Use of Biological Reference Points for the Conservation of Atlantic Salmon (*Salmo salar* L.) in the River Lune, North West England.

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Abstract

This paper deals with the development and use of biological reference points for salmon conservation on the River Lune, England. The Lune supports recreational and net fisheries with annual catches in the region of 1,000 and 1356 salmon respectively. Using models transported from other river systems, biological reference points exclusive to the Lune were developed; specifically the number of eggs deposited and carrying capacity estimates for age 0+ and 1+ parr. The conservation limit was estimated at 11.9 million eggs and between 1989 and 1998 was exceeded in two years. Comparison of juvenile salmon densities in 1991 and 1997 with estimates of carrying capacity indicated that 0+ and 1+ parr densities were at around 60 % of carrying capacity and may relate to the number of eggs deposited in 1990 and 1996 being approximately 70% of the target value.

The paper discusses the management actions taken in order to ensure that the management target of the conservation limit being met four years out of five is delivered. It also discusses the balance between conservation and exploitation and the socio-economic decisions made in order to ensure parity of impacts on the rod and net fisheries. The regulations have been enforced since 1999 and the paper concludes with an assessment of the actions taken to deliver the management targets, over the last five years.

Key words: Biological Reference Points, *Salmo salar*, Fisheries management.

Introduction

Biological Reference Points (BRP) have been developed in order to provide managers and scientists with an ability to assess the status of their fish stocks and evaluate and manage the level of exploitation. BRPs take two forms; *limits* (*conservation limit*) and *targets* (*management target*) [United Nations 1995; FAO 1996; Garcia 1996). The conservation limit is the point below which the stock level should not fall, and the Agency has defined that stocks should exceed the limit four years out of five (Environment Agency 1998). The management target is the stock level to aim at to ensure the desired outcome and in the case of salmon management in England and Wales reflects the conservation limit and the probability of falling below the limit (Potter, MacLean, Wyatt and Campbell 2003).

The use and derivation of various BRPs for managing salmon has been reviewed by Potter et al. (2003). Of the various options ICES (1995) concluded that salmon should be managed around the stock level which would provide the maximum sustainable yield and this stock level has been adopted by NASCO (1998) as the conservation limit. The harvest strategy adopted by NASCO (1998) is one of fixed escapement whereby salmon can only be harvested once the spawning requirement has been met (Hilbourn and Walters 1992).

The Lune net fishery is presently regulated through a Net Limitation Order (NLO) that effectively limits the number and types of nets that can legally operate. A NLO is time limited and must be reviewed every 10 years. At the end of 1999 the NLO was due to finish and the opportunity arose to assess whether further restrictions on exploitation were necessary to ensure the conservation of the stock. This paper describes the assessment of the status of the stock, the management action taken and the results of that action.

Study Area

Description of the Catchment

The River Lune rises in Cumbria in North West England and flows westward entering Morecambe Bay, south of Lancaster, some 105 kilometres from its source (Figure 1). The catchment (1,223 km^2) is mainly rural with pasture for cattle and sheep, hay and silage production being the primary landuse. The river passes through several small towns and villages with Lancaster, situated close to its confluence with Morecambe Bay, being the main urban area. The catchment has 422.73 hectares of salmon nursery habitat. This is based on a Geographical Information System (GIS) assessment of the total length of river available (346.6 km) multiplied by river widths, measured at the time of routine surveys. It excludes habitat that was not accessible because of impassable barriers.

Description of the Fisheries

The river supports major net and rod salmon (*Salmo salar*) and sea trout (*Salmo trutta*) fisheries. In the period from 1989 to 1999, the salmon fishery supported 37 commercial net fishermen (10 drift nets, 26 haaf nets and 1 seine net), taking on average 2,146 (range: 892 to 3,894) salmon annually. The Lune is also fished by around 1,100 anglers and the average annual catch during the same eleven-year period was 1,332 (range: 793 to 2,100) salmon. The total economic value of the net and rod fisheries (1998 prices) is estimated to be £65.5K and £540K per year, respectively. In addition, the net fishery generates gross revenues of £40K per year and the rod fishery produces gross expenditure of £675K per year (GIBB Environmental. 1999). Of the 37 net fishermen 19 (7 drift and 12 haaf net fishermen) could be regarded as dependent on salmon fishing for part of their income and the remainder classified themselves as recreational fishermen.

Fisheries Monitoring

A Logie 2100A resistivity fish counter is situated approximately 4 km upstream from the tidal limit (Figure 1). The efficiency of the counter at counting upstream migrating salmonids was 86.9% and downstream migrants 79.9% (Aprahamian, Nicholson, McCubbing and Davidson 1996). Electric fishing of juvenile salmonids has been carried out on a six yearly basis with surveys being undertaken at approximately 100 sites in each of the following years; 1991, 1997 and 2003 (Figure 1).

