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Restocking programmes for salmon (*Salmo salar L.*) in Ireland – how successful have they been ?

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ABSTRACT

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Restocking is a widely used tool in Ireland to mitigate against the loss of salmon populations caused by creation of hydropower dams, river drainage and pollution. Strategies have included restocking with all stages in-river supplemented with substantial releases of hatchery-reared smolts. The efficacy of restocking with regard to establishing self-sustaining stocks is examined in light of ongoing problems in fresh water and poor and declining marine survival with reference to returns from coded wire tagged salmon and recoveries in broodstocks at rearing stations.

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INTRODUCTION

Stocking and rearing salmonids is an established technique for artificially increasing salmonid productivity with the objective being to increase the adult numbers available to the system. In recent years, up to 1 million reared salmon smolts have been released into Irish rivers. There is also extensive use of eggs, fry and parr to supplement these smolt releases. Artificial propagation has the advantage that the mortality associated with juvenile development in the wild (over 95%) can be substantially reduced by rearing the progeny of wild or artificially produced parents to eyed egg, fry, parr or smolt stage, in the relative safety of a hatchery. This is due to the elimination of many of the factors (competition for food, predators, disease etc) which normally operate on the wild population and limit production under natural circumstances. In general however, stocking has become a panacea for any river system which has, or appears to have, a reduced stock. Stocking in the past has often been carried out in systems where the natural productivity was not known, and invariably, follow up surveys were not carried out to assess the actual benefits of the stocking operation. There is clearly a need to establish a policy with regard to stocking practices, which will protect wild stocks from indiscriminate stocking or other population manipulation.

In 1993, Ireland was considered to have a:
" widespread, abundant and self-sustaining population of Atlantic salmon" (Whilde 1993).

Although the report noted that salmon were under pressure from commercial exploitation they were not considered to be threatened at the time.

The most recent assessment carried out in 2007, under Irelands commitments to the European Councils Directive on the Conservation of Habitats, Flora and Fauna (92/43/EEC) states that :

"The salmon population in Ireland has declined by 75% in recent years and although salmon still occur in 148 Irish rivers, only 43 of these have healthy populations". (Anon. 2008a)

Factors leading to this decline are described in the above report and include reduced marine survival (probably as a result of climate change), poor river water quality (resulting from factors such as inadequate sewage treatment, agricultural enrichment, acidification, erosion and siltation), forestry related pressures and over-fishing. Concerns related to factors causing mortality at sea, such as diseases, parasites and marine pollution are also noted. Although the range where salmon were to be found was classified as good, the population size was considered bad, habitat condition was considered poor with

future prospects also considered poor. The overall classification for the Atlantic salmon in Ireland was described as "Bad".

In recent years river specific Conservation Limits have been derived for all Irish salmon rivers (Crozier et al 2004, Prevost et al 2004, Ó Maoiléidigh et al 2004). In line with this, fishery management measures in Ireland from 1997 to 2006 have been aimed at reducing exploitation on returning stocks and increasing escapement and meeting these Conservation Limits. A significant increase in escapement of wild fish is likely in many rivers following the Irish Governments decision in 2006 to close the mixed stock salmon fishery. This fishery was estimated to intercept between 30 to 50% of all returning wild salmon to Irish waters (ICES 2008). However, despite this expected increase in escapement, many Irish rivers will still fail to meet their required Conservation Limits (Anon 2008b). Conversely, several rivers which had been meeting and exceeding their conservation limits will see a significant surplus over this requirement due to the closure of the mixed stock fishery. Therefore the use, or continued use of hatchery stocks in the rebuilding process and in stock management needs to be considered in this context.

In a wider context, the North Atlantic salmon Conservation Organisation (NASCO) have adopted a Precautionary Approach to salmon management and conservation (NASCO 1998). In this context, management strategies include stock rebuilding as part of the conservation strategy (NASCO 2004). These rebuilding strategies include fisheries management, habitat enhancement and protection, control of interactions between wild and aquaculture fish and restocking. NASCO (2006) have noted that stocking is widely carried out by many government and private entities for enhancement, mitigation, restoration, rehabilitation or ranching purposes and advise that

"*while these programmes are sometimes successful, it is now known that stocking can also have negative impacts on wild salmon stocks and other species, and poor hatchery practices may negatively impact the characteristics of the wild stock that we wish to conserve"*.

