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The role of stocking in recovery of the River Tyne salmon fisheries.

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EXECUTIVE SUMMARY

This report describes the role that stocking has played in the recovery of salmon stocks in the River Tyne. The Tyne salmon rod catch has increased from very low levels in the 1950s to 2,585 in 2002, being the single biggest in England and Wales. This increase has been attributed variously to the stocking programme and to natural processes, but the relative importance of these mechanisms has never been objectively assessed. The stocking programme, through Kielder hatchery, was set up by a legal agreement specifically to mitigate for the loss of salmon spawning and rearing area resulting from the construction of Kielder reservoir in the late 1970s. Objectives of this report were to 1) assess the numerical contribution of stocking to Tyne salmon stocks and rod fisheries, including impacts on the timing and extent of the rod catch changes; and 2) assess the return rates of stocked fish back to the major fisheries.

The demise of the Tyne salmon is attributed mainly to estuarine water quality decline, resulting from industrial and urban sewage pollution that was at its worst in the 1950s. Water quality has greatly improved following reduction in industrial activity and improvements to effluent treatment and disposal during the 1960s to 1980s. The time course of stock recovery appears to have followed that of water quality, which was erratic and inconsistent in the early years. Fish deaths still occur intermittently in the estuary.

No formal monitoring of the Tyne stocking programme has been carried out. The report considers three main sources of information: stocking history, returns to rod and net fisheries from a microtagging programme, and the patterns of rod catch and effort in the Tyne and adjacent rivers. Simple models were used to estimate the total numbers of returning stocked fish based on the microtag returns of sub-samples of 1+ stocked fish. There was uncertainty in the assumed parameters in the models, so minimum and maximum values were used to bracket the likely range about a best estimate, to illustrate the effect of the assumptions.

The annual mitigation requirement is for 100,000 0+ and 60,000 1+ salmon, but the actual stockings have always exceeded the combined total of 160,000, by a factor of 1.6 up to 1986 and by 1.9 up to 2002. Stocking began in 1979, first returns from hatchery-produced parr were in 1980 and estimated returns peaked between 1984 and 1987. Percentage returns of stocked parr to the coast and to the river have declined since the start of the programme, due to overall reductions in marine survival. Estimates of the long term (1980-2000) weighted returns to the coast and river were 0.6% (best estimate, with a range 0.5–0.8%) and 0.3% (range 0.1-0.6%) respectively. Over the same time the weighted contributions to the North East Coast Fishery and the Tyne rod catch were 1.5% (range 1.2-2.0%) and 6% (range 3-14%) respectively. Current (post-1995) contributions to annual rod catch are mainly 2-7%. In the early years, contributions to the run and escapement were higher because the natural recovery was in its early stages. Between 1983 and 1986, annual hatchery contributions peaked between 22 and 42%. The hatchery contribution to total cumulative spawning over the hatchery start-up period (1980 and 1986) was 20% (range 9-43%). Conversely, the natural contribution was estimated at 80% (range 57-91%)

The roles of natural recovery and stocking are discussed. Natural recovery was probably some combination of production from the residual stock that was always

present in the Tyne and straying into the Tyne by salmon from other rivers. Re-colonisation of depleted rivers by natural straying has received little attention, but examination of the literature revealed a number of examples. Even at the low straying rates expected, given the very large source stock of salmon migrating annually through Tyne coastal waters, such a process gives a potential breeding stock of several hundred fish into the river annually. Sea trout catch recovery occurred at rates similar to those of salmon, but with very little stocking. This demonstrates that a species with a broadly similar migratory life history to salmon, and crucially dependent upon estuarine water quality, did recover by largely natural processes. Evidence for natural recovery in Tyne salmon is based on:

- The increasing Tyne catches and fishing effort, pre-dating first stocking returns by at least 15 years. This effect was also seen in the Rivers Wear and Tees.
- The evidence from electro-fishing surveys of juvenile salmon in the North Tyne in 1978/9, pre-dating stocking returns.
- Microtag returns, indicating that the cumulative spawning during the first 6 years of the programme was predominantly from wild fish.

It was not possible to detect a statistically significant impact of stocking on catches. Nevertheless, it is most likely that the overall contribution of 20% (9-43%) to the cumulative run would have accelerated and stabilised stock recovery in its early stages, when water quality improvements were still inconsistent annually. The original intention of stocking was to mitigate for lost salmon production upstream of the Kielder dam, and that has been consistently achieved. There remains an unresolved difficulty in identifying or evaluating the long-term sustainable benefits of the stocking programme, resulting from the later generations of the progeny of hatchery-origin parents. No information on this was available for the Tyne, but genetic studies on this may be feasible and are recommended.

The overall conclusion is that the dominant recovery process has always been natural recolonisation, but stocking was probably an important contributory factor in accelerating and stabilising recovery of the salmon stocks during the early years. Both recovery processes were crucially influenced by the time course of water quality improvement.

The report briefly discusses some implications for stocking, noting that the arguments for or against the use of stocking do not depend solely on the outcome of the River Tyne programme. There are plenty of circumstances where stocking is an important and sometimes essential tool in fisheries management. On the Tyne itself the reservoir mitigation was only practicable through stocking. Continuing intermittent fish deaths in the Tyne estuary present the need to have restoration-stocking facilities on tap. Other rivers in England and Wales will need variously pump-priming or restoration stocking to support stocks. These require hatchery expertise and facilities to be permanently available, for they cannot be mothballed and then brought back on line to any useful timetable. But when and how to use stocking are fishery management questions that can best be answered when informed by the type of assessment offered in this report, which permits an objective evaluation of the benefits.

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1. Introduction

This report describes the role that stocking from Kielder hatchery has played in recovery of the river Tyne salmon stocks. Salmon rod catches on the Tyne have increased considerably since the 1960s, such that the river now produces the biggest rod catch in England and Wales. In 2002 the declared rod catch was 2,585, being 17% of the total. A large net fishery also occurs in coastal waters off the North East coast. This recovery has been attributed to a combination of factors, including water quality improvements, natural processes and stocking. However, some accounts have emphasised the role of the hatchery (Marshall, 1992; Charlton and Francis, 1992; Carrick and Gray, 2001); while others have suggested that its role may be less important than natural processes (Champion, 1991; Environment Agency, 1997).

An objective description of the recovery, evaluating the influence of the stocking programme and other factors, has never been carried out. The benefits of salmon stocking and hatcheries has been debated for over 100 years (e.g. Day, 1887, Anon. 1902, Calderwood, 1924, amongst many others), usually without much factual information to support the arguments. As salmon stocks are in decline across much of the North Atlantic (e.g. Anon., 2002), all management options are under close scrutiny. Stocking has been subject to a number of reviews, better informed now with an accumulation of scientific understanding and information about impacts and benefits (e.g. Aprahamian *et al.*, 2003; Cowx, 1998; Fleming, 2001; Harris, 1994; Hutchinson, 1991; McGinnitty *et al.*, 2003). A review of the stocking programme is timely and of interest in the context of the Tyne recovery in particular and the application of stocking in general.

The overall aim of the report is to establish the extent to which stocking and other factors have been instrumental in the Tyne's recovery. Specific objectives are to: 1) assess the numerical contribution of stocking to river Tyne stocks and rod fisheries, including impacts on the timing and extent of the rod catch changes; and 2) assess the return rates of stocked fish back to the major fisheries. The report focuses on the Tyne stocking programme. It does not review the overall cost-effectiveness of stocking or the performance of Kielder hatchery.

The performance of adjacent rivers, some recovering from degraded states and others regarded as notionally healthy, is examined to provide context for the Tyne study, so brief details of the results of stocking into these rivers are included in the report. Sea trout recovery on the Tyne has also been substantial, but with only very limited stocking. This has been advanced as evidence that natural recovery has been also the dominant process for salmon (e.g. Champion, 1992) and the arguments behind this are discussed.

No formal monitoring of the Tyne stocking programme has been carried out and this presents some difficulties in this evaluation. A further complication is that several factors have been changing simultaneously during the period of recovery, each having potential impacts on its trajectory. The report therefore draws on a range of data and information in taking two broad approaches.

1) Modelling of tag recovery from the extensive microtagging programme initiated by MAFF, for the purposes of evaluating the interceptory fisheries (Jowitt and Russell, 1994).

2) Exploration of long-term rod catches to examine relationships with influencing factors, including the hatchery, marine survival changes and the timing of environmental improvements. These are compared with some hypothetical recovery profiles that might be expected under alternative scenarios.

The report begins with descriptions of water quality changes and the stocking programme, which set the background for the following analysis.

2. Background

2.1 A brief review of water quality changes in the Tyne, Wear, Tees and Coquet

Water quality in the estuary is considered to be a significant factor in the decline and recovery of the Tyne's salmon fishery. It has been the subject of several reports over the last century (e.g. Bull (1931), James (1972), NRA (1996 & 1997)) but, as for the fish themselves, there has been no long-term monitoring programme covering the period described here. Thus closely linking water quality change with fisheries status is not a feasible option. This section sets out to describe water quality changes inferred and, in later years, demonstrated to have arisen as a consequence of industrial and sewerage system changes.

Salmon were formerly very abundant in the Tyne and during the 19th century combined annual rod and net catches of more than 100,000 were reported, although most of this catch was from in-river netting. Uncontrolled exploitation of kelts and smolts was also reported (Netboy, 1968). Catches by both rods (Fig 1) and nets had started to decline during the late 19th century. The in-river net fishery was finally banned in 1934, but was by then effectively not viable due to falling catches and the reluctance of buyers to accept fish that tasted tarry (Netboy, 1968).

While over-fishing was likely to have been a significant factor, the biggest cause for the decline in salmon numbers is thought to have been the deterioration in water quality, particularly in the estuary, due to industrialisation and population growth during the 19th and early 20th centuries (Champion, 1991; Marshall, 1992). Lead and zinc had been mined in the catchment for many centuries, but production peaked in the nineteenth century and ended in 1917. Meanwhile, coal-mining came to dominate the economy of the North East, with the Tyne as its major port. Port development led to major dredging of the estuary between 1860 and 1888 and to increasing industrial activity. Tyneside was home to a variety of industries with significant polluting potential: tanneries, alkali works, breweries, gas works, coke works and abattoirs were among those to dispose of their effluents to the tidal river. The arrival of dependable public water supplies and the water closet resulted in the river receiving large amounts of untreated sewage as well as industrial effluents.

As a consequence, measured water quality in the estuary was bad and led to extensive mortalities of smolts (Bull, 1931). In 1912, zero dissolved oxygen was recorded at Newcastle quayside. A MAFF committee that sat between 1922 and 1931 produced a final report declaring that during the summer months there was serious deoxygenation between Ryton and Wallsend (Marshall, 1992). Given such conditions, it is surprising that the salmon run persisted as long as it apparently did, but records show catches of a few hundred salmon most years through the 1930s (Fig. 1). It was only after World

War II that virtually none were reported. Zero catches were reported in 1951 and 1959.

From this low point, salmon and sea trout rod catches started to recover in the mid-1960s. This is thought to have coincided with the run-down, and final closure in 1967, of an ICI plant at Low Prudhoe, which had been built in 1941 to produce ammonia for munitions and fertiliser. Meanwhile, through legislative change, more extensive powers to control pollution were administered successively by River Board, River Authority, Water Authority, the National Rivers Authority and currently the Environment Agency.

Similar controls on existing discharges to estuaries did not apply until the 1980s, with the implementation of the 1974 Control of Pollution Act. Estuarial water quality continued to improve and several factors may have played a part. The construction of the Tyneside Interceptor Sewer and Howdon sewage treatment works has been well-documented; various industries have closed, most notably Tyneside’s three major coke works and Stella Power Station, or their discharges have been treated. Construction of the sewerage system and Howdon sewage treatment works began in 1973, with the first flows receiving primary treatment in 1980. By 1993, all the major outfalls to the estuary had been connected and the old sewage treatment works at Prudhoe was abandoned in favour of connection to the Interceptor. By the end of 2000, all the minor outfalls were also connected and Howdon sewage treatment works had been upgraded to provide secondary treatment. The last of the three coke works closed in 1985.

The impacts of this on estuarine water quality have been clear: since the 1970s, average dissolved oxygen concentrations in the estuary have risen markedly while ammonia concentrations have fallen. Even so, salmon mortalities have occurred in the upper estuary intermittently, usually associated with warm summers. Champion (1991) reported deaths of 200-300 salmon in 1989 and 1990 respectively. Further deaths were noted in the early 1990’s, and in 1995 and 1996, it is estimated that 2,000 and 1,200 salmon respectively died during the summer months in the estuary (Environment Agency 1996, 1997). There have continued to be reports of fish deaths in the estuary in the years 1997 to 2002, on a smaller scale, usually less than 100 annually. In 2003 around 2,000 adult salmon died (based on recovery of 1,138 dead fish), associated with extended periods of low flow and high temperatures.

In summary, estuarine water quality decline was regarded as the main cause of salmon (and sea trout) decline on the Tyne. Its improvement has been in stages, with key events being the closure of the ICI plant in the mid-1960s and the combined effects of final coke oven closure and greatly improved sewerage systems during the 1980s.

Of the other salmon rivers in North East England, the Wear and Tees have also suffered significant pollution due to urban and industrial development, but both have recovering salmon runs. In contrast to the Tyne, the major impacts on the Wear have been in the freshwater catchment, rather than in the estuary. The population density of the Wear’s freshwater catchment is about an order of magnitude higher than that of the Tyne, with comparatively little development on the estuary. The Port of Sunderland is at the mouth of the river and, in contrast to the Tyne, dredging of the estuary has not been extensive. The decline of the coal industry, particularly coke-making, and improvements to sewage treatment have led to significant improvements in the quality of the freshwater Wear and a steady increase in salmon rod catches.

