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Assessing the status of Scottish Atlantic salmon (*Salmo salar* L.) stocks using reported catch data: a modelling approach to account for catch and release in the rod & line fishery

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Summary

In the absence of direct counting systems, the abundance of Atlantic salmon stocks in Scotland is generally estimated indirectly using reported rod fishery data. The widespread adoption of catch and release in Scottish rod fisheries provides a challenge for such assessment techniques, however, as a proportion of fish released from the rod fishery may be re-caught and hence inflate the catch statistics by appearing in the reported data more than once.

This report describes a modelling approach which has been developed to correct the reported catch of Scottish rod fisheries by accounting for recaptures associated with these data. The number of recaptures is modelled using estimates of exploitation rate, retention rate in the rod fishery and mortality following release. Model output at a range of notional exploitation rates was compared with reported catch over the period 1994 (when catch and release was first reported within the fishery) to 2013.

It is concluded that catch and release inflates the reported catch data and that this effect increases through the time series as the take-up of catch and release within the rod fishery increased. However, regardless of this effect, the general trends in the reported catch data over the time series were similar to those generated by the model. This was true even at high notional exploitation rates which emphasize the differences between reported catch and model output.

It is important that the potential effects of catch and release on rod catch trends is kept under review and that efforts are made to collect data that increase the reliability of our abundance indicators in the future. An important development in this regard is the construction of a network of well validated counters that will not only provide direct estimates of stock abundance in relation to particular river systems, but will also improve our knowledge of exploitation rates across a wide range of Scottish salmon stocks.

1. **Introduction**

Ideally, the abundance of returning adult Atlantic salmon, *Salmo salar* L., should be derived from appropriately sited and validated counting systems. In the absence of such direct measures, however, abundance is generally estimated indirectly using reported fishery data (see for example ICES, 2014; Crozier *et al*, 2003).

Data from fish counters are currently available for stocks from few Scottish catchments (Simpson, 2003; Thorley *et al*., 2005), although plans are being developed to extend this network. Interim methods using both reported fishery data and direct counts, where available, are currently used to assess the status of Scottish salmon stocks (Marine Scotland Science, 2014a). Scottish salmon fishery statistics are derived from returns made in response to an annual questionnaire sent to the proprietors or occupiers of fisheries (Marine Scotland Science, 2014b). Data from both net and rod fisheries have been collected since 1952.

Net fisheries have been in decline for much of the period since 1952 and are currently at historically low levels (Marine Scotland Science, 2014c). Such declines are not mirrored in the rod fishery, however, and these long term trends have resulted in a major shift in the composition of Scottish salmon catches. In 1952, rod catch comprised 11% of the total reported catch compared to 73% in 2013 (Marine Scotland Science, 2014c). The decline in the net fisheries has also resulted in a decline in the geographical range covered by these fisheries. Salmon fishery statistics are routinely summarised across 109 Districts which correspond either to a single river catchment together with adjacent coast or to groups of neighbouring river catchments and associated coastline (Marine Scotland Science, 2014b). In 2013, rod catch returns were received from fisheries in 97 districts (89% of the total) while net fisheries were associated with only 25 districts (23%). Assessment of Scottish salmon stocks are therefore generally undertaken using rod catch statistics (Marine Scotland Science, 2014a).

Catch and release is seen as a method of maintaining rod fisheries while providing a measure of protection for stocks in a period where the numbers of adult salmon returning to home waters has been falling. It has been practiced by rod fisheries throughout much of Canada and USA since the early 1980s and has been adopted in many European countries in more recent years (ICES, 2014). In Scotland, the proportion of the annual rod catch accounted for by catch and release has increased from 8% of the annual rod catch in 1994, when such information was first recorded, to 80% in 2013 (Marine Scotland Science, 2014c).

A proportion of fish released from the rod fishery may be re-caught and hence inflate the catch statistics by appearing in the reported data more than once (ICES, 2009). As rod catch is a key index in the assessment of Scottish salmon stocks, the effects of the increasing adoption of catch & release should be accounted for. Unfortunately, although some studies document recaptures of tagged fish (Anon, 2013a; Anon, 2013b; ICES, 2009; Kindness, 2010), no large scale data sets are currently available from which models of expected recapture rates may be developed.