Other potential consequences outlined by NASCO include: depression of the survival and abundance of indigenous populations and straying of stocked fish into nearby rivers and protagonists of restocking are advised by NASCO to consider fully the risks as well as the benefits arising from stocking.

There have been several recent reviews on restocking and the use of hatchery reared progeny of Atlantic salmon (e.g. Cowx, 1994 and 1998; Fleming and Petersson, 2001; Aprahamian *et al*., 2003; McGinnity *et al*., 2003, Cross et al., 2007). Given that salmon stocks are in decline across much of the North Atlantic (ICES 2008) there is a need for rational and effective methods to be applied for stock rebuilding.

In this paper, stocking histories of the last 13 years in Ireland are reviewed along with the extent of hatchery activity, the numbers of fish being taken from the wild for stripping, juveniles being produced, rivers being stocked and returns in relation to meeting specific objectives in this instance the attainment of Conservation Limits.

MATERIALS AND METHODS

In 1994, the Fisheries Research Centre (and subsequently the Marine Institute from 1996) began collecting records of all of the stocking activities in Ireland in an effort to establish the scale of restocking programmes i.e. the number and size of the rivers being stocked, the numbers and source of any wild fish being removed for broodstock purposes and the possible impacts and effects on wild salmon stocks. Under this programme, (ESOPS, Enhancement Stocks – Origin, Progress and Status) all hatchery operators have been requested to supply details of the broodstock captured, eggs produced, and all locations, dates and numbers of progeny at each life stage released into the wild. In this way a comprehensive overview of the stocking activities in Ireland has been produced since 1995.

In order to quantify the returning adults from the various stocking strategies using different life-history stages of Atlantic salmon in Ireland, conversion factors for the survival of eyed ova, unfed fry, fry and parr to the smolt stage are required. These have derived from deEyto et al., 2007, McGinnity, 1997 and McGinnity (pers. comm). Subsequently, conversion of smolts to adults is based on returns from the Irish National Coded Wire Tagging and Tag Recovery Programme (Ó Maoiléidigh et al, 2001). The conversion factors used are presented in Table 1. A distinction is made when converting smolts from plantings to adult returns and smolts reared entirely in the hatchery to adult returns. In the former, the survival rates generated in the National CWT programme for "wild" Irish smolts is used which would be considerably higher in most instances than hatchery reared smolts. Similarly, the exploitation rates used for adults derived from the returns of planted smolts is also based on the wild exploitation index on the assumption that the planted progeny will have spent more time in the wild and will subsequently behave more like true wild salmon. This will result in higher overall returns of planted hatchery progeny (eyed ova to parr) than assuming survivals and exploitation rates derived for smolts reared entirely in the hatchery.

The main objective of most restocking programmes in Ireland has generally been to restore depleted salmon stocks. While often significant returns of salmon have been generated from these programmes, the difficulty has been in gauging the long term success of the strategy. This was essentially due to the lack of an acceptable population "benchmark" with which to measure the outcome of the restocking projects.

In 1998, the **North Atlantic Salmon Conservation Organisation** (NASCO, 1998) adopted the precautionary approach to fisheries management (as outlined in FAO, 1995, 1996). Central to this was agreement that management measures should be aimed at maintaining all salmon stocks in the NASCO Convention Area above pre-agreed Conservation Limits. The Conservation Limit for Atlantic salmon is defined by NASCO as:

"the spawning stock level that produces long term average maximum sustainable yield as derived from the adult to adult stock and recruitment relationship".

Ideally river specific stock and recruitment analysis would be the most accurate way to determine river specific Conservation Limits (Crozier *et al.,* 2004). However, the acquisition of these relationships is resource intensive as they require a long time scale to cover many generations and a wide range of stock levels. Typical relationships are based on 20 to 30 years of stock and recruitment data. It will, for the foreseeable future, be necessary to transport CLs from data-rich rivers to data-poor rivers (Prévost *et al*., 2003). To this end a Bayesian hierarchical modeling framework has been developed to transport stock and recruitment information between rivers and to set Conservation Limits for individual rivers accordingly (Crozier *et al.,* 2004, Ó Maoiléidigh *et al.,* 2004). These Conservation Limits form the basis of the "benchmark" used in this study to gauge the overall and long term success of these stocking programmes.