Materials and Methods

Biological Reference Point

The establishment of reference points for the River Lune assumed a Beverton and Holt stock recruitment curve.

$$R = 1/(1/\alpha + \beta/S) \qquad \text{equation 1}$$

Where:

S = Stock (eggs $100m^{-2}$)

R = Recruits (smolts $100m^{-2}$)

α = carrying capacity in terms of number of smolts $100m^{-2}$.

β = egg-smolt survival

The carrying capacity of 0+ and >0+ parr were calculated using stream order (o) and altitude (a) as follows (Wyatt and Barnard 1997):

$$0{+}\ CC = -1.6113.\ 0.971o.0.0983a.-00779a^2o.-000506a^3.-0002635a^3o.-0.2572o^2.-0.0001328a^3o^2 \qquad \text{equation 2}$$

$$>0{+}\ CC = -2.5440.0.0437a.-002231a^2.-0.0575ao.0.02189ao^2.0.0001881a^3o \qquad \text{equation 3}$$

Where:

o = $\log_e$ transformed Shreve index of stream order (1:50,000)

a = ((Altitude/10) – 14.13) in metres

The proportion of age 0+ and 1+ parr becoming smolts was estimated to be 4.26% and 43.6% (Wyatt and Barnard 1997), respectively. This estimated the carrying capacity of the freshwater habitat at 2.956 smolts 100 m^{-2}, giving a total smolt output of 125,000 smolts. The density-independent survival rate from egg to smolt (β) has been taken as 3.0.

The replacement line was determined assuming density independent survival from smolt to the stage prior to commencement of exploitation (in the fishery of the West coast of Ireland). It was calculated using the following parameters: marine survival (13%), fecundity (5596 eggs) and proportion female (51.6%). The estimate of marine survival is a weighted average assuming a survival rate back to home waters for 1SW and MSW of 11 and 5 % respectively and a proportion of ISW fish in the stock of 85% (Jones and McCubbing 1993). It also assumes that salmon take on average three months to migrate from Northwest Ireland to home waters.

The stock size giving the maximum sustainable yield was 280 eggs $100m^{-2}$ (Conservation limit). The Environment agency has also defined that the acceptable risk of the stock falling below the conservation limit is one year in five. The management target, which reflects this level of risk, was determined by multiplying the standard deviation of the number of eggs deposited between 1989-1998 (69.96) by the 80% point on the normal distribution curve (0.842). This gave a management target of 340 eggs $100m^{-2}$ (Figure 2).

Egg deposition

The number of eggs deposited were calculated as follows:

$$\gamma = ((\delta - a\varepsilon - b\zeta)(1 - c)\eta \qquad \text{equation 4}$$

where:

γ = Total number of eggs deposited

δ = Count of salmon at Forge Weir

a = Correction factor for under declaration of rod catch (1.1)

ε = Declared rod catch

b = Post catch and release mortality (0.15) [Walker and Walker, 1992; Webb 1998; A. Gowans and C. Durie pers. comm.]

ζ = Number of salmon caught and released

c = Pre-spawning in river mortality (0.1) [Clarke, Evans, Elery and Mee 1994]

η = Average fecundity (2,888 eggs).

Exploitation in the net fishery

The average level of exploitation over the period 1989 to 1998 was estimated using average catches for drift and haaf nets as follows:

$$\theta = (d\iota + e\kappa)/\lambda \qquad \text{equation 5}$$

Where:

θ = Exploitation rate

d = Mean number of salmon caught annually by one drift net (142)

ι = Number of drift nets operating

e = Mean number of salmon caught annually by one haaf net (32)

κ = Number of haaf nets operating

λ = Mean total number of salmon entering the Lune prior to any net exploitation (7,431).

The model was used to provide an approximate guide to the level of exploitation that might be expected if the number of nets was reduced. The best estimate of the actual level was derived using the fishermen's individual catch returns.

Results

Status of stocks (1989 – 1998)

The number of salmon entering the Lune, the net and rod catch, the count at Forge Weir and the number of spawners is shown in Figure 3a-e. The mean number of fish entering the estuary over this period, prior to any exploitation was estimated at 7,400 salmon. At the current level of exploitation the net catch of salmon would be approximately 2,200 (mean net exploitation 29.9%) giving a count at Forge Weir of 5,200 and with a rod catch of ~1 370 salmon (mean rod exploitation 26.4%) this would leave potentially 3,800 salmon to spawn.

The management target of 340 eggs $100m^{-2}$ equivalent to a spawning stock of 4,981 salmon, effectively means that on average there was a shortfall of 1, 200 salmon (Figure 4).