On the Tees, the freshwater catchment upstream of Darlington is sparsely populated and the water quality in freshwater is not considered to have been a major constraint on historic salmon run. The major polluting inputs to the Tees have been to the estuary, as on the Tyne, although there are clear differences. The Teesside conurbation has about one third of the population of that of Tyneside, so sewage pollution has been less. However, industrial developments on the Tees estuary have resulted in substantially more polluting discharges in the 20th century than on the Tyne. Petrochemicals, steel-making and another ICI ammonia plant all contributed to the virtual elimination of the Tees' salmon run and it is only in recent years that progressive discharge improvements have improved water quality to the extent that salmon can pass through the estuary. As a simplification, the Tees can be viewed as about 20 years behind the Tyne in the progress of its clean-up. An additional factor on the Tees is the building, in 1995, of a barrage midway along the estuary.

In contrast to the Tyne, Wear and Tees, the Coquet has suffered little polluting impact. The human population density is low both in the freshwater catchment and on the estuary. The catchment is on the northern edge of the Northumberland coalfield, so the impacts of coal-mining are slight and limited to small tributaries of the lower river. Although it is a smaller river, the relative proximity of the Coquet to the Tyne means that salmon migrating from and to the two rivers are likely to encounter similar pressures during their time at sea. The Coquet is thus considered to be the best river to use as an unpolluted "control" river for comparison with the Tyne.

2.2 Origins and purpose of Kielder hatchery

Independently from the water quality changes, a large water supply reservoir was constructed at Kielder, in the upper reaches of the North Tyne (Fig 2) and completed in 1980. The operating regime specifies a compensation flow of 1.32 cumecs in the North Tyne, or 18% of the naturalised flow at Grid Ref. NY710880. The reservoir construction resulted in the loss of over 30 miles of rearing habitat (equivalent to around 220,000 m^2 of rearing area), through flooding of the valley and blocked access to the upstream area.

It is estimated that the catchment area upstream of Kielder could, under pristine conditions, have contributed in the region of 25-30,000 smolts to the Tyne's annual smolt output (Environment Agency, unpublished). This number is comparable to the smolt output likely to be derived from stocking of salmon at the mitigation level of 160,000 fish per annum. This level of stocking is therefore commensurate with the loss of production caused by the construction of the reservoir.

Accordingly, a mitigation agreement through the Reservoir Act specified that 100,000 0+ and 60,000 1+ salmon would be reared and released into the Tyne annually to compensate for the permanent loss of upstream area. The Kielder hatchery was built near the reservoir specifically to meet this agreement and began release of juveniles to the Tyne in 1979 (Fig 3). The mitigation requirement has normally been well exceeded and since 1990 extra stocking has been carried out to compensate for the intermittent estuarine mortalities. Because the rearing capacity is greater than that required for the Tyne alone, the hatchery production has also been extended to other rivers such as the Tees, Wear, Esk, Trent and wider afield. Recently, salmon have been reintroduced to the Derbyshire River Dove, a tributary of the Trent, using fish reared at Kielder hatchery from Tyne broodstock.

2.3 Previous assessments

The Freshwater Biological Association carried out surveys of the salmonid populations of the North Tyne in 1978/79, as part of the impact assessment for Kielder reservoir (Ottaway, 1979). The results show that, on the basis of observed fry and parr abundance, in an estimated wetted area of 368,033m^2 lost by dam construction, the estimated annual salmon smolt production ranged between 2,305 and 17,254. This is equivalent to 0.6-4.7 smolts / 100m2, which is a modest production for an upland area, although higher production rates might be expected elsewhere in the catchment. NB the lost area estimate quoted above is higher than that given in Section 2.2. The reason for this is unclear, but the larger area estimated in the FBA study may have been because their report considered all potential salmon producing water rather than that which was considered to be prime salmon nursery area. No 0+ parr were found in the 1979 survey, an absence attributed by Ottaway to low spawning density in 1978 and to water quality problems caused by Kielder dam construction, which was intensive at the time. Nevertheless, the observations demonstrate the existence of a moderate salmon population in the Tyne before the stocking programme began.

No formal monitoring of the stocking programme has ever been carried out. Fortuitously, a long-term microtagging programme, was initiated by the MAFF Fisheries Laboratory Lowestoft (latterly CEFAS) in 1983 to investigate the patterns and relative levels of exploitation of salmon from various parts of England and Wales in coastal and distant water interception fisheries. As part of this programme, extensive tagging was carried out at Kielder hatchery. Initially (1983-93) tagging was carried out by CEFAS, but has been continued in more recent years (1994-2000) by the National Rivers Authority and the Environment Agency. Fish tagged at Kielder hatchery have been released into a number of North East rivers, in addition to the Tyne.

The aim of the MAFF/CEFAS work was to estimate the relative contribution of North East salmon to the high seas fisheries off Greenland and the Faroes and in various home-water interception fisheries (Russell and Potter, 1996). For this purpose not all stocked fish needed to be tagged and this imposed a significant constraint on analysis of the tagging data for the present purpose of stocking evaluation. The results of the tagging programme were summarised by Jowitt and Russell (1994) who made some reference to the effectiveness of the Kielder stocking programme. The microtagging data have also been used to compare the performance of hatchery and wild salmon smolts (Potter and Russell, 1994) and to examine factors affecting return rates (Russell, 1994).

3. Kielder stocking programme

3.1 Numbers stocked

Salmon

A minimum of 160,000 juvenile salmon has been stocked into the Tyne each year. These have normally been some mixture of 0+ salmon parr, that is fish which were stocked in the same year that they were hatched, and 1+ parr, that is fish which were stocked in the year following their hatching year. Varying proportions of the fish released as 1+ were microtagged. Up to 600,000 fish have been stocked annually (Fig 3, Table 1). Overall, between 1979 and 2000, most (72%) have been 0+ fish and 1+ salmon have never formed more than 60% of the annual stocking (Fig 4). Smolts were stocked in two years, 1979 (12,500) and 1982 (10,000). Recently, smolts have been produced using an experimental ranching programme in which parr are stocked into Kielder Burn (above the reservoir), trapped as they migrate out of the Burn and then transported by lorry and released below the dam. In 2003 5,500 smolts were produced in this way.

Scale examination of tagged adult fish recovered in net and rod fisheries (Russell, unpublished) has shown that on average most (66%) are of river age two (known as S2 smolts). Of the remainder, around 33% are of river age one (S1 smolts), with a very few fish (<1%) migrating as three year-old smolts. Given the relative sizes of the fish at the time of release, it is assumed that the majority of 0+ fish (assumed stocked between August and October) migrated as two year-old smolts and therefore remained in the river for around 20 months, including two winters, after stocking. For 1+ fish (stocked in March/April) the fish either remained for a short period (1-2 months) before migrating (as S1 smolts) or for 13-14 months before leaving for sea as 2+ smolts. In practice, the proportions of one and two year-old smolts resulting from different tagged batches have varied markedly from year to year (Jowitt and Russell, 1994).

The rivers Tees and Wear, also regarded as ‘recovering’ rivers, were stocked with parr from Kielder hatchery, but with generally much lower numbers, although the Tees was stocked comparatively heavily between 1992 and 1995 (Fig 5a, b; Table1), and the recovery performance of these is briefly compared with the Tyne. The Coquet, which is used in this report as a control river, was also stocked but at even lower levels than the three recovering rivers (Table 1).

Sea trout

Compared with salmon, very few sea trout have been stocked into the Tyne (Table 2). 5,000 eggs were stocked in 1979; between 1986 and 1989 27,500 0+ parr were introduced and a further 95,000 eyed ova were stocked in 1993. In addition, an unspecified number (thought to be small) of eggs left over from contract hatchery production were stocked in some years. Small numbers of sea trout parr were also microtagged in one year, but returns were very low and details have not been included in this report.

3.2 Broodstock sources and collection

At the start of the programme eggs were brought in from Scottish rivers (Table 3). Between 1978 and 1983 65% of the 2,465,000 ova laid down in Kielder were of

Scottish origin, 26% from the Tyne and 9% from the Wear and Coquet. Thereafter, Tyne broodstock only were used for rearing fish for release to the Tyne.

Broodstock have normally been taken from three tributaries on the Tyne system: the North Tyne, Rede and South Tyne (Fig 6). Over the period 1986 to 1997, the proportions coming from these areas have been 61%, 28% and 11% of total Tyne broodstock, respectively. In some years, smaller numbers of broodstock were also collected from other rivers.

Microtagged salmon found during broodstock collection were counted from 1986, when first returns were expected. The percentage incidence is shown in Fig 7. Overall, the percentage occurrences were 11.6 %, 6.3% and 1.0% respectively in the North Tyne, Rede and South Tyne (Table 4). Note that because not all hatchery-released fish were tagged a proportion of other, unmarked, fish in the collected broodstock will also have been of hatchery origin.

3.3 Rearing practice

Two methods have been used to rear salmon at Kielder through the initial stages of development to first feeding: troughs and deep substrate incubators. The former has been standard hatchery practice for many years, but incubators were introduced in 1989, based on MAFF trails of a technique that had been in use in North America since the 1960s. These incubators have been shown to improve the growth and survival of young fry (Scott, 1990), and the system has been further developed and considerably improved at Kielder. To provide an initial indication as to whether rearing methodology might have also affected long-term survival of fish, two batches of fish reared by the different methods were microtagged and released in 1990. Recapture rates for the trough and incubator fish were 4.6 and 6.6 per 1,000 released respectively (Jowitt and Russell, 1994). The results, were not statistically different, but suggested that incubators might offer long-term advantage over trough-rearing that required further testing. Anecdotal evidence indicates major benefits to growth and survival from the use of these incubators (P. Gray and P. Rippon, personal communication).

3.4 Stocking locations

Within the Tyne, the locations chosen for stocking (Fig 8) have changed with time. In the early years fish were stocked in the North Tyne, Rede and South Tyne, from which broodstock were collected as returning numbers increased (see 3.2). Of 251,880 mictro-tagged salmon, the percentages stocked into the tributaries were 61.3, 21.43 and 17.5% in the N. Tyne, Rede and S. Tyne respectively. In later years, fish were stocked into under-utilised areas, based on the evidence of electro-fishing surveys.

3.5 Stocking out procedures

Fish have been stocked by bulk stocking (i.e. grouped in a few selected release locations) and by trickle stocking, in which fish are distributed more sparsely, with the intention of reducing early mortality through competition with each other and wild fish. A provisional trial to compare the methods in the North Tyne in 1991, produced recapture rates of 5.5 and 3.6 fish per 1,000 released respectively (Jowitt and Russell, 1994), suggesting no benefit from trickle stocking, but further work is required to reliably establish this. Currently, fish are stocked at 5,000-10,000 per site.

4. Methods

4.1 Dealing with uncertainty

The following account describes various approaches used to model the data from microtag returns and rod catches. Such data are subject to numerous sources of error and thus uncertainty in parameter estimation. These are inevitable when working with fisheries data and derive variously from the necessity to make assumptions, errors in the model structure, errors in sampling and the over-riding natural variation seen in natural systems. The use of assumptions introduces potentially subjective errors and to reduce these a range of assumptions was used for critical parameters. By this means a best (most likely) value was chosen, coupled with a likely minimum and maximum values, in order to bracket the likely true value. Justification for these assumptions is given in Appendix I. More rigorous, complex methods of modelling uncertainty are available, but for present purposes this bracketing approach is considered to give acceptable results. To streamline reporting and discussion of results the best estimate (BEST) is normally quoted, with a range of estimates (MIN-MAX) where appropriate

4.2 Hatchery microtagging tagging programme

Microtagging began in 1983 (first releases in 1984) and stopped in 2000. In most of these years between 30 and 60% of the 1+ fish produced at the hatchery were tagged (Fig 4). Jowitt and Russell (1994) describe the microtagging programme in detail, noting that the small size of the parr prior to release, due to the low temperatures of the hatchery (an entirely natural feature of the upper North Tyne), was at the lower limit for successful microtagging. The mean size of salmon tagged each year ranged from 5.3 to 10.2 cm, with the majority of batches lying within the lower part of this range. Survival increases with size (e.g. Salminen, 1997) and evidence from recapture rates in the 1980s showed that size range of salmon at tagging could lead to recapture rates increasing from around 1 to 18 per 1,000 fish released (Jowitt and Russell, 1994).

In view of the fact that hatchery-reared fish were at the lower limit of sizes suitable for tagging, it was necessary to select the larger fish for tagging. This did not affect the aims of the microtagging programme, but introduces difficulties in interpreting the results in terms of the overall survival of fish stocked from the hatchery, since smaller fish have been shown to survive less well in the wild. None of the smaller 0+ fish released from Kielder were microtagged and 1+ fish were routinely graded prior to tagging to select larger fish. Initially, this was achieved using a fish grader, although this was a fairly imprecise process given the practical difficulties of grading fish of such a small size and with a limited size range. Thus, smaller fish were subsequently hand-sorted and ‘rejected’ at the time of tagging. Therefore, the average size of tagged 1+ parr was greater than that of the untagged 1+ parr released. This variation was always present, but its magnitude varied between years depending upon growth in the hatchery prior to tagging.