RESULTS

Table 1 provides a summary of salmon hatchery stocking activities in Ireland since 1995. The total number of eggs produced in all stocking programmes combined has ranged from 4.5 million to 10.8 million (average 7.6 million) per annum. The scale of stocking with the various life stages has varied, but stocking with unfed fry has dominated numerically with upwards of 4.5 million being planted in some years (average 3.2 million). One year old smolts were the next most dominant life-stage with up to 790,000 being released (average 575,000). Parr releases are also significant with up to 614,000 released (average 383,000). Stocking with eyed ova and fry has also been carried out but at a lower volume.

Between 1,300 and 2,354 adult males and 1,448 to 2,763 females have been used annually to generate the progeny for stocking with the ratio usually close to 1:1. Since 1995, up to 17 separate hatchery facilities have been in operation with between 10 and 12 in recent years. This includes small satellite rearing facilities which may take progeny from other hatcheries. Generally speaking the national output of juvenile stages for restocking programmes has been remarkable consistent over the years.

Stocking strategies have been quite variable even within individual rivers (Table 2). Some rivers have been stocked consistently over the years while others have had very small or sporadic introductions. Eight rivers have only been stocked on a single occasion. Forty five individual rivers, out of a possible 150 or so salmon rivers nationally, have been stocked in the last 15 years to some degree. Of these 8 have had eyed ova planted, 30 have been stocked with unfed fry, 18 with fry, 22 with parr, 21 with 1+ smolts and 3 with 2+smolts. There are four major hatcheries producing the bulk of the material i.e. the Erne at Cathaleen's Fall, the Shannon at Parteen, the Lee at Inniscarra and the Corrib at Cong. The former three release salmon as part of a programme to mitigate for lost production due to the building of hydro-electric dams on these rivers. Eyed ova planting has been important numerically in the Erne and the Owenmore rivers

in some years. Similarly, significant stocking with unfed fry has taken place on the rivers Shannon, Erne, Cork Blackwater, Lee and Barrow. Stocking with fry has extensively taken place on the Shannon, Cork Blackwater (in one year only), the Erne, Deel and Screebe. Parr have been stocked at high levels into the Corrib, Erne, Shannon and Lee while smolts (1+) have been used extensively in the Shannon, Erne, Lee and Bundorragha. Stocking with 2+ smolts has not be extensively carried anywhere during this period.

The magnitude of the potential returns estimated from these releases has been compared to the individual Conservation Limits for these rivers to gauge, at least in numerical terms the possible contribution these stocking activities might have on the wild stocks. The issue of quality of the returning fish and their ability to perform as well on spawning beds or in survival through subsequent life-history stages compared to wild stocks is not dealt with in the instance.

Given that the primary aim of most stocking programmes is to restore depleted stocks, rivers have been grouped according to whether they are currently failing to meet Conservation Limits and those which are already meeting CLs. Within the category of rivers failing to meet Conservation Limits currently, rivers which are subject to mitigation measures due to the building of hyrdo-electric dams are dealt with separately. In this instance rivers which are being stocked but where the intention is to harvest or remove all of the returning adults are not included in this analysis as the progeny are not expected to contribute to wild runs subsequently (i.e. Burrishoole, Bundorragha, Screebe).

There are 10 rivers (without hydro installations) which are failing to meet Conservation Limits and which have been stocked at some time or another in the last 13 years. In the case of the Rivers Boyne, Barrow, Nore, Suir, Maigue, Fergus and Eske, the estimated return from the stocking programme was on average 5% or less than the Conservation Limit required for these rivers in numbers of salmon. Stocking has been intermittent, and was mainly carried out up to 2000 for four of the former rivers. Consistent stocking has taken place on the Maigue since 1995 and on the Fergus since 2000 but these rivers are still consistently failing to meet their Conservation Limits (attainment of CL 16% for the Maigue and 29% for the Fergus).

For the River Deel, estimated returns should have potentially generated between 10 and 40% of the spawning population on average in some of the early years, but more recent contributions would be far less.

