Submission to the Mixed Stock Fisheries Priority for Action Group, January 2009.

Mixed Stock Fisheries - Science Overview

J C MacLean and G W Smith

Fisheries Research Services, Freshwater Laboratory, Field Station, Inchbraoch House, South Quay, Ferryden, Montrose, DD10 9SL

Introduction

The publication of "A Strategic Framework for Scottish Freshwater Fisheries" (Scottish Government, 2008), which was developed in conjunction with stakeholders with an interest in fish and fisheries, has the following vision; "Scotland will have sustainably-managed freshwater fish and fisheries resources that provide significant economic and social benefits for its people." In the document, a number of Priorities for Action (PFAs) have been identified for detailed consideration. The remit of the Mixed Stock Fisheries Group is detailed under PFA Project 2.5. The project descriptor is wide ranging and is intended to encompass all aspects of mixed stock fisheries with contributions from representatives from a number of organisations.

This overview paper will concentrate on Atlantic salmon (*Salmo salar* L.) which is an iconic and valuable natural resource. The species has, in the recent past, supported large fisheries not only in Scotland, but in other salmon producing countries throughout the North Atlantic and on the feeding grounds off West Greenland and the Faroe Isles (ICES, 2008). Over the last two decades, declines in marine survival have been recorded in the few monitored sites that exist throughout the species range, including Scotland (Potter and Crozier, 2000; Crozier *et al.*, 2003; ICES, 2008; FRS, 2006) and this, coupled with the restriction or closure of many fisheries, has led to a general decline in catches (ICES, 2008). These events have further focussed efforts to develop management tools using the best available scientific knowledge. For example, river specific conservation limits (CLs) are now used to assess stock status in several countries (ICES, 2008).

This paper will consider the structure of Scottish salmon stocks, discuss what a mixed stock fishery (MSF) is and consider the available scientific evidence in defining both the scale and level that fisheries may be considered MSFs.

Populations and stocks

The term "mixed stock fishery" is in common usage but can have many different connotations and interpretations. Crucial to the efficient functioning of the MSF PFA group is the adoption of an agreed working definition. To understand what a mixed stock fishery is, it is first necessary to consider the definition of a stock.

The term "stock" has been repeatedly used synonymously with the word "population", often leading to confusion, or at best, lack of clarity. It is therefore imperative that we have an unambiguous understanding of the meaning of both these terms. This issue was addressed by the ICES North Atlantic Salmon Working group more than a decade ago (ICES, 1996). A population is a clearly defined biological term and

comprises a group of individuals of the same species occupying a particular geographic area. Populations may be relatively small and closed, as on an island or in a valley, or they may be more diffuse and without a clear boundary between them and a neighbouring population of the same species. For species that reproduce sexually, however, members of a population interbreed either exclusively with members of their own population or, where populations overlap, to a greater degree than with members of other populations.

Our current understanding of the population structure of salmon in Scotland has been informed and synthesised from a number of scientific investigations. Salmon returning to freshwater at different times of the year exhibit clear phenotypic differences (Shearer, 1992). Radio tracking studies of returning adult salmon, for example, have demonstrated that the time of entry into freshwater is related to spawning distribution (Laughton and Smith, 1992; Webb 1998; Smith *et al.,* 1998; Smith and Johnstone, 1996; Webb, 1992; Walker and Walker, 1991). This run-timing attribute has, in turn, been shown to have a heritable component (Stewart *et al.*, 2002). The salmon that spawn in the Girnock Burn, a tributary of the River Dee, are thus a run-timing subset of the stock that returns to the River Dee as a whole (Youngson, *et al.*, 1994). Such studies have led to the conclusion that salmon are organised in biologically functional units (populations) at scales which are not yet well defined but may be visualised on spatial scales of around 10km of river length and, in useful temporal terms, as monthly returning units.

An important attribute of populations is that, by definition, their population dynamics may be more or less independent and they can evolve independently from one another (Garcia de Leaniz *et al.*, 2007). Thus, the ideal management system would be one that operated at the population scale. However, considerably more research is required before distinct populations, and the boundaries between adjacent populations, can be identified. Furthermore, robust estimates of abundance are rarely available at such scales and as a consequence management, in practice, must operate at a larger scale.

In contrast to the clear biological definition of a population, a stock is a group of individuals, not defined by biology (but usually envisioned as comprising a number of populations) but by management needs. For example we can refer to the West Greenland stock, The North East Atlantic Commission multi – sea winter stock, the Scottish stock, the Tweed stock and the upper Tweed stock. All of these stock definitions are acceptable. The scale chosen depends on the level at which one intends to manage, and often, the level at which data availability allows one to manage. In practice, many home water countries manage, by regulation of fisheries, at the level of the river stock, those fish returning to spawn to a single river catchment.

