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Report on Sea Lice Epidemiology and Management in Ireland with Particular Reference to Potential Interactions with Wild Salmon *(Salmo salar)* and Freshwater Pearl Mussel *(Margaritifera margaritifera)* Populations

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Introduction

Stock levels of Atlantic salmon in Ireland and the northeast Atlantic have been declining since the 1970s prompting studies into possible underlying factors affecting survival, which include overexploitation (Piggins 1980; Rago *et al.* 1993; Potter & Dunkley 1993), dams (MacCrimmon & Gots 1979), pollution (Hesthagen & Hansen 1991; Moriarty 1996), climate change (Friedland *et al*. 2005; Peyronnet *et al*. 2007; Todd *et al*. 2008), salmon farm escapees (Crozier 2000; Karlsson *et al.* 2011; Glover *et al*. 2012), by-catch in commercial marine fisheries (Hansen *et al*. 2003; Mork *et al*. 2012) and predation (Butler *et al*. 2006). Salmon recruitment in the northeast Atlantic has also been shown to correlate to the Atlantic Multi-Decadal Oscillation (Friedland *et al.* 2009). Similar patterns of stock decline exist for commercially exploited gadoids (cod, haddock and whiting) in the North Sea (Hislop 1996). It is clear that no single factor is responsible for the decline of stocks (Armstrong *et al.* 1998). Parrish *et al.* (1998) classified Irish stocks as stable, together with Scotland, Iceland, northwest France, mid & northern Norway and Russia. The remaining European stocks are classified as either declining or extirpated. The 2013 National Parks and Wildlife Services (NPWS) *Atlantic salmon Article 17 Species Assessment* (Habitats Directive) described Atlantic salmon population in Ireland as stable from 2001 to 2012 (Anon. 2013). This report also describes the long term trend from 1988 to 2012 as decreasing.

As a result of the observed decline in salmon stocks in Ireland conservation measures have been put in place and strengthened including restrictions to existing fisheries, closures of mixed stock fisheries and introduction of carcass tagging and quota systems (O'Maoileidigh *et al.* 2004). As part of this suite of measures the concept of controlling harvest based on a surplus of fish over and above a calculated conservation limit was implemented. This rationale was introduced on the recommendation of *The Salmon Management Task Force* (Anon. 1996). The task force recommended the setting of a total allowable catch which would be based on the achievement of "Spawning Escapement Targets". These escapement targets were to be set on the best available data for each catchment validating through post-hoc monitoring where necessary, and by determining whether spawning escapement targets were being achieved. O'Maoileidigh *et al.* (2004) reported on the development of the conservation limits for each salmon river and on preliminary precautionary catch advice for 2004. As a result of these initiatives the commercial fishery was progressively reduced from 219,649 fish in 2002 to 182,000 fish in 2003 and 161,951 fish in 2004. Since 2005, *The Standing Scientific Committee* has provided published data on conservation limits. These are published in a series of reports on the Status of Irish Salmon Stocks including precautionary catch advice for the following year (Appendix 1).

In 2009 two Non-Governmental organizations (NGOs) submitted a legal complaint (Anon. 2009 a) against Ireland to the EU Commission (*EU Pilot Case 764/09/ENV1*). The substance of the complaint was that Ireland was failing to comply with the Habitats Directive and the Environmental Impact Assessment Directive in three named fisheries; the Delphi (Bundorragha River), the Newport Fishery (Newport River) and the Ballynahinch Fishery (Ballynahinch River). The complainants also cited a failure to protect both the salmon (*Salmo salar*) and the freshwater pearl mussel (*Margaritifera margaritifera*). In responding to the complaint a detailed scientific investigation was undertaken. Long term research and specifically commissioned studies were accessed and their data drawn on to ensure a comprehensive and accurate response based on the best available scientific data and information. This report sets out this information, together with the associated studies and data which formed the basis of the scientific response to the complaint. The complaint was closed in favour of the State on the 11th of October 2012.

Methodology

The status of salmon stocks in each of the fisheries mentioned in the complaint was assessed by reference to their achievement of the conservation limit set for each river (O'Maoileidigh *et al.* 2004) utilising the methodology developed by *the Standing Scientific Committee* of the Salmon Commission (Appendix 1) and used by the NPWS to report on the status of Ireland's salmon stocks to the EU Commission in compliance with the Habitats Directive Article 17 (Anon. 2013).

Using the same methodology the status of stocks was determined at a river basin district level and compared with the location of licensed salmonid aquaculture operations and the status of the freshwater habitat. The locations and active salmon aquaculture sites was obtained from the series of annual reports on the results of the National Survey of sea lice *Lepeophtheirus salmonis* Kroyer and *Caligus elongatus* Nordmann on fish farms in Ireland (O'Donohoe *et al.* 2008; O'Donohoe *et al.* 2010; O'Donohoe *et al.* 2012).

Water quality data was obtained from the Environmental Protection Agency (EPA) (McGarrigle *et al.* 2010). River water quality was classified by percentage of channel length meeting Class A unpolluted standard (McGinnity *et al.* 2003). Class A (unpolluted) waters include the categories High Status and Good Status waters as defined in the Water Framework Directive (WFD). Such waters support healthy, natural populations of salmon and trout.

River Basin Districts are the administrative areas into which Ireland's inland waters are divided for the purpose of management under the European Union's Water Framework Directive (*WFD: 2000/60/EC*). The proportion of these rivers meeting their Conservation Limits was established for each year. Salmon rivers with a population of less than ten salmon were excluded from the analysis.

Data on sea lice control was obtained from the annual reports on the National Survey of Sea Lice (O'Donohoe *et al.* 2013). This monitoring has been in place since 1991 and was given a formal and legislative basis with the publication of a *Sea Lice Monitoring and Control Protocol* in 2000 (Appendix 2).

In the same year (2000) a long term study was initiated to assess the potential impact of sea lice infestation on outwardly migrating salmon smolts (Jackson *et al.* 2011 b). This work was undertaken to ensure that decision making in respect of sea lice control would be evidence and science based.

Experimental Design

By treating experimental batches of tagged fish, prior to release, with a prophylactic dose of SLICE®, a commercial sea lice therapeutant, the fish can be protected from infestation with the salmon louse, *Lepeophtheirus salmonis*, for up to nine weeks (Copley *et al.* 2007; Jackson *et al.* 2011 b). The active ingredient in SLICE® is emamectin benzoate, an animal medicine licensed for use in Ireland as a treatment for sea lice infestation on salmon. As salmon smolts are known to migrate quickly out of the bays and into the open sea, treated smolts will have moved well offshore before the protective effects of the SLICE® treatment have worn off. Studies at Burrishoole have shown that salmon smolts have moved into coastal waters within 48 hours (Moore *et al.* 2008) and post smolt recapture data (Shelton *et al.* 1997; Dadswell *et al.* 2010) has shown that smolts from the study area have travelled a distance of over 700 kilometres in seven weeks and are in an area north of Scotland and west of Norway. By comparing return rates of treated fish with untreated control fish, it is possible to differentiate any additional mortality associated with sea lice infestation in the first six to eight weeks post migration (Jackson *et al.* 2011 a). This methodology has been employed on a series of releases of ranched stocks from the Burrishoole River, the Bundorragha River (Delphi) and at a number of other locations (Appendix 3) on Ireland's south and west coast (Jackson *et al.* 2011 a&b). In addition data published by Gargan *et al.* (2012) using non-indigenous hatchery stocks transferred into salmon and sea trout rivers and imprinted there for 5 to 8 weeks has been included in a meta-analysis together with previously unpublished data from both Burrishoole and Bundorragha (Delphi) (Jackson *et al.* 2013 a).

Tagging, Tag Recovery and Data Analysis

Experimental batches of fish were all tagged with coded wire tags. Pre-smolts were microtagged according to the methods of Browne (1982), whereby a 1mm long magnetised tag, etched with a specific batch code was injected into the nose cartilage of the juvenile fish. The code identifies the origin and release circumstances of any fish subsequently recaptured. All fish were anaesthetised when tagged and the adipose fin was removed to facilitate the identification of these fish in the recovery programme. A quality control check was made on the tagged fish to ensure that the tag has been correctly magnetised. Tagging mortality and tag loss were also estimated and subsequent analyses were based on the numbers of fish migrating rather than the number of fish tagged. Information on capture location and return data of the experimental groups was gathered as part of an ongoing Irish National Coded Wire Tag Recovery Programme (Browne *et al.* 1994; O'Maoileidigh *et al.* 2004).

Prior to 2007 catches from coastal commercial fisheries (drift nets, draft nets, etc.) were monitored at 15 major salmon landing ports in Ireland. These fisheries operate between May and July inclusive and catches were scanned consistently during this period. Over 50% of the catch landed in Ireland was sampled for tags each year. The number of tagged salmon taken in these fisheries (raised data) was estimated by multiplying the actual number of tagged salmon recovered in each area, by the ratio of the total declared salmon landings in these areas to the sample size examined. An adjustment for non-catch fishing mortality due to losses from nets and non-reporting of catches was also applied as part of this process. This methodology, as used in the compilation of returns for ICES and NASCO, ensures the avoidance of sampling bias and the comparability of data with other national and international estimates of marine survival. The raw data supporting these estimates are in Appendix 3.

Complete upstream and downstream trapping facilities at the Marine Institute hatchery, situated on the Burrishoole river system in Co. Mayo, ensured an accurate count of the numbers of tagged adult salmon returning to the hatchery location. The number of fish entering the river was derived from total trap data and angling for the Burrishoole system. For fresh water, the percentage return was calculated using the actual number of tags recovered divided by the number of fish migrating.

Analyses

Two way contingency tables were used to calculate expected returns for comparison against observed returns for each pair of treatment and control batches using the chi-squared test. The resultant *p* values were corrected using the Bonferroni procedure for multiple tests. Regression lines with 95% confidence intervals were fitted to the data set for the treated and control groups as a first step in evaluating the trends in the data. A scatterplot of percentages with a Lowess smoother was found to give a more appropriate visual representation of the data.

Statistical Analyses

The primary analysis was carried out using the generalised logistic model and then a secondary analysis was carried out by treating the percentages as continuous (weighted) response variables (Jackson *et al.* 2013 a).