Consistent stocking has also taken place on the River Bunowen and potential estimated returns representing on average 10% of the Conservation Limit have been attained. However this river is only meeting 68% of its Conservation Limit currently.

There are four rivers which have been harnessed for hydro-electrical power generation. Of these the highest estimated return of hatchery fish relative to the Conservation Limit is to the River Lee, with over 10% of the required Conservation Limit being generated.

However, despite consistent restocking this river is estimated to be only meeting 2.2% of its Conservation Limit (based on the runs of wild fish past the fish counter) suggesting that the overall contribution of the hatchery fish is probably much less. Early restocking programmes for the river Erne are likely to have generated up to 40% on average of the returns required to meet the Conservation Limit. However, more recent contributions are estimated to be much lower (less than 5%) and the river is far below its Conservation Limit (only 9.5% of Conservation Limit being attained currently based on upstream counts). Both the Liffey and Shannon are only generating a small fraction of the Conservation Limit in numbers of salmon.

There are 12 rivers meeting or exceeding their Conservation Limit where stocking is carried. Again, stocking is variable both in numbers and frequency. In nearly all instances, the returns generated are far higher in proportion to the required Conservation Limit than the rivers which are failing to meet their Conservation Limits. The longest series of stocking activities are for the Cork Blackwater, Caragh, Corrib, Ballinahinch, Erriff, Owenmore and Crana. Returns relative to the Conservation Limit requirement have varied over time and between rivers but generally have been between 5 and 20% on average. Extensive stocking in some years has resulted in the returns of hatchery fish being higher than the Conservation Limit requirement with this increase representing a doubling in some instances.

DISCUSSION

Stocking and rearing salmonids is an established technique for artificially increasing their productivity with the objective being to increase the adult numbers available to the system. In recent years, up to 1 million reared salmon smolts have been released into Irish rivers. There is also extensive use of eggs, fry and parr to supplement these smolt releases. Artificial propagation has the advantage that the mortality associated with juvenile development in the wild (over 95%) can be substantially reduced by rearing the progeny of wild or artificially produced parents to eyed egg, fry, parr or smolt stage, in the relative safety of a hatchery. This is due to the elimination of many of the factors (competition for food, predators, disease etc) which normally operate on the wild population and limit production under natural circumstances. Some river systems are dependant on stocking to establish an annual run of migratory salmonids and in the short to medium term stocking may be the only viable method of maintaining high levels of smolt output. In general however, stocking has come to be regarded as a panacea for any river system which has, or appears to have, a reduced stock. Stocking in the past has generally been carried out in systems where the natural productivity was not known, and invariably, follow up surveys were not carried out to assess the actual benefits of the stocking operation.

The term stocking is defined as
"*the deliberate release of Atlantic salmon into the wild at any stage of their life-cycle for enhancement, mitigation, restoration, rehabilitation or ranching purposes*" (NASCO 2006).

Stocking with hatchery reared salmon has been carried out in Ireland since the start of the 1900's usually with the intention of to boosting stocks or as a response to specific management problems such as fish kills caused by either chronic or acute pollution incidences, loss of habitats due to impoundments or other land use activities. In Ireland this practice has not been widespread and generally the hatchery progeny have been released in their parents river of origin and relatively few rivers have had introductions of non-indigenous fish. The number and locations of hatcheries operating in the 13 years examined in this review are probably not much different for the past 30 years or so. Unfortunately, there has been little follow up assessment as to the efficacy of this practice with regard to generating adult returns and more importantly the real contribution to spawning and subsequent generations by way of electro-fishing, smolt trapping, mark-recapture studies, catch samples and catch surveys. In many respects, the goal of the hatchery programme should be to establish a self sustaining run of salmon (i.e. a return of salmon which meets and exceeds its Conservation Limit). There should be no further need for the hatchery unless other persistent problems have not been eliminated and the goal has not been achieved.