What is a mixed stock fishery?

The North Atlantic Salmon Conservation Organisation (NASCO) was established to promote the conservation, restoration, enhancement and rational management of salmon stocks in the North Atlantic Ocean through international co-operation (NASCO, 1988). NASCO has regulatory responsibilities for fisheries that exploit salmon originating in another Party's area. The NASCO definition of a stock is as follows (NASCO, 2000):

"A management unit comprising one or more salmon populations. This would be established by managers, in part, for the purpose of regulating fisheries. (The term

may be used to describe those salmon either originating from or occurring in a particular area. Thus, for example, salmon from separate rivers are referred to as “river stocks” and salmon occurring at West Greenland may be referred to as the “West Greenland stock”).”

Many home water countries now manage at the level of a river stock, and NASCO has defined a MSF as follows (NASCO, 2000):

“A fishery exploiting a significant number of salmon from two or more river stocks.”

A recent paper by Potter and Ó Maoiléidigh (2006) has recognised that river fisheries can be mixed stock but makes a pragmatic decision, for the purposes of defining a management unit that can be used, that fisheries outside estuary limits should be deemed MSFs.

We suggest that the NASCO definition of a MSF could be used by the MSF PFA Group on the basis that it is internationally recognised, is in use in some home water countries and will allow the work of this Group to proceed. We will use this definition in the following sections.

Evidence based examples of MSFs in Scotland

Recently mixed stock fisheries in home water countries have come under increased scrutiny for a number of reasons. The general decline in salmon stock status throughout the North Atlantic has focussed attention on all active fisheries. Further, the observation that declines in salmon populations are not generally uniform across stocks, and that the status of stocks may thus vary within any given home water country, has underlined the particular difficulties faced when managing fisheries which exploit a range of stocks.

Adopting the NASCO definitions of both “stock” and “mixed stock fishery” we can now look at relevant data to assess the extent to which the methods currently employed to exploit salmon in Scotland may be thought of as MSFs according to these definitions. All salmon fisheries fall into one of three broad categories. Fixed engine fisheries largely operate in coastal areas. Within this category, bag nets, stake nets and jumper nets operate throughout Scotland, while poke nets and haaf nets are restricted to the Solway Region. Net and coble fisheries are beach seine operations which are generally restricted to estuaries and the lower reaches of rivers. Rod and line fisheries comprise recreational angling activities which generally take place within river systems.

Here we consider two types of data generated from adult coastal tagging and smolt tagging experiments. In both cases, results may be influenced by reporting rates as well as recapture rates but the extent of these influences cannot readily be quantified.

<u>Coastal tagging investigations</u>

Coastal tagging experiments were carried out at a number of fixed engine fisheries around the Scottish coast over the period 1952 to 1988 (Shearer, 1992). Salmon were removed from the fish trap, externally tagged and released back into the sea. The location and type of gear of subsequent recaptures were noted. The primary aim was to describe the movements of salmon along the Scottish coasts adding to the

knowledge base obtained by similar experiments conducted previously by Menzies (1937, 1938a, 1938b, 1938c, 1949). In addition, in the context of MSFs, these studies provide an indication of the subsequent migration patterns of the salmon being exploited in the fixed engine fisheries and thus allow some limited inference to be drawn as to the origin of fish exploited by these fisheries.

Two general features of the recapture distribution are common to all of these studies. First, the majority of recaptures were taken close to the site of initial capture. Second, recaptures were also taken considerable distances away from the tagging site, albeit in relatively small numbers. An example of the recapture distributions, by recapture method, is shown in Figure 1. While the distribution of recaptures is influenced by the location of fisheries, their exploitation levels and the coastal migration routes of salmon, the widely dispersed nature of the tag returns suggests that, even though the river of origin of the tagged salmon is not known, fixed engine fisheries are highly likely to be MSFs according to the NASCO definition. These studies, however, are limited in their usefulness in the current context in that they provide no data to assess the extent to which net and coble and rod and line fisheries may be thought to be MSFs, nor is it possible to quantify the degree to which fish originating from a given river system may be expected to be exploited by fixed engine, net & coble and rod & line fisheries some distance from that river.