Comparing the percentage returning without adjusting for the fact that the percentages represent considerably different denominators, limits the discriminatory power of the analysis. To overcome this one needs to allow a comparison of the proportion of fish returning (i.e. a binomial response variable) between the treated and control groups to be made, while adjusting for release year and river location and for the differing number of fish migrating for each treatment/release year/location combination. A logistic regression model was fitted to model the probability of returning as a function of treatment group and release time (and their interaction) while adjusting for the association between fish released from the same location and for the differing numbers migrating from each location and year. The best model identified was one containing an interaction between release year and treatment in order to adjust for the fact that the positive effect of the treatment differed across release years. A generalised mixed model was fitted to the data by the Laplace approximation and model diagnostics were carried out by examining plots of residuals and fitted values for goodness of fit.

A linear model (i.e. an Analysis of Variance) was fitted where the response variable was the percentage returns (weighted by migration) with treatment, location and release date as factors. Initially a model containing all two and three way interactions between the factors was fitted and then non-significant terms were removed based on backwards elimination. Both relative and absolute risk differences were reported which is consistent with the CONSORT statement (Schulz *et al.* 2010), which encompasses various initiatives to alleviate the problems arising from inadequate reporting of randomized controlled trials (Consolidated Standards of Reporting Trials, http://www.consort-statement.org/).

Results

An examination of the conservation status of salmon from the three fisheries named in the complaint showed that all three rivers were meeting their conservation objectives; Bundorragha, Newport and Ballynahinch (Fig. 1). In each case the rivers support a recreational fishery and in two cases support a commercial draft net and a commercial recreational fishery. All three rivers have consistently met their conservation limits since 2008 and have had a significant estimated surplus available for exploitation. The estimated surplus available for exploitation was stable in all three from 2008 to 2011 (Fig. 1).

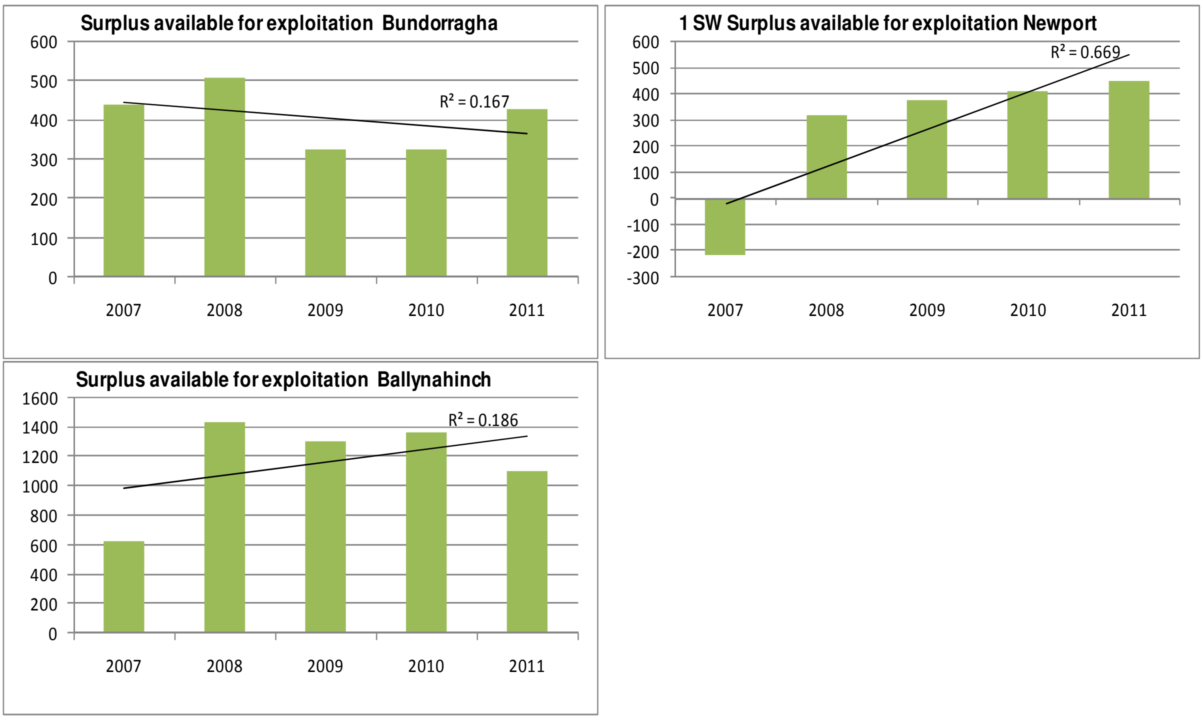

Figure 1. Status of salmon stocks in the Delphi (Bundorragha River), the Newport Fishery (Newport River) and the Ballynahinch Fishery (Ballynahinch River) from 2007 to 2011 showing surplus available for exploitation. The conservation status is calculated based on a five year rolling average of adult returns. The drift net fishery closed in 2007.

Based on data from the *Standing Scientific Committee of the National Salmon Commission* reports (Appendix 1).

Finfish Farm Locations

Jackson *et al*. (2013 b) found no geographic correlation between the presence of salmon farms and failure of rivers to meet their Conservation Limits at a River Basin District level. In fact, the rivers in the River Basin Districts with salmon farms have performed best in terms of meeting their Conservation Limits and also in terms of ability to support a commercial catch by way of a commercial draft net fishery (Fig. 2).

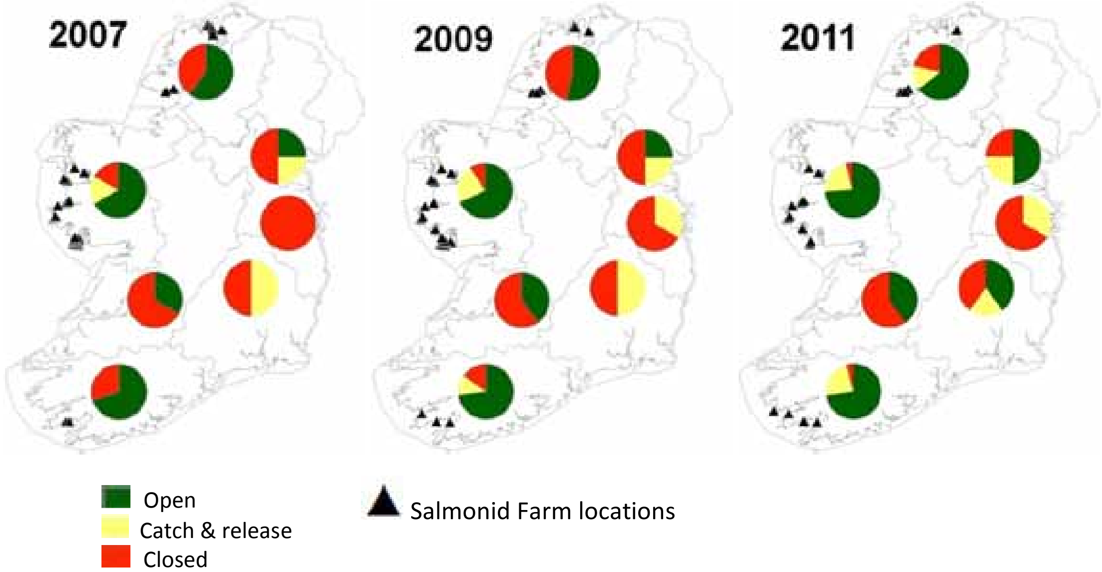

Figure 2. Map showing the proportion of rivers in each River Basin District which are either open for fishing, being fished on a Catch & Release basis or closed to exploitation. Locations of salmon farm sites operational in each year are indicated (after Jackson *et al*. 2013 b).

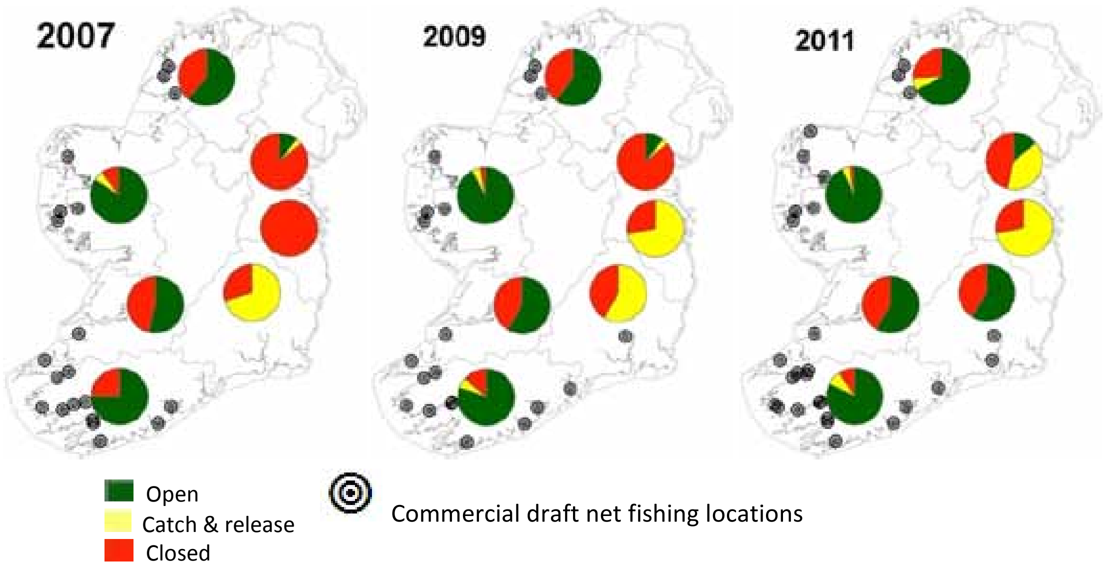

Figure 3. Map showing the proportion of rivers, measured as fluvial area accessible to salmon (m^2), in each River Basin District which are open for fishing, being fished on a Catch & Release basis, or closed to angling. Locations of commercial salmon draft net fishing sites are indicated(after Jackson *et al*. 2013 b).

The data supporting these conclusions is presented in Appendix 4 (Jackson *et al*. 2013 b) showing the data on rivers open for exploitation, including the taking of fish and on a catch & release basis. There is an increase in the rivers open nationally from 42 in 2007 to 48 in 2011. When broken down by River Basin District the trend is similar with numbers open either remaining static or increasing. The total number of rivers assessed varies slightly from year to year. This is a feature of the reports and arises due to sub-catchments being classified differently from time to time. The same data is also presented as the proportions of fluvial area accessible to salmon (Fig. 3) with commercial draft net fishing on open rivers highlighted. The West and Southwest River Basin Districts have consistently the highest proportion of rivers open throughout the period; the results are similar when expressed in terms of fluvial area accessible to salmon. The next highest proportion of rivers open is in the Northwest River Basin District.