In the absence of such empirical data, particularly from Scottish rod fisheries, this report describes an interim modelling approach which uses best available information to estimate effects of multiple captures of released fish on the reported Scottish rod catch. Outcomes of the model are considered to assess whether failing to account for multiple captures would be expected to change general interpretation of trends in rod catch.

2. The Model

Model Structure

The catch and release model has been developed to correct reported catch data by accounting for multiple recaptures of released fish in a rod fishery where both catch and release and the retention of landed fish is practiced (Figure 1). The number of first time captures in the reported catch is derived by estimating the total number of recaptures in both the released and retained data sets and subtracting these from the reported numbers. The probability of recapture following release is assumed to be equal to the exploitation rate (proportion of available salmon captured) and independent of the number of previous releases.

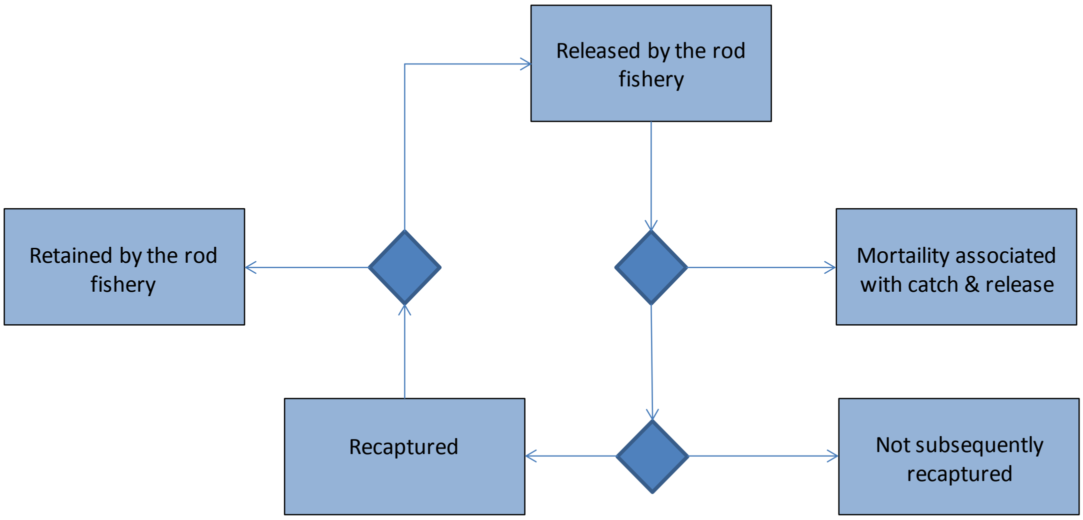

Figure 1. Fate of fish released by the rod fishery

In the simplest case, the absence of post handling mortality after release and where the fishery practices total catch and release, the relationship between the reported released catch (Rel) and the number of salmon at first capture (C_1) may be modelled as

$$C_1 = Rel - Rel\ .\ \varepsilon$$

where ε = the exploitation rate (Appendix 1).

This equation may be expanded to include both information on post handling mortality of released fish (assuming that mortality rate is independent of the number of previous releases) and the retention of recaptured salmon by adjusting the number of fish available to be recaptured (Appendix 1):

$$Rel\ \rightarrow Rel\ .\ \sigma\ .\ \rho$$

where σ = proportion surviving once released and ρ = proportion of captured fish subsequently released. Thus

$$C_1 = Rel - Rel\ .\ \varepsilon\ .\ \sigma\ .\ \rho$$

Similarly, correcting the reported retained catch (Ret), the number of retained salmon which were not previously released (Ret_{cor}) may be modelled as

$$Ret_{cor} = Ret - Rel\ .\ \varepsilon\ .\ \sigma\ .\ (1 - \rho)$$

Summing C_1 and Ret_{cor} provides an estimate of the corrected total (retained and released) rod catch.