Smolt tagging investigations

Smolt tagging studies have the major advantage over coastal tagging experiments in that the river of origin of the tagged smolts is known. Furthermore, the adult recapture data from these studies allow us to assess the degree to which all three types of legal fishery (described above) may be considered MSFs. On the down side, information is available from only two stocks; the North Esk (FRS, 2005a) and the Girnock Burn, a tributary of the river Dee (FRS, 2005b). Both are long term monitored sites where abundance information is collected at a number of stages throughout the salmon's life cycle for assessment and research purposes. At both these locations, emigrating smolts have been externally tagged with modified Carlin tags and subsequent adult recaptures collated to provide information on the extent to which salmon from these stocks are exploited by individually identifiable (method and geography) fisheries. For the North Esk, the available adult tag return data from the smolt years 1991 to 2007 were pooled; for the Girnock Burn, the available adult tag return data from the smolt years 1969 to 1980 were pooled.

Table 1 summarises the number of adult recaptures by location (by region and combined district) and fishing method of salmon tagged as smolts in the North Esk. Table 2 summarises the results for salmon tagged in the Girnock. The main findings, for both stocks are that although the majority of recaptures were concentrated in the region/combined district from which the stock originates, for no method were recaptures restricted to the Region of origin. Under NASCO definitions, therefore, all three methods may be thought of as MSFs.

The analysis can be extended by including reported catches to estimate the effect of both distance from the river of origin and fishing method on the relative impact of Scottish fisheries on North Esk and Girnock stocks. For each of the three types of legal fishery (fixed engine, net and coble and rod and line), the number of recaptures in each geographic region were expressed relative to the average reported catch in that region over the appropriate time period (tag returns per 10,000 fish caught). The results for the North Esk stock are shown in Figure 2(a-c) and, for the Girnock stock, in Figure 3(a-c) using a ramped colour coding system, where a logarithmic scale has

been used to best illustrate the patterns shown over a wide range of relative recapture rates. Note that patterns of tag return rate can be compared for a given stock between fishing methods, but comparisons between stocks are invalid as tagging rates differ. Note, as for the coastal tagging experiments described above, that the distribution of recaptures was influenced by the location of fisheries, their exploitation levels, and the coastal migration routes of salmon.

All three types of legal fishery impacted upon the tagged stock not only in the region from which they originated (the North East region) but in other more distant regions. The North East region had the highest tag return rate, followed by regions adjacent to the North East region and then more distant regions. The relative impact of west coast fixed engine fisheries at some distance from the river of origin were of the same order as rod and line fisheries in the neighbouring regions. These patterns were similar for both the North Esk and Girnock stocks.

In conclusion, using the NASCO definition of a MSF, all three types of legal fishery can be described as mixed stock fisheries but the relative impact of a fishery on a river stock will depend both on fishing method and the distance at which it operates from that river. For example, rod and line fisheries in the adjacent Moray Firth and East regions have a similar impact upon the North Esk stock as fixed engine fisheries in the more distant North, North West and Solway regions (Figure 2). The smolt tagging and recapture information considered here is limited to the two stocks where such information exists. The number of recaptures is small but it is the best information available. However, the consistency in the tag return patterns between the two stocks suggests there may be a common pattern among stocks, Data from west coast stocks are not available but would be particularly valuable in testing this assertion.

Future approaches to investigating MSFs in Scotland

Mixed stock fisheries are not inherently detrimental to stock status. Any fishery, single stock or mixed stock, only poses a problem if it exploits stocks where there is no exploitable surplus. MSFs do, however, present particular management difficulties in that an assessment of the stock composition of such fisheries is required before their impact on a given stock may be assessed. In this regard the results of the smolt tagging analysis outlined above may provide the first steps in a pragmatic solution to this issue. However, a more rigorous analysis based on population genetics is more likely to provide a robust solution.

Genetic techniques offer the best and most cost effective route to understanding which stocks are exploited by fisheries in Scotland. Such techniques are now routinely applied in assigning the catch at West Greenland to continent of origin and these analyses are used in the formulation of the annual management advice from International Council for the Exploration of the Sea (ICES) to NASCO (King *et al.*, 2001; Koljonen *et al.*, 2007; ICES, 2008). Such techniques have also been recently applied at a finer scale on the west coast of Scotland in relation to the rivers of Loch Feochan as well as to mixed population fisheries within rivers, for example, in Finland, where catches have been assigned to individual tributaries of the River Teno (Vähä *et al.*, 2007).