Habitat Quality

Jackson *et al.* (2013 b) also found a significant geographical correlation between water quality in the catchment as measured by percentage Class A channel length and percentage of rivers meeting Conservation Limit (R^2=89.1%, p=0.001) (Fig. 4). The data to support these graphs can be found in Appendix 5.

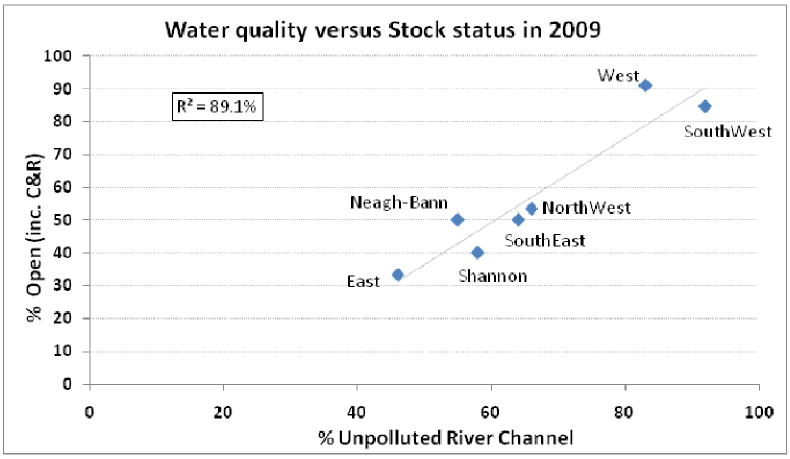

Figure 4. Relationship between salmon stock status as measured by percentage of rivers open for exploitation and water quality of river channels, grouped by River Basin District. A regression line is fitted with R^2 value indicated (after Jackson *et al*. 2013 b).

Sea Lice Monitoring

The National Sea Lice Monitoring and Control Programme monitors sea lice levels on farmed salmonids in Ireland. Following the introduction of a revised management strategy to underpin the Sea Lice Monitoring and Control Protocols (Appendix 2) there was a steady and sustained improvement in sea lice control (Jackson 2011). The strategy was aimed at implementing a more strategic approach to lice control at a bay level and targeting efforts on the spring period where there is a potential for impacts on wild smolts embarking on their outward migration. Trends in sea lice infestation on farmed fish (Fig. 5) in May, the peak period for wild salmon smolt migration have shown a strong downward trend since the introduction of the new management strategy. The data to support these graphs can be found in Appendix 6.

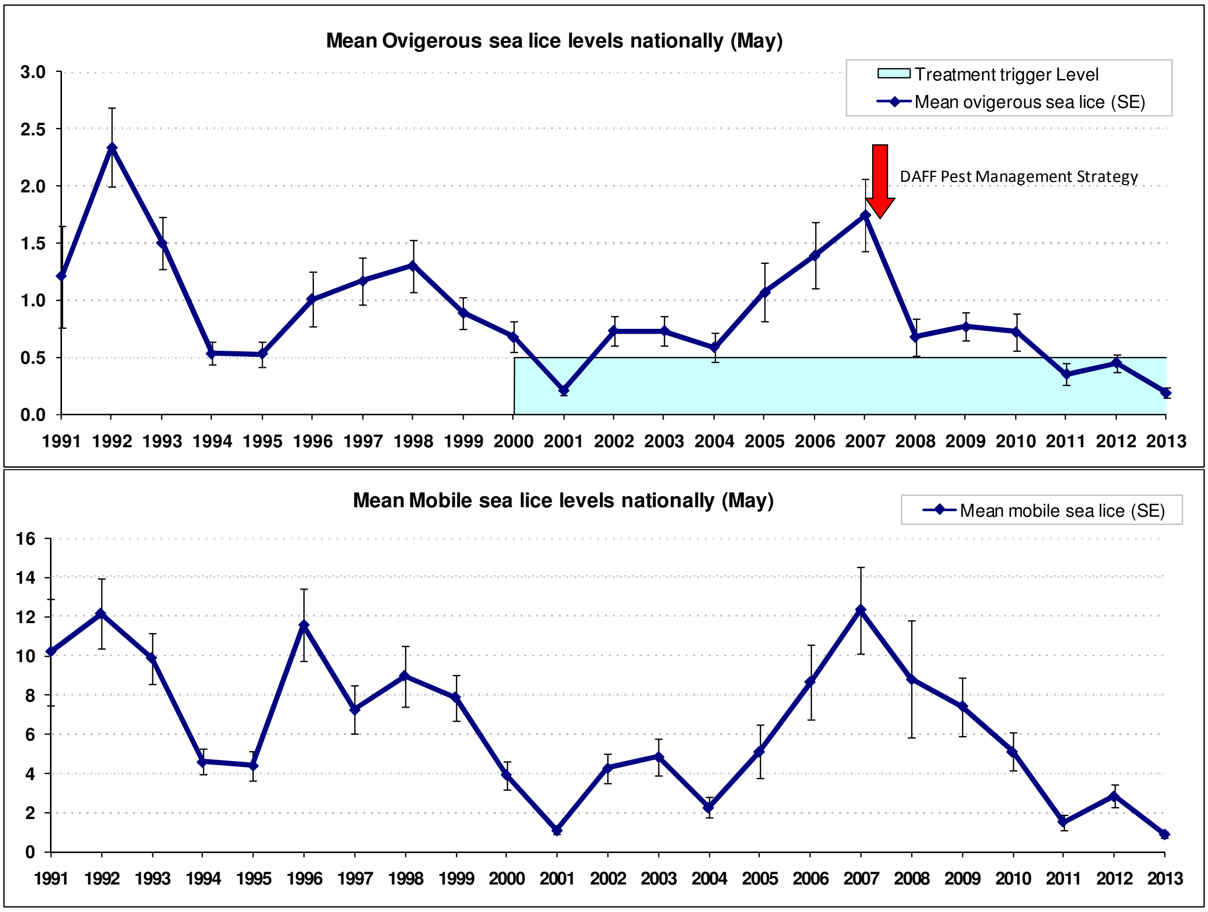

Figure 5. Annual trend of mean ovigerous and total mobile *L. salmonis* on one-sea-winter salmon in May of each year (SE).

Freshwater Pearl Mussel (*Margaritifera margaritifera*).

In respect of the freshwater pearl mussel (*Margaritifera margaritifera*) the complaint cites the loss of host fish for the glochidial larvae as being an issue which is impacting on populations of the mussel in the three fisheries which are the subject of the complaint. The Freshwater Pearl Mussel Sub-Basin Management Plans (Anon. 2009 b) identify the catchments of the specified pearl mussel populations. Of the 27 populations identified 26 were found to be in unfavourable conservation status. Two of the rivers in the complaint, the Bundorragha and the Newport contain specified pearl mussel populations. The conclusions of the Freshwater Pearl Mussel Sub-Basin Management Plans (Anon. 2009 b) and the North South II project Report (Moorkens, 2010) was that juvenile salmon were found in all 26 catchments surveyed, juvenile trout were present in 25 of the 26 catchments surveyed and that glochidial attachment to fish was detected in 12 catchments. Consequently there is no evidence to support the theory that changes in salmonid populations have contributed to the current unfavourable status of the freshwater peal mussel in Ireland. In contrast the evidence from these and previous studies carried out by the National Parks and Wildlife Service (NPWS) provide overwhelming evidence that declines were caused by sedimentation and eutrophication of juvenile and adult mussel habitats (*pers. comm*. NPWS).

Long Term Studies of Sea Lice Infestation Impact on Smolts

The results of the long term study to assess the potential impact of sea lice infestation on outwardly migrating salmon smolts showed evidence of a decline in survival in both treated and control batches over time. The numbers of returning fish recovered for each experimental release is shown in Figure 6 (Jackson *et al*. 2011 b). Percentage survival for the same groups is shown in Figure 7 (Jackson *et al*. 2011 b). A trend of decreasing survival rates in both treated and control groups over time can be clearly observed. Percentage survival ranged from a maximum of just over 10% in the 2001 release treated group (10.28%) to a minimum of just over 1% in the 2008 early release control group (1.07%). The maximum difference in percentage survival between treated and control groups was in the early release group in 2006 when the percentage return for the treated group was 6.82% as against 4.44% in the control group. Percentage survival rates for all groups are outlined in Table 1 (Jackson *et al*. 2013 a).

Table 1. Summary data on release groups of salmon including percentage survival, chi-squared value and *P* value with Bonferroni correction (after Jackson *et al.* 2013 a).