Setting Model Parameters

Exploitation rates

There is little published information regarding rod exploitation rates on Scottish salmon stocks, although exploitation rates associated with fisheries on the North Esk are reported to ICES annually (eg MacLean *et al*, 2014). A fish counter is situated in the lower reaches of the river and exploitation rates for fisheries above the counter are estimated as reported rod catch (retained and released) expressed as a proportion of the net upstream count. Annual rod exploitation rates within the range 6% to 15% have been reported over the period 1984 to present (MacLean *et al*, 2014). Additionally, in a study of adult salmon returning to the River Spey, 25% of early running fish caught by rods, tagged and released were subsequently recaptured (Thorley *et al*., 2007).

The current model has been run at a range of exploitation rates (5%, 10%, 20% and 30%) to cover these reported values.

Mortality associated with catch and release

In recent years, ICES has considered both the level of pre-spawning mortality for salmon caught and released by anglers (ICES, 2009; ICES 2012) and also how estimates of catch and release mortality are currently incorporated into national stock assessments (ICES, 2010).

In controlled studies, higher temperatures have been associated with increased mortality and in particular, incidental mortality from catch and release appeared to increase with water temperatures above 20°C (ICES, 2012). Logbooks from a number of Russian fisheries indicated that hooking in the gills, which resulted in profuse bleeding likely to result in mortality, occurred in 5% to 7% of the catches. Similarly, in a study from a single river in Norway, 7% of the salmon were described as deeply hooked (hooked in the throat) and 7% were also characterised as being in bad condition at release (ICES, 2009).

Estimates of catch and release mortality used in national stock assessments vary considerably (ICES, 2010). Within Canada, an estimate of 5 to 15% (mean 10%) is used for Newfoundland & Labrador whereas in the Gulf Region the correction is 3% to 6% and in Scotia/Fundy the numbers of fish released is reduced by 4% in the assessments to take account of catch and release mortality. In the North East Atlantic, a 20% mortality of released fish is used in assessments for England & Wales, while no account is taken of catch and release mortality in either Norway or Ireland (ICES, 2010).

A catch and release mortality of 10% is assumed in the current model.

Released fish subsequently caught and retained by the rod fishery

The proportion of the Scottish rod catch accounted for by catch and release has generally increased since 1994, when such information was first recorded (Marine Scotland Science, 2014c), and these reported catch data are used to derive the model parameters for the appropriate year. Thus, losses to the rod and line (retained) fishery for any given year are estimated as the proportion of the total Scottish rod catch accounted for by the retained catch. Estimates are provided both for the annual and spring (for the purposes of this report defined as multi sea-winter fish taken before 1 May) catch (Table 1).

Table 1

The proportion of the total Scottish rod catch accounted for by the retained catch. Data for annual catch and spring catch for the years 1994 (when catch and release was first recorded) to 2013 are shown separately.

	Proportion retained	
Year	**Annual**	**Spring**
1994	0.921	0.992
1995	0.859	0.876
1996	0.851	0.875
1997	0.820	0.894
1998	0.817	0.806
1999	0.717	0.714
2000	0.680	0.628
2001	0.617	0.506
2002	0.585	0.528
2003	0.446	0.421
2004	0.502	0.423
2005	0.455	0.356
2006	0.449	0.335
2007	0.394	0.255
2008	0.384	0.224
2009	0.335	0.184
2010	0.296	0.135
2011	0.273	0.093
2012	0.264	0.091
2013	0.201	0.082

3. Results

The catch and release model was run for the years 1994 (when catch and release was first recorded) to 2013. Reported catch data was corrected on the basis of a series of exploitation rates (5%, 10%, 20% and 30%). Separate runs of the model were conducted for the annual reported Scottish rod catch and for the spring (multi sea-winter fish taken before 1 May) component.

Clearly, the total (retained and released) reported rod catch exceeded model estimates throughout the period for which the model was run, both in respect of annual (Fig. 2) and spring catches (Fig. 3).