Crucial to the implementation of genetic stock identification methods is the collection of comprehensive and appropriate baseline samples. FRS and EU partners are currently engaged in a 3-year programme (SALSEA Merge) which will establish a baseline that would enable the origin of Atlantic salmon to be determined at regional

level. In addition, FRS and the Association of Scottish River & Fishery Management Trusts (RAFTS) are about to commence a collaborative programme of genetic work with the aim of understanding the structuring of river stocks of Atlantic salmon into breeding populations using a suite of 14 micro satellite loci. The information collected has the potential to be used for identifying MSFs within and outside rivers, and to determine the relative contributions made by the different contributing stocks. Based on work currently underway in Ireland, greater than 90% of fish in most areas would be expected to be assigned to river of origin provided the local data sets cover >95% of overall Scottish production. Some problems with temporal stability of the baseline may occur, for example due to population crashes or introgression with escaped farmed salmon, but these can be addressed and it is anticipated that within 3 to 4 years the RAFTS-FRS data would provide a suitable basis for the assignment of fishery catches to river stock of origin across a substantial area of Scotland.

Summary

- A prerequisite to developing a strategy for mixed stock fisheries (MSF) is an agreed definition of the term “mixed stock fishery.” Before this point can be reached there is a requirement to understand the meaning of the term “stock” and to distinguish this from the term “population” with which it is often used synonymously. Populations are biological entities defined essentially as a group of individuals which interbreed almost exclusively with members of their own population. This attribute enables them to evolve independently of other populations and hence they are the desired management unit. Until populations can be identified and demarcated, management must operate at a larger and more aggregated level. Stocks are groups of individuals not defined by biology, but by management criteria and hence phrases such as “the West Greenland stock” and “river stock” are in common usage.

- The NASCO definition of a MSF is “A fishery exploiting a significant number of salmon from two or more river stocks.” The NASCO definition is used here to assess the extent to which all 3 legal types of fishery operating in Scotland are MSFs using evidence based examples.

- Consideration of coastal tagging experiments undertaken in the 1950s to 1980s suggest that fixed engine fisheries are highly likely to be MSFs but they provide no information to assess whether net and coble or rod and line fisheries are MSFs. Smolt tagging investigations, carried out on the North Esk and Girnock Burn stocks, show that fixed engine, net and coble, and rod and line fisheries may all be considered MSFs. Furthermore, they allow comparisons of the relative impact of different types of fishery, and of fisheries located at varying distances from the origin of stock under consideration.

- Mixed stock fisheries are not inherently detrimental to stock status but do pose a problem for management. Essentially, the impact of MSFs on particular stocks cannot be assessed until the composition of the exploited stock has been determined. Genetic stock identification techniques have the potential to identify MSFs and to determine the relative contributions made by the different contributing stocks. FRS is currently collaborating with RAFTS to collect the baseline information required to realise this aim and expects that within 3 to 4 years suitable data will be available to assign fishery catches to river stock origin for a substantial part of Scotland.

References

Crozier, W.W., Potter, E.C E., Prévost, E., Schon, P–J., and Ó Maoiléidigh, N. 2003. A co-ordinated approach towards the development of a scientific basis for management of wild Atlantic salmon in the north-east Atlantic (SALMODEL – Scientific Report Contract QLK5–1999–01546 to EU Concerted Action Quality of Life and Management of Living Resources). Queen's University of Belfast, Belfast. 431 pp.

FRS. 2005a. The North Esk: Scotland's monitored salmon river. http://www.frs-scotland.gov.uk/Delivery/Information_resources/information_resources_view_document.aspx?resourceId=23700&documentId=1620

FRS. 2005b. The Girnock and Baddoch fish-traps on Deeside. http://www.frs-scotland.gov.uk/Delivery/Information_resources/information_resources_view_document.aspx?resourceId=23700&documentId=1631

FRS. 2006. Marine mortality in Atlantic salmon. http://www.frs-scotland.gov.uk/Delivery/Information_resources/information_resources_view_document.aspx?resourceId=23700&documentId=1923

Garcia de Leaniz, C., Fleming, I.A., Einum, S., Verspoor, E., Jordan, W.C., Consuegra, S., Aubin-Horth, N., Lajus, D., Letcher, B.H., Youngson, A.F., Webb, J.H., Vøllestad, L.A., Villanueva, B., Ferguson, A., Quinn, T.P. 2007. A critical review of adaptive genetic variation in Atlantic salmon: implication for conservation. Biol. Rev. 88, 173–211.

ICES 1996. Report of the Working Group on North Atlantic Salmon. Moncton, Canada. 10–19 April 1996. ICES CM 1996/Assess: 11, Ref. M. 227 pp.

ICES. 2008. Report of the Working Group on North Atlantic Salmon.Galway, Ireland, 1–10 April, 2008. ICES CM 2008/ACOM:18. 236 pp.

King, T.L., Kalinowski, S.T., Schill, W.B., Spidle, A.P., Lubinski, B.A. 2001. Population structure of Atlantic salmon (*Salmo salar* L.): a range wide perspective from microsatellite DNA variation. Molecular Ecology, 10, 807-821.