In general the results above suggest that the contribution being made by hatchery reared intervention (in this instance simply in terms of adult numbers being generated) is minimal for rivers where the stocks are failing to meet Conservation Limits. The objective of establishing self-sustaining runs of salmon in the first instance and the further objective of meeting the required Conservation Limit are unlikely to be fulfilled with the present strategy. The overall problems associated with the operation of hyrdo-electric dams add further complications and difficulties in meeting these objectives and it is likely that restocking with hatchery progeny will not in itself provide the solution and in fact may limit the re-establishment of small quasi-wild populations which could have established following extensive restocking in earlier years. The presence of such populations (i.e. returning adults which were not released as eggs, fry parr or smolts but are the offspring of fish which had spawned naturally in the wild) needs to be verified in order to protect early establishing populations A first step in this instance would be to cease restocking in these areas in order to identify if and where there are such small but established populations and steps taken to avoid any further restocking which might cause a reduction in the fitness of the newly established population e.g. by hybridization with less well adapted newer introductions or direct competition for resources.

There are several rivers in Ireland meeting and exceeding their Conservation Limits that are stocked extensively. The subsequent returning adults can represent a significant addition to the adult spawning population and there should be concerns relating to the negative impacts of genetic introgression if this proportion is large and persistent. The counter argument that these stocks would fail to meet their Conservation Limits without this intervention should be critically examined in light of current information on genetic interactions. The idea of "boosting" the natural productive capacity of a river or stream may seem desirable but this must be balanced with the possible negative genetic consequences in the long term (McGinnity et al, 2003). Certainly, the need to stock into rivers which are clearly meeting the productive capacity naturally should be examined

both in terms of potential negative biological effects on existing wild stocks, the concerns about using hatchery progeny as a legitimate conservation management tool and simply whether it is good value for the money being invested in these programmes.

Other methods of stock enhancement exist and recent management measures aimed at restricting or eliminating mixed stock fisheries, restricting recreational and in-river commercial fisheries, have been put in place in Ireland and should allow a significantly higher proportion of spawners to access freshwater and their spawning areas. Significant EU legislation now exists to improve water quality and this should also have benefits in terms of salmon stock restoration. There is clearly a need to establish a policy with regard to stocking practices, which will protect wild stocks from indiscriminate stocking or other population manipulation and identify appropriate circumstances for the use of hatchery reared Atlantic salmon.

On the basis of the results presented here we conclude that extensive stocking programmes undertaken in Ireland over the last thirteen years have made little real contribution to the productivity of Irish rivers or to the goals of restoring self-sustaining salmon runs. Furthermore, evidence from recent experiments suggesting that artificial introductions are likely to depress rather than enhance the productivity of natural populations, including feral or quasi-wild populations that have been established by successful hatchery programmes, suggests that more caution and planning is required before hatchery reared progeny are released into the wild . Consequently we recommend that the terms of reference of and the current supportive breeding programmes being undertaken in Ireland be reviewed in the light of the data presented here.

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Table 1 Conversion rates for the survival of juvenile stages of salmon to the smolt stage, survival rates of wild smolts to adult returns and exploitation rates on wild salmon. The lower panel has the survival rates of hatchery reared smolts to adult returns and exploitation rates on hatchery reared salmon released as smolts.

Period	Eyed ova to smolt Min	Max	Unfed fry to smolt Min	Max	Fry to smolt Min	Max	Parr to smolt Min	Max	Smolt to adult (from planting) Min	Max	Expl. rate on adults (from plantings) Min	Max
1995-1999	*0.005*	*0.034*	*0.005*	*0.034*	*0.070*	*0.130*	*0.150*	*0.370*	*0.080*	*0.20*	*Min*	*0.6*
2000-2007	*0.005*	*0.034*	*0.005*	*0.034*	*0.070*	*0.130*	*0.150*	*0.370*	*0.064*	*0.06*	*0.3*	*0.4*

Period	Hatchery smolts to adults Min	Max	Expl. rate of hatchery smolts Min	Max
1995-1999	*0.01*	*0.08*	*0.6*	*1.0*
2000-2007	*0.01*	*0.05*	*0.3*	*0.9*