Juvenile population (1989 – 1998)

In 1991 the density of 0+ and >0+ parr were 241% and 54% of the levels predicted from the model. In 1997 the densities were 51% and 64% for 0+ and >0+ parr respectively (Figure 5). The higher densities of 0+ parr in 1991, when compared with 1997, are likely to be related to the level of stocking in that year with over 0.7 million 0+ parr stocked. The fact that the > 0+ parr densities in 1991 and 1997 and the density of 0+ parr in 1997 were approximately 60% that predicted from the model suggests that the population is either presently limited by the quality of the habitat or by the number of eggs deposited.

The fact that the numbers of eggs deposited in 1989 & 1990 and in 1995 & 1996 were approximately 70% of the target value (>ca. 340 eggs $100m^{-2}$) suggests that the lack of spawners was preventing the stock from meeting its conservation limit. If this is the case then the output of smolts from the Lune would be approximately two thirds (ca.1.95 smolts $100m^{-2}$) that of pristine conditions (ca.3.0 smolts $100m^{-2}$) where the number of eggs deposited was

not limiting (>ca. 340 eggs $100m^{-2}$). This amounts to approximately 80,000 smolts giving a return to the river of around 8, 000 adults, similar to what was observed between 1989 and 1999 (7, 400 salmon).

Action to meet management target

The management objective for the River Lune is to ensure that the stock is meeting its conservation limit four years out of five while maintaining an economically viable and sustainable fishery. The aim is to ensure that the long-term average number of salmon spawning is 4, 981, giving an egg deposition of 340 eggs $100m^{-2}$. During the period 1989 – 1999 spawners numbers averaged ~3, 800 effectively ~1, 200 salmon less than the required amount.

To achieve the target of ~5,000 spawners, exploitation by the net fishery would needed to reduce to below 15% (Figure 6). This could be through a number of combinations ranging from 2 drift plus 26 haaf nets to 7 drift and 5 haaf nets (Figure 7).

Of the 36 fishermen possibly effected by the need to reduce exploitation, 19 (7 drift net and 12 haaf net fishermen) were dependent on salmon fishing for part of their income. However, based on the individual fisherman's catch record protecting the 19 dependent fishermen would not however achieve the required reduction in exploitation to 15% but would only achieve a reduction to 16.5% (Table 1). Protecting all the fishermen but reducing the number of days available to fish was considered, but the reduced catch was not adequate to provide an economic return to the netsmen. Thus for social reasons and to try and ensure an economically sustainable fishery it was decided to guarantee the livelihood of the 19 dependent netsmen.

The reduction in net exploitation to 16.5% would lead to an extra 1,054 salmon entering freshwater and vulnerable to exploitation in the rod fishery. Mean exploitation in the rod fishery between 1989 and 1998 was 26.4%, thus of the 1,054 extra salmon it would be expected that 278 fish would be killed in the rod fishery, 78 would die before spawning which would leave potentially 698 salmon to spawn. Supporting the 19 dependent fishermen resulted in a shortfall of 146 salmon which together with the expected increased catch of 278 fish meant that 424 rod caught salmon need to survive to spawn. The predicted effect of reducing net exploitation would be to increase the mean annual catch to 1,634 salmon this represents the mean catch between 1993 and 1998 of 1,356 plus the additional 278 salmon.

Options available to reduce angling fishing effort included method restriction, season restriction or bag limit or a combination of the options. There was not enough information on the effectiveness of different methods employed by anglers and because of uncertainty in run-timing and abundance of different cohorts the outcome of any regulation was difficult to predict. Bag limits were an option that would allow changes to be modelled and was acceptable to the angling community.

The frequency distribution of catch by individual anglers ranged from zero to greater than 20 salmon caught by an angler per year (Figure 8). Assuming 1198 anglers (mean 1993-1998) fishing per year and an annual catch of 1634 salmon the effect of various bag limits on the number of salmon spawning suggests that a four fish bag limit would ensure that >424 fish would survive the rod fishery so that the management target of ~5,000 salmon was met (Table 2). (To be over precautionary, a catch and release mortality of 40% was assumed, in this scenario). The effect of the 4 fish bag limit on the exploitation rate (taken as the percentage of fish killed as opposed to the percentage of fish caught) was estimated to reduce the rate by

9.4% to 17%. This also assumes that there will be little redistribution of catch between anglers.

Outcome of management actions

In 2000 the following management actions were taken to ensure the conservation limit was met 80% of the time:

- Net fishery was reduced to 12 haaf nets and 7 drift nets
- Rod fishery – bag limit of 4 salmon.

The effect of the management action during the period 2000 – 2004 is shown in the Figure 9 a&b. In all four years the management target of approximately 5000 salmon was met and the density of juvenile salmon recorded in 2003 had improved substantially. The net exploitation over the five year period averaged 13.82%, ranging from 5.7 to 18.3%. The rod exploitation in terms of percentage of the stock caught averaged 14.8% (range: 10.0 – 18.9%) and in terms of percentage killed the mean was 7.96% (range: 5.0 – 10.7%).