The differences between the size of the tagged 1+ parr and the untagged 1+ and 0+ parr, and the year to year variability in the sizes of the fish released from Kielder hatchery, introduce further difficulties in assessing the overall survival of stocked fish. These size differences affect the resulting smolt age of the fish and thus the duration of, and level of mortality during, the freshwater phase. It was evident from the tag recoveries that the majority (66%) of tagged fish have migrated as two year-old smolts (S2s), with most of the remainder (33%) migrating mainly as one year-olds (S1s). Very few fish (<1%) migrated as S3s. However, the relative proportion of fish of different smolt ages did vary markedly from year to year. The smolt age composition of the untagged fish released from Kielder hatchery as parr was not known. Accordingly, the untagged 1+ parr were been assumed to have the same smolt age composition as the tagged fish and the smaller 0+ parr were assumed to have all migrated as S2s. This assumption is conservative and errs in favour of survival estimates for hatchery fish, because the untagged fish were smaller than the tagged ones and would therefore have tended to be older smolts.

Concerns have been raised about the potential impact of microtags, which are magnetic, on the ability of salmon to navigate and home. However, a recent review concluded that there was no evidence for interference with magnetic orientation due to the presence of a tag, and that the homing ability of microtagged fish was comparable to that of unmarked fish and fish marked with other tags (Solomon and Thompson, 2001). Tagging also had no detectable effect on the survival of the parr tagged at Kielder. Tagged parr held in tanks for several months after tagging showed that post-tagging mortalities at Kielder were insignificant and no different to those of untagged batches (Jowitt and Russell, 1994), and growth rates were similarly unaffected.

Tag loss rates were assessed prior to release of the 1+ parr, often after a period of some months in the hatchery. These were used to derive a best estimate of tagged fish actually released in each batch of fish (Jowitt and Russell, 1994).

Salmon were normally tagged in the period between November and February, typically with one tagging period in November and a second in February. Fish were then kept in the hatchery before release as parr in March and April. Yearling (0+) fish were normally stocked in late summer.

Most tagged fish were released to the Tyne system in line with mitigation requirements, but some batches were released into the Tweed, Coquet, Wear, Tees, Esk, and more recently the Dove (in Trent catchment). Some of these releases (e.g. Tweed and Wear) were derived from broodstock collected from these other rivers. Only the batches of microtagged fish released to the River Tyne have been analysed in the context of this report.

4.3 Microtag recovery

Tags were recovered through an active annual catch screening programme throughout the north-east coast net fishery and rod recaptures were based on a promoted voluntary return scheme (Jowitt and Russell, 1994). Both programmes were supported by a reward scheme to encourage tag recoveries. The coastal tag recovery programme had extensive coverage throughout the North East coast fishery area and tags were also reported through a screening programme in distant water fisheries.

4.4 Raising factors

Not all recaptured, tagged fish were reported, either because it was not possible to screen the entire catch (nets), or because of failure to notice tags or lack of awareness of the scheme or simply failure to respond (rods). Adjustments were therefore made to the reported tag numbers, based on various independent sampling methods, to raise these values to whole catch. The derivations of the different raising factors used for nets and rod recaptures are given in Appendix I. A range (MIN, BEST, MAX) of raising factors was used.

4.5 Modelling returns using microtagging data

The CEFAS microtagging programme was designed to investigate exploitation in distant water fisheries, not to address the contribution of Kielder-origin salmon to homewater net and rod fisheries. Nonetheless, the tagging data provide the only direct assessment of such contribution, but only for one component of the fish that are routinely stocked (the larger 1+ parr). It should also be noted that tagged fish have only been released for 17 (1984-2000) of the 24 years considered here (1979-2002). However, these tagged fish provide a core of data throughout most of the programme and a baseline against which data for the other two groups (0+ and the smaller 1+) can be set.

The microtag data were used to estimate:
- returns to the coast, before the North East Coast net fishery,
- returns to the river, before the rod fishery,
- contributions to the rod catch and
- contributions to spawning escapement (i.e. the total spawners in each year, and cumulative spawners)

In all cases only returns from fish stocked into the River Tyne have been considered. The calculations to derive these estimates are outlined below

For nets, the total number of tags caught in the fishery was estimated by raising the number of tags recovered in the scanned sample to the total declared catch.

> The landings in the home water net fishery (adjusted* catch) = *Ln*
> (* from declared catch x 1.08, to account for under-reporting)
> The number of fish examined for tags (scanned sample) = *Xn*
> The number of tags recovered in the scanned sample = *Rn*

The number of tagged fish caught in the net fishery (*Cn*) was calculated from:

$$Cn = \frac{Rn * Ln}{Xn}$$

For rods, the number of tags recovered (*Rr*) in the fishery was simply multiplied by the rod raising factor (Fr, see Appendix I). Thus the number of tagged fish caught in the fishery (*Cr*) is calculated from:

$$Cr = Rr * \mathrm{Fr}$$

To extend these data to the entire hatchery contribution, it was necessary to incorporate estimates of returns of untagged 1+ and 0+ parr. This requires assumptions to be made regarding the relative survival of these fish compared with the tagged batches. It has been noted that, because of grading prior to tagging, the tagged 1+ fish were larger, on average, than the untagged fish (Section 4.2). Since survival will be size dependent (e.g. Jowitt & Russell, 1994; Salminen, 1997) it has been assumed that the untagged 1+ parr will have survived less well than their tagged cohorts. A scaling factor (*v*) was used to adjust the return rates of these smaller fish, BEST=0.8 (i.e. 80 % of the tagged fish) range 0.7-0.9 (Appendix I). For the substantially smaller 0+ fish released in the autumn, over-winter mortality will have been an additional and significant source of mortality compared with the tagged 1+ parr. The scaling factor for this (*w*) was BEST=0.25, range 0.1–0.5 (Appendix I).

Calculations were carried out separately for 1SW and for MSW salmon sea age classes and the estimates lagged and summed to give totals for each year of return. MSW salmon comprised mainly two-sea-winter (2SW) fish and all MSW fish were assumed to have returned as such. Variability in the smolt age of the fish derived from the 1+ parr (Section 4.2) was taken into account in assessing the contribution to the net fishery. Raised tag recaptures were apportioned between S1 and S2 smolt year classes for 1SW and MSW salmon. However, there were insufficient returns to allow this approach for the rod caught fish, so an assumed smolt age of 2 years was applied in lagging the recoveries to the different cohorts of hatchery fish.

The total catch of Kielder-origin fish in the rod and net fisheries, for each age class was derived as follows, let

No. of tagged 1+ parr in year n = *An*
No. of untagged 1+ parr in year n = *Bn*
No. of untagged 0+ parr in year n-1 = *Dn*
Scaling factor to allow for relative 'value' of untagged 1+ parr = *v*
Scaling factor to allow for relative 'value' of untagged 0+ parr = *w*

Thus the catch of Kielder-origin fish in the net fishery (*Cntot*) is given by:

$$Cntot = Cn + (Cn * \frac{Bn}{An} * v) + (Cn * \frac{Dn}{An} * w)$$

And that in the rod fishery (*Crtot*) is given by:

$$Crtot = Cr + (Cr * \frac{Bn}{An} * v) + (Cr * \frac{Dn}{An} * w)$$

These estimates provide the contribution of Kielder fish to the net and rod catches for those years where tag recovery data exist. For years when no tagging took place, average observed tag recovery rates were used to estimate 1SW and MSW returns. Because there were systematic differences in return rates (higher in the earlier years) data were averaged for the first four and last four years of observations and applied to the years without direct observations as shown below

1986-89	observations applied to estimate 1981-1985 (1SW) returns
1987-90	observations applied to estimate 1982-1986 (MSW) returns
1993-96	observations applied to estimate 1998-2002 (1SW) returns
1994-97	observations applied to estimate 1998-2002 (MSW) returns

An adjustment is needed for the net fishery to enable the Kielder contribution to be expressed relative to the catch of English fish in the net fishery, because the majority of the salmon taken in the north east coast fishery are destined for Scottish rivers (Anon. 1996). The proportion of English fish is believed to have risen over recent years as stocks in North East rivers have recovered. For the purpose of this assessment, 5% of the fish were assumed to be of English origin up to 1975 (Potter and Swain, 1982), increasingly steadily over the period to 25% more recently. These are the same values that are used for assessment purposes by ICES (Anon., 2002).

Returns back to the coast (Rn) and river (Rr) were derived by applying assumed exploitation rate values to rod and net catches:

Exploitation rate in net fishery = *U*
Exploitation rate in rod fishery = *u*

$$\mathrm{Rn} = \frac{Cntot}{U} \qquad \textit{and} \qquad \mathrm{Rr} = \frac{Crtot}{u}$$

For rod fisheries, estimates of exploitation were assumed to have increased linearly between 1980 and 1999. Current values of 0.149 and 0.201 were used for 1SW and MSW salmon respectively, taken from the Tyne Salmon Action Plan (Environment Agency, 1998). Values through the period were adjusted assuming that they were originally half what they were at the end, so starting exploitations were 0.074 and 0.105 for the two age groups respectively. The effect of assuming this extent of change was tested by trialing proportional changes of 0.2 (i.e. 1980 U was 80% of the 1999 value) and 0.8 (i.e. U in 1980 was 20% of the 1999 value).

For the north east net fishery, there were no direct estimates of exploitation rate; a value of 0.4 has been assumed (throughout the period) for 1SW salmon and a value of 0.35 for MSW salmon. Similar overall values applied in an earlier review of the fishery (Anon, 1996).

4.6 Rod Catch and Effort Data

4.6.1 *Catch correction*

Annual declared rod catches were obtained from rod licence returns. The declared catch underestimates true catch by an amount that has varied over time. The following correction factors were used, based on Current Salmon Action Plan Guidelines (EA, 2003).

Period	Proportion of catch declared	Correction factor
Pre 1992	0.64	1.56
1992/1993	0.53	1.90
1994 *et seq.*	0.91	1.10

Where appropriate, catches have been adjusted using these factors.

Catches are determined by available stock and by fishing effort, but the relationship with effort is complex and modified as much by angler behaviour as by river flows and other environmental variables. Effort data were obtained from Marshall (1992), by reading from a graph of annual licence sales.

Catch standardised to long term means (1950–2000) were used to show and compare relative patterns of long term change in different rivers. In some cases catch (N) data were transformed by $\log_{10}(N+1)$, to account for the few zero values, in order to stabilise variances and also to more easily compare proportional changes. Data for salmon and sea trout were analysed using linear regression, and analyses of covariance and variance.

4.6.2 *Catch change Models*

Three simple scenarios of temporal recovery were examined, assuming successively logarithmic increase in stock, a logistic increase and a stepped model.

Logarithmic increase:

$N_t = N_{t-1}.10^{-(mt)}$

Where Nt = catch in year t
N_{t-1} = catch in year t-1
m = a constant

Logistic:

Data were fitted to Nt = $k/(1+ e^{(a+rt)})$
Where k= asymptotic catch, related to carrying capacity of the river.
a = a constant
r = a constant, equivalent to rate of increase
t = time (in years)

k can be estimated directly from the data or constrained by prior knowledge of the system under study. In this case data were available from a previous study of salmon rod catch variation in relation to catchment size around England and Wales (Crozier *et al.* 2003). The linear regression of lg10 (mean salmon catch 1994-1998) and lg10 wetted accessible stream area was used (excluding Tyne data) to give an estimate of the maximum catch (upper 95%ile prediction limit), likely for a river of the Tyne's size. This value was used to constrain the logistic curve fit.

Stepped model:

This used the EA's "TAPIR" temporal analysis program to look for statistically-significant temporal changes in the log-transformed annual rod catch (adjusted as described in 4.6.1) for the period from 1952 to 2001. TAPIR first looks for statistical outliers in the data set (none were found), then identifies any consistent seasonal pattern and adjusts the data to remove the seasonal pattern (not in this case, as there is only one reading per year). It then uses a cusum analysis to fit to the data a step-change model that minimises residual variance. Finally, it fits a piece-wise linear model and tests whether any of these linear trends account for variations in the data better than the corresponding step-change model. An important feature of this analysis is that change points are derived automatically from the data, rather than being pre-selected. Thus, the results reported here are the objectively-derived models which statistically best fit the temporal patterns in the rod catch data.

4.6.3 *Control river*

The Coquet is located about 37 km north of the Tyne, but it is not affected by any significant freshwater or estuarine environmental impacts (Section 2.1) and was selected as a control river against which to compare the Tyne. The implicit assumption being that the long-term changes in factors affecting marine survival are likely to be similar in the two adjacent catchments, furthermore no major stocking activities are known to have affected the Coquet. Thus comparison of the difference between the two can be taken as a relative measure of changes resulting from factors, such as natural recovery following water quality improvements or the stocking programme, acting on the Tyne alone.

4.6.4 *Marine mortality*

A confounding factor in long term salmon catch analysis is the influence of changing marine mortality over the time period. There is considerable evidence to show that this mortality has changed since the 1970s (e.g. Mills, 2000, Anon. 2003) and this will have influenced the rate of recovery of any salmon stock. No direct measures of marine survival are available for the Tyne. The nearest river where suitable data are available is the North Esk. In addition, ICES have produced estimates of annual spawner abundance for the Southern European stock to which the Tyne nominally belongs (e.g. Anon., 2002). These were used to provide background information on long term changes in marine survival.