			Control			Slice			Chi-squared Test	
Group Name	**Release date**		**Estimated Migration number**	**Raised Returns**	**Control**	**Estimated Migration number**	**Raised Returns**	**Slice**	**p-value**	
Delphi 01 BUR	02/05/2001	Jackson *et al* , 2011 (a)	6385	984.8	15.55	6392	1216.6	19.11	<0.001	*
Delphi 01 DEL	02/05/2001	Jackson *et al* , 2011 (a)	6395	892.2	14.11	6368	836.1	13.24	0.176	
Burr 01	03/05/2001	Jackson *et al* , 2011 (b)	10039	996.6	9.88	5496	565.1	10.28	0.487	
Burr 02	01/05/2002	Jackson *et al* , 2011 (b)	5989	542.3	9.10	5960	543.7	9.12	0.89	
Gowla 03	28/04/2003	Gargan *et al* , 2012	4822	20.4	0.42	4955	225.6	4.55	<0.001	*
Invermore 03	29/04/2003	Gargan *et al* , 2012	4594	37.7	0.82	4589	88.6	1.93	<0.001	*
Burr 03	01/05/2003	Jackson *et al* , 2011 (b)	4587	373.8	8.15	4745	471.1	9.93	0.003	
Gowla 04	07/04/2004	Gargan *et al* , 2012	4699	91.0	1.94	4655	164.6	3.54	<0.001	*
Invermore 04	08/04/2004	Gargan *et al* , 2012	4671	96.2	2.06	4653	105.4	2.27	0.484	
Erriff 04	12/04/2004	Gargan *et al* , 2012	4229	107.9	2.55	4325	101.8	2.35	0.551	
Burr 04	29/04/2004	Jackson *et al* , 2011 (b)	4369	398.2	9.11	4437	403.3	9.07	0.974	
Erriff 05	04/04/2005	Gargan *et al* , 2012	4689	8.4	0.18	4659	171.8	3.69	<0.001	*
Gowla 05	07/04/2005	Gargan *et al* , 2012	4735	317.8	6.71	4583	306.3	6.68	0.95	
Invermore 05	08/04/2005	Gargan *et al* , 2012	4750	111.2	2.34	4716	195.8	4.15	<0.001	*
Delphi 05	26/04/2005		8893	831.1	9.35	8471	1038.4	12.26	<0.001	*
Burr 05	28/04/2005	Jackson *et al* , 2011 (b)	3867	183.2	4.71	3793	253.0	6.67	<0.001	*
Lee 06	04/04/2006	Jackson *et al* , 2011 (a)	5131	10.0	0.19	5207	10.0	0.19	0.974	
Burr 06 Apr	26/04/2006	Jackson *et al* , 2011 (b)	4779	211.0	4.44	4809	326.0	6.82	<0.001	*
Screebe 06	28/04/2006	Jackson *et al* , 2011 (a)	9618	121.0	1.26	10990	157.0	1.43	0.29	
Delphi 06	29/04/2006		8788	172.4	1.96	10560	477.9	4.53	<0.001	*
Burr 06 May	04/05/2006	Jackson *et al* , 2011 (b)	8000	334.0	4.21	3907	180.0	4.61	0.276	
Erne 06	04/05/2006	Jackson *et al* , 2011 (a)	10357	68.0	0.66	5752	70.0	1.22	<0.001	*
Burr07	24/04/2007	Jackson *et al* , 2011 (b)	6784	440	6.40	6746	491	7.29	0.069	
Delphi 07	26/04/2007		9719	567.4	5.84	9451	550.8	5.83	0.986	
Delphi 08 DEL	28/04/2008		10811	183.0	1.69	16346	293.0	1.79	0.54	
Burr 08 Apr	29/04/2008	Jackson *et al* , 2011 (b)	6832	76.0	1.11	6719	97	1.44	0.086	
Burr08 May	06/05/2008	Jackson *et al* , 2011 (b)	3392	54.0	1.59	3413	72	2.11	0.113	
Burr 09	28/04/2009		6640	300.0	4.47	6881	267	3.88	0.064	

* Comparisons that were still significant after a Bonferroni correction.

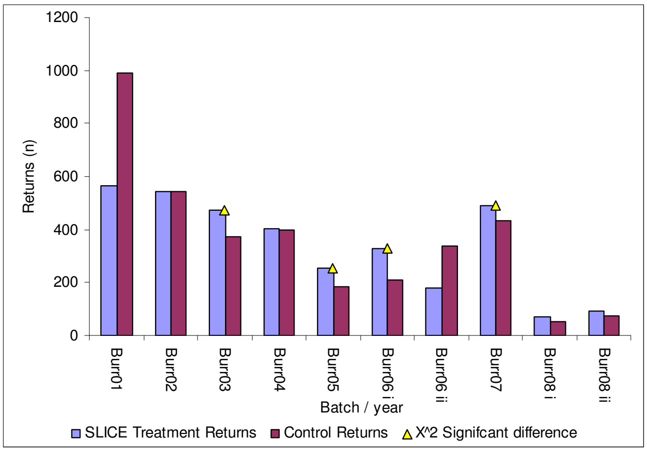

Figure 6. Time series, numbers of fish returning from treated and control groups (after Jackson *et al.* 2011 b).

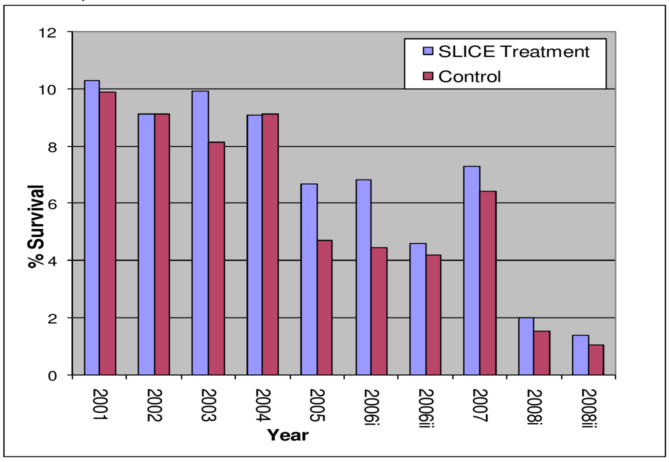

Figure 7. Time series, percentage survival of treated and control groups (after Jackson *et al.* 2011 b).

Clear declines in returns in both treated and non-treated batches were apparent over the experimental time period, Figure 8. An ANCOVA was used to assess relationships between these declining rates (Fig. 8). Independently regression lines of the declines in returns were extremely significant (p>0.001; n= 10 for each), however no difference between the mean returns was found (analysis of variance, n=20) (Jackson *et al*. 2011 b). A common regression of the two (Fig. 9) sets was extremely significant (p< 0.001; n=20) though there was no difference between the rates of decline between treated and non-treated returns (n=20) or between their instantaneous returns when corrected to a common decline rate (Fig. 10) after Sokal & Rohlf (1995).

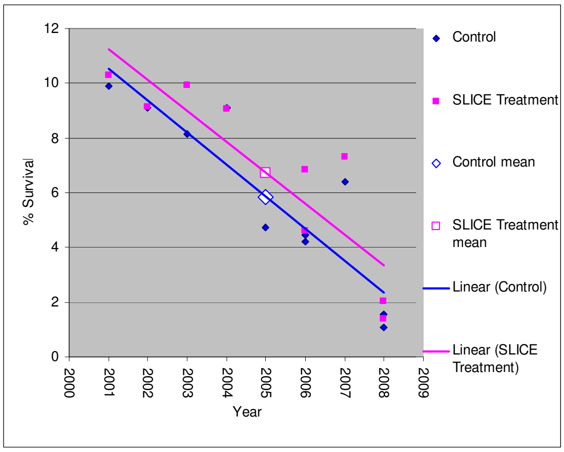

Figure 8. Time series of treated (y=-1.132x+12.383; r^2=0.774) and control (y=-1.166x+11.691; r^2=0.811) groups with their respective mean returns over the time period and regression lines fitted (after Jackson *et al.* 2011 b).

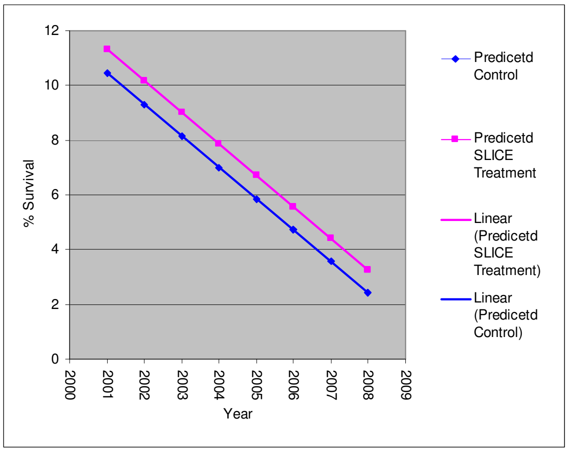

Figure 9. Regressions of time series of treated (y=-1.149x+12.467; r^2=1.0) and control (y=-1.149x+11.606; r^2=1.0) groups fitted to a common slope by an ANCOVA (after Jackson *et al.* 2011 b).

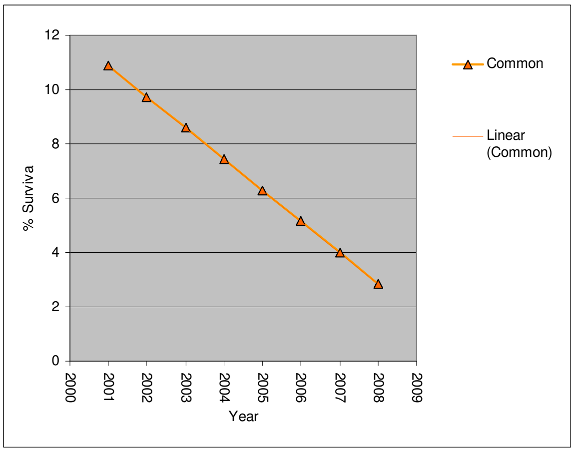

Figure 10. Common regression slope and intercept as defined by an ANCOVA of treated and control groups (y=-1.149x+12.037; r^2=1.0) (after Jackson *et al.* 2011 b).

Jackson *et al.* (2011 a) showed that while treatment with SLICE® generally resulted in a higher percentage return than the untreated control group (9 out of 10 cases, sign test) in the majority of releases, six out of ten, this difference was not significant when compared using chi-squared tests. In 2006 the early release group showed the greatest difference in percentage survival, which was extremely significant, however the difference in return in the later release group between treated and control batches was not significant. Over the period of the study the relationships between rates of return for treated and control batches exhibit similar trends.

The study found that "the difference in percentage survival between the treated and control groups is not significant (ANCOVA) but the fact that the treated groups have higher survival in nine out of ten cases is significant (sign test)". The authors concluded that the results over the study period would suggest that the level of infestation pressure by *L. salmonis* experienced by the outwardly migrating smolts was not of a level to be a consistently significant source of additional marine mortality because no significant difference in survival rates was found between treated and unprotected groups.

The highly significant decline in marine survival over the study period was independent of whether the fish were treated to protect against infestation with sea lice or not.

This led the authors to conclude that while the results show a strong and significant trend in increasing marine mortality of Atlantic salmon originating in the study area they also point to infestation of outwardly migrating salmon smolts with the salmon louse (*L. salmonis*) as being a minor component of marine mortality in the stocks studied and not being implicated in the observed decline in survival rate (Jackson *et al.* 2011 b).

Jackson *et al.* (2013 a) reporting on the results of a meta-analysis in which data on 352,142 migrating salmon from twenty eight releases, at eight locations along Ireland's south and west coasts covering a nine year period (2001 to 2009) concluded that while sea lice induced mortality on outwardly migrating smolts can be significant, it is a minor and irregular component of marine mortality in the stocks studied and is unlikely to be a significant factor influencing conservation status of salmon stocks (Fig. 11).