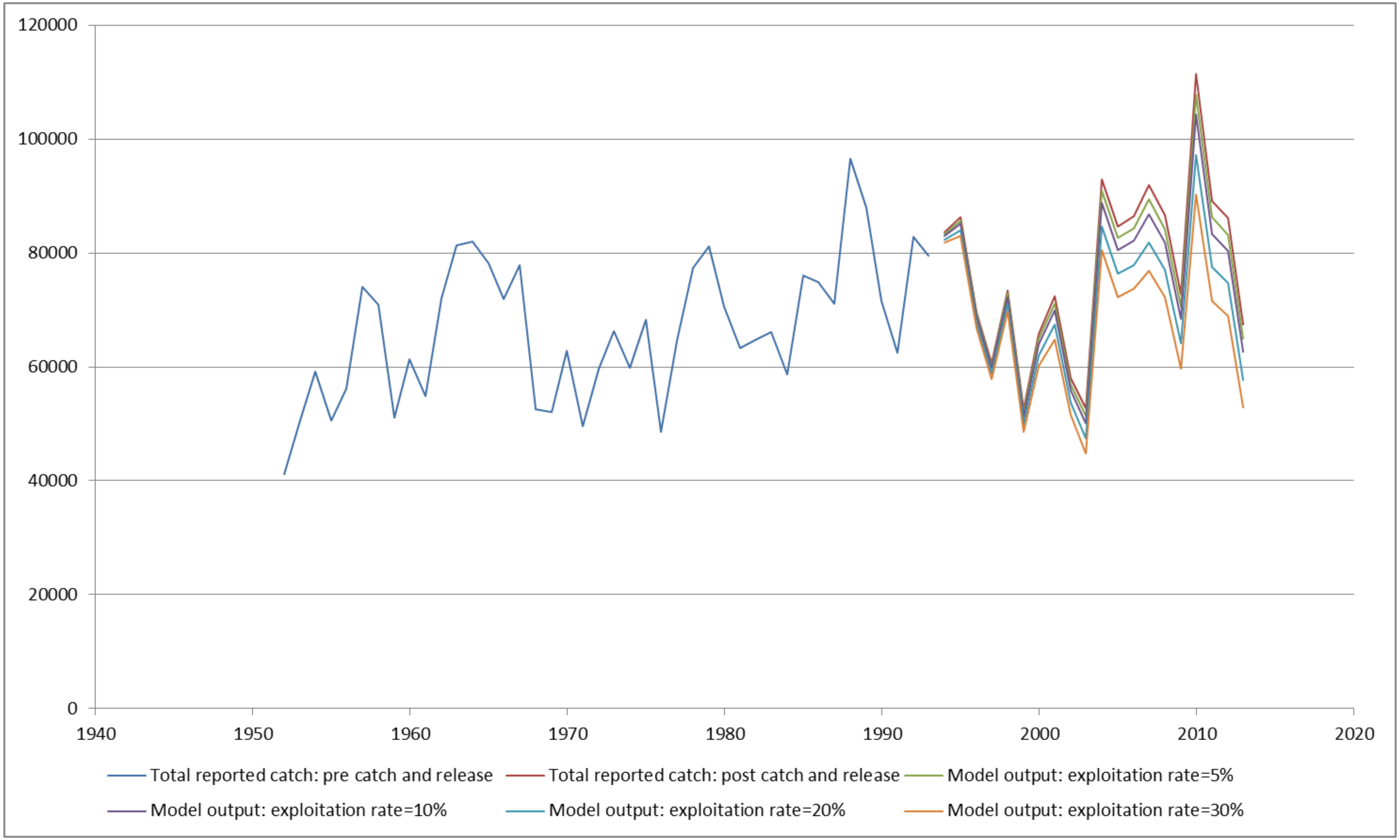

Figure 2. The reported annual Scottish rod catch (retained and released) and model outputs at a series of notional exploitation rates.