5. Results

5.1 Microtag returns

5.1.1 Microtag returns, general

Over the period 1986 to 1997 inclusive, 1,279 tagged salmon derived from hatchery-reared parr released to the River Tyne were recovered as a result of the sampling programme in the north east coast fishery. This comprised 871 1SW salmon (68.1%) and 408 (31.9%) MSW fish. The scanning programme in the coastal fishery ceased after 1997. Recoveries from the rod fishery on the River Tyne have been based on voluntary returns, and extend over a longer period (1986 to 2000 inclusive). Although the tagging programme at Kielder continued until 2000, relatively few fish were tagged and only one tagged fish has been reported from the Tyne rods in the years 2001 and 2002. Between 1986 and 2000, 216 River Tyne origin fish were recaptured by rods in the Tyne (excluding the few fish recaptured in other rivers), comprising 66 (30.6%) grilse and 150 (69.4%) MSW fish. The tag data show that, while the nets have mainly taken Kielder-origin fish as grilse, probably reflecting both the timing of the fishery and gear selectivity, the rods have predominantly exploited MSW salmon.

Tags were also recovered during broodstock collection (Table 4), mainly in three tributaries the North Tyne, Rede and the South Tyne; in which, during the period 1988- 1999, the weighted mean microtag incidences were 11.6, 6.3 and 1.0% respectively. These levels reflected the stocking strategy, with more releases of tagged parr into the North Tyne than in the Rede or South Tyne. Levels of broodstock collection in the three rivers, were 1,251, 606 and 226 salmon respectively. Stocking back into the three rivers was approximately in proportion to broodstock removal (some parr were more extensively distributed around the Tyne, and occasionally elsewhere). Peaks in broodstock percentage tag incidence were in 1991 (Rede and South Tyne) and 1992 (North Tyne). These values underestimate the proportion of stocked fish returning, because not all were tagged, and also that return rates were related to stocking location.

5.1.2 Returns in distant water interceptory fisheries

Kielder-origin salmon will have contributed to high seas and homewater interception fisheries other than the North East Coast fishery over the period. Microtagged salmon have been recovered in a number of such fisheries (Russell & Potter, 1996). Table 5 provides details of estimated total tag recoveries in these fisheries (i.e. scaled up using appropriate raising factors) for Kielder-origin fish released to the Tyne. These estimates have not been adjusted to take account of untagged Kielder fish and, other than noting their occurrence; no further analysis of these returns has been incorporated into this report.

5.1.3 Contribution to the North East Coast fishery and returns to the coast

Estimates of annual catches of hatchery-origin fish of Tyne origin in the net catch peaked at 2,937 (range 2,481-3,510) in 1986 (Table 6, Fig 9). These represented 4.3% (3.6-5.1) of the total adjusted North East Coast (NEC) catch. Over the whole stocking programme to date the weighted contribution to the net catch was 1.5% (1.2-2.0), of which 73% were estimated to have been recaptured as 1SW salmon (grilse).

Return rates of Kielder-origin salmon to the coast (pre-net fishery) peaked for fish released in 1985 at 2.78% (2.34-3.34%), but have been less that 1% since 1986 (Fig 10) and the weighted overall returns were 0.62% (0.48-0.82%) (Table 6). These rates were based on all fish stocked and the values would have been different if expressed for fish stocked as 0+ or as 1+, being lower and higher than these reported values, respectively. For example the overall return rate (releases 1984-1997) to the coast of just the microtagged 1+ fish was 1.21%. Adjusting these values for an average net exploitation rate of 0.375 gives a return to the river of 0.77%.

5.1.4 Contribution to the Tyne rod fishery, escapement and returns to the river

Stocked fish would have first returned to the rod fishery in 1980 (Fig 11), as 1SW salmon from the smolt stocking of 1979. Up to 1986, as more fish were stocked annually, the catch of returning hatchery fish increased (Fig 11), reaching a peak of 274 in 1986 (range 128 to 566) (Table 7). Percentage hatchery contributions to total catch were highest (>20%) between 1983 and 1986 with a maximum annual contribution in 1984 of 42% (range 17-96%). Thereafter annual hatchery contribution rapidly decreased, such that current (mean post-1995) levels are mainly between 2 and 7% (Fig 12, Table 7).

Estimated total spawning escapement closely followed the catch curve because its estimation was based on catch data. Absolute contributions of hatchery fish to spawning escapement steadily increased from 1980 (19-155 spawners) up to the peak (975–4,515) in 1985/6 (Fig. 13, Table 7). Hatchery-derived annual escapement rapidly decreased by 1991, thereafter remaining fairly constant at around 200-700 (BEST) or 500-1,700 fish (MAX). Estimates of the annual percentage contribution to spawners were the same as for the contribution to rod catch, because of the calculation method. The total cumulative spawning from 1980 up to 1986 was taken as a best summary of the total spawning escapement of the wild and hatchery returning adults. 1986 was the time when hatchery contribution to the cumulative total was maximised (Fig 14) and therefore gives the most favourable measure of hatchery contribution and is convenient because, before 1986, few second-generation fish would have returned. Hatchery percentage contribution to the early (1980-1986) cumulative total spawners was estimated at 20% (9-43%) (Fig 15, Table 7).

Percentage return of hatchery fish to the river (i.e. after net and before rod fishery) peaked in 1986 at 0.87% (0.45-1.55%), decreasing thereafter to < 0.2% since 1992 (Fig 16, Table 7b). Overall weighted mean return rate, based on releases over the whole period, was 0.27% (0.12-0.59%) Table 7.

5.1.5 Effects of assumptions

Assumptions were made in parameters used to adjust microtag returns in order to estimate overall returns of all stocked fish. This was done to approximate the uncertainty (beyond that from measurement and sampling errors) inherent in the estimates, by adopting a range of parameters to cover the likely values. Not all parameters were adjusted. For example rod exploitation rate was assumed to have doubled (increased by 50%) linearly between 1980 and 1999 and no alternative scenarios were routinely postulated for the calculation. The true extent and pattern of exploitation change is not known. However, to illustrate the potential effect alternative values of a 20% and 80% change were tested on the BEST (50%) estimates of key result values and are shown below

Result	80% change	50% change = “BEST”	20% change
% cumulative hatchery spawners, to 1986	17.8	20.2	21.2
Max annual % hatchery contribution to spawners	42.0	42.0	42.0
Weighted % return to river	0.37	0.27	0.22
Weighted % hatchery fish in rod catch	6.5	6.5	6.5

The effect of the other parameters was more significant when considering the long-term variation in hatchery returns. The parameters used to calculate MIN, BEST and MAX estimates are summarised below

Variable	MIN	BEST	MAX
Rod tag raising factor (Fr)	1.2	2.0	3.0
Scaling factor for untagged 1+ (*v*)	0.7	0.8	0.9
Scaling factor for all 0+ (*w*)	0.1	0.25	0.5

The origin of these values is outlined in Appendix I and these were intended to give a realistic picture of the circumstances prevailing during the majority of this study period, particularly in the earlier years, when the implication of stocking for Tyne stock recovery were most important. However, there have been improvements in hatchery procedures at Kielder, e.g. the use of incubators beginning in 1989, which have reportedly greatly increased the early growth and survival of salmon in the hatchery (Gray, Pers. comm.). Thus the most appropriate values for *v* and *w* in recent (post-1989) times may be higher than used in these calculations and may be lower in the early period. But because there has been no quantitative monitoring of hatchery fish growth performance, the relative changes cannot be assessed and no adjustments to *v* or *w* have been made in the main results. However, an idea of the potential impacts of changing values for parameters, Fr, v and w on estimates of key results is shown below for five alternative scenarios.

Result	original BEST Fr=2.0 *V*=0.8 *W*=0.25	(1) Fr=1.2 *V*=0.5 *W*=0.1	(2) Fr=3.0 *V*=1.0 *W*=0.5	(3) Fr=3.0 *V*=1.0 *W*=0.8	(4) Fr=4 *V*=0.9 *W*=0.5	(5) Fr=4 *V*=0.8 *W*=0.25
Cumulative % hatchery spawners, to 1986	20.2	9.8	45.7	58.3	57.7	40.4
Max annual % hatchery contribution to spawners	42.0	13.2	100.3	134.6	128.0	84.1
Weighted % return to coast (NB no Fr used)	0.62	0.38	0.87	1.05	0.61	0.62
Weighted % return to river	0.27	0.10	0.62	0.81	0.79	0.54
Weighted % hatchery fish in rod catch	6.5	2.3	14.8	19.8	19.1	13.0

These trials show that the upper (MAX) values of *v* and *w* selected originally are at the limits of likelihood. Clearly, values of annual % hatchery contribution > 100% are impossible and even the maximum value (96.0%) attained in the original variable selection is inconceivably high, given the extant salmon population known to be already in the Tyne well before that time. A values of Fr = 4 gave maximum annual % hatchery contributions of an extremely unlikely (given known natural salmon production at the start of the programme) 84.1% to an impossible 128%. Which is why such a high raising factor was rejected as a reasonable upper limit for Fr. The MIN, BEST, MAX values throughout the report are shown to illustrate the effects of alternative parameters, but these are not the same as true estimates of probability distributions.

5.2 Rod catch and fishing effort changes

5.2.1 Comparison of timing and pattern with other recovering rivers

In only two years, 1951 and 1959, were no rod-caught salmon reported from the Tyne during the last hundred years (the lack of catch between 1901 and 1924 is taken as lack of data rather than actual zero catches). Catches began to increase around the mid 1960s and thereafter have increased, with fluctuations, to the present day (Fig 1). In comparison, increased catches first became evident on the Wear and Tees in 1965 and 1982 respectively (Fig 17). Assuming that the first returns from stocking will be 1SW fish one year after 1+ stocking, then catch recovery predated the first stocking returns by 15+, 16 and 3 years on the Tyne, Wear and Tees respectively.

Fishing effort affects catches, but not in direct proportion because rod effort depends quite significantly on angler perceptions of likely success, i.e. within reason, effort tends to follow fish abundance and catchability (determined by, for example, flows and temperature). This effect is seen in the plots of effort (licence sales) against time (Fig 18). Catch-per-licence data were fitted closely (R^2= 0.796) by an exponential curve (Fig 19).

Linear regression of log-transformed data (N+1) was used to give preliminary estimates of recovery in rod catch over the overall recovery periods to the present. Start dates for the regressions were taken as 1951,1964 and 1981 for the Tyne, Wear and Tees respectively (Fig 17, Table 1). Analysis of covariance demonstrated that there was no significant difference between the slopes. Using an alternative start date of 1959 (the last year with zero reported catch) for the Tyne made no difference to the outcome of the analysis.

However, inspection of catches indicated that the rates were not in fact constant over time, thus the trajectory was not exponential over the whole period. In the Tyne (Fig 20) and Wear for example the exponential fit consistently overestimated catch during the last eight years. Therefore the simple log-linear model did not capture all the changes over the time period. This was to be expected for three main reasons. First catches were being used as a direct index of stock size. While this was a necessary approximation, the relationship between stock and catch is complex and variable. Second, a range of factors influences the size of returning stock. These include stocking rates and natural recovery (both of which may be modified by marine survival), changes in net fishery exploitation, density-independent factors affecting freshwater survival (and thus smolt output), density-dependent factors (e.g. competition affecting freshwater survival) and, not least, water quality. All these are likely to alter over time and modify the rate of change. Third, there is a limit to salmon production in any catchment, based on carrying capacity of the accessible freshwater environment, so catches will flatten out at some point. A more realistic model was needed to reflect the likely population changes.

A seriously depleted salmon population of a river, such as in the Tyne in the 1950s, might be expected to recover naturally, once limiting factors are removed and if other factors remained constant. The recovery would tend to follow the pattern shown by most organisms expanding into a limited environment and follow a classic model such as the typical logistic curve (e.g. Krebs, 1978). This model would give the intuitively reasonable result of slow initial rates, followed by rapid recovery rate in the intermediate stages, concluding by slowing down as the system's capacity is reached. The carrying capacity of the Tyne is not known, but an approximation was obtained from the relationship between mean catch and wetted stream area (Fig 21). The predicted long term average rod catch from a river of the Tyne's size was 1,626, a value that is already being exceeded, as the 2002 adjusted catch was 2,844. This deviation is not unexpected considering the variance seen in catches. The maximum predicted adjusted catch (from the upper prediction limit) was 4,588 and a reasonable guess at the likely maximum was taken as about halfway between these two values i.e. 3,500. Applying this to constrain a logistic curve gave an illustrative view of a smoothed stock recovery on the Tyne (Fig 22) that is an improvement on the exponential curve (Fig 20). The three curves in Fig 22 show the effects of varying the upper limit of catch: a maximum k=4,588 (based on the predicted maximum catch), a medium k=3,500 (see above) and a low k=2,702 (being the value of k fitted by the actual catch data). The data fit a logistic curve quite closely, but there are still steps and peaks, due to factors not accounted for in this simple model. The next stage in analysis was to explore these steps and fluctuations.

The catch data were analysed by the TAPIR software to detect significant (at 2% level) step changes and significant upward steps in the Tyne catch were recorded in 1965, 1977, and 1987 (Fig 23). The four statistically significant periods were.

1952-1964:	geometric mean catch 10
1965-1976:	geometric mean catch 182
1977-1986:	geometric mean catch 495
1987-2001:	geometric mean catch 1,816

These are statistically identified steps and do not imply that changes were as sudden as indicated in Fig 23. Fluctuations in the catch (and catch per licence) data are also autocorrelated, that is adjacent points are not statistically independent, leading to tracking of fluctuations that are simply a consequence of the data rather than some external factor. Evidently, the trajectory of the Tyne catch recovery was some complex combination of stepped, progressive and autocorrelated change, constrained within a limit equivalent to an average annual catch that probably lies between 2,844 (as the largest adjusted catch observed to date) and 4,588.