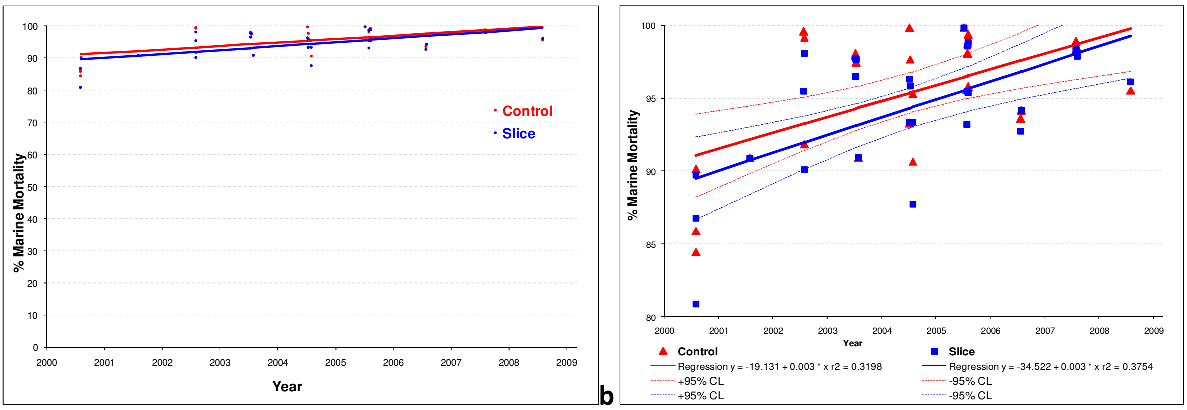

Figure 11. a. Percentage of marine mortality from both the control and treated groups with regression lines fitted. **b.** Plot expanded to show regression line and 95% confidence intervals for both groups.

Regression lines fitted to the combined data (Torrisson *et al.* 2013) show that rates of return for treated and control batches exhibit a similar trend as did the time series for Burrishoole (Jackson *et al.* 2011 b). A trend in increasing marine mortality in both treated and control groups is evident, which suggests that the decline is independent of treatment status and that infestation with the salmon louse is not implicated.

After correction using the Bonferroni adjustment, 11 of the 28 release groups or approximately 40% showed a significant difference in return rate between treated and control groups (Table 1). Of the 352,142 migrating salmon, 18,208 were recovered representing a sample proportion of 5.17% (95% confidence interval 5.1%, 5.2%). The small margin of error in the confidence interval is a consequence of the large sample size. This result suggests that, in the population of salmon represented by the sample provided, between 5.1% and 5.2% of salmon released are likely to return. The average marine mortality over the period of the study is therefore >94%, between 94.8% and 94.9%.

There was a reduction in the percentage returning by year with a large reduction evident from 2001 to 2004 (Fig. 12) (Jackson *et al*. 2013 a). There is a suggestion that the proportion returning is higher for the treated group across time but that the magnitude of the difference in proportions between the groups differs across time (i.e. there appears to be a Release Date by Treatment Group interaction). In order to visually assess the additional effect, if any, of the Location on the proportions returning, a plot of the percentage returning by Release Year and Location panelled by Treatment Group with a Lowess smoother superimposed, is given in Figure 12(Jackson *et al*. 2013 a). There is evidence that the percentage returning by Year differs between locations. The highest returns were evident in the Bundorragha (Delphi) with the lowest evident in the Erriff. The output from the generalised logistic model identified a significant treatment effect (p<0.001).

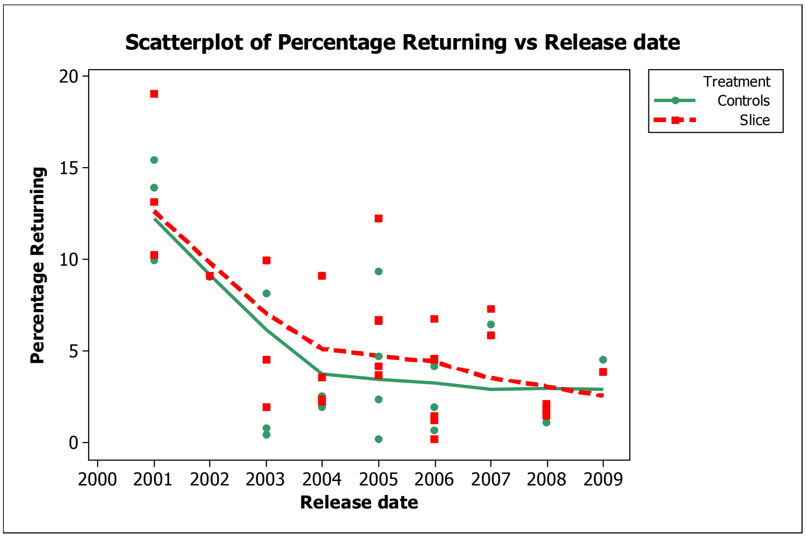

Figure 12. Percentage of salmon returning for each treatment group with Lowess smoother (after Jackson *et al.* 2013 a).

The odds of a fish returning were reported as 1.14:1 (95% confidence interval 1.07, 1.21) in favour of the treated group. The estimated probability of a treated fish returning (averaging over all years and rivers) was calculated as 0.097 compared to an estimated probability of a control fish returning of 0.086 an absolute difference of 0.011 (approximately 1% or 10 fish in a thousand).

The outputs of the linear model (ANOVA) showed evidence of significant Treatment (p=0.034), Location (p<0.001) and Release Date (p<0.001) effects (Fig. 13) (Jackson *et al*. 2013 a). The authors reported that the highest returns were in the Bundorragha (Delphi) with Erriff having the lowest. The table within Figure 13 (Jackson *et al.* 2013 a) of the adjusted means (i.e. adjusting for migration, treatment and release date) identifies locations that have significantly different mean percentages as those that do not share a letter in common. Bundorragha (Delphi) and Burrishoole were comparable while both were significantly different (i.e. higher) to Gowla, Invermore and Erriff. The authors found no evidence of a difference between Screebe, Erne, Lee, Gowla, Invermore and Erriff.

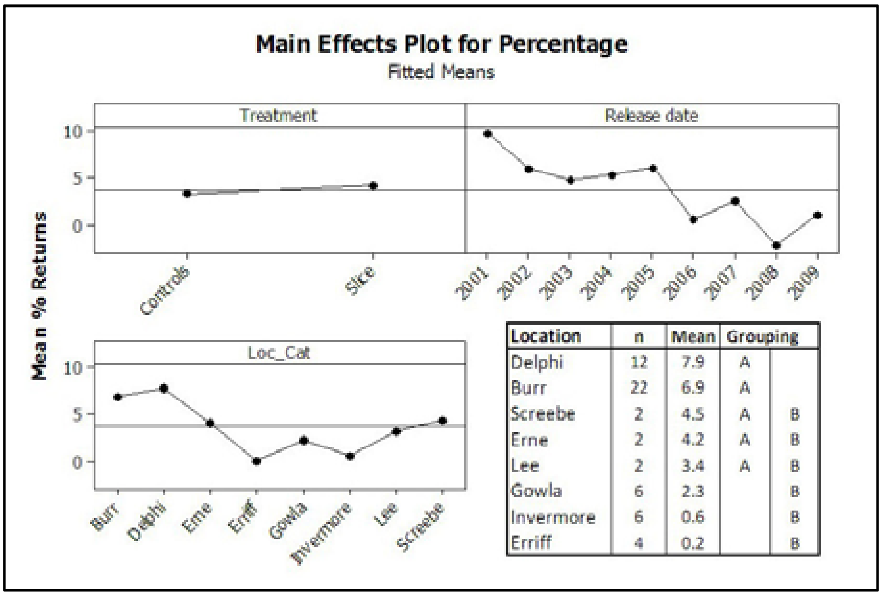

Figure 13. ANOVA; plot of adjusted mean percentages (after Jackson *et al.* 2013 a).

The authors reported sea lice induced mortality as significant in just under 40% of the releases in the study, small as a proportion of the overall marine mortality rate (which was in the region of 90%) and in absolute terms approximately 1% (representing 10 fish in a thousand) (Fig. 11).

The studies in Gowla, Invermore and Erriff relied on the transfer of ranched pre-smolts from an alkaline river body (Lough Corrib) to distant acidic rivers (Appendix 3). This may account for the markedly lower survival in these groups (Table 1), which in certain cases (e.g. Invermore and Erriff) was an order of magnitude lower than the means for the other rivers. Recent research suggests that the effects of acid water (Staurnes *et al.* 1996) and the interactive effects of acidification and salmon lice infestation on post-smolt survival (Finstad *et al.* 2007) result in reduced survival through increased predation and straying. This may limit the value of data based on stocks relocated into acid waters before release.

Conclusions

In reaching the conclusions set out in this report, the authors had regard to; the available scientific data; the regulations and statutory instruments currently in place for the management of the wild salmon resource and the aquaculture industry; and the provisions of the relevant national and EU legislation.

Based on the evidence from the peer reviewed studies, the information collected as part of the National Sea Lice Monitoring and Control Programme, the scientific reports published by the Marine Institute, the National Parks and Wildlife Service and international experts, and in-line with expert advice provided by several Government Departments and agencies the authors concluded that there was a robust and effective management programme in place to control sea lice infestation on farmed fish, and that there was no evidence to support any suggestion that the three named fisheries were being adversely affected by unusual levels of sea lice infestation, whether of farmed origin or from other sources.

The authors further concluded that the complaint in respect of impacts on the freshwater pearl mussel (*Margaritifera margaritifera*) had no basis.

The studies on the impacts of lice infestation on smolts (Jackson *et al.* 2011 a&b; Jackson *et al.* 2013 a) suggest that while sea lice induced mortality on outwardly migrating smolts can be significant, it is a minor and irregular component of marine mortality in the stocks studied and is unlikely to be a significant factor influencing conservation status of salmon stocks. Studies in Norway have reported similar results (Skilbrei *et al.* 2013). This conclusion is further supported by the findings of Jackson *et al.* (2013 b) which found no correlation between the presence of aquaculture and the performance of adjacent wild salmon stocks.

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APPENDICES

Appendix 1

Standing Scientific Commission Reports

Anon. (2005). Report of the Standing Scientific Committee of the National Salmon Commission - The Status of Irish Salmon Stocks in 2004 and Precautionary Catch Advice for 2005. *Department of Communications, Marine and Natural Resources*, Dublin.

