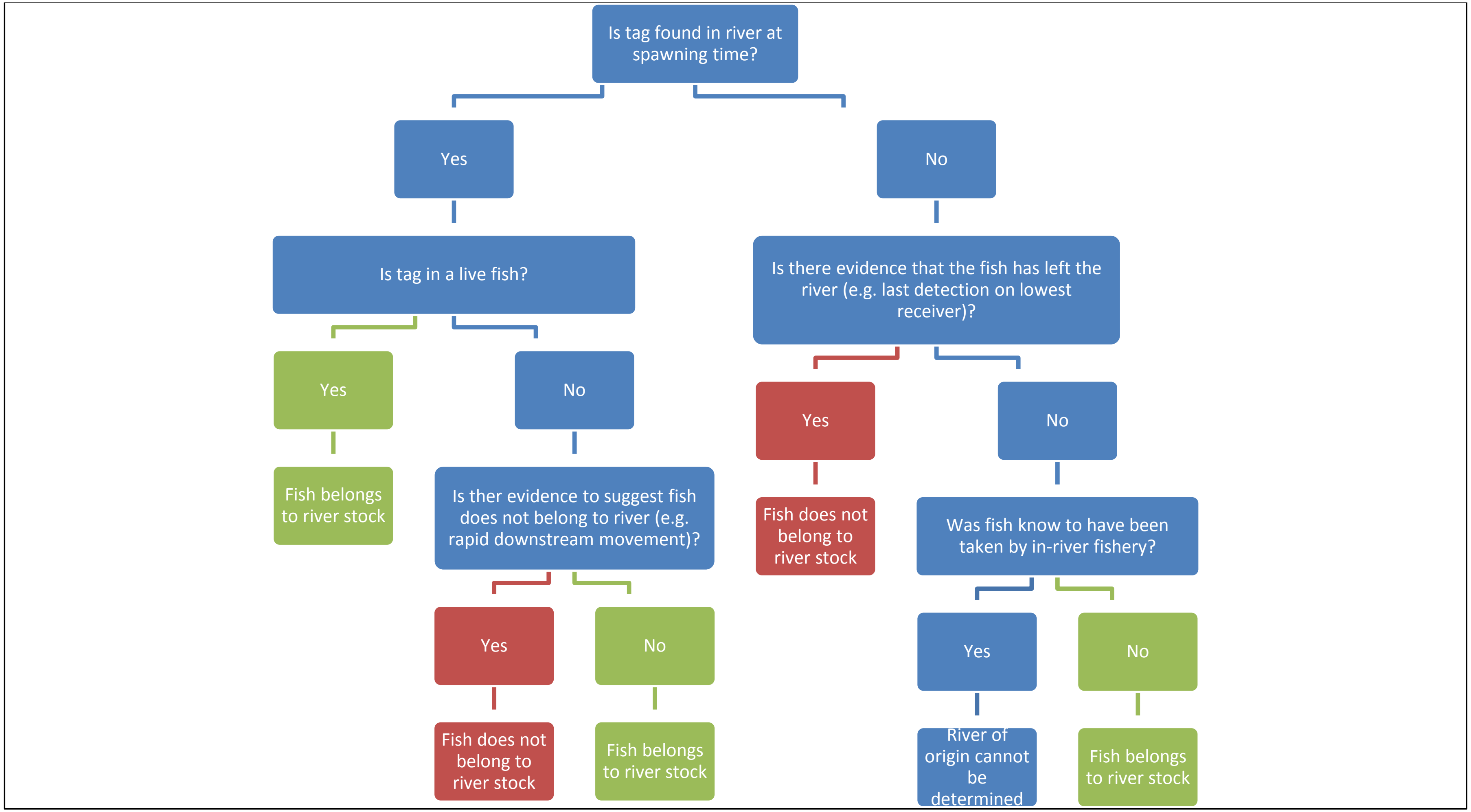
When assessing the likelihood of intercepting Atlantic salmon destined for other rivers, it is important to consider their geographic proximity to the point of tagging (e.g. Shearer, 1986) in light of migration routes along the coast (Mills, 1989; Malcolm *et al*., 2010). For example, the lower proportion of tagged salmon entering the Aberdeenshire Dee in the study by Smith & Johnstone (1996) relative to that reported by Smith *et al*. (1994) probably reflects the greater distance of the point of tagging from the river mouth (Smith & Johnstone, 1996).

For tagged fish sourced from the coastal net fishery, entry into a given monitored river and subsequent return to sea, sometimes followed by entry into a different monitored river, was a feature in both 2012 and 2013, with 27.1 % and 35.7 % of the fish detected in fresh water in 2012 and 2013 respectively exhibiting such behaviour. One possible explanation for this behaviour is that fish destined for a particular river stray into another river before dropping out of the system and presumably heading for their intended river. Another explanation is that such fish enter a particular river and find conditions within the river to be unsuitable or intolerable to them at the time and therefore drop out of the system. This phenomenon has been observed previously. For example, Stewart *et al*. (2009) noted that among over-summering Atlantic salmon returning to rivers in the Cromarty Firth in northeast Scotland, 50 % of fish which entered rivers subsequently dropped back to the estuary and ascended adjacent rivers. Stewart *et al*. (2009) noted that fish residing in non-natal rivers generate mixed stock fisheries such that exploitation in any one river may affect stocks from a range of rivers.