Discussion

Biological reference points provide an objective measure of assessing the status of stocks and determine whether any management action is required (Potter et al. 2003). Ideally the reference points should be based on the stock- recruitment relationship for the individual salmon stock (ICES 1995). For the Lune no specific stock-recruitment curve exists and the main uncertainties relating to the parameters used to derive the reference points are the values used for the maximum reproductive rate, the carrying capacity and marine survival. Sensitivity analysis was carried to investigate which combination of α, β and marine survival best explained the current situation.

Juvenile production is presently limited either by the quality of the habitat or by the number of egg deposited and there is certainly evidence to suggest that the population was currently limited by the number of eggs deposited (Figure 4). The numbers of eggs deposited in 1990 and 1996 (giving rise to the 1991 and 1997 year-classes) were approximately 70% of the target value which ties-in with the observation that parr and fry densities were at around 60 % of carrying capacity (Figure 5). Thus there is no major evidence suggesting that the carrying capacity is below potential (2.956 smolt $100m^{-2}$). In hindsight this is also supported by the 2003 survey results (Figure 9b).

If it is accepted that net exploitation (29.9%), rod exploitation (26.4%) are reasonably accurately known and that there is no major evidence suggesting that the carrying capacity is below potential (2.956 smolt $100m^{-2}$). Then the remaining areas of uncertainty in generating Lune specific reference points were marine survival and egg to smolt survival. The values used to determine the conservation limit were those which came closest to describing the observed situation. These were a marine survival of 9 - 10% and egg-smolt survival of 2 - 3% (Figure 10). Certainly a marine survival of ~10% is consistent with data from other British rivers, specifically the North Esk (ICES 2003) and the Welsh Dee (I. Davidson pers. comm.) both of which are intensively monitored. The value used for the density-independent survival rate from egg to smolt (β) was taken as 3.0. This is similar to that found on the River Bush (N. Ireland) of 3.03% and slightly higher than that reported from Girnock Burn (Scotland) of

2.0% (Wyatt and Barnard 1997). Also, Myers, Bowen and Barrowman (1999) have shown for a number of North American rivers the value to range from 0.7-8.9% with a mean of 4.3%

Deterministic models were used to assess the likely impact of management actions and sensitivity analysis to determine the optimal outcome. The management action taken does appear to have ensured an economically sustainable net and rod fishery. The net exploitation was inline with that predicted from the model however, the lower than expected rod exploitation rate can be explained by 1) the foot and mouth epidemic in 2001 which reduced access to the river as did the drought in 2003 and 2) there has been a major change in attitude towards the killing of salmon. Since 1993 there has been a steady increase in the percentage of salmon released following capture to about 50% (Figure 11).

The Environment Agency, following the advice of NASCO, has adopted the MSY reference point as the conservation limit. This reference point has certain advantages over maximum smolt and the replacement point as it can be defined mathematically irrespective of the stock-recruitment relationship and ensures some level of exploitation of the stock (Potter et al. 2003). However, MSY does have two disadvantages. Firstly the reference point that stakeholders, both net and rod fishers, can most easily identify with is maximum smolt as opposed to maximum catch. The stakeholders have a desire to contribute towards salmon management and intuitively there is a belief that the aim should be ensure the maximum production from fresh water. This has lead stakeholders to focus a high proportion of their resources into improving the habitat for salmon. However, the implication of a maximum smolt target may not have been considered and on the Lune this equated to an egg deposition level of ~ 430 eggs $100m^{-2}$. This is an increase of 25.5% over the management target (340 eggs $100m^{-2}$) and thus, under present conditions, the stock would only be able to support a catch and release fishery. It is generally assumed that the reference point is based on pristine freshwater conditions maybe not in terms of access to spawning areas, but certainly in terms of habitat quality. Though where there are severe water quality problems which will take a number of years and substantial resources to address intermediate targets may need to be considered. The second disadvantage with the MSY reference point is that it is in part dependent on marine conditions and a deterioration in marine conditions for salmon survival will result in a reduction in the MSY reference point. In recent years there has been a decline in marine survival (ICES 2003). Mangers have two options either to reduce the management target in relation to the new status quo or to maintain the target at the historic level effectively compensating for the change in conditions. So though MSY can be clearly defined mathematically there are issues regarding the impact of changes in marine survival and what management action is appropriate. It also has important implications with regard to the credibility of fishery mangers and scientists with stakeholders as a reduction in marine survival would mean a lower target, which is counter to their belief. This is obviously not an issue with a maximum smolt target but does mean that a proportion of the stock can be killed. Whether these issues are ultimately to be resolved remains unclear, at the moment.