Table 2 Stocking of various life-stages of Atlantic salmon in Ireland since 1995

Jan - Dec	Production	Stripping		Production Eyed Ova		Released (Jan - Dec)						
Year	Hatcheries	Male	Female	Million's	Av./F.male	Eyed Ova	Unfed Fry	Fry	Parr	Smolts 1	Smolts 2	Total
1995	13	2,046	2,205	6.750515	3,061	113,360	464,413	3,031,750	488,513	295,196	0	**4,393,232**
1996	17	2,016	2,082	7.321852	3,517	185,877	3,209,351	217,300	307,192	520,199	0	**4,439,919**
1997	17	1,869	2,109	8.189486	3,883	226,420	3,735,658	544,398	443,318	500,389	140	**5,450,323**
1998	17	2,339	2,763	10.842924	3,924	1,167,237	4,158,878	502,329	348,898	460,311	0	**6,637,653**
1999	13	2,354	2,454	9.456507	3,854	0	4,227,732	114,909	256,675	610,071	650	**5,210,037**
2000	12	1,712	2,020	9.206557	4,557	*227,458*	*3,814,682*	*0*	*116,927*	*493,726*	*0*	***4,652,793***
2001	12	2354	2622	8.151113	3108	144,240	3,466,630	82,240	349,304	526,297	3400	***4,572,111***
2002	13	1,633	1,951	7.767942	3,981	75,020	2,929,323	57,000	600,158	598,246	0	***4,259,747***
2003	15	2,088	2,208	8.009743	3,627	257,969	3,495,993	138,106	314,924	770,618	0	***4,977,610***
2004	14	1,634	1,753	6.732957	3,841	94,640	2,575,193	67,900	286,753	606,426	0	***3,630,912***
2005	14	2,306	2,463	8.450144	3,431	131,164	4,585,800	98,500	422,785	661,439	5,995	***5,905,683***
2006	12	1,816	1,907	6.64129	3,483	137,030	3,181,205	72,000	426,388	790,711		***4,607,334***
2007	10	1,370	1,448	4.930522	3,405	6,500	1,946,216	30,800	614,070	640,397	0	**3,237,983**
2008	12	1,525	1,575	4.596473	2,918	65,000						
Average		1,933	2,111	7.6462875	3,614	202,280	3,214,698	381,326	382,762	574,925	849	4,767,334