Koljonen, M-L. King, T.L. and Nielsen, E.E. 2007. Genetic Identification of populations and individuals. In: The Atlantic salmon: Genetics, Management and Conservation (eds. E. Verspoor, L. Stradmeyer and J. Nielsen), pp. 270-298. Blackwell Publishing, Oxford.

Laughton, R. and Smith, G.W. 1992. The relationship between date of river entry and the estimated spawning positions of adult Atlantic salmon (*Salmo salar* L.) in two major Scottish east coast rivers. In: Wildlife Telemetry: Remote Monitoring and Tracking of Animals (ed. By Priede, I.G. and Swift, S.M.), pp. 423-433. Ellis Horwood Ltd, Chichister.

Menzies, W.J.M. 1937. The movements of salmon marked in the sea. I. The North-west coast of Scotland in 1936. Fisheries, Scotland, Salmon Fish., 1937, No. I, 17pp.

Menzies, W.J.M. 1938a. Some preliminary observations on the migration of salmon on the coasts of Scotland. Rapp. Cons. Explor. Mer., 108, 18-35.

Menzies, W.J.M. 1938b. The movements of salmon marked in the sea. II. West coast of Sutherland in 1937. Fisheries, Scotland, Salmon Fish., 1938, No. I, 9pp.

Menzies, W.J.M. 1938c. The movements of salmon marked in the sea. III. The island of Soay and Ardnamurchan in 1938. Fisheries, Scotland, Salmon Fish., 1938, No. VII, 9pp.

Menzies, W.J.M. 1949. The Stock of Salmon – Its Migrations, Preservation and Improvement. The Buckland Lectures for 1947. Edward Arnold & Co., London.

NASCO. 1988. Handbook – Basic Texts. NASCO, Edinburgh.

NASCO. 2000. Guiding Definitions of Terms Used in Salmon Fisheries Management. NASCO, SCPA(00)11. NASCO, Edinburgh.

Potter, E.C.E. & Crozier, W.W. 2000. A perspective on the marine survival of Atlantic salmon. In: The Ocean Life of Atlantic Salmon, environmental and Biological Factors Influencing Survival. pp. 19-36. Ed. by D. Mills. Fishing News Books, Oxford. 228pp.

Potter, E C E and Ó Maoiléidigh, N 2006. Review of Mixed Stock Fisheries For Atlantic Salmon In European Community Waters, Excluding The Baltic Sea. Preparatory Paper for the European Commission. 51pp.

Scottish Government. 2008. A strategic framework for Scottish freshwater fisheries. Edinburgh: Scottish Government, 52p.

Shearer, W.M. 1992. The Atlantic salmon. Natural history, exploitation and future management. Halstead Press, New York: 244pp.

Smith, G.W., Nelson, K., Youngson, A.F. and Carss, D. 1998. The movements and estimated spawning positions of late-running adult Atlantic salmon (*Salmo salar* L.) returning to the Aberdeenshire Dee. Fisheries Research Services Report, 3/98, 11pp.

Smith, I.P. and Johnstone, A.D.F. 1996. Migration of adult Atlantic salmon (*Salmon salar* L.) in the Aberdeenshire Dee, 1995. Fisheries Research Services Report, 5/96, 16pp.

Stewart, D. C., Smith, G. W., and Youngson, A. F. 2002. Tributary-specific variation in timing of return of Atlantic salmon (*Salmo salar*) to fresh water has a genetic component. Canadian Journal of Fisheries and aquatic Sciences, 59: 276-281.

Vähä, J-P, Erkinaro, J., Niemela, E., Primmer, C.R. 2007. Life-history and habitiat features influence within-river genetic structure of Atlantic salmon. Molecular Ecology, 16: 2638-2654.

Walker, A.F. and Walker, A.M. 1991. The Little Gruinard Atlantic salmon catch and release tracking study. In: Wildlife Telemetry: Remote Monitoring and Tracking of Animals (ed. By Priede, I.G. and Swift, S.M.), pp. 434-440. Ellis Horwood Ltd, Chichister.

Webb, J.H. 1992. The behaviour of adult Atlantic salmon (Salmo salar L.) in the River Tay as determined by radio telemetry. Scottish Fisheries Research Report, 52, 19pp.

Webb, J.H. 1998. Catch and Release: the survival and behaviour of Atlantic salmon angled and returned to the Aberdeenshire Dee in spring and early summer. Scottish Fisheries Research Report, 62, 16pp.

Youngson, A.F., Jordan W.C., and Hay, D.W. 1994. Homing of adult Atlantic salmon (*Salmo salar* L.) to a tributary stream in a major river catchment. Aquaculture 121: 59-67.