Overall, the radio tracking data show that the coastal net fishery near the mouth of the River South Esk is mixed-stock, catching spring salmon destined for several major rivers in the northeast of Scotland. The proportion of the catch destined to spawn in the River South Esk was estimated at 8 % to 29 %.

5.5 APPENDICES

Appendix 5.5: Decision tree used to assign radio tagged salmon to the River South Esk stock.



Part 6: Discussion & Conclusions

This investigation has shown that South Esk spring salmon spawn predominantly, but not exclusively, in the upper catchment. Of the 24 fish tracked successfully until spawning time over three years, 20 fish (83.3 %) spawned in the upper catchment. Of these, 16 fish were found in Glen Clova, suggesting that this area is an important spawning area for spring salmon. Electrofishing surveys showed that in general, sites on the River South Esk performed close to or better than the mean national expectation for sites with similar habitat characteristics indicating that the River South Esk is not performing worse than expected, and in many cases exceeds expectations. There was no evidence of sites in the upper catchment being markedly worse than those in the lower catchment. Indeed, the converse was true, with sites in the lower catchment generally performing worse than expected. Prior to 2013, electrofishing surveys in the lower catchment were scarce. Surveys carried out in 2013 and 2014 demonstrate poor densities of salmon fry relative to expectation in the Pow Burn and the Lemno Burn, although the Noran Water generally performed very well. Of the sites fished in the upper catchment, those in Glen Clova were generally performing better relative to expectation than sites fished elsewhere in the upper catchment. Although we cannot be sure that fry caught during electrofishing surveys were the progeny of spring fish, the results of the radio tracking work mean we can be confident that electrofishing surveys in the upper catchment were carried out in the general area where spring fish spawn. When considered together, these results suggest no unexpected problems with productivity of salmon fry in the upper catchment where the majority of spring fish spawn.

Effort data relating to the spring salmon rod fishery was scarce. However, effort data relating to an 11-year period (2002 to 2012 inclusive) were sourced from one of the six rod fisheries contributing most to the overall spring salmon rod catch on the River South Esk. These data provided evidence of a reduction in rod effort over the period for which data are available, notably a step-change in the percentage of beat days let from 2005 onwards. Catch per unit of effort (CPUE) tended to be relatively stable across the time series as a whole, although there was evidence of a decline in later years (2007 to 2012). Examination of the high definition data revealed a significant decline in effort over the period 2007 to 2012, and this coincided with a significant decline in CPUE over the same period. Further evidence for a reduction in rod fishing effort came from a subset of “high definition” data available for the period 2007 to 2012 inclusive, which also showed a tendency for the number of rods booked per beat day let to decline, despite the number of beat days let remaining relatively constant over this period. Translating these results to the River South Esk as a whole requires a degree of caution, since these effort data were sourced from just one fishery. Nonetheless, the fishery providing the data is among those contributing most to the overall spring rod catch on the river. If the effort data available from this fishery are typical of other spring salmon rod fisheries up and down the river, then there is the possibility that declining rod catches of spring salmon on the River South Esk reflect a decline in rod fishing effort.

The coastal net fishery adjacent to the River South Esk was found to be highly mixed stock, catching fish which were subsequently detected in several major rivers in the northeast of Scotland (the Rivers Spey, Don, Dee, North Esk, South Esk and Tay). Given that tagged fish could have entered rivers other than those that were being monitored for tags, the number of rivers in which fish were detected should be viewed as a minimum estimate. The proportion of the catch from the coastal net fishery destined to spawn in the River South Esk was estimated at 8 % to 25 % in 2012 and at 11 % to 29 % in 2013. Therefore, up to an estimated 29 % of the spring salmon catch from the coastal net fishery may have been destined to spawn in the River South Esk.

It was not possible to use genetic tools (SNPs) to identify geographic origins within the South Esk catchment because there was not sufficient spatial genetic differentiation between areas within the system. Similarly, SNPs could not be used to determine the representation of different rivers stocks in the nets because there is not enough differentiation detectable among the large Scottish east coast rivers using the techniques employed.

In conclusion, considering the early running component of the River South Esk salmon stock, the majority of fish spawn in the upper catchment, and it is encouraging that densities of salmon fry in this area are generally as good as or better than expected. The limited available rod fishing effort data suggest a decline in angling effort for spring fish coinciding with a reduction in CPUE in recent years. Between 8 % and 29 % of the spring salmon catch from the coastal net fishery adjacent to the River South Esk was estimated to be destined to spawn in the River South Esk.

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