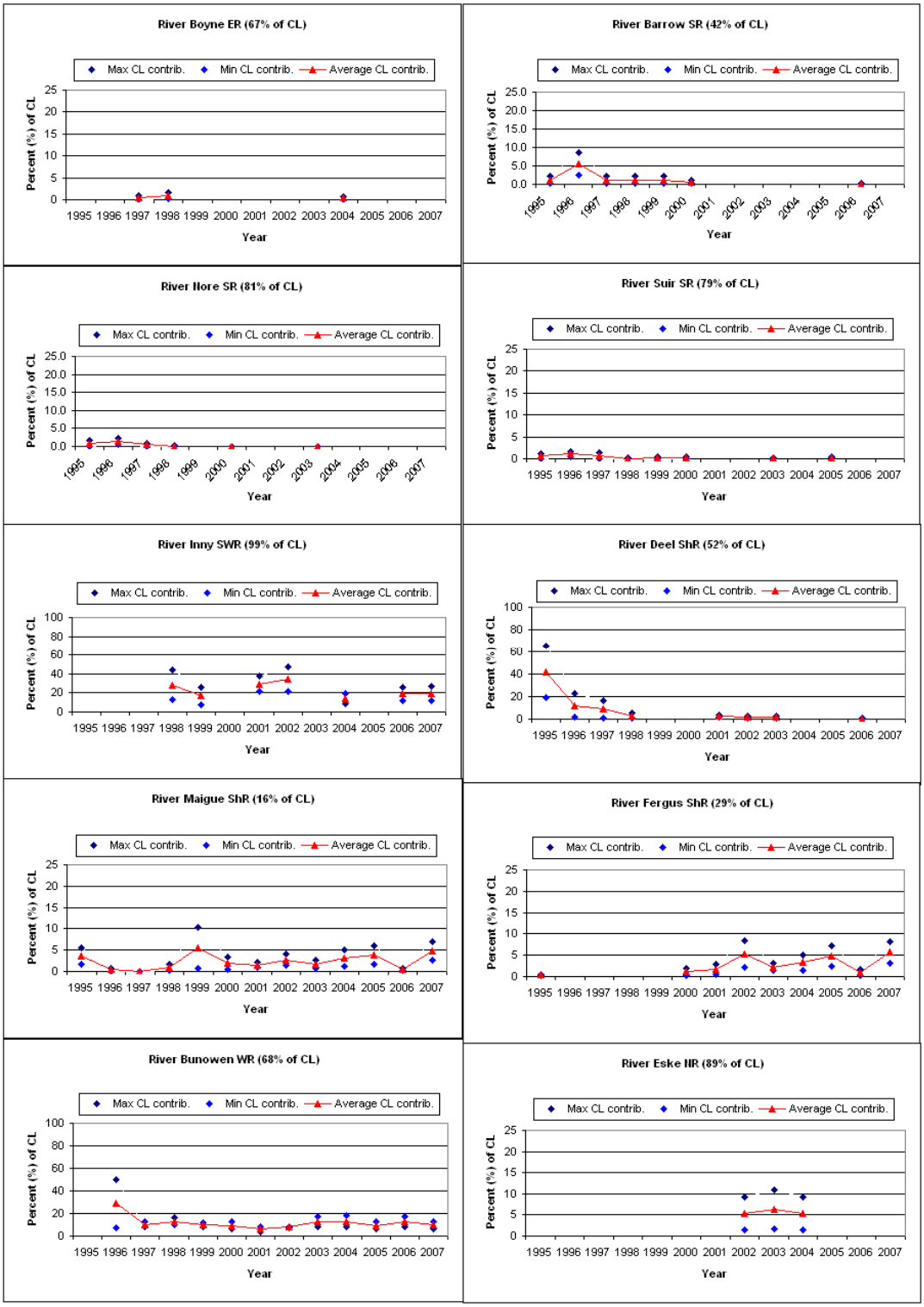

Figure 1 Estimated potential returns of hatchery reared Atlantic salmon relative to Conservation Limit requirements – Rivers currently below CL

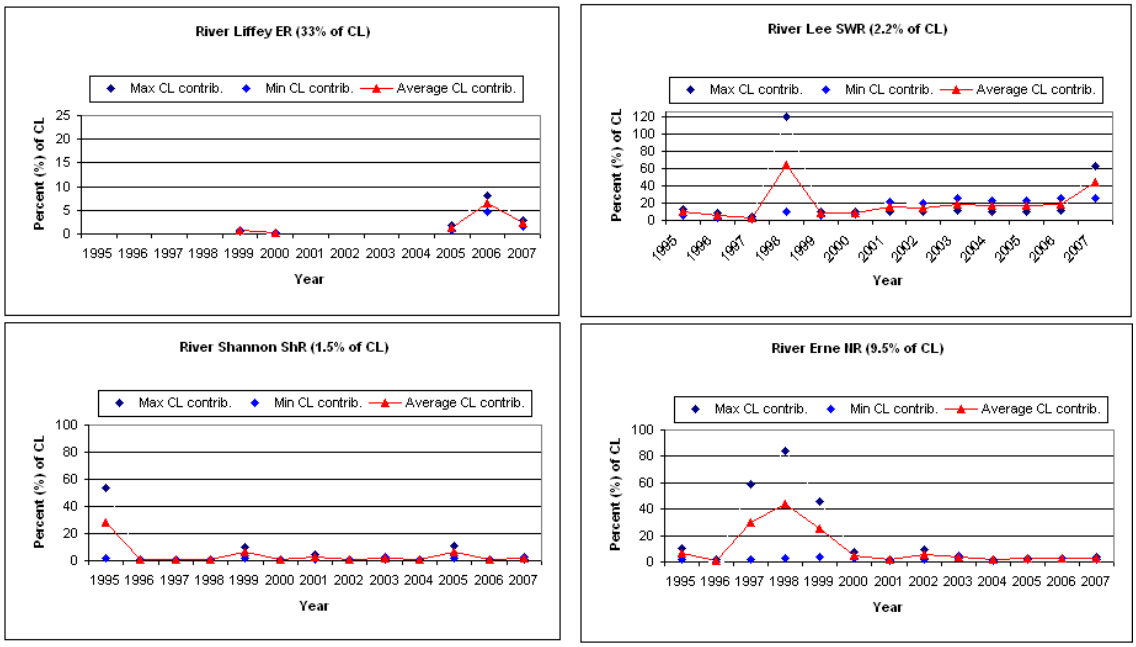

Figure 2 Estimated potential returns of hatchery reared Atlantic salmon relative to Conservation Limit requirements – Rivers currently below CL and with hydro-electric installations