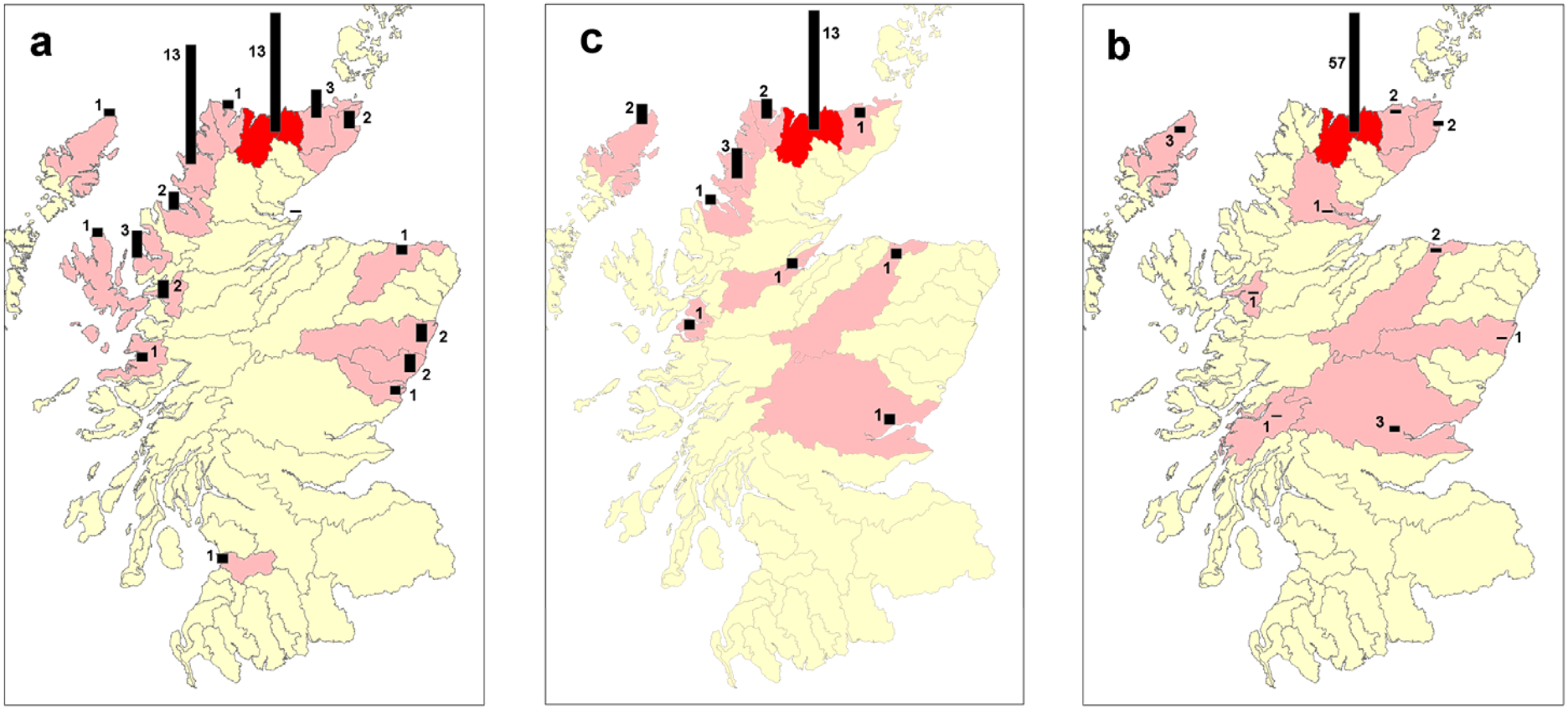

Figure 1. The geographical distribution, by method, of returns of salmon and grilse tagged at three north coast fixed engine fisheries. Tagging sites were situated in the districts coloured red, other districts from which returns were reported are shown in pink. Height of the black bar is proportional to the number of returns, which is also given beside the bar.

a. fixed engine fisheries
b. net & coble fisheries
c. rod & line fisheries

(a)

(b)

(c)