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Salmon Microtag Recovery Reports

2002 Microtag Recovey Report- Report On The Coded Wire Tag Returns For 2002
Dr Niall O'Maoileidigh, Anne Cullen, Tom McDermott

2003 Microtag Recovey Report - Report On The Coded Wire Tag Returns For 2003
Dr Niall O'Maoileidigh, Anne Cullen, Tom McDermott

2004 Microtag Recovey Report - Report On The Coded Wire Tag Returns For 2004
Dr Niall O'Maoileidigh, Anne Cullen, Tom McDermott

2005 Microtag Recovey Report - Report On The Coded Wire Tag Returns For 2005
Dr Niall O'Maoileidigh, Anne Cullen, Tom McDermott

2006 Microtag Recovey Report - Report On The Coded Wire Tag Returns For 2006
Dr Niall O'Maoileidigh, Anne Cullen, Tom McDermott

2007 Microtag Recovey Report - Report On The Coded Wire Tag Returns For 2007
Dr Niall O'Maoileidigh, Anne Cullen, Tom McDermott

2008 Microtag Recovey Report - Report On The Coded Wire Tag Returns For 2008
Dr Niall O'Maoileidigh, Anne Cullen, Tom McDermott

2009 Microtag Recovey Report - Report On The Coded Wire Tag Returns For 2009
Dr Niall O'Maoileidigh, Anne Cullen, Tom McDermott

2010 Microtag Recovery Report - Report On The Coded Wire Tag Returns For 2010
Dr Niall O'Maoileidigh, Anne Cullen, Nigel Bond

2011 Microtag Recovey Report – Report On The Coded Wire Tag Returns For 2011
Anne Cullen

Statutory Instruments

Department Of Communications, Marine and Natural Resources
Fisheries Acts 1959 To 2006 - Conservation Of Salmon And Sea Trout Bye-Law No. 814, 2006.

Department Of Communications, Marine and Natural Resources
Fisheries Acts 1959 To 2006 - Conservation Of Salmon And Sea Trout Bye-Law No. 815, 2006

Department Of Communications, Marine and Natural Resources
Fisheries Acts 1959 To 2006 - Conservation Of Salmon And Sea Trout Bye-Law No. C.S. 287, 2006

Department Of Communications, Energy and Natural Resources
Fisheries Acts 1959 To 2006 - Conservation Of Salmon And Sea Trout Bye-Law No. 845, 2008

Department Of Communications, Energy and Natural Resources
Fisheries Acts 1959 To 2006 - Conservation Of Salmon And Sea Trout Bye-Law No. 846, 2008

Department Of Communications, Energy and Natural Resources
Fisheries Acts 1959 To 2006 - Conservation Of Salmon And Sea Trout Bye-Law No. C.S. 301, 2008

Department Of Communications, Energy and Natural Resources
Inland Fisheries Acts 1959 To 2010 - Conservation Of Salmon And Sea Trout (Bag Limits) Bye-Law No. 874, 2010

Department Of Communications, Energy and Natural Resources
Inland Fisheries Acts 1959 To 2010 - Conservation Of Salmon And Sea Trout (Catch And Release) Bye-Law No. 873, 2010

Department Of Communications, Energy and Natural Resources
Inland Fisheries Acts 1959 To 2010 - Conservation Of Salmon And Sea Trout (Closed Rivers) Bye-Law No. C.S. 306, 2010
http://www.dcenr.gov.ie/Natural/Inland+Fisheries/Legislation/Bye+Laws/

Appendix 2.

Department of the Marine and Natural Resources

Roinn na Mara agus Acmhainní Nádúrtha

Monitoring Protocol No. 3

for

Offshore Finfish Farms-
Sea Lice Monitoring and Control

(subject to revision from time to time)

11 May, 2000

Leeson Lane, Dublin 2
Lána Chill Mochargán
Baile Átha Cliath 2

Tel +353 1 619 9200
LoCall 1890 44 99 00
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e-mail comntact@marine.irlgov.ie
GTN +1 18

Monitoring Protocol No. 3
for
Offshore Finfish Farms -
Sea Lice Monitoring and Control

1. Monitoring Regime Required

All finfish farms are obliged to monitor for sealice on an ongoing basis and to take remedial action. This involves the inspection and sampling of each year class of fish at all fish farm sites fourteen times per annum, twice per month during March, April and May and monthly for the remainder of the year except December-January. Only one inspection is carried out during this period.

2. Purpose of Monitoring

The four purposes of the National Sea Lice-Monitoring Plan are:

- To provide an objective measurement of infestation levels on farms
- To investigate the nature of the infestations
- To provide management information to drive implementation of the control and management strategies
- To facilitate further development and refinement of the control and management strategies.

3. Monitoring and Control Strategy

The sea lice monitoring and control strategy has five principal components:

- Separation of generations
- Annual following of sites
- Early harvest of two sea-winter fish
- Targeted treatment regimes, including synchronous treatments
- Agreed husbandry practices

Together, these components work to reduce the development of infestations and to ensure the most effective treatment of developing infestations. They minimise lice levels whilst controlling reliance on, and reducing use of, veterinary medicines. The separation of generations and annual following prevent the vertical transmission of infestations from one generation to the next, thus retarding the development of infestations. The early harvest of two sea winter fish removes a potential reservoir of lice infestation and the agreed practices and targeted treatments enhance the efficacy of treatment regimes. One important aspect of targeted treatments is the carrying out of autumn / winter treatments to reduce lice burdens to as close to zero as practicable on all fish, which are to be over-wintered. This is fundamental to achieving zero / near zero egg bearing lice in spring. The agreed husbandry practices cover a range of related fish health, quality and environmental issues in addition to those specifically related to lice control.

4. Trigger Levels for Treatment

The setting of appropriate treatment triggers is an integral part of implementing a targeted treatment regime. Treatment triggers during the spring period are set close to zero in the range of from **0.3 to 0.5** egg bearing females per fish and are also informed by the numbers of mobile lice on the fish. Where numbers of mobile lice are high, treatments are triggered even in the absence of egg bearing females. Outside of the critical spring period, a level of **2.0** egg bearing lice acts as a trigger for treatments. This is only relaxed where fish are under harvest and with the agreement with the Department of Marine and Natural Resources or its agent.

Over the period since the initiation of SBM, treatment triggers have been progressively reduced from a starting point of 2.0 per fish during the spring period to the current levels which are the optimal sustainable at present. These trigger levels will be kept under review in the light of advances in lice control strategies. Triggered treatments are underpinned by follow up inspections and, where the Department or its agent considers it to be necessary, by sanctions. Sanctions employed include, peer review under the SBM process, conditional fish movement orders and accelerated harvests.

5. Synchronous Sea Lice Treatment and Control in Bays

All fish farms operating in a particular bay will be required to undertake appropriate synchronous sea lice treatment and control strategies through the Single Bay Management/CLAMS process. The Department of Marine and Natural Resources or its agent reserves the right to devise appropriate strategies for synchronous action by fish farms in any bay.

6. Sampling Strategy

The Irish sampling strategy methodology is designed to:

- Provide a robust and reliable objective measure of lice numbers on farmed fish
- Operate within a framework which is cost effective and capable of being carried out over the range of installations which are in use in offshore farming
- Take account of weather conditions, fish health issues, environmental effects and animal welfare considerations.

There are four key components to this sampling strategy: the sampling method, the sampling frequency, the sample size and reporting mechanisms.

6.2 Sampling Method

The full methodology is laid out in ***Appendix 1.*** It is essentially a non-destructive sampling method. Fish are removed at random from the cages and anaesthetised, to reduce stress and risk of injury. All adult and sub-adult mobile lice are then removed from the fish and retained for examination before the fish are allowed to recover and returned to the cage. Lice which become detached from the fish in the anaesthetic are collected and included in the lice count for the sample to ensure that lice numbers are not under reported. As it involves the handling of live animals and as there are animal welfare issues involved, the sampling process is subject to peer review and a licensing process. Strict limits are imposed on the number of fish which may be sampled and changes to these limits must be justified.

6.3 Frequency Sampling

The sampling frequency will fourteen inspections per year, plus any follow-up inspections required where instructions to reduce lice levels have been issued or such other frequency as may be determined by the Department or its agent.

6.4 Sample Size

The target number of fish sampled is sixty per inspection, comprising two samples of thirty fish. One sample is taken from a standard cage, inspected at each inspection, and one from a cage selected at random. Where there are difficulties in obtaining the full sample size, every effort will be made to obtain a minimum of ten fish in each sample. (This sample size is statistically robust and also takes into consideration the practicalities and animal welfare issues involved in carrying out the programme. The standard cage allows for the monitoring of within cage trends and the random cage acts as a spot check).

6.5 Reporting of Lice Monitoring

Monthly reports are compiled for each site of mean numbers of egg bearing lice and total mobile lice of each species. These reports are circulated to the farms, the Department of the Marine and Natural Resources, the Marine Institute, the Central Fisheries Board, the Regional Fisheries Boards, Save Our Sea Trout, the Western Gamefishing Association and the Irish Salmon Growers' Association. This ensures that detailed information on the levels pertaining on farms is available to all interested parties. These reports are designed to give a clear, unambiguous measure of the infestation level at each site and to act as a basis for management decisions.

Appendix 3

Recovery data (unraised & raised) of hatchery smolts transferred from alkaline to acidic rivers.

Group Code	Release Date	MicroTag Code	Control / Treated	Stock	Hatchery	Release River	Estimated Number Released	Total Tags Recovered	
								Unraised	Raised
Gowla 03	28/04/2003	24780	Control	Cong	Cong	Gowla	4822	3	20
Gowla 03	28/04/2003	24779	Slice	Cong	Cong	Gowla	4955	35	226
Gowla 04	07/04/2004	34793	Control	Cong	Cong	Gowla	4699	22	91
Gowla 04	07/04/2004	34792	Slice	Cong	Cong	Gowla	4655	51	165
Gowla 05	07/04/2005	44789	Control	Cong	Cong	Gowla	4735	53	318
Gowla 05	07/04/2005	44788	Slice	Cong	Cong	Gowla	4583	54	306
Invermore 03	29/04/2003	24782	Control	Cong	Cong	Invermore	4594	9	38
Invermore 03	29/04/2003	24781	Slice	Cong	Cong	Invermore	4589	17	89
Invermore 04	08/04/2003	34795	Control	Cong	Cong	Invermore	4671	26	96
Invermore 04	08/04/2004	34794	Slice	Cong	Cong	Invermore	4653	37	105
Invermore 05	08/04/2005	44787	Control	Cong	Cong	Invermore	4750	17	111
Invermore 05	08/04/2005	44786	Slice	Cong	Cong	Invermore	4716	31	196
Erriff 04	12/04/2004	34796	Control	Cong	Cong	Erriff	4229	34	108
Erriff 04	12/04/2004	34797	Slice	Cong	Cong	Erriff	4325	44	102
Erriff 05	04/04/2005	44784	Control	Cong	Cong	Erriff	4689	2	8
Erriff 05	04/04/2005	44785	Slice	Cong	Cong	Erriff	4659	37	172

Recovery data (unraised & raised) of hatchery smolts reared and released within same river system.