A number of confounding factors influence long-term catch, some of which can be reduced by comparing the Tyne to baseline controls. Two options were explored. First, the Tyne sea trout, which are likely to have been subject to the same general pattern (but not necessarily levels) of fishing effort, reporting and estuarine water quality, but very little sea trout stocking took place (Table 2). Second, the river Coquet annual salmon catch. The differences between the Tyne salmon and Coquet control provide indices of the extent to which the Tyne salmon catch (= stock index) has changed once the factors that act jointly on the rivers' salmon stocks are removed.

5.2.2 Comparison of salmon and sea trout changes

The catch recovery rates for both species were very close (Fig 24), indicating common trends in stocks and / or in factors influencing fishing effort or efficiency. The difference between the logged catches fluctuated considerably with large peaks in relative salmon abundance in the 1960s and the late 1970s and a smaller peak in the late 1980s, since when sea trout have become relatively more abundant (Fig 25).

5.2.3 Comparison of Tyne and Coquet salmon rod catches

The Coquet catches were stable in the long term between 1950 and 2000, but a reduction occurred during the mid-1970s, followed by an increase to the late 1980s that was similar to the increase in the Tyne (Fig 26). Applying TAPIR analysis to the Coquet data revealed four statistically significant periods separated by step changes:

- 1952-1956: geometric mean catch 313
- 1957-1967: geometric mean catch 713
- 1968-1985: geometric mean catch 262
- 1986-2001: geometric mean catch 598

The difference between the Tyne and Coquet adjusted catches increased over time and indicated comparatively little change during the 1970s, but increased in the 1980s (Fig 27). The slopes of the regression lines (difference vs time) for the ten year periods before and after 1980 in Fig 27 were compared by analysis of covariance, but no differences were detected and for neither period were the regressions significant ($P>0.05$) (Table 8).

5.2.4 Marine factors

The declining % returns to the river of microtagged Kielder salmon, even in the face of reducing net exploitation, suggest that marine survival decreased overall during the study period. But within a trend of decline the evidence from a number of studies is of fluctuation and critical periods. Standardised return rates for MSW salmon in the North Esk are shown in Fig 28 with standardised values of spawning size of Southern European salmon stocks as estimated by ICES (Anon., 2002). The data show a common pattern of increase during the 1980s, peaking in 1986-88, then decline from 1990 (Fig 28). The increase coincides with the rapid increase in Tyne catches, and Coquet and Wear catches in the late 1980s. Peak in salmon runs into the North Esk also occurred in 1988 (J. MacLean, pers. comm.) and in the return rates of smolts back to the River Imsa in Southern Norway between 1987 and 1989 (Anon., 2002).

6. DISCUSSION

6.1 Patterns of recovery

The fitting of various curves to the catch data assumes that catch follows stock. Although catch is often used as a surrogate for stock, the practice has a number of well-recognised flaws because the relationship between catch and stock is unlikely to be a direct one. However, no alternative was available and even with this constraint some basic statements can be made. The general pattern of an early slow increase, followed by accelerating rate as the breeding population becomes established, concluding with a slow down as the river’s carrying capacity is approached seems intuitively reasonable. The catch per effort plot (Fig 19), which takes some account of effort change illustrates the slow, but accelerating, early increase. The overall change was approximated by a logistic curve, for illustrative purposes, but other types of curve, for example the asymmetrical Gompertz curves (Krebs, 1978), may be better approximations. However the issue here is not the detail of population modelling, but rather the principle of slow-fast-slow rates of change and the recognition that the stocking operation coincided with an increase in recovery rate that would have been expected in a natural population. Stocking was probably a contributory factor in that acceleration, but the question is by how much?

Superimposed on the notional logistic population recovery pattern were seen clear step changes. These would be expected in actual response data and probably reflect the pattern of water quality recovery, which was inconsistent in the early years, modified by marine survival variation. Marine survival increase is thought to be the likely explanation for the peak in catches seen in the late 1980s. Similar increases were seen in many rivers in England and Wales, more widely across North East Atlantic salmon stocks (summarised in the ICES salmon spawners estimates, Fig 31) and in the nearby River North Esk.

6.2 Factors affecting salmon recovery in the Tyne

The debate about stock recovery in the Tyne is commonly expressed as a choice between the roles of water quality improvement and stocking, but this misrepresents the issues. Restoration of good water quality, in the Tyne's case in the estuary, is an essential prerequisite for recovery of any self-sustaining salmon river, by any means. The key issue is this: as water quality improved in the Tyne what caused the increase in its salmon stock? There are two candidate mechanisms, natural processes and artificial stocking. These are not mutually exclusive, both require good water quality and are subject to a range of other influences, such as survival at sea and carrying capacity in freshwater. The actual pattern of catch recovery was evidently complex and influenced by several factors sometimes acting simultaneously.

The role of natural processes in recovery

Catches began to increase on the Tyne at least 15 years before the first significant hatchery releases returned to the river and so must have been due to natural recovery. Its beginning in the mid-1960s and the second spurt in the 1980s coincided with water quality improvements; but the latter was probably enhanced by a short-term increase in marine survival and supported by hatchery production. Catch recovery pre-dating any significant returns from stocking was also seen in the Rivers Wear and Tees.

In the Tyne, catch increases in the mid-1960s could be attributed simply to greater fishing effort; for in a fully populated and lightly exploited river an increase in effort usually brings increased catch, in the short term at least. However, the Tyne salmon stocks had been at very low levels for many years and it is extremely unlikely that anglers would have increased fishing effort in the absence of evidence of increased runs. The most likely process was that the recognition of increased runs led to increasing effort and thus increasing catches. Thus, the increased licence sales themselves are thought to have been indicative of improving runs.

Natural recovery can occur in two ways. First, recruitment (i.e. new fish added to the stock year on year) from the breeding of any residual native Tyne salmon stock. Second, straying into the Tyne from salmon stocks native to other rivers as they migrated through Tyne coastal waters. The feasibility of these two mechanisms is discussed below.

The Tyne salmon stock was never completely eliminated by the water quality problems in the estuary, although it became greatly depleted. A zero catch was recorded in two years (1951 and 1959); but at such low stock levels these were most probably chance events associated with low fishing effort and variable fishing conditions (1959 was a famously hot summer). Because the salmon life cycle lasts usually between four and seven years, some adult fish would have been at sea in those years and juveniles would have been present also in the river. Therefore a salmon stock was always present during the nadir of the Tyne in the 1950s. No direct estimates of adult stock size are available, but adjusted annual salmon catches averaged 12 (max. 39) between 1951 and 1964. Acknowledging the caution necessary with such small counts and the potential inaccuracy of records (probably tending to under-record catch), at a notional exploitation rate of 5%, this indicates an average run size of 200-300, ranging up to around 800. The provenance of these fish cannot be determined; they could be residual Tyne stock or strays, but distinguishing between these is impossible retrospectively.

The role of straying in natural recovery of Atlantic salmon has not received much attention as a stock recovery process and it is usually discussed in the context of salmon straying *from* a stock to other rivers. In this case the interest lies in straying *into* the Tyne and there are no direct measurements of this.

Although predominantly a homing species, straying is a normal property of salmon, enabling them to colonise new rivers and to maintain a low level of gene flow (Thorpe, 1994; Quinn, 1993). The extent of straying, which is always very low, seems to be variable and to depend upon the source of the strays, proximity and similarity of the donor and receiving rivers and the level of population in the colonised river.

The breeding success of straying adult salmon is thought to be particularly low in a river fully populated by native salmon because of competition from natives during spawning and juveniles stages (Thorpe, 1994; Quinn, 1993; Vasemagi *et al.*, 2001). However, when the resident salmon population is very small, then straying is potentially a more successful, colonising process. Such conditions would have obtained in the Tyne in the early stages of recovery in the 1960s and 1970s, when native populations were low. Moreover, there were potential strays from the very large migratory stock of salmon moving through Tyne coastal waters, bound for rivers in North East England and the Scottish East coast.

So what evidence is there for colonisation by straying? Maxwell (c. 1900) wrote “Reference will be made hereafter to the effect of removal of Bywell Dam on the North Tyne in 1862, whereby that river became in an amazingly short space of years the most prolific salmon river in England”. Similar tributary recovery has been seen in the Whiteadder on the Tweed (Campbell, pers. com.). Such straying into tributaries from within a river with a strong main stem run might be expected to be efficient colonisation, but whole-river recoveries, from between-river strays, have also been reported.

True straying requires that fish breed in the receiving river, rather than just making exploratory forays into the lower reaches of rivers (Quinn, 1993), which latter process is quite common. Potter & Russell (1994) give straying rates (*from* donor rivers) for North East English stocks of ~2% for wild fish and 3% for hatchery fish, based on microtag recoveries. Jonsson *et al.* (2003) reported 6% straying *from* the Imsa, in Norway. The Potter and Russell (*op.cit*.) study also provided evidence of straying rates *into* rivers. In an early report of the North East river microtagging programme (covering 1986 to 1992) they reported results from stocking hatchery and wild fish into the Tyne, Wear and Coquet and recoveries (by rod and broodstock collection) in these rivers plus the Tees, Esk and others further away. Their data show that, of total recoveries of 182 wild fish and 198 hatchery fish, the percentages representing strays *into* rivers other than the ones into which they were stocked was 1.6% and 3.0% for wild and hatchery fish respectively. Not all these fish would necessarily have spawned but, given the huge potential donor source in coastal waters off the Tyne, only a small proportion would need to stray to seed a recovering river.

Vasemagi, *et al.* (2001) described spontaneous recolonisation of a Finnish river, where the native salmon stock was driven to extinction by pollution, by wild fish from adjacent rivers. Sandoy and Langgaker (2001) reported rapid natural recolonisation of salmon in Norwegian rivers in which populations had been eliminated by acidification. Salmon have been reported recently back in the Mersey, Lancashire, in the absence of stocking, following water quality improvements. In this case however, full breeding colonisation has not yet been possible because of other physical barriers.

In these examples, as the Tyne, there were known to be substantial salmon stocks in coastal waters migrating to adjacent rivers and this is an important prerequisite for straying to be an effective colonisation mechanism. The River Dove represents a contrasting situation. This tributary, lying a long way up the Trent system, has very few salmon present in its estuary, so the possibility of colonisation by straying is extremely low. This is a clear case for hatchery intervention through pump priming; and stocking has been successful in re-establishing salmon returns to the Dove.

Is it possible to establish what contribution straying might make? Thorpe (1988) has suggested that straying rates, into stocks, of 1-2% would be acceptable for retaining genetic variation as well as sustaining a low level of gene flow. He was referring to well-populated rivers; but in a seriously depleted river, with unoccupied habitats, effective straying rates are likely to be higher for reasons noted above (Vasemagi *et al.*, 2001; Thorpe, 1994). A range of straying rate of 1-5% can be taken for illustrative purposes. At such straying rates and a conservative notional run size of say 20,000, in a normal pristine state, the Tyne salmon stock might receive around 200 to 1,000 spawners. These straying fish would be continuously present as *potential* colonisers, irrespective of the condition of the estuary and the state of the Tyne stock. However, their recruitment potential would only have been realised as estuarine conditions improved and the barriers to survival and passage were gradually eliminated.

The above discussion presents a plausible mechanism for natural recovery based on natives and strays, but it is not evidence of such a process. That comes from the observed timing of catch recovery discussed above and from the estimates of microtag returns. By 1986, at the peak of hatchery contribution, wild fish comprised the majority of the total cumulative spawning effort since the start of hatchery programme (80%, range 57-91%).

Further evidence of natural salmon recovery is given by the results of electro-fishing surveys carried out by the FBA in the North Tyne (Ottaway, 1979) which gave, in the area lost to the dam, minimum estimates of 26,809 fry and 11,567 parr. Taking uncertainty into account, the FBA estimated that the salmon population was equivalent to annual smolt production of between 2,305 and 17,245, equivalent to 0.6

to 4.7 smolts/100m^2. Such values lie within the “low” to “medium/high” categories of salmon smolt production, as reviewed by Symons (1979). This is in an upland area, representing about 6-7% of the Tyne wetted area and total juvenile salmon production in the Tyne catchment as a whole would have been considerably greater, at a time before any stocked fish would have returned. Assuming a wetted area of 542 ha (Tyne Salmon Action Plan) these smolt rates are equivalent to total annual smolt outputs of 36,000 to 270,000. These are indicative potential outputs, the actual output to sea at that time would have been variable, depending on estuarine water quality.

The recovery of sea trout catches in the Tyne was simultaneous with that of the salmon and occurred at virtually the same rate, but very few sea trout were stocked and so the recovery was almost entirely through natural processes. The fact of sea trout recovery has sometimes been used to support the view that natural recovery enabled by water quality improvements, would also have been important in salmon (Champion, 1991). This is a reasonable argument, but there are some points of difference between the species that should be considered. First, the exploitation rate on sea trout is thought to be lower than salmon on the Tyne, so the catch index underestimates actual sea trout run. Second, it is likely that there was always a substantial trout population in the freshwater Tyne above the polluted estuary. This would have been a major source of sea trout smolts, which, whenever estuarine conditions improved, would have been able to pass to sea and return as adults. Though the same principle would have applied to salmon, the starting production of salmon juveniles was certainly much lower. Furthermore, sea trout tend to be marginally more resistant to water quality challenges than salmon. Third, the sea trout is a multiple spawner, i.e. compared to salmon more females return to spawn for more than one year. This might be expected to give a potential for inherently more stable and faster recovery than salmon, whose females mostly spawn only once. Interestingly, sea trout stocks in the North East rivers have an unusually low incidence of repeat spawning (Solomon, 1995; Harris, 2002). Thus, while multiple spawning does occur in the Tyne sea trout they are, of all the English and Welsh stocks, the most similar to salmon.

