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# The fecundity of wild Irish Atlantic salmon *Salmo salar* L. and its application for stock assessment purposes

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ABSTRACT

Management of many salmon populations is based on maintaining individual stocks above a conservation limit defined as the maximum sustainable yield point from a stock recruitment (SR) relationship. A crucial input parameter of any SR analysis is an accurate measure of fecundity. Atlantic salmon (*Salmo salar* L.) fecundity data from nine rivers in Ireland were collated and analysed, providing the first comprehensive multi-river assessment of egg numbers for Irish stocks. The number of eggs in wild 1SW fish (1 sea winter, also known as grilse) varied with fish size and also according to the source river. When expressed as eggs per kg of fish, river was a less important explanatory variable. The number of eggs in wild fish averaged 3441 for 1SW fish and 6059 for MSW (multi-sea winter) fish, respectively. Egg diameter also varied with fish size and source river. A negative binomial model of egg number per fish, with weight as the only explanatory variable, accounted for 60% of the explained deviance in this dataset. When applied to a large national dataset of fish weights from angling records, this model allows river-specific fecundity to be estimated for salmon populations with varying life history characteristics. The model predicts that the fecundity of Irish salmon is at the lower end of the range reported for Atlantic salmon across Europe.


## 1. Introduction

Since the mid-1980s, Atlantic salmon (*Salmo salar* L.) populations have declined in all three stocks complexes currently assessed by the International Council for the Exploration of the Sea (ICES, 2013). Even though fishing effort at sea has been substantially reduced on these stocks, marine survival remains low (Chaput, 2012). Changes in climatic conditions (Friedland et al., 2014), feeding opportunities in the marine ecosystem (Beaugrand and Reid, 2012), the extent of marine aquaculture (Otero et al., 2011) and confounding freshwater influences (Russell et al., 2012) have all been explored as possible causes of this decline. It is likely that many marine and freshwater factors act in combination to impact salmon populations, and conservation efforts must take an integrative approach (Todd et al., 2011).

Atlantic salmon fisheries management in many countries (e.g. France, Ireland, England, Wales and Norway) is based on managing to river-specific conservation limits, defined as the stock level that will achieve long- term average maximum sustainable yield (MSY) (NASCO, 1998; ICES, 2013). Central to the estimate of river-specific conservation limits are adult-to-adult stock recruitment curves, which allow the estimation of a target for spawning escapement of sufficient females to maintain a sustainable population. However, the life cycle of salmon can be quite variable, with fish spending between one and four years in freshwater, and between one and three years in the ocean (Milner et al., 2003). The combination of years spent in freshwater and marine environments result in fish of very different sizes and hence variable female fecundity, as fish size is the primary determinant of fecundity in all salmon species (Thorpe et al., 1984; Beacham and Murray, 1993; Moffett et al., 2006; Reid and Chaput, 2012). To account for this variability among age cohorts, stock recruitment analyses can use the number of eggs that a female carries, rather than the number of spawning females. In Ireland, river-specific conservation limits are calculated using the Bayesian model described by Prévost et al. (2003) which

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transfers stock recruitment information from index rivers to data-poor rivers using wetted area (McGinnity et al., 2012) and latitude as predictive variables. For any given wetted area and latitude, the model predicts the optimum number of eggs per $m^2$ required to maintain stocks at MSY. Management of Irish salmon populations has used this as the basis of maintaining stocks above MSY (the defined conservation limit) since 2006 (Ó'Maoiléidigh et al., 2004; Standing Scientific Committee on Salmon, 2012). River specific conservation limits, in terms of eggs per $m^2$, are compared to estimates of egg deposition by the current spawning cohort, to assess whether a population is likely to be meeting conservation requirements. The current egg deposition is estimated by taking an average of the previous five years runs of adult salmon (rod catch corrected using exploitation rates, or counter data), applying a sex ratio correction, and then multiplying the resulting number of females by an estimated fecundity.

The number of eggs carried by a female must be known or estimated to quantify the fecundity of a salmon. Instances where wild fish are stripped and egg numbers estimated are very rare, and researchers have had to rely on data from single or index rivers (Moffett et al., 2006; Bacon et al., 2012), hatchery proxies (Ó'Maoiléidigh et al., 2004) or historical records (Pope et al., 1961; Aprahamian et al., 2006). At the time of the development of river-specific conservation limits for Irish rivers (Ó'Maoiléidigh et al., 2004), egg numbers of wild Irish salmon were not widely reported. Point estimates of 3400 and 8000 per 1SW and MSW fish, respectively, were applied, based principally on historical observations from the hatchery stock in the Burrishoole system (Marine Institute, unpublished data). As several studies have shown that egg number varies according to fish size (Pope et al., 1961; Baum and Meister, 1971; Thorpe et al., 1984), spawning habitat (Beacham and Murray, 1993; Bacon et al., 2012), growth rate (Jonsson et al., 1996; Quinn et al., 2004), age (Moffett et al., 2006) and spawning history (Reid and Chaput, 2012), the collation of new and updated datasets was required to aid progress in conservation efforts. The application of a size specific estimate of fecundity is particularly important in the context of Irish conservation efforts, as a wealth of salmon size data are now available from the national angling logbook scheme which was instigated in 2001 (IFI, 2013).