Group Code	Release Date	MicroTag Code	Control / Treated	Stock	Hatchery	Release River	Estimated Number Released	Total Tags Recovered	
								Unraised	Raised
Delphi 01 BUR	02/05/2001	44713	Control	Burrishoole	Delphi	Bundorragha	6385	372	985
Delphi 01 BUR	02/05/2001	44714	Slice	Burrishoole	Delphi	Bundorragha	6392	423	1217
Delphi 01 DEL	02/05/2001	44723	Control	Delphi grilse	Delphi	Bundorragha	6395	303	892
Delphi 01 DEL	02/05/2001	44724	Slice	Delphi grilse	Delphi	Bundorragha	6368	285	836
Delphi 05	26/04/2005	44790	Control	Burrishoole	Delphi	Bundorragha	8893	543	831
Delphi 05	26/04/2005	44791	Slice	Burrishoole	Delphi	Bundorragha	8471	609	1038
Delphi 06	29/04/2006	54708	Control	Burrishoole	Delphi	Bundorragha	8788	142	173
Delphi 06	29/04/2006	54713	Slice	Burrishoole	Delphi	Bundorragha	10560	414	478
Delphi 07	26/04/2007	54721	Control	Burrishoole	Delphi	Bundorragha	9719	534	567
Delphi 07	27/04/2007	54722	Slice	Burrishoole	Delphi	Bundorragha	9451	526	551
Delphi 08 DEL	28/04/2008	54740	Control	Delphi grilse	Delphi	Bundorragha	10811	175	183
Delphi 08 DEL	28/04/2008	54749	Slice	Delphi grilse	Delphi	Bundorragha	10551	160	167
Delphi 08 DEL	28/04/2008	54750	Slice	Delphi grilse	Delphi	Bundorragha	5795	119	126
Burr 01	03/05/2001	204713 A	Control	Burrishoole	Burrishoole	Burrishoole	10039	416	997
Burr 01	03/05/2001	204701 A	Slice	Burrishoole	Burrishoole	Burrishoole	5496	259	565
Burr 02	01/05/2002	34705 A	Control	Burrishoole	Burrishoole	Burrishoole	3079	160	287
Burr 02	01/05/2002	34706 A	Control	Burrishoole	Burrishoole	Burrishoole	1596	77	138
Burr 02	01/05/2002	184747 B	control	Burrishoole	Burrishoole	Burrishoole	1314	58	117
Burr 02	01/05/2002	184761 B	Slice	Burrishoole	Burrishoole	Burrishoole	4748	248	456
Burr 02	01/05/2002	34707 A	Slice	Burrishoole	Burrishoole	Burrishoole	1212	55	89
Burr 03	01/05/2003	24774	Control	Burrishoole	Burrishoole	Burrishoole	4587	126	374
Burr 03	01/05/2003	24777	Slice	Burrishoole	Burrishoole	Burrishoole	4745	145	471
Burr 04	29/04/2004	44764	Control	Burrishoole	Burrishoole	Burrishoole	4369	151	398
Burr 04	29/04/2004	34788	Slice	Burrishoole	Burrishoole	Burrishoole	4437	162	403
Burr 05	28/04/2005	54702 A	Control	Burrishoole	Burrishoole	Burrishoole	3867	96	183
Burr 05	28/04/2005	44724 A	Slice	Burrishoole	Burrishoole	Burrishoole	3793	114	253
Burr 06 Apr	26/04/2006	14782 A	Control	Burrishoole	Burrishoole	Burrishoole	4299	180	180
Burr 06 Apr	26/04/2006	14764 A	Control	Burrishoole	Burrishoole	Burrishoole	480	31	31
Burr 06 Apr	26/04/2006	24782 A	Slice	Burrishoole	Burrishoole	Burrishoole	4809	326	326
Burr 06 May	04/05/2006	24791 A	Control	Burrishoole	Burrishoole	Burrishoole	8000	334	334
Burr 06 May	04/05/2006	24783 A	Slice	Burrishoole	Burrishoole	Burrishoole	3907	180	180
Burr07	24/04/2007	44764a	Control	Burrishoole	Burrishoole	Burrishoole	3391	229	229
Burr07	24/04/2007	34792a	Control	Burrishoole	Burrishoole	Burrishoole	3393	211	211
Burr07	24/04/2007	34798a	Slice	Burrishoole	Burrishoole	Burrishoole	6746	491	491
Burr 08 Apr	29/04/2008	34777a	Control	Burrishoole	Burrishoole	Burrishoole	6832	76	76
Burr 08 Apr	29/04/2008	54741	Slice	Burrishoole	Burrishoole	Burrishoole	6719	97	97
Burr08 May	06/05/2008	14781a	Control	Burrishoole	Burrishoole	Burrishoole	3392	54	54
Burr08 May	06/05/2008	24767a	Slice	Burrishoole	Burrishoole	Burrishoole	3413	72	72
Burr 09	28/04/2009	54754	Control	Burrishoole	Burrishoole	Burrishoole	6640	300	300
Burr 09	28/04/2009	54755	Slice	Burrishoole	Burrishoole	Burrishoole	6881	267	267
Lee 06	04/04/2006	24779 A	Control	Lee	Carrigadrohid	Lee	5131	10	10
Lee 06	04/04/2006	24780 A	Slice	Lee	Carrigadrohid	Lee	5207	10	10
Screebe 06	28/04/2006	54707	Control	Screebe	Screebe	Screebe	9618	121	121
Screebe 06	28/04/2006	54716	Slice	Screebe	Screebe	Screebe	10990	157	157
Erne 06	04/05/2006	54715	Control	Erne	Ballyshannon	Erne	10357	68	68
Erne 06	04/05/2006	54714	Slice	Erne	Ballyshannon	Erne	5752	70	70

The number of tagged salmon taken (raised) was estimated by multiplying the actual number of tags recovered in each area (unraised) by the ratio of the total declared landings to the sample size examined. An adjustment for non-catch fishing mortality and non-reporting of catches was also applied. For comparative purposes it is important to use raised figures as in each catchment the proportions sampled vary considerably.

Microtag Recovery Reports are archived in the Marine Institute Library, Oranmore, Co. Galway.

Information on capture location and return data of the experimental group (unraised).