These species differences might potentially lead to faster relative recovery of sea trout compared to salmon, although the catch data did not show any consistent differences between them (Fig 24). However, catch time series may not be suitable for investigating inter-specific variation in intrinsic population growth because of confounding factors such as differential changes in exploitation rate or marine survival. The similar catch changes, irrespective of any underlying population rate differences, support the view that sea trout and salmon recoveries were both enabled by estuarine water quality improvements. This argument is unaffected by any inter-specific recovery rate differences. The similarities between the species are more striking and more informative than the differences. Both have vulnerable smolt stages, migrating at broadly the same time of year (sea trout a little earlier, normally), crucially dependent upon good estuarine conditions and both have migrations of adults back into the river, also requiring good water quality in the estuary. The sea trout recovery occurred in spite of a very little stocking, and for all practical purposes can be regarded as a natural process. This does not prove that natural recovery occurred in salmon, but it shows that natural recovery of a similar migratory salmonid species occurred in the Tyne and so offers a *prima facie* case that such a process is likely to have occurred in salmon. It does not show that the hatchery was not a contributory factor in salmon recovery, rather it is entirely uninformative on that point. If the recovery of sea trout was dependent upon improving environmental conditions, then its pattern provides an indicator of the extent and time course of water quality improvements in the estuary. These conditions would have been experienced also by salmon.

In summary, the argument for natural recovery is based on:

- existence of a plausible mechanism (re-colonisation by some combination of a residual population and inward straying),
- the timing of catch and effort changes, which predate hatchery returns,
- the observation of moderate populations of salmon juveniles in the Tyne in the late 1970s, which predate hatchery returns,
- the majority of escapement has always been wild fish, based on microtag data, and
- the simultaneous recovery, without significant stocking, of a cohabiting migratory species, sea trout, with broadly similar life-cycle.

The role of stocking in recovery

The microtag results confirm that stocking of the Tyne produced adult returns to the river. Moreover, the numbers of fish stocked were more than sufficient to meet the mitigation agreement for lost smolt recruitment caused by impoundment. The questions are what proportion returned, how much did they contribute to the various fisheries and escapement, what was the sustainable net benefit, and how fast might the recovery have been without stocking?

Individual samples of broodstock had microtag incidences up to 30%, and because not all fish were marked, the incidence of hatchery fish in those samples would have been higher. However, because of precise homing of stocked fish to the areas of stocking (Potter and Russell, 1994), the numbers and proportions of returning microtagged salmon were highest where most stocking took place, which were also those where broodstock collection was focussed. Consequently, broodstock collections were highly biased samples and across the catchment as a whole the hatchery contribution to runs would have been expected to be a lot lower.

Currently, direct stocking returns are estimated to provide 2-7% of the Tyne's annual salmon run. This is roughly equivalent to the lost production due to the dam, although requiring a higher level of stocking to maintain this return than was initially envisaged in the mitigation plan, probably because present day marine survival is lower. The contribution of stocking to recovery was probably greatest during the period 1983 to 1986, when output from the hatchery was increasing and natural recruitment was still comparatively low. During that period, annual hatchery contribution ranged between 22% and 42% for four consecutive years. Annual contributions do not give a true impression of contribution to stock recovery, because the progeny of each year's breeding is dissipated in later returns over a three to four year period, owing to divided migration and return. Cumulative spawning over the period 1980 to 1986 is a better approximation of contribution to later generations, and the estimated total contribution from the hatchery was around 20% (8-43%) of the rod catch (and by implication the in-river run).

While statistical evidence is lacking, the injection of hatchery-origin spawners during the early stages of recovery was probably important at a time when the annual catches were still highly variable, because of the annually fluctuating progress of estuarine water quality improvements. The mechanism was probably more than simply increasing annual numbers of spawners, because the expanded distribution of salmon brought about by dispersed hatchery releases may have accelerated re-colonisation of the catchment as a whole. But some workers have cautioned that prior residence of juvenile hatchery-origin salmonids could reduce the success of natural colonisers (Quinn, 1993;Vasemagi, *et al.*, 2001), which could slow down natural colonisation and limit the overall benefit. On the other hand, it makes management sense to move as fast as possible through the early phases of recovery because small salmon stocks, with low growth potential, are more vulnerable to chance fluctuations leading to extinction through depensatory recruitment (Routledge and Irvine, 1999; Einum *et al.*, 2003). This is an argument for pump priming to kick-start stock recovery. But the analysis presented here suggests that the benefits of pump priming are likely to vary according to the potential for natural recovery. On the Tyne, where natural recovery processes were already underway and always contributed the greater part of returning stock, they would be proportionally lower than on a river where natural recovery was unlikely, such as the River Dove. It should be remembered that on the Tyne the management aim of stocking was mitigation, not pump priming.

In evaluating options to stock for pump priming purposes, the fisheries management objectives and constraints determine the decisions. The choice in each circumstance is some trade-off between the economic costs and ecological or genetic risks of stocking and the benefits of increasing the rate of recovery. It is not possible to say for sure how the Tyne recovery would have proceeded without stocking, but the relative contributions of natural and hatchery returns (80:20 ratio) indicate that the recovery would have continued without stocking. Also, it is likely that the escapement contributed by stocking (20%) would have accelerated and stabilised the recovery at that critical, early stage.

A difficulty that may accompany stocking is that the use of broodstock taken from the river will be partially offset by lost wild production of those fish (Harris, 1994), reducing the net benefits. However, in the first few years of the Tyne programme, most (65%) of the eggs came from Scottish sources, reducing demand on native spawners, so this problem did not occur in the Tyne. In later years, where possible, broodstock were mainly taken from microtagged returns, also minimising demands on wild stocks.

The above discussion relates to direct returns of stocked fish, but no conclusions can be made regarding the long-term sustainability of the hatchery-origin progeny compared with wild parent lines. NASCO (2002) defines wild fish as those having parents that had completed their life-cycle entirely in the natural environment. The first examples of such fish (third-generation) returning to the Tyne would have originated from the hatchery programme by around 1988. In the evaluation reported here, performance of F2 and later generations of hatchery-bred parents has been assumed to be the same as that of wild natives, but this may have over-estimated long term hatchery benefits. The long-term performance of second generation and later fish of hatchery-reared or non-native parents has been questioned (e.g. Fleming *et al.*, 2000). Recent experimental evidence from Ireland has shown that life-time success of farmed fish and backcrosses with wild fish can be substantially reduced compared with native stock (McGinnity *et al.*, 2003). Line-bred farm salmon were never used as Tyne broodstock, which were obtained as Tyne "returnees" each year. Under those circumstances, any reductions in life-time performance resulting from hatchery intervention are unlikely to have been as large as those reported by the Irish study.

Genetic arguments have scarcely figured in this assessment because there is no information on the topic in the Tyne context. Scottish origin eggs were used between the years 1978 and 1983. Their use could have led to fitness reduction through hybridisation, which may have actually reduced the rate of natural recovery (Ferguson, pers. comm.). But there is no way of detecting the scale of this effect in the Tyne with currently available information. Further work to explore genetic lineages in the Tyne is being considered.

Return rate to the coast is an important variable in determining the overall benefits of a stocking programme. Percentage returns decreased overall during the study period, probably due to reducing marine survival. Overall weighted mean was 0.6% (0.5-0.8%). Recent values, which on one hand will have benefited from better hatchery practice, but on the other hand will be influenced by lower marine survivals, were mostly in the range 0.3% to 0.6%. These are within the range reported for studies elsewhere for hatchery stock (Aprahamian *et al.*, 2003). Potter and Russell (1994) reported return rates (recaptures in all fisheries) of 0.7% and 6.0% respectively for hatchery and wild salmon from North East Coast rivers, including the Tyne. All studies elsewhere have reported higher return rates for comparable wild stages than for hatchery fish (Aprahamian *et al.*, 2003). Returns to the river are reduced by coastal fisheries and in the Tyne overall return to the river was 0.3% (range 0.1-0.6%). These values are for combined stocking of 0+ and 1+ and each group will be different. Even allowing for a very reduced coastal exploitation post the 2003 net buy-out the returns to the river are most unlikely to be more than 1%. Such values contrast with those sometimes quoted for the Tyne, e.g. 13% of tagged fish returning to the river (Carrick and Gray, 2001).

This review has shown that the role of stocking was probably important during an early key phase, but has always formed a smaller component of Tyne salmon recovery than natural processes. The report's aim was to address the debate illustrated above through an objective assessment, within the constraints of available information. During its preparation it was apparent that a conclusion that stocking was probably not the dominant reason for the Tyne recovery could be misconstrued. Some concluding comments on this are required. The arguments for or against the use of hatcheries and stocking do not depend solely on the outcome of the River Tyne programme, although these results put the benefits of stocking into better perspective. In the authors' view, there are plenty of circumstances where stocking is an important and sometimes essential tool in fisheries management. On the Tyne itself the reservoir mitigation was only practically achievable by stocking and this was successfully delivered through the efficiency of the Kielder hatchery operation; indeed mitigation, and not restoration, was its original purpose. Continuing intermittent fish deaths in the Tyne estuary present the need to have restoration-stocking facilities on tap. Other rivers in England and Wales will need variously pump-priming or restoration stocking to support stocks. These require the hatchery expertise and facilities developed at Kielder (and elsewhere) to be permanently available, for they cannot be mothballed and then brought back on line to any useful timetable. When and how to use stocking are fishery management questions that can only be answered if informed by the type of assessment offered in this report, which permit an objective evaluation of benefits.

7. CONCLUSIONS

7.1 The Tyne salmon recovery started about 15 years before the first significant returns from stocking and resulted from natural re-colonisation that was enabled by improving estuarine water quality.

7.2 Between 1980 and 1986, the cumulative totals of wild and hatchery-derived spawners were estimated to be 80% and 20% respectively. Natural re-colonisation has always been the dominant process of stock recovery.

7.3 Stocking was likely to have been an important contributory factor in accelerating and stabilising recovery during the early years, when the natural recovery was still slow and variable due to the erratic progress of water quality improvements.

7.4 The long-term sustainable benefits of later generation progeny of hatchery-origin fish remain equivocal, because there was no way of investigating the issue. Work to assess the feasibility of genetic studies to track the long-term reproductive success of these fish is recommended.

7.5 The hatchery production consistently met or exceeded mitigation requirement to compensate for the Kielder reservoir.

7.6 Current (post-1995) annual contribution of direct hatchery returns to Tyne run size and catch is estimated to be mainly between 2 and 7 %.

7.7 Over the period 1980 to 2000 overall weighted mean return rate to the coast (pre North East Coast fishery) of all stocked fish combined was 0.6% (0.5-0.8%).

7.8 Over the period 1980 to 2000 overall weighted mean return rate to the river (pre rod fishery) of all stocked fish combined was 0.37% (0.1-0.6%).

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Table 1 Salmon stocking records for selected North East rivers

	Tyne					Wear				Tees				Coquet		
Year	**0+**	**1+**	**Tagged 1+**	**total 1+**	**Smolts**	**0+**	**1+**	**Tagged 1+**	**total 1+**	**0+**	**1+**	**Tagged 1+**	**Total 1+**	**0+**	**1+**	**Tagged 1+**
1979	135000	0	0	0	12500	40000	0	0	0	0	0	0	0	20000	0	0
1980	152000	70000	0	70000	0	30000	0	0	0	0	0	0	0	0	0	0
1981	340000	60000	0	60000	0	0	0	0	0	0	0	0	0	0	0	0
1982	150000	80000	0	80000	10000	0	0	0	0	0	0	0	0	0	0	0
1983	130000	160000	0	160000	0	0	0	0	0	0	0	0	0	0	0	0
1984	140000	153000	16912	169912	0	0	0	0	0	0	0	0	0	0	0	0
1985	40000	100000	20030	120030	0	0	0	20156	20156	0	0	10059	10059	0	0	10045
1986	160000	23000	25433	48433	0	22000	1400	0	1400	0	0	0	0	4000	0	10075
1987	80000	103000	34688	137688	0	0	0	0	0	0	0	0	0	25000	0	0
1988	135000	100000	42482	142482	0	25000	25000	10125	35125	25000	25000	10372	35372	25000	0	10222
1989	150000	25000	42096	67096	0	30000	30000	0	30000	30000	30000	0	30000	30000	30000	0
1990	165000	15000	16666	31666	0	0	0	10000	10000	0	0	11400	11400	0	0	14019
1991	240000	0	43947	43947	0	50000	0	5586	5586	50000	0	8329	8329	0	0	5178
1992	198000	80000	44295	124295	0	0	0	10050	10050	220000	0	30287	30287	35000	500	5185
1993	243000	30000	28369	58369	0	0	0	14802	14802	200000	32000	10112	42112	0	0	0
1994	390000	39000	20858	59858	0	0	3000	9014	12014	200000	32000	32194	64194	0	0	0
1995	100000	33000	29221	62221	0	0	0	0	0	180000	16000	14497	30497	0	0	0
1996	450000	32500	28624	61124	0	0	7500	7300	14800	100000	14000	10572	24572	0	0	0
1997	480000	80000	53095	133095	0	0	0	0	0	0	0	0	0	0	0	0
1998	80000	85000	15214	100214	0	0	0	0	0	0	0	0	0	0	0	0
1999	300000	80000	21591	101591	0	0	0	0	0	0	0	0	0	0	0	0
2000	270000	143000	21144	164144	0	0	0	0	0	0	0	0	0	0	0	0
2001	300000	100000	0	100000	0	0	0	0	0	0	0	0	0	0	0	0
2002	350000	100000	0	100000	0	0	0	0	0	0	0	0	0	0	0	0
Total	5178000	1691500	504665	2196165	22500	197000	66900	87033	153933	1005000	149000	137822	286822	139000	30500	54724