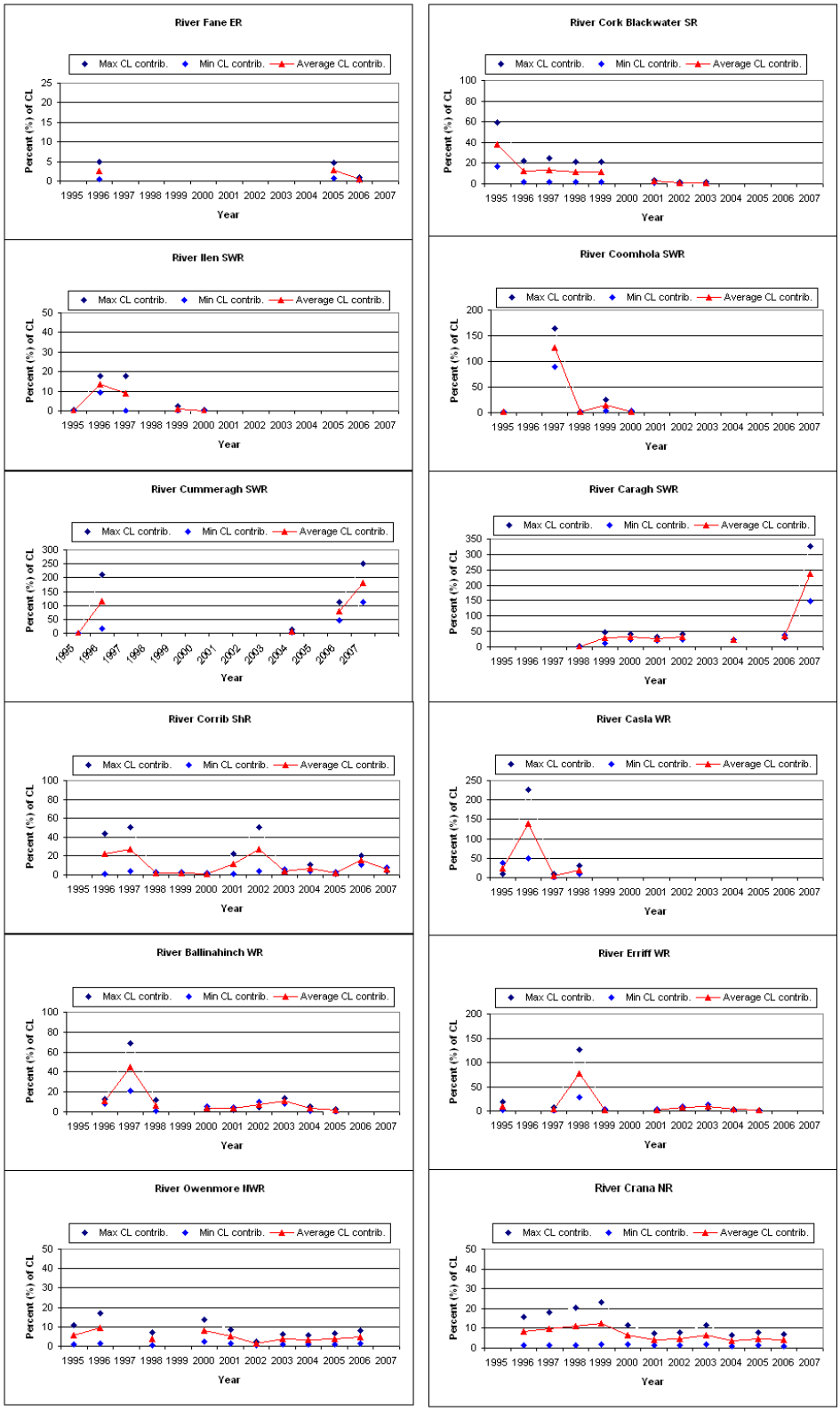

Figure 3 Estimated potential returns of hatchery reared Atlantic salmon relative to Conservation Limit requirements – Rivers currently above CL

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