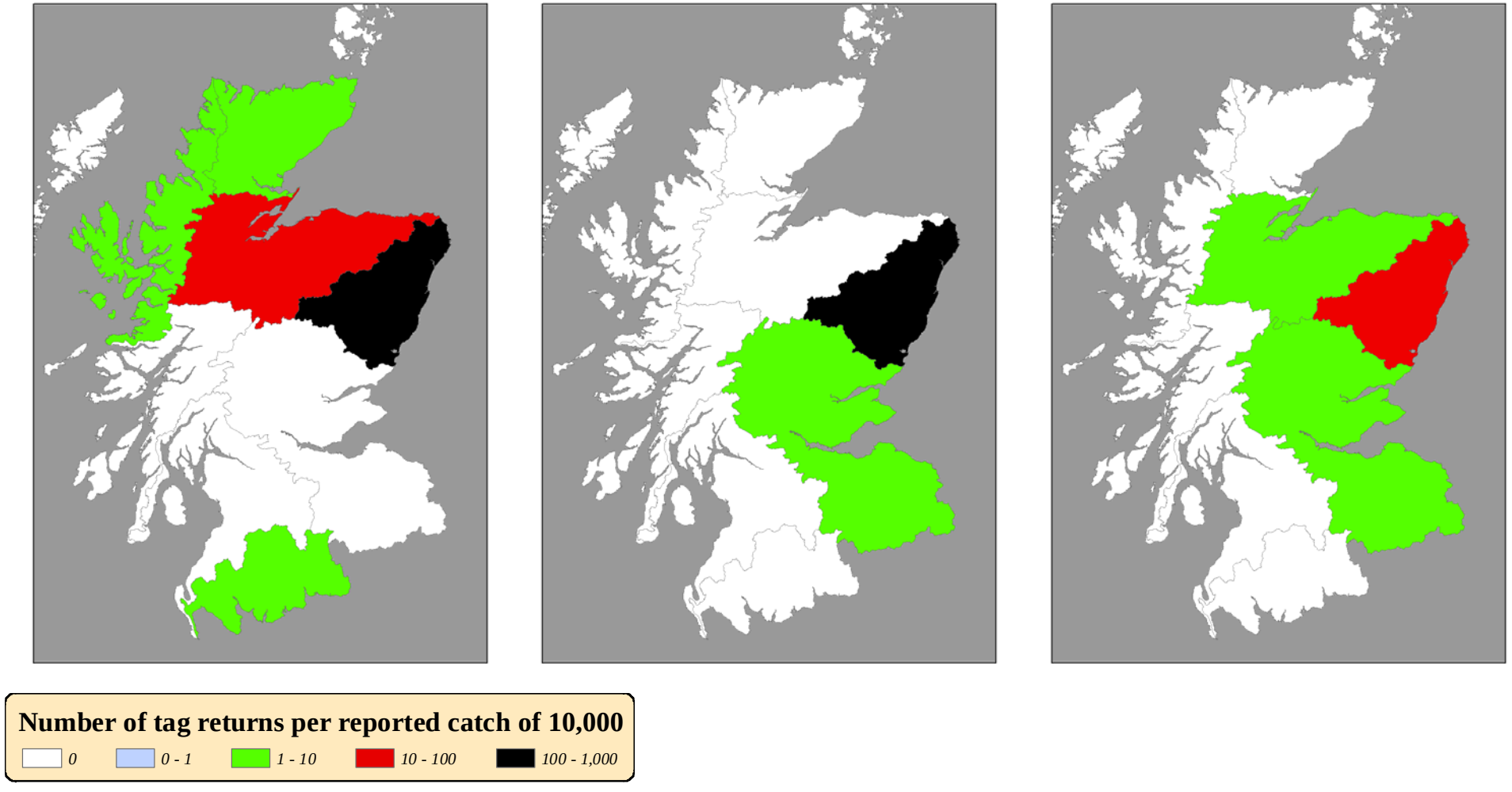

Figure 2(a - c). Tag return rate for North Esk smolts relative to the regional catch (returns per 10,000 fish caught) for (a) fixed engine, (b) net and coble and (c) rod and line fisheries.

(a)

(b)

(c)