Table 2 Sea trout stocking records for the River Tyne

Year	Eggs in Kielder hatchery	fry in Kielder hatchery	Stocked into Tyne	Stocking stage/location
1979	400000	50000	5000	eggs
1980	117000		0	
1981	0		0	
1982	0		0	
1983	252000	60000	?	
1984	175000	70000	0	
1985	175000	110000	0	
1986	150000	75000	7500	underyearlings
1987	225000	30000	10000	underyearlings
1988	350000	30000	0	
1989	405000	30000	10000	underyearlings
1990	564000		0	
1991	100000		0	
1992	110000		0	
1993	285000		95000	S.Tyne
1994	125000		95000	S.Tyne
1995	235000		0	
1996			200000	N. Tyne and Rede
1997	250000		0	
1998	70000		0	
1999	125000		0	Wear
2000	120000		0	
2001			170000	Devil's water (Tyne)
2002				
SUM=	4233000	455000	592500	

Table 3 Records of egg sources and numbers 1978 to 1983, for stocking the Tyne
(NB in estimating % Scottish and Tyne contributions, the Wear has been excluded, years 1980 and 1982, hence sums <100%)

Year	Source	Number	% Scottish	% Tyne
1978	Kincardine	100,000	**81.7**	**18.3**
	Tay	100,000		
	Ullapool – genetics unknown	100,000		
	Tyne	55,000		
1979	Kincardine	96,000	**83.7**	**16.3**
	Tay	110,000		
		40,000		
1980	Kincardine	210,000	**23.4**	**35.8**
	Coquet	105,000		
	Wear	105,000		
	Tay	155,000		
		321,000		
1981	Kincardine	96,000	**57.1**	**42.9**
	Tay	104,000		
		150,000		
1982	Kincardine	96,000	**36.5**	**18.3**
	Wear	5,000		
	Conon	114,000		
		48,000		
1983	Kincardine	135,000	**88.7**	**11.3**
	Conon	120,000		
	Wester Ross	60,000		
	Tyne	40,000		
		TOTALS	%	
	Scottish	1,596,000	**64.7**	
	Wear +Coquet	215,000	**8.7**	
	Tyne	654,000	**26.5**	

Table 4 Numbers of collected fish and microtag incidence, during broodstock collections in Tyne tributaries

Year	North Tyne			Rede			South Tyne		
	Total	Tagged	%tagged	Total	Tagged	%tagged	Total	Tagged	%tagged
1986*	66	0		28	0		7		0.0
1987*	67	0		56	0		22		0.0
1988	56	3	5.4	33	3	9.1	26	0	0.0
1989	81	6	7.4	22	0	0.0	6	0	0.0
1990	61	10	16.4	54	0	0.0	31	0	0.0
1991	134	18	13.4	20	6	30.0	23	1	4.3
1992	106	22	20.8	44	3	6.8	0	0	
1993	138	20	14.5	68	6	8.8	21	0	0.0
1994	109	14	12.8	34	3	8.8	0	0	
1995	63	10	15.9	69	2	2.9	24	0	0.0
1996	84	8	9.5	54	3	5.6	29	0	0.0
1997	112	6	5.4	22	0	0.0	13	0	0.0
1998	133	12	9.0	27	3	11.1	8	0	0.0
1999	41	1	2.4	75	4	5.3	16	1	6.3
SUM	1251	130	**11.6**	606	33	**6.3**	226	2	**1.0**

* overall % tag estimates exclude 1986 and 1987, because no tags expected by then

Table 5 Numbers of Tyne microtagged salmon stocked into the Tyne and recovered in distant waters fisheries

River	Year	Faroes		W. Greenland	Scotland		Ireland/NI		Total
		1SW	MSW	1SW *	1SW	MSW	1SW	MSW	
Tyne	1985						2		2
	1986	3	3	93	33		24		156
	1987	8		46		2	14		69
	1988		2	19			3	2	26
	1989		2	8	6				16
	1990		2						2
	1991	16	4				5		25
	1992			7			1		8
	1993	1					6		7
	1994						1	8	9
	1995						4		4
	1996							2	2
	1997						4		4
	1998							3	3
	Total	**27**	**13**	**173**	**39**	**2**	**64**	**16**	**333**

Table 6a Estimates of hatchery returns, based on microtag returns in net fishery, using MIN parameters

NetMINest

Year	Stocking 0+	1+	%1+tgd	Estimated hatchery fish in net catch, lagged to year: From 1+ stocking 1SW	MSW	Total	From 0+ stocking 1SW	MSW	Total	From 1+ and 0+ stocking 1SW	MSW	Total	Adjusted NEC net catch	Hatchery net catch	% Hatchery net catch	Total hatchery return to coast	%return ref to 1+ stock yr
1979	135000	0															
1980	152000	70000											49,442	30.5	0.1	23	0.68
1981	340000	60000		136	0	136				136	0	136	74,642	136.0	0.2	348	0.59
1982	150000	80000		349	37	386	64	0	64	413	37	450	54,180	449.7	0.8	1,137	0.45
1983	130000	160000		355	90	444	72	16	88	427	106	533	83,459	569.2	0.7	1,395	0.95
1984	140000	169912	10	577	92	668	161	18	179	738	110	848	64,039	847.9	1.3	2,176	1.65
1985	40000	120030	17	862	150	1,012	71	41	112	933	191	1,124	61,944	1123.6	1.8	2,877	2.34
1986	160000	48433	53	2,142	222	2,364	99	18	117	2,241	240	2,481	68,499	2481.0	3.6	6,288	0.87
1987	80000	137688	25	792	634	1,427	123	42	165	915	676	1,591	39,034	1591.3	4.1	4,220	0.20
1988	135000	142482	30	193	79	272	19	7	26	211	86	297	54,917	297.4	0.5	774	0.67
1989	150000	67096	63	139	42	181	18	4	22	157	46	203	44,769	203.5	0.5	525	0.25
1990	165000	31666	53	351	115	466	24	12	35	375	127	502	55,652	501.8	0.9	1,300	0.21
1991	240000	43947	100	142	153	295	28	10	39	170	163	333	27,463	333.2	1.2	891	0.28
1992	198000	124295	36	73	44	117	25	4	29	98	48	146	21,756	145.6	0.7	381	0.32
1993	243000	58369	49	154	56	210	32	12	43	186	67	253	45,144	253.1	0.6	657	0.42
1994	390000	59858	35	148	138	286	27	12	40	176	150	326	50,278	326.2	0.6	869	0.11
1995	100000	62221	47	187	146	333	70	22	92	257	169	425	57,467	425.2	0.7	1,123	0.15
1996	450000	61124	47	67	99	165	19	24	44	86	123	209	20,067	208.6	1.0	565	0.44
1997	480000	133095	40	126	31	157	60	7	67	186	38	224	23,676	224.2	0.9	574	0.22
1998	80000	100214	15	136	76	211	18	33	51	154	108	262	19,726	262.1	1.3	694	0.19
1999	300000	101591	21	214	164	378	82	8	91	296	173	469	28,980	468.7	1.6	1,233	0.53
2000	270000	164144	13	172	124	296	88	38	126	260	162	421	46,822	421.4	0.9	1,111	0.25
2001	300000	100000		201	126	326	15	40	55	215	166	381	39,004	381.2	1.0	1,012	0.03
2002	350000	100000		253	203	456	55	7	62	308	210	518	33,458	517.6	1.5	1,369	

NB 12,500 and 10,000 smolts stocked in 1979 and1982 respectively

Variables	
scaling factor for untagged 1+ =	0.7
scaling factor for untagged 0+ =	0.1

Wtd mean % return to coast=	0.48
Wtd mean % contribution to NEC catch=	1.2

Table 6b Estimates of hatchery returns, based on microtag returns in net fishery, using BEST parameters

NetBESTest

Year	Stocking 0+	Stocking 1+	%1+tgd	Estimated hatchery fish in net catch, lagged to year: From 1+ stocking 1SW	MSW	Total	From 0+ stocking 1SW	MSW	Total	From 1+ and 0+ stocking 1SW	MSW	Total	Adjusted NEC net catch	Hatchery net catch	% Hatchery net catch	Total hatchery return to coast	%return ref to 1+ stock yr
1979	135000	0															
1980	152000	70000											49,442	41.3	0.1	31	0.92
1981	340000	60000		155	0	155				155	0	155	74,642	155.4	0.2	399	0.82
1982	150000	80000		399	42	441	160	0	160	559	42	601	54,180	600.9	1.1	1,517	0.68
1983	130000	160000		405	103	508	180	40	221	586	143	729	83,459	774.0	0.9	1,904	1.19
1984	140000	169912	10	659	105	764	403	45	449	1,062	150	1,213	64,039	1212.6	1.9	3,106	2.03
1985	40000	120030	17	985	172	1,156	178	101	279	1,163	273	1,436	61,944	1435.8	2.3	3,687	2.78
1986	160000	48433	53	2,392	254	2,646	247	45	292	2,639	299	2,937	68,499	2937.3	4.3	7,450	1.01
1987	80000	137688	25	880	710	1,590	306	105	411	1,186	815	2,001	39,034	2001.2	5.1	5,294	0.26
1988	135000	142482	30	203	86	289	46	18	64	250	104	354	54,917	353.5	0.6	921	0.79
1989	150000	67096	63	152	45	197	45	10	55	197	55	252	44,769	252.1	0.6	650	0.32
1990	165000	31666	53	382	126	508	59	29	88	441	155	596	55,652	596.0	1.1	1,545	0.30
1991	240000	43947	100	148	166	314	71	26	97	218	192	411	27,463	410.6	1.5	1,095	0.37
1992	198000	124295	36	76	46	122	61	10	72	137	56	193	21,756	193.4	0.9	504	0.40
1993	243000	58369	49	160	57	216	79	29	109	239	86	325	45,144	324.9	0.7	843	0.59
1994	390000	59858	35	160	146	306	68	31	99	228	177	405	50,278	405.4	0.8	1,077	0.16
1995	100000	62221	47	199	157	355	174	56	230	373	213	586	57,467	585.7	1.0	1,540	0.24
1996	450000	61124	47	71	105	177	48	60	109	120	166	286	20,067	285.5	1.4	773	0.56
1997	480000	133095	40	134	33	167	151	18	169	285	51	335	23,676	335.4	1.4	857	0.33
1998	80000	100214	15	155	86	241	46	82	127	201	168	369	19,726	368.8	1.9	982	0.30
1999	300000	101591	21	244	188	432	206	21	227	450	209	659	28,980	658.7	2.3	1,721	0.64
2000	270000	164144	13	197	142	338	219	94	314	416	236	652	46,822	651.9	1.4	1,714	0.32
2001	300000	100000		229	143	373	37	101	137	266	244	510	39,004	510.2	1.3	1,363	0.03
2002	350000	100000		289	232	521	137	17	154	426	249	675	33,458	675.1	2.0	1,776	

NB 12,500 and 10,000 smolts stocked in 1979 and1982 respectively

Variables	
scaling factor for untagged 1+ =	0.8
scaling factor for untagged 0+ =	0.25

Wtd mean % return to coast=	0.62
Wtd mean % contribution to NEC catch=	1.53

Table 6c Estimates of hatchery returns, based on microtag returns in net fishery, using MAX parameters