In conclusion BRPs provide an objective way of assessing the status of stocks and they provide a rational for discussion of management options with stakeholders. The actions taken on the Lune do appear to have been successful in meeting the management objective of at least 5,000 salmon annually and increasing the stock of salmon, presumably because the freshwater habitat was under-utilised. Though similar responses to a reduction in exploitation of an increase in the stock available to spawn have been reported elsewhere (Jensen, Zubchenko, Heggberget, Hvidsten, Johnsen, Kuzmin, Loenko, Lund, Martynov, Næsje, Sharov & Økland 1999; Einarsson & Gudbergsson 2003; Dempson, O'Connell & Schwarz 2004) there has not necessarily been a concomitant increase in juvenile production / smolt

output (Dempson *et al.* 2004). This indicates the importance of trying to determine what is the key factor limiting the population.

Management through the use of reference points has the advantage that a minimum spawning biomass is maintained, ensuring that the stock is conserved and, if excess fish are available allowing an abstraction fishery to persist. However, when a stock is below its conservation limit and under threat, it is essential that a framework exists that assists managers to take appropriate action. Instruments need to be available that are flexible and can be implemented rapidly, when action is needed to ensure the conservation of the stock.

The views expressed are those of the authors and not necessarily those of the Environment Agency.

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Table 1. Mean exploitation (range) in relation to differing amounts of fishing effort, for the period 1993-97.

Number of Nets	Selection criteria	Exploitation (fishing - 5 days per week)
30 (10 drift, 1 seine & 19 haaf)	19 dependent netsmen + 11 highest catches	28.8%
25 (10 drift & 15 haaf)	19 dependent netsmen + 6 highest catches	26.2%
19 (7 drift &12 haaf)	Dependent netsmen	16.5%
13 (6 drift & 7 haaf)	Dependent netsmen with >10% dependency on the fishery	13.5%
10 (5 drift & 5 haaf)	Five highest catches for drift and heave nets.	11.9%

Table 2. The number of salmon estimated that would be saved from a 1-5 fish annual bag limit.

Bag Limit	No. taken	No. Released	Died Post release	Total saved	No. anglers affected
1 Salmon	408	1227	491	736	234
2 Salmon	642	993	397	596	154
3 Salmon	796	839	335	504	110
4 Salmon	906	728	291	437	81
5 Salmon	987	647	259	388	61

Figure legends

Figure 1. The Lune catchment showing the location of electric fishing sites and the resistivity fish counter at Forge weir.

Figure 2. The derived stock-recruitment curve for the River Lune showing the position of the conservation limit and management target. Solid curve represents the Beverton and Holt stock recruitment relationship, the dotted straight line is the replacement line.

Figure 3. Trend in the run of salmon entering the Lune prior to any homewater exploitation, net catch, count at Forge weir and rod catch between 1989 and 1999.

Figure 4. Tend in the estimated total number of salmon spawning and the density of eggs deposited between 1989 and 1999 and the relationship to the management target.

Figure 5 Estimate of observed density of juvenile salmon in relation to carrying capacity.

Figure 6. Spawning escapement in relation to exploitation

Figure 7. Percentage exploitation rates for various combinations of drift and haaf nets.

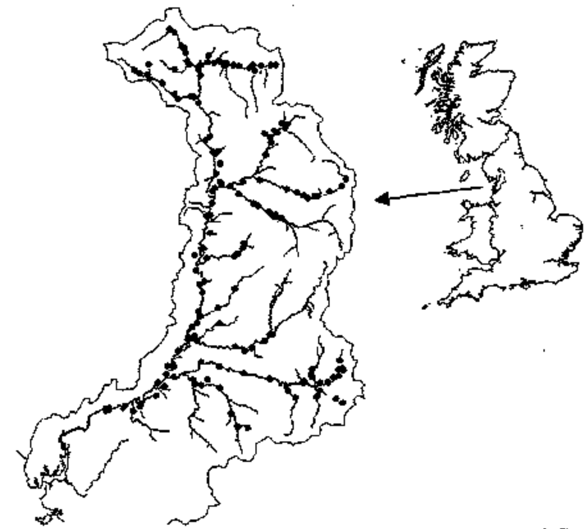
Figure 8. Proportion of anglers catching between 0 and >20 salmon per year (1993-1998).

Figure 9. Estimate of the number of spawners (1989 – 2004) in relation to the management target, (A) and of observed density of juvenile salmon in relation to carrying capacity (B). The restrictions to the net and rod fishery came in at the start of 2000 fishing season

Figure 10. The performance of the Lune stock and how it compares with that estimated under conditions of 9-10% marine survival, 2-3% egg-smolt survival and a carrying capacity of 2.956 smolts $100m^{-2}$ (straight line).