Release Date	MicroTag Code	Control / Treated	Stock	Hatchery	Release River	Estimated Number Released	Donegal	Mayo	Gal / Lim	Kerry	W Cork	S Coast	SE Coast	Other	N Irl	Trap	Rods	Draft	Brood	Stray	Total tags Recovered unraised
28/04/2003	24780	Control	Cong	Cong	Gowla	4822	0	1	2	0	0	0	0	0	0	0	0	0	0	0	3
28/04/2003	24779	Slice	Cong	Cong	Gowla	4955	3	6	24	1	0	0	0	0	0	0	0	0	0	1	35
07/04/2004	34793	Control	Cong	Cong	Gowla	4699	0	4	10	0	0	0	0	0	0	0	3	0	3	2	22
07/04/2004	34792	Slice	Cong	Cong	Gowla	4655	4	8	15	0	0	0	0	0	0	0	10	0	11	3	51
07/04/2005	44789	Control	Cong	Cong	Gowla	4735	2	5	30	0	0	0	0	0	0	11	0	0	0	5	53
07/04/2005	44788	Slice	Cong	Cong	Gowla	4583	2	6	26	0	0	0	0	0	0	8	0	0	0	12	54
29/04/2003	24782	Control	Cong	Cong	Invermore	4594	4	1	3	0	0	0	0	0	0	0	0	0	1	0	9
29/04/2003	24781	Slice	Cong	Cong	Invermore	4589	2	4	8	0	0	0	0	0	0	0	0	0	0	3	17
08/04/2003	34795	Control	Cong	Cong	Invermore	4671	2	7	8	0	0	0	0	0	0	0	0	0	6	3	26
08/04/2004	34794	Slice	Cong	Cong	Invermore	4653	6	5	7	1	0	0	0	0	0	0	0	0	14	4	37
08/04/2005	44787	Control	Cong	Cong	Invermore	4750	1	2	10	0	0	0	0	0	0	1	0	0	0	3	17
08/04/2005	44786	Slice	Cong	Cong	Invermore	4716	0	2	18	2	1	0	0	0	0	0	0	0	0	8	31
12/04/2004	34796	Control	Cong	Cong	Erriff	4229	4	5	7	0	1	0	0	0	0	0	2	0	12	3	34
12/04/2004	34797	Slice	Cong	Cong	Erriff	4325	16	10	2	0	0	0	0	0	0	0	1	0	12	3	44
04/04/2005	44784	Control	Cong	Cong	Erriff	4689	0	0	1	0	0	0	0	0	0	1	0	0	0	0	2
04/04/2005	44785	Slice	Cong	Cong	Erriff	4659	0	4	12	1	1	0	0	0	0	13	5	0	0	1	37
02/05/2001	44713	Control	Burrishoole	Delphi	Bundorragha	6385	11	85	109	1	2	0	0	0	0	0	37	0	125	2	372
02/05/2001	44714	Slice	Burrishoole	Delphi	Bundorragha	6392	15	103	146	1	3	0	0	1	0	0	47	0	106	1	423
02/05/2001	44723	Control	Delphi grilse	Delphi	Bundorragha	6395	13	70	120	3	0	0	0	1	0	0	9	0	87	0	303
02/05/2001	44724	Slice	Delphi grilse	Delphi	Bundorragha	6368	11	71	104	3	1	0	0	0	0	0	10	0	84	1	285
26/04/2005	44790	Control	Burrishoole	Delphi	Bundorragha	8893	1	2	49	0	0	0	0	0	0	0	158	0	296	37	543
26/04/2005	44791	Slice	Burrishoole	Delphi	Bundorragha	8471	3	4	68	0	0	0	0	0	0	0	171	0	318	45	609
29/04/2006	54708	Control	Burrishoole	Delphi	Bundorragha	8788	0	0	11	0	0	0	0	0	0	0	42	0	86	3	142
29/04/2006	54713	Slice	Burrishoole	Delphi	Bundorragha	10560	0	0	25	0	0	0	0	0	0	0	114	0	265	10	414
26/04/2007	54721	Control	Burrishoole	Delphi	Bundorragha	9719	0	0	56	0	0	0	0	0	0	0	113	0	361	4	534
27/04/2007	54722	Slice	Burrishoole	Delphi	Bundorragha	9451	0	0	41	0	0	0	0	0	0	0	137	0	341	7	526
28/04/2008	54740	Control	Delphi grilse	Delphi	Bundorragha	10811	0	0	6	0	0	0	0	0	0	138	29	0	0	2	175
28/04/2008	54749	Slice	Delphi grilse	Delphi	Bundorragha	10551	0	0	6	0	0	0	0	0	0	138	9	0	0	7	160
28/04/2008	54750	Slice	Delphi grilse	Delphi	Bundorragha	5795	0	0	8	0	0	0	0	0	0	93	15	0	0	3	119
03/05/2001	204713 A	Control	Burrishoole	Burrishoole	Burrishoole	10039	11	82	62	10	11	2	0	1	0	150	2	0	80	5	416
03/05/2001	204701 A	Slice	Burrishoole	Burrishoole	Burrishoole	5496	9	47	29	4	6	1	0	1	0	98	3	0	61	0	259
01/05/2002	34705 A	Control	Burrishoole	Burrishoole	Burrishoole	3079	9	32	23	1	0	0	0	0	1	23	0	0	69	2	160
01/05/2002	34706 A	Control	Burrishoole	Burrishoole	Burrishoole	1596	4	10	6	1	1	0	0	0	0	17	1	0	37	0	77
01/05/2002	184747 B	control	Burrishoole	Burrishoole	Burrishoole	1314	1	16	4	0	1	0	0	0	0	8	0	0	28	0	58
01/05/2002	184761 B	Slice	Burrishoole	Burrishoole	Burrishoole	4748	11	66	32	1	0	0	0	0	0	33	0	0	105	0	248
01/05/2002	34707 A	Slice	Burrishoole	Burrishoole	Burrishoole	1212	3	10	5	0	0	0	0	0	0	7	0	0	30	0	55
01/05/2003	24774	Control	Burrishoole	Burrishoole	Burrishoole	4587	10	11	24	1	2	0	0	0	0	11	12	0	55	0	126
01/05/2003	24777	Slice	Burrishoole	Burrishoole	Burrishoole	4745	13	18	26	3	4	0	0	1	0	18	11	0	51	0	145
29/04/2004	44764	Control	Burrishoole	Burrishoole	Burrishoole	4369	12	27	16	1	8	0	0	0	0	48	2	0	37	0	151
29/04/2004	34788	Slice	Burrishoole	Burrishoole	Burrishoole	4437	14	32	11	3	6	0	0	1	1	43	8	0	42	1	162
28/04/2005	54702 A	Control	Burrishoole	Burrishoole	Burrishoole	3867	2	6	0	0	0	0	0	0	0	38	10	0	39	1	96
28/04/2005	44724 A	Slice	Burrishoole	Burrishoole	Burrishoole	3793	0	7	5	0	1	0	0	0	0	41	8	0	52	0	114
26/04/2006	14782 A	Control	Burrishoole	Burrishoole	Burrishoole	4299	0	0	0	0	0	0	0	0	0	75	13	0	92	0	180
26/04/2006	14764 A	Control	Burrishoole	Burrishoole	Burrishoole	480	0	0	0	0	0	0	0	0	0	13	3	0	15	0	31
26/04/2006	24782 A	Slice	Burrishoole	Burrishoole	Burrishoole	4809	0	0	0	0	0	0	0	0	0	137	34	0	155	0	326
04/05/2006	24791 A	Control	Burrishoole	Burrishoole	Burrishoole	8000	0	0	0	0	0	0	0	0	0	142	20	0	171	1	334
04/05/2006	24783 A	Slice	Burrishoole	Burrishoole	Burrishoole	3907	0	0	0	0	0	0	0	0	0	68	13	0	99	0	180
24/04/2007	44764a	Control	Burrishoole	Burrishoole	Burrishoole	3391	0	0	1	0	0	0	0	0	0	227	0	0	0	1	229
24/04/2007	34792a	Control	Burrishoole	Burrishoole	Burrishoole	3393	0	0	0	0	0	0	0	0	0	209	0	0	0	2	211
24/04/2007	34798a	Slice	Burrishoole	Burrishoole	Burrishoole	6746	0	0	0	0	0	0	0	0	0	491	0	0	0	0	491
29/04/2008	34777a	Control	Burrishoole	Burrishoole	Burrishoole	6832	0	0	0	0	0	0	0	0	0	76	0	0	0	0	76
29/04/2008	54741	Slice	Burrishoole	Burrishoole	Burrishoole	6719	0	0	0	0	0	0	0	0	0	97	0	0	0	0	97
06/05/2008	14781a	Control	Burrishoole	Burrishoole	Burrishoole	3392	0	0	0	0	0	0	0	0	0	54	0	0	0	0	54
06/05/2008	24767a	Slice	Burrishoole	Burrishoole	Burrishoole	3413	0	0	0	0	0	0	0	0	0	72	0	0	0	0	72
28/04/2009	54754	Control	Burrishoole	Burrishoole	Burrishoole	6640	0	0	1	0	0	0	0	0	0	298	0	0	0	1	300
28/04/2009	54755	Slice	Burrishoole	Burrishoole	Burrishoole	6881	0	0	1	0	0	0	0	0	0	266	0	0	0	0	267
04/04/2006	24779 A	Control	Lee	Carrigadrohid	Lee	5131	0	0	0	0	0	0	0	0	0	0	0	0	10	0	10
04/04/2006	24780 A	Slice	Lee	Carrigadrohid	Lee	5207	0	0	0	0	0	0	0	0	0	0	0	0	10	0	10
28/04/2006	54707	Control	Screebe	Screebe	Screebe	9618	0	0	0	0	0	0	0	0	0	3	18	0	100	0	121
28/04/2006	54716	Slice	Screebe	Screebe	Screebe	10990	0	0	0	0	0	0	0	0	1	0	20	0	136	0	157
04/05/2006	54715	Control	Erne	Ballyshannon	Erne	10357	0	0	0	0	0	0	0	0	1	0	0	0	67	0	68
04/05/2006	54714	Slice	Erne	Ballyshannon	Erne	5752	0	0	0	0	0	0	0	0	0	0	0	0	70	0	70

Appendix 4

Salmon rivers open for exploitation, including catch & release, by River Basin District. Where rivers are open they are above their Conservation Limit, where they are C&R (catch and release of fish caught) they are close to their Conservation Limit (Jackson *et al.* 2013 a).

River Basin District		Number of Rivers				Percentage of rivers (%)		
	Year	Open	C & R	Closed	Total	Open	C & R	Closed
Northwest	2007	9	0	6	15	60	0	40
	2008	7	0	8	15	47	0	53
	2009	8	0	7	15	53	0	47
	2010	8	2	5	15	53	13	33
	2011	9	2	3	14	64	14	21
West	2007	16	4	4	24	67	17	17
	2008	17	5	1	23	74	22	4
	2009	15	5	2	22	68	23	9
	2010	18	4	1	23	78	17	4
	2011	17	5	1	23	74	22	4
Shannon	2007	2	0	4	6	33	0	67
	2008	2	0	3	5	40	0	60
	2009	2	0	3	5	40	0	60
	2010	2	0	3	5	40	0	60
	2011	2	0	3	5	40	0	60
Southwest	2007	14	0	6	20	70	0	30
	2008	15	4	2	21	71	19	10
	2009	19	3	4	26	73	12	15
	2010	19	0	5	24	79	0	21
	2011	16	5	1	22	73	23	5
Southeast	2007	0	2	2	4	0	50	50
	2008	0	3	3	6	0	50	50
	2009	0	3	3	6	0	50	50
	2010	1	2	2	5	20	40	40
	2011	2	1	2	5	40	20	40
East	2007	0	0	2	2	0	0	100
	2008	0	1	2	3	0	33	67
	2009	0	1	2	3	0	33	67
	2010	0	1	2	3	0	33	67
	2011	0	1	2	3	0	33	67
Neagh-Bann	2007	1	1	2	4	25	25	50
	2008	1	1	2	4	25	25	50
	2009	1	1	2	4	25	25	50
	2010	1	1	2	4	25	25	50
	2011	2	1	1	4	50	25	25
National	2007	42	7	26	75	56	9	35
	2008	42	14	21	77	55	18	27
	2009	45	13	23	81	56	16	28
	2010	48	10	20	78	62	13	26
	2011	48	15	13	76	63	20	17

Appendix 5

Water quality data and percentage of rivers open in each River Basin District (Jackson *et al.* 2013 b).

River Basin District (Ireland)	EPA 2007-2009	% open (Inc. C&R)
Southwest	92	85
West	83	91
Northwest	66	53
Southeast	64	50
Shannon	58	40
Neagh-Bann	55	50
East	46	33

Appendix 6

Mean ovigerous and total mobile *L. salmonis* on one-sea-winter salmon in May of each year with standard error (SE).

Year	Mean ovigerous *L. salmonis* per fish	Standard Error	Mean mobile *L. salmonis* per fish	Standard Error
1991	1.21	0.44	10.19	2.74
1992	2.34	0.34	12.15	1.78
1993	1.50	0.23	9.87	1.31
1994	0.53	0.10	4.61	0.66
1995	0.53	0.11	4.39	0.72
1996	1.01	0.24	11.56	1.84
1997	1.17	0.21	7.27	1.21
1998	1.30	0.23	8.97	1.55
1999	0.89	0.14	7.86	1.18
2000	0.68	0.13	3.91	0.71
2001	0.21	0.04	1.10	0.21
2002	0.73	0.12	4.26	0.74
2003	0.73	0.13	4.84	0.94
2004	0.58	0.13	2.28	0.51
2005	1.07	0.25	5.12	1.34
2006	1.39	0.29	8.65	1.93
2007	1.74	0.32	12.35	2.21
2008	0.68	0.16	8.81	2.99
2009	0.77	0.12	7.42	1.49
2010	0.72	0.16	5.11	0.98
2011	0.35	0.10	1.51	0.37
2012	0.45	0.08	2.84	0.58
2013	0.19	0.04	0.89	0.17

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