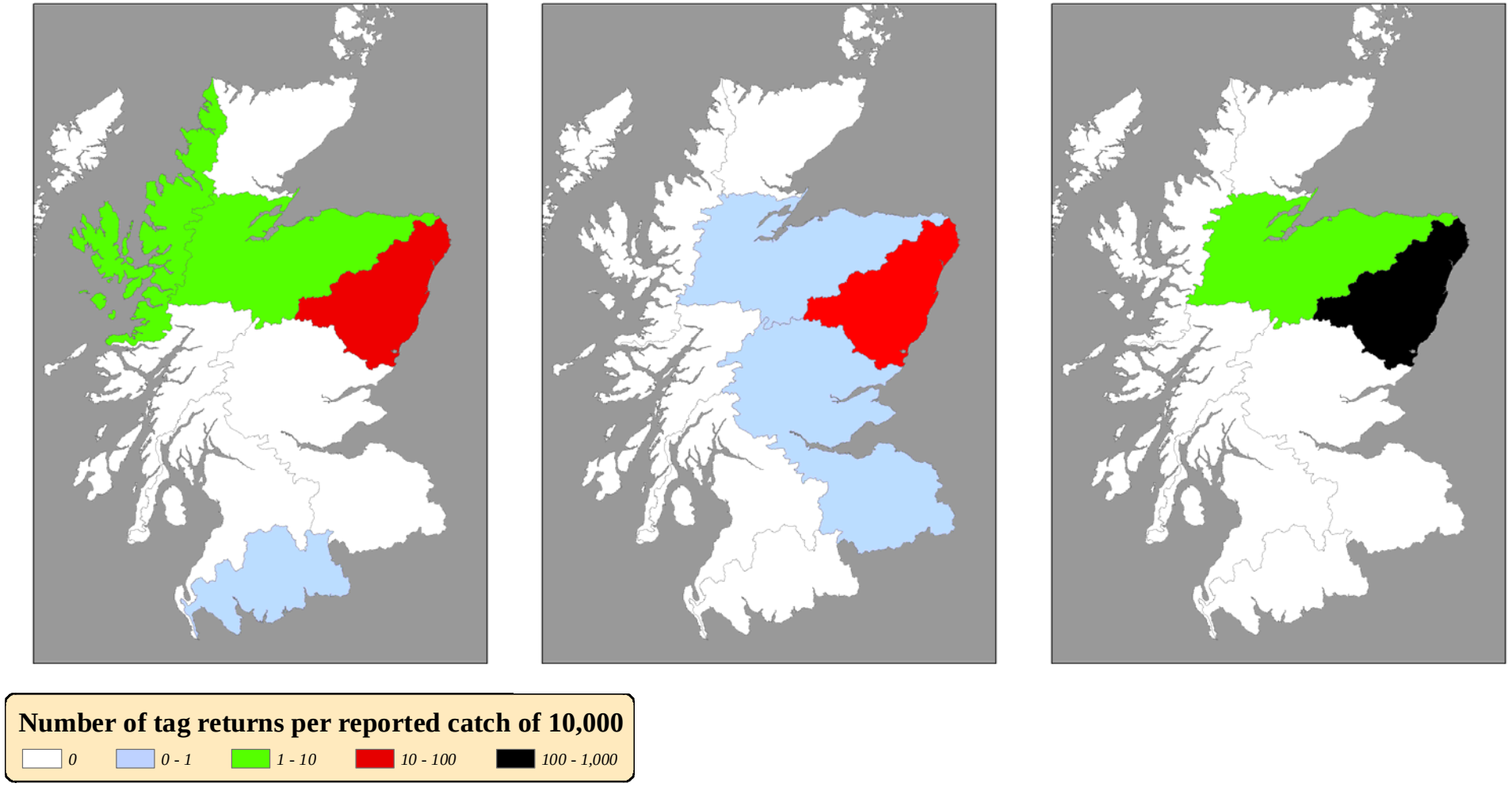

Figure 3(a - c). Tag return rate for Girnock Burn smolts relative to the regional catch (returns per 10,000 fish caught) for (a) fixed engine, (b) net and coble and (c) rod and line fisheries.

Table 1. The number and distribution, of adult recaptures, by combined district and region, of tagged North Esk smolts.

Region	Combined district	Number of recaptures by method		
		Fixed engine	Net and coble	Rod and line
East	Tweed		5	2
	Tay			2
North East	S Esk	71	3	10
	N Esk & Bervie	**181**	**106**	**68**
	Dee	27	1	5
	Don	4		4
	Ythan	1		
Moray Firth	Deveron			3
	Spey			5
	Lossie	1		
	Findhorn	1		
	Conon & Alness	1		
North	Halladale & Strathy	1		
North West	Inchard to Kirkaig	1		
	Ewe	1		
West				
Clyde Coast				
Solway	Nith	1		
Orkney				
Shetland				
Outer Hebrides				

Table 2. The number and distribution, of adult recaptures, by combined district and region, of tagged Girnock Burn smolts.

Region	Combined district	Number of recaptures by method		
		Fixed engine	Net and coble	Rod and line
East	Tay		6	
North East	S Esk	15		5
	N Esk & Bervie	51	37	3
	Dee	**82**	**28**	**83**
	Don	2		8
Moray Firth	Deveron			4
	Spey	3	1	7
	Findhorn	2		
	Conon & Alness	1		
North West	No breakdown to combined district available	4		
West				
Clyde Coast				
Solway	Nith	1		
Orkney				
Shetland				
Outer Hebrides				