Figure 11. Trend in the percentage of salmon on the River Lune released following capture between 1993 and 2004.

Figure 1. The Lune catchment showing the location of electric fishing sites and the resistivity fish counter at Forge weir.



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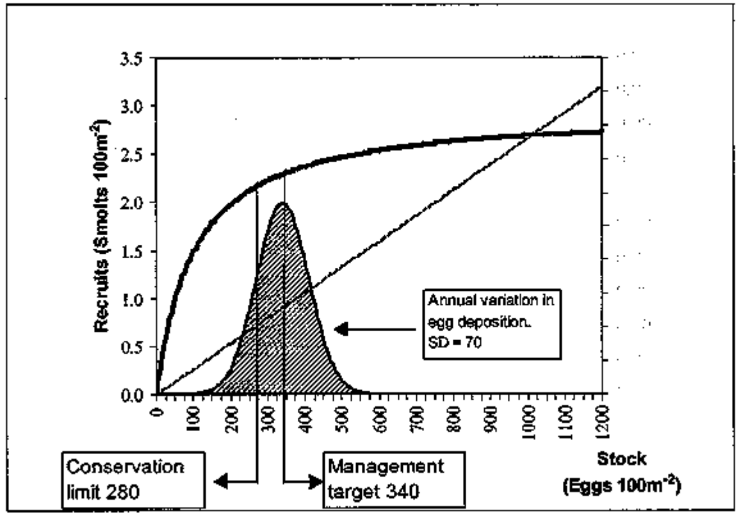

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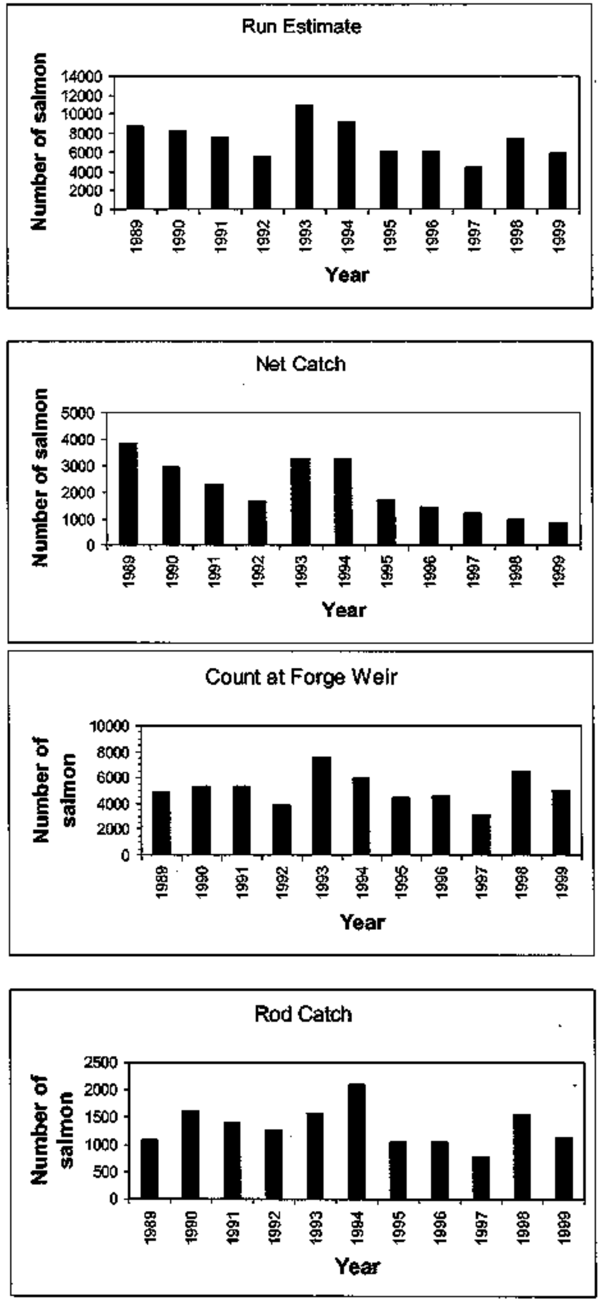