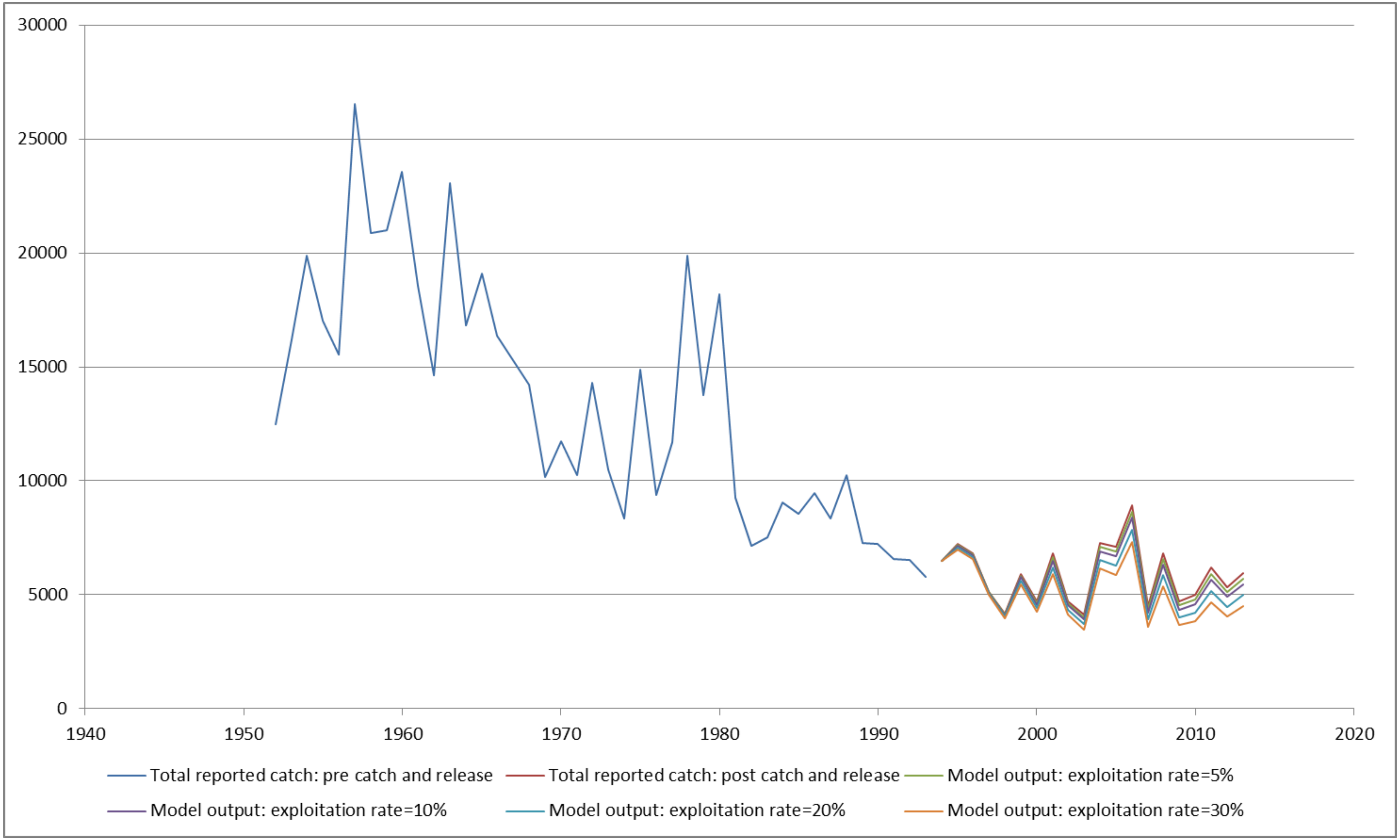

Figure 3. The reported spring Scottish rod catch (retained and released) and model outputs at a series of notional exploitation rates.

The difference between reported catch and model output increased both as the notional exploitation rate increased and with the increasing take-up of catch and release in the fishery over time (Table 1). It is important to note, however, that these differences were generally modest, within 15% even at relatively high notional exploitation rates and catch & release take-up (Tables 2a and 2b). At the extreme, with exploitation rates set at 30% and catch & release accounting for 92% of the catch, reported catch exceeded model output by 25% (Table 2b).