The aims of this paper are three fold: (1) provide descriptive statistics for the number and size of eggs of wild Atlantic salmon in Ireland; (2) assess the main sources of variation in egg number and hence; (3) formulate a predictive model that can be used to estimate egg deposition in Irish salmon rivers, using fish size data collected by recreational and commercial fishermen. Although the main focus of this paper is egg number, egg size is also described and analysed, as a strong relationship between egg number and egg size has been documented for many salmon populations (Fleming, 1996; Quinn et al., 2011; Bacon et al., 2012; Reid and Chaput, 2012).

## 2. Methods

### 2.1. Egg data collation

Fecundity data were collected from wild female salmon originating in nine Irish salmon catchments between 1992 and 2012 (Fig. 1). Individual fish that were noted as 'partial shed' were excluded from the analysis (6 fish). Partially shedded fish were noted when an egg mass was still felt in the body, which was not released on further stripping. The total number of individual fish included was 338. Twenty-four aggregated data sets were also collated and generally comprised an average number of stripped eggs for a group of fish. Groups contained varying, and sometimes unspecified amounts of individuals, and were not included in any statistical analysis, but are included in Table 1 for reference purposes.

Fish were collected towards the end of each year (generally November and December) specifically for use as brood stock. Where possible, females were collected from traps (Burrishoole, Bush, Corrib, Shannon, Erriff). In rivers with no permanent traps (Owenmore, Feale, Mulkear, Bunowen), females were either electrofished or caught in draft nets before any obvious signs of spawning were observed (e.g. fresh redds). This allows some confidence that the samples did not include partially spent fish. Where possible, individual measurements of fork-length (cm), wet weight (kg), number of eggs stripped, number of residual eggs (eggs left behind in the body cavity after stripping) and the egg size (diameter of a single egg) were collected. Information about freshwater age, sea age and spawning history were also included for fish where scales had been read. As repeat spawners are currently not thought to be a significant component of Irish salmon populations, every effort was made to sample only maiden fish (i.e. fish spawning for the first time), and scale readings indicated that only one fish in the dataset was a repeat spawner. This was an important consideration as repeat spawners are known to have significantly different fecundities when compared to maiden fish (Reid and Chaput, 2012), and inclusion of repeat spawners in this analysis would have led to some bias in the estimates. Fish were stripped by hand and, depending on the source, were either culled or released back to the wild. The number of eggs stripped from each fish was estimated once they were water hardened after a number of hours. A volumetric or displacement method was used to estimate egg number in all cases. The total volume of stripped eggs was measured in a suitable container. A subset of these eggs (e.g. 200 eggs) was then counted out, and the volume of this known quantity measured in a graduated cylinder. This allowed the total number of eggs to be estimated. While there was some variation in the finer details of this method according to the hatchery where stripping took place, the general methodology was the same across the whole dataset. Egg size was measured by lining out a known number of eggs (usually 25–30) in a trough with an inbuilt ruler and dividing the result by the number of eggs to get the diameter of a single egg.

### 2.2. Analysis of variability in egg number and size

Egg size (diameter of one egg expressed in cm) was available for 7 out of the 8 rivers. Female weight (kg), year, sea age, river and freshwater age, along with two-way interactions between female weight and the other variables were included in an analysis of the variation in egg size. This analysis was carried out using generalised additive models (GAM) with a Gaussian distribution. Weight and year were included as continuous variables, while all other covariates were included as factors. Weight was fitted in the model as a smoothing function. Model selection was carried out using the Akaike's Information Criterion (AIC) and analysis of variance (ANOVA) tables.

In order to assess the main sources of variation in the egg number of wild salmon, generalised linear models (GLM) using negative binomial distributions were fitted to the data (McCullagh and Nelder, 1989). GLMs were used as egg numbers are count data, and are always non-negative. While a Poisson distribution is often used to model egg number (Moffett et al., 2006), initial analysis indicated a high amount of overdispersion in this dataset. This was not surprising, as the variance of the egg number per fish in this dataset was much larger than the mean. Therefore, a negative binomial distribution was considered appropriate, and was used with a log-link function (Zuur et al., 2009). Explanatory variables for the egg number analysis included female weight (kg), year, sea age, river and freshwater age. Two-way interactions between female weight and the other variables were also included. Weight and year were