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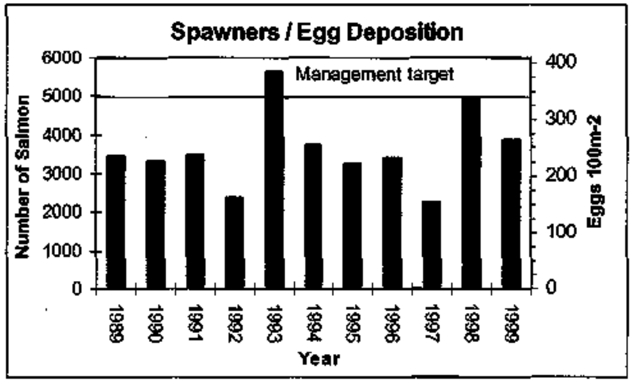
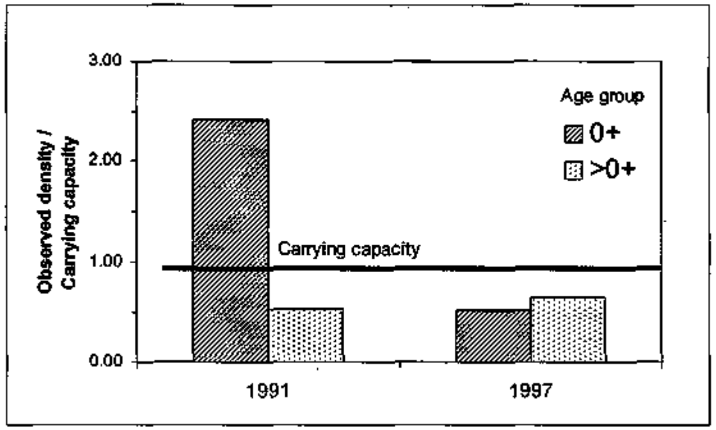


Figure 5 Estimate of observed density of juvenile salmon in relation to carrying capacity.



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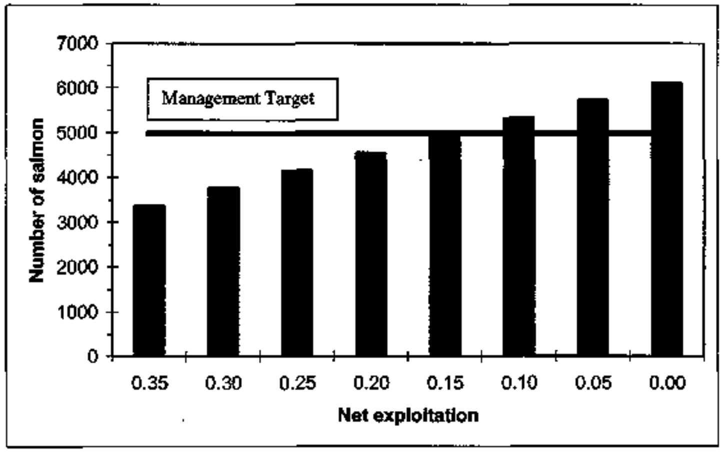


Figure 7. Percentage exploitation rates for various combinations of drift and haaf nets.

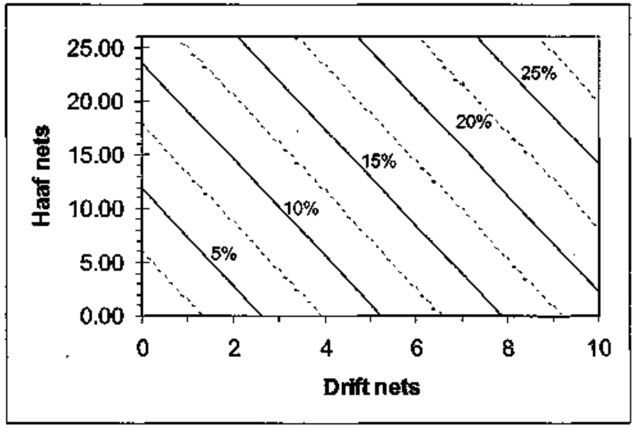


Figure 8. Proportion of anglers catching between 0 and >20 salmon per year (1993-1998)

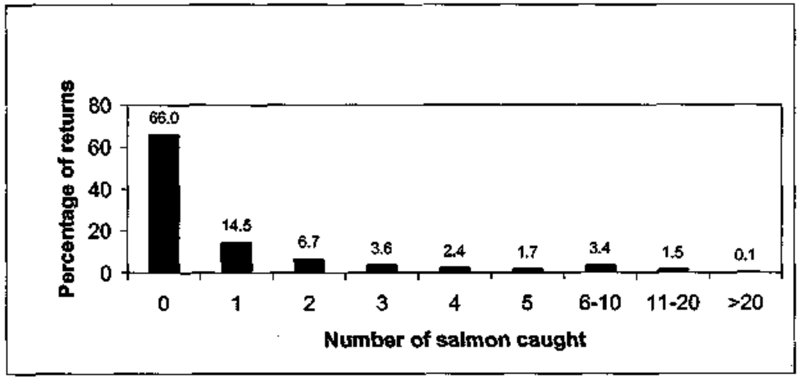
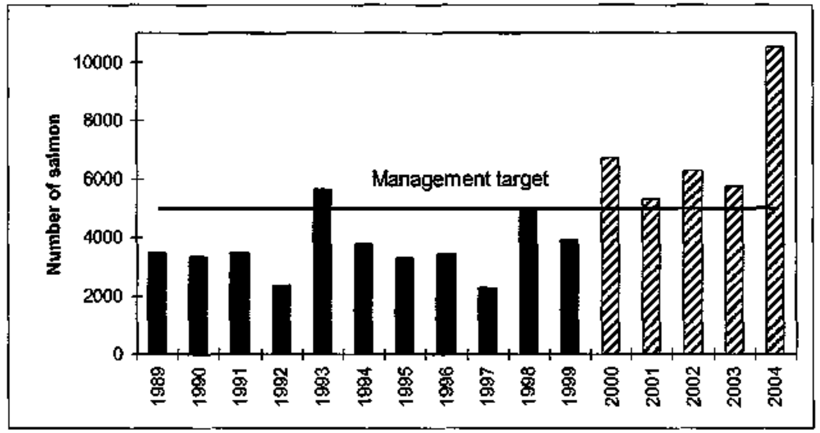