Table 2a

The difference between reported annual Scottish rod catch (retained and released) and model output at a series of notional exploitation rates. Differences are expressed as a proportion of the reported catch.

	Exploitation rate (%)			
Year	**5%**	**10%**	**20%**	**30%**
1994	0.4%	0.7%	1.4%	2.1%
1995	0.6%	1.3%	2.5%	3.8%
1996	0.7%	1.3%	2.7%	4.0%
1997	0.8%	1.6%	3.2%	4.9%
1998	0.8%	1.7%	3.3%	5.0%
1999	1.3%	2.5%	5.1%	7.6%
2000	1.4%	2.9%	5.8%	8.6%
2001	1.7%	3.4%	6.9%	10.3%
2002	1.9%	3.7%	7.5%	11.2%
2003	2.5%	5.0%	10.0%	15.0%
2004	2.2%	4.5%	9.0%	13.4%
2005	2.5%	4.9%	9.8%	14.7%
2006	2.5%	5.0%	9.9%	14.9%
2007	2.7%	5.5%	10.9%	16.4%
2008	2.8%	5.5%	11.1%	16.6%
2009	3.0%	6.0%	12.0%	18.0%
2010	3.2%	6.3%	12.7%	19.0%
2011	3.3%	6.5%	13.1%	19.6%
2012	3.3%	6.6%	13.3%	19.9%
2013	3.6%	7.2%	14.4%	21.6%

Table 2b

The difference between reported spring Scottish rod catch (retained and released) and model output at a series of notional exploitation rates. Differences are expressed as a proportion of the reported catch.

	Exploitation rate (%)			
Year	**5%**	**10%**	**20%**	**30%**
1994	0.0%	0.1%	0.2%	0.2%
1995	0.6%	1.1%	2.2%	3.3%
1996	0.6%	1.1%	2.3%	3.4%
1997	0.5%	1.0%	1.9%	2.9%
1998	0.9%	1.8%	3.5%	5.3%
1999	1.3%	2.6%	5.1%	7.7%
2000	1.7%	3.4%	6.7%	10.1%
2001	2.2%	4.4%	8.9%	13.3%
2002	2.1%	4.2%	8.5%	12.7%
2003	2.6%	5.2%	10.4%	15.6%
2004	2.6%	5.2%	10.4%	15.6%
2005	2.9%	5.8%	11.6%	17.4%
2006	3.0%	6.0%	12.0%	18.0%
2007	3.4%	6.7%	13.4%	20.1%
2008	3.5%	7.0%	14.0%	21.0%
2009	3.7%	7.3%	14.7%	22.0%
2010	3.9%	7.8%	15.6%	23.3%
2011	4.1%	8.2%	16.3%	24.5%
2012	4.1%	8.2%	16.4%	24.6%
2013	4.1%	8.3%	16.5%	24.8%

Although differences between the model outputs and reported catch tended to be greatest in the latter parts of the time series, when take-up of catch and release was greatest, overall trends in model output were broadly similar to those in the reported data. This remained true even at the highest notional exploitation rates set in the model.

4. **Discussion**

The output from the catch and release model and resulting conclusions will depend on the assumptions inherent within the model. Of these, the most critical are likely to be that the probability of recapture following release is equal to the exploitation rate and independent of the number of previous releases and also that mortality rate is independent of the number of previous releases. There are no established large scale data sets which may be used to test these assumptions empirically, however. The approach outlined in this report remains, therefore, the best available tool with which to assess the impact of catch and release on rod catch data, but can be refined as data are produced to test the underlying assumptions.

Catch and release inflates the reported catch data. Further, the difference between reported catch and model output increases through the time series as the take-up of catch and release increases. However, at a national level, the general trends in the reported catch data over the time series were similar to those generated by the model both for annual and spring catch. This was true even at high notional exploitation rates which provide the highest differences between reported catch and model output. Thus, despite there being an increase in the take-up of catch and release from 8% to 80% in the annual catch and 1% to 92% in the spring catch over the past 20 years (Table 1), assessments of national stock trajectories based on reported data were similar to those derived from model output at all exploitation rates tested.