Figure 9. Estimate of the number of spawners (1989 – 2004) in relation to the management target, (A) and of observed density of juvenile salmon in relation to carrying capacity (B). The restrictions to the net and rod fishery came in at the start of 2000 fishing season.



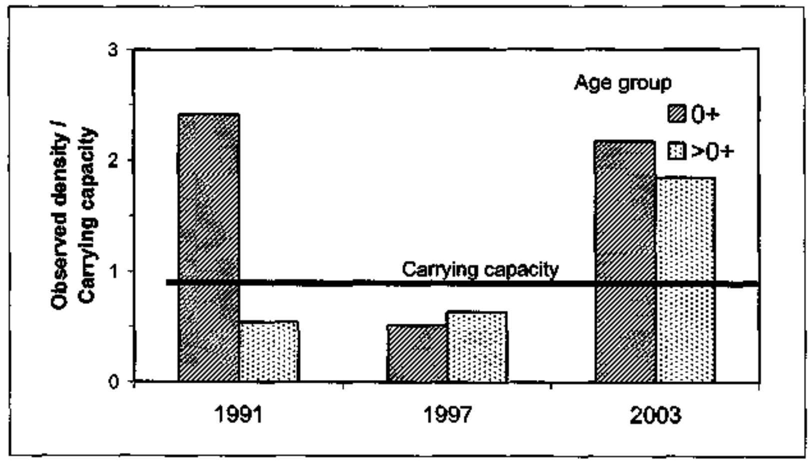


Figure 10. The performance of the Lune stock and how it compares with that estimated under conditions of 9-10% marine survival, 2-3% egg-smolt survival and a carrying capacity of 2.956 smolts $100m^{-2}$ (straight line).

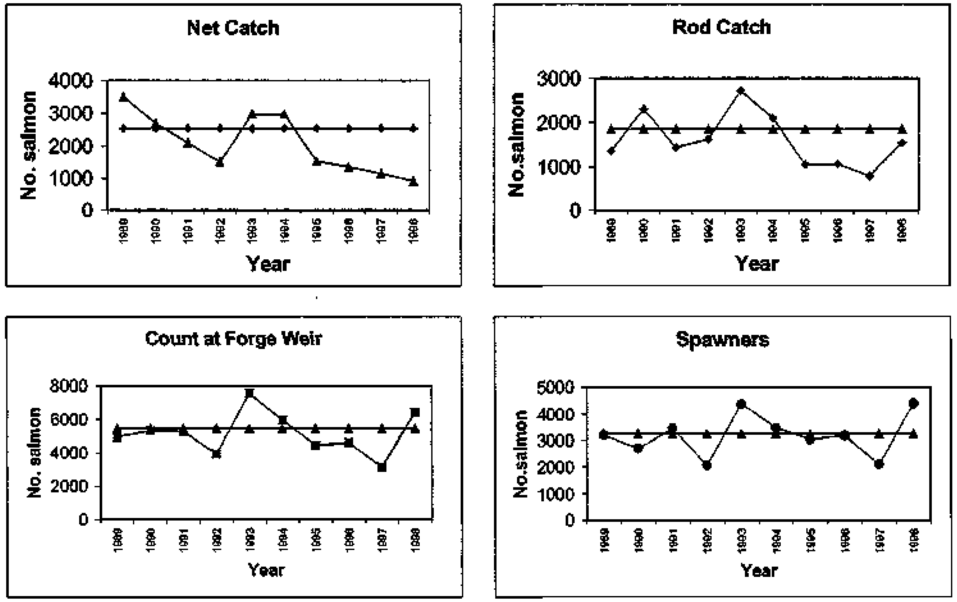


Figure 11. Trend in the percentage of salmon on the River Lune released following capture between 1993 and 2004.