In recent years the percentage of salmon subsequently released has increased to historically high levels (Table 1). If such high release rates are maintained in the future, although the absolute number of fish may be unclear given uncertainties in the actual exploitation rates on individual stocks, the trends will be the same for the reported and adjusted catches. This effect is best illustrated by the last several years of the spring salmon data (Fig. 3), where model output and reported catch data track closely as the percentage of spring salmon subsequently released remains relatively stable (Table 1).

In addition to changes in the uptake of catch and release, changes in the exploitation rate would also affect trends in the catch numbers both directly and indirectly in relation to the numbers subsequently recaptured (demonstrated in this analysis by comparing among the model output lines in Fig. 2 & 3). Trends seen in catch data could therefore be due to changes both in the fishery and the stock and interpretation of any change in catches, whether associated with catch and release or not, should therefore be undertaken with caution.

It is important that the potential effects of catch and release on rod catch trends is kept under review and efforts are made to collect data that increase the reliability of our abundance indicators in the future. An important development in this regard is the construction of a network of well validated counters that will not only provide direct estimates of stock abundance in relation to particular river systems, but will also improve our knowledge of exploitation rates across a wide range of Scottish salmon stocks.

5. **Acknowledgements**

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Appendix 1

The catch and release model has been developed to account for multiple recaptures of released fish in a rod fishery where both catch and release and the retention of landed fish is practiced. The probability of recapture following release is assumed to be equal to the exploitation rate (proportion available salmon captured) and independent of the number of previous releases.

In the simplest case, i.e. the absence of post handling mortality and where the fishery practices total catch and release, the relationship between the reported catch (R) and the number of salmon at first capture (C_1) can be described by the following equations:

$$
\begin{aligned}
R &= C_1 + C_2 + \cdots + C_\infty \\
&= C_1 + C_1\varepsilon^1 + \cdots + C_1\varepsilon^{\infty-1} \\
&= C_1\ \ 1 + \varepsilon^1 + \cdots + \varepsilon^{\infty-1} \\
&= C_1\ \ 1 + \frac{\varepsilon}{1-\varepsilon} \\
&= C_1 + \frac{C_1\varepsilon}{1-\varepsilon} \\
&= \frac{C_1\ \ 1-\varepsilon}{1-\varepsilon} + \frac{C_1\varepsilon}{1-\varepsilon} \\
&= \frac{C_1\ \ 1-\varepsilon\ \ + C_1\varepsilon}{1-\epsilon} \\
&= \frac{C_1 - C_1\varepsilon + C_1\varepsilon}{1-\varepsilon} \\
&= \frac{C_1}{1-\varepsilon} \\
C_1 &= R\ \ 1-\varepsilon \\
&= R - R\varepsilon
\end{aligned}
$$

Where ε = the exploitation rate (proportion available salmon captured) and C_n = the number of salmon capture at catch number n.

The difference between the reported catch and the number of salmon at first capture can therefore be calculated as:

$$
\begin{aligned}
R - C_1 &= R -\ \ R - R\varepsilon \\
&= R\varepsilon
\end{aligned}
$$

Expressed as a proportion of the reported catch (P) this becomes:

$$P = \frac{R\varepsilon}{R}$$
$$= \varepsilon$$

These equations can be expanded to include information on post handling mortality and retention of rod caught salmon by adjusting the number of fish available to be recaptured:

$$R \rightarrow R\sigma\rho$$

Where σ = proportion surviving once released and ρ = proportion of captured fish subsequently released.

The two main equations therefore become:

$$C_1 = R - R\varepsilon\sigma\rho$$

$$P = \varepsilon\sigma\rho$$

From this it can be seen that the influence of *ε, σ* and *ρ* is the same – i.e. a doubling of any of the parameters will lead to a doubling of the percentage error. As the proportion of captured fish subsequently released has risen by approximately ten times between 1994 and 2013 it is likely that this will have the biggest influence on any bias in the catch data.

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