NetMAXest

Year	Stocking 0+	Stocking 1+	%1+tgd	Estimated hatchery fish in net catch, lagged to year: From 1+ stocking 1SW	MSW	Total	From 0+ stocking 1SW	MSW	Total	From 1+ and 0+ stocking 1SW	MSW	Total	Adjusted NEC net catch	Hatchery net catch	% Hatchery net catch	Total hatchery return to coast	%return ref to 1+ stock yr
1979	135000	0															
1980	152000	70000											49,442	56.8	0.1	42	1.25
1981	340000	60000		175	0	175				175	0	175	74,642	174.8	0.2	452	1.17
1982	150000	80000		449	47	496	320	0	320	769	47	816	54,180	816.2	1.5	2,057	1.03
1983	130000	160000		456	115	571	361	80	441	817	196	1,013	83,459	1069.8	1.3	2,642	1.50
1984	140000	169912	10	741	118	859	807	91	897	1,548	209	1,757	64,039	1756.8	2.7	4,493	2.53
1985	40000	120030	17	1,108	193	1,301	356	203	559	1,464	396	1,860	61,944	1859.6	3.0	4,790	3.34
1986	160000	48433	53	2,641	286	2,927	494	89	584	3,135	375	3,510	68,499	3510.4	5.1	8,910	1.22
1987	80000	137688	25	968	785	1,753	613	210	823	1,581	995	2,576	39,034	2575.7	6.6	6,795	0.34
1988	135000	142482	30	214	93	307	93	36	128	307	129	435	54,917	435.3	0.8	1,134	0.95
1989	150000	67096	63	166	47	213	90	20	110	255	67	323	44,769	322.7	0.7	831	0.43
1990	165000	31666	53	412	137	549	119	58	177	531	194	726	55,652	725.6	1.3	1,883	0.44
1991	240000	43947	100	154	180	333	141	52	193	295	231	527	27,463	526.5	1.9	1,399	0.50
1992	198000	124295	36	78	48	126	123	21	144	201	69	270	21,756	269.8	1.2	699	0.51
1993	243000	58369	49	165	58	223	158	59	217	323	117	440	45,144	440.2	1.0	1,142	0.84
1994	390000	59858	35	171	155	325	137	62	199	307	217	524	50,278	524.4	1.0	1,389	0.22
1995	100000	62221	47	210	167	378	349	112	461	559	280	838	57,467	838.4	1.5	2,196	0.38
1996	450000	61124	47	76	112	188	97	121	218	173	233	406	20,067	406.0	2.0	1,098	0.72
1997	480000	133095	40	142	35	177	301	36	337	444	71	514	23,676	514.1	2.2	1,310	0.49
1998	80000	100214	15	174	97	271	91	164	255	266	261	526	19,726	526.4	2.7	1,409	0.46
1999	300000	101591	21	275	211	486	411	42	453	686	253	939	28,980	939.3	3.2	2,439	0.79
2000	270000	164144	13	221	159	380	439	189	628	660	348	1,008	46,822	1007.9	2.2	2,644	0.43
2001	300000	100000		258	161	420	73	201	274	331	363	694	39,004	694.0	1.8	1,865	0.04
2002	350000	100000		326	261	586	274	34	308	600	294	894	33,458	894.1	2.7	2,340	

NB 12,500 and 10,000 smolts stocked in 1979 and1982 respectively

Variables		Wtd mean % return to coast=	0.82
scaling factor for untagged 1+ =	0.9	Wtd mean % contribution to NEC catch=	2.03
scaling factor for untagged 0+ =	0.5		

Table 7a Estimates of hatchery returns, based on microtag returns in rod fishery, using MIN parameters

Rod_MINest

Year	Stocking			Estimated recaps in rod fish, lagged to year						Hatchery fish in rod catch			Adjusted rod catch	% Hatchery fish in catch	Total H in run from stocking yr	%return to river	Total spawners	Hatchery origin spawners
			%1+	From 1+ stocking			From 0+ stocking			From 1+ and 0+ stocking								
	0+	1+	tagged	1SW	MSW	Total	1SW	MSW	Total	1SW	MSW	Total						
1979	135000	0	_										488		185	0.26		
1980	152000	70000	_							3	0	3	633	0.4	527	0.26	6548	29
1981	340000	60000	_	5	0	5	0	0	0	5	0	5	393	1.2	519	0.24	3842	46
1982	150000	80000	_	13	10	24	4	0	4	17	10	27	384	7.1	875	0.21	3553	254
1983	130000	160000	_	13	29	42	4	8	13	18	37	58	395	14.7	965	0.31	3470	482
1984	140000	169912	10	21	29	50	10	9	19	31	38	69	417	16.6	758	0.25	3485	580
1985	40000	120030	17	31	46	78	4	21	25	36	67	103	1129	9.1	347	0.13	9009	822
1986	160000	48433	53	46	68	114	5	9	14	51	77	128	919	13.9	401	0.45	7000	975
1987	80000	137688	25	25	21	46	4	12	16	29	33	63	2048	3.1	256	0.09	14925	456
1988	135000	142482	30	23	6	29	1	3	4	24	8	33	2265	1.4	276	0.12	15809	228
1989	150000	67096	63	7	23	30	1	2	3	8	26	33	1161	2.9	266	0.13	7770	224
1990	165000	31666	53	16	21	37	1	7	8	17	28	46	1728	2.6	311	0.17	11113	293
1991	240000	43947	100	5	17	22	3	3	5	8	19	28	1064	2.6	388	0.19	6577	172
1992	198000	124295	36	10	20	31	2	12	14	13	32	45	2063	2.2	278	0.08	12277	266
1993	243000	58369	49	19	28	47	5	7	11	24	35	59	2305	2.6	140	0.05	13212	337
1994	390000	59858	35	13	28	40	5	7	12	18	35	52	1394	3.7	105	0.03	7705	288
1995	100000	62221	47	5	15	20	2	10	12	7	26	32	1360	2.4	214	0.05	7256	173
1996	450000	61124	47	3	9	12	1	7	8	4	16	20	1834	1.1	157	0.10	9454	102
1997	480000	133095	40	0	9	9	0	6	6	0	15	15	1606	0.9	217	0.04	8005	76
1998	80000	100214	15	11	21	32	1	21	22	12	42	54	1989	2.7	167	0.03	9592	262
1999	300000	101591	21	11	13	23	11	2	12	22	14	36	2088	1.7	126	0.07	9749	168
2000	270000	164144	13	5	4	10	3	11	13	8	15	23	2527	0.9	64	0.01	11431	104
2001	300000	100000	_	6	13	19	1	11	12	7	24	31	2764	1.1	nd	0.00	12125	136
2002	350000	100000	_	8	16	24	3	2	4	10	18	28	2844	1.0	nd	0.00	12098	120

NB 12,500 and 10,000 smolts stocked in 1979 and1982 respectively

Variables	
Rod raising factor(Fr) =	1.2
scaling factor for untagged 1+(v)	0.7
scaling factor for untagged 0+(w	0.1
proportional change in U =	0.5

	SPAWNERS cusum_1986
Total	36908
wild	33720
hatche	3188
%Hcur	8.6

Max annual %=	16.6
Max 3yr mean% =	12.5
wtd return to river %=	0.12
wtd %H in rod catch%=	2.7

Table 7b Estimates of hatchery returns, based on microtag returns in rod fishery, using BEST parameters

Rod_BESTest

Year	Stocking			Estimated recaps in rod fish, lagged to year						Hatchery fish in rod catch			Adjusted rod catch	% Hatchery fish in catch	Total H in run from stocking yr	%return to river	Total spawners
			%1+	From 1+ stocking			From 0+ stocking			From 1+ and 0+ stocking							
	0+	1+	tagged	1SW	MSW	Total	1SW	MSW	Total	1SW	MSW	Total					
1979	135000	0	_										488		369	0.62	
1980	152000	70000	_							7	0	7	633	1.1	1271	0.62	6548
1981	340000	60000	_	9	0	9	0	0	0	9	0	9	393	2.3	1277	0.60	3842
1982	150000	80000	_	25	20	45	16	0	16	41	20	61	384	15.9	2283	0.54	3553
1983	130000	160000	_	25	55	80	18	35	53	43	90	140	395	35.4	2098	0.68	3470
1984	140000	169912	10	41	55	96	40	39	79	81	94	175	417	42.0	1705	0.57	3485
1985	40000	120030	17	60	88	148	18	88	105	78	176	253	1129	22.4	765	0.29	9009
1986	160000	48433	53	86	130	216	19	39	58	105	169	274	919	29.8	769	0.87	7000
1987	80000	137688	25	47	35	82	17	52	68	63	87	150	2048	7.3	573	0.19	14925
1988	135000	142482	30	41	10	51	5	11	16	46	21	67	2265	3.0	554	0.25	15809
1989	150000	67096	63	13	40	53	4	9	12	17	49	66	1161	5.7	695	0.34	7770
1990	165000	31666	53	29	36	65	6	28	34	35	65	99	1728	5.7	684	0.38	11113
1991	240000	43947	100	9	29	39	12	10	23	22	40	61	1064	5.7	864	0.41	6577
1992	198000	124295	36	18	35	53	10	49	59	28	84	112	2063	5.4	719	0.20	12277
1993	243000	58369	49	33	50	82	20	27	48	53	77	130	2305	5.6	375	0.15	13212
1994	390000	59858	35	22	49	71	21	28	49	44	77	120	1394	8.6	277	0.09	7705
1995	100000	62221	47	8	26	35	9	42	52	18	69	86	1360	6.4	635	0.14	7256
1996	450000	61124	47	5	16	21	4	28	33	9	45	53	1834	2.9	316	0.20	9454
1997	480000	133095	40	0	16	16	0	25	25	0	41	41	1606	2.5	683	0.12	8005
1998	80000	100214	15	20	36	56	5	89	93	25	124	149	1989	7.5	473	0.08	9592
1999	300000	101591	21	20	22	42	44	8	52	64	29	93	2088	4.5	269	0.15	9749
2000	270000	164144	13	10	8	17	11	44	55	21	52	73	2527	2.9	158	0.03	11431
2001	300000	100000	_	12	25	37	3	46	49	14	71	85	2764	3.1	nd	0.00	12125
2002	350000	100000		15	31	46	11	8	18	25	38	64	2844	2.2	nd	0.00	12098

NB 12,500 and 10,000 smolts stocked in 1979 and1982 respectively

Variables	
Rod raising factor(Fr) =	2
scaling factor for untagged 1+(v)	0.8
scaling factor for untagged 0+(w	0.25
proportional change in U =	0.5

	SPAWNERS cusum_1986
Total	36908
wild	29445
hatchery	7464
%hatchery	20.2

Max annual %=	42.0
Max 3yr mean% =	30.4
wtd return to river %=	0.27
wtd %H in rod catch%=	6.5

Table 7c Estimates of hatchery returns, based on microtag returns in rod fishery, using MAX parameters

Rod_MAXest

Year	Stocking			Estimated recaps in rod fish, lagged to year						Hatchery fish in rod catch			Adjusted rod catch	% Hatchery fish in catch	Total H in run from stocking yr	%return to river	Total spawners
				From 1+ stocking			From 0+ stocking			From 1+ and 0+ stocking							
	0+	1+	%1+ tagged	1SW	MSW	Total	1SW	MSW	Total	1SW	MSW	Total					
1979	135000	0	_										488		662	1.36	
1980	152000	70000	_							15	0	15	633	2.4	2793	1.36	6548
1981	340000	60000	_	15	0	15	0	0	0	15	0	15	393	3.9	2851	1.34	3842
1982	150000	80000	_	43	33	76	48	0	48	91	33	124	384	32.2	5345	1.27	3553
1983	130000	160000	_	43	93	135	54	104	158	97	197	307	395	77.9	4172	1.35	3470
1984	140000	169912	10	69	93	161	121	117	238	189	210	400	417	96.0	3567	1.19	3485
1985	40000	120030	17	101	149	250	53	263	316	154	412	566	1129	50.1	1572	0.60	9009
1986	160000	48433	53	142	219	361	58	116	174	201	335	536	919	58.3	1368	1.55	7000
1987	80000	137688	25	76	53	130	50	156	205	126	209	335	2048	16.4	1210	0.41	14925
1988	135000	142482	30	66	15	81	16	33	49	82	48	130	2265	5.7	1041	0.47	15809
1989	150000	67096	63	21	63	83	11	26	37	32	88	121	1161	10.4	1660	0.82	7770
1990	165000	31666	53	46	56	102	17	85	102	64	141	204	1728	11.8	1423	0.78	11113
1991	240000	43947	100	15	45	60	36	31	68	51	77	128	1064	12.0	1817	0.87	6577
1992	198000	124295	36	28	55	83	31	146	177	58	201	259	2063	12.6	1701	0.47	12277
1993	243000	58369	49	51	78	129	61	82	143	113	160	272	2305	11.8	910	0.35	13212
1994	390000	59858	35	36	77	113	63	84	147	99	160	260	1394	18.6	665	0.22	7705
1995	100000	62221	47	13	41	54	28	127	155	42	168	209	1360	15.4	1641	0.36	7256
1996	450000	61124	47	7	25	32	12	85	98	20	111	130	1834	7.1	598	0.37	9454
1997	480000	133095	40	0	24	24	0	75	75	0	99	99	1606	6.2	1812	0.31	8005
1998	80000	100214	15	32	55	88	14	266	280	46	321	367	1989	18.5	1175	0.20	9592
1999	300000	101591	21	32	34	66	133	23	156	166	56	222	2088	10.6	525	0.29	9749
2000	270000	164144	13	16	12	28	33	133	166	50	145	194	2527	7.7	354	0.08	11431
2001	300000	100000	_	20	43	62	9	137	146	28	180	208	2764	7.5	nd	0.00	12125
2002	350000	100000	_	25	52	77	32	23	55	57	75	132	2844	4.6	nd	0.00	12098

NB 12,500 and 10,000 smolts stocked in 1979 and1982 respectively

Variables	
Rod raising factor(Fr) =	3
scaling factor for untagged 1+(v)	0.9
scaling factor for untagged 0+(w	0.5
proportional change in U =	0.5

	SPAWNERS cusum_1986
Total	36908
wild	20935
hatchery	15973
%Hcum	43.3

Max annual %=	96.0
Max 3yr mean% =	67.3
wtd return to river %=	0.59
wtd %H in rod catch%=	14.4

Table 8 Comparisons of regressions describing relationship between Tyne-Coquet difference (log10 rod catch, N+1) for period 1970-1979 and 1980 – 1989.

y=aX +b	70-79	upper 95%CL	lower 95%CL	P value	80-89	upper 95%CL	lower 95%CL	P value
a=	0.0045	0.0669	-0.0580	0.892	0.0471	0.0924	0.0018	0.076
b=	0.0602	0.4478	-0.3274	0.769	0.0225	-0.2196	-0.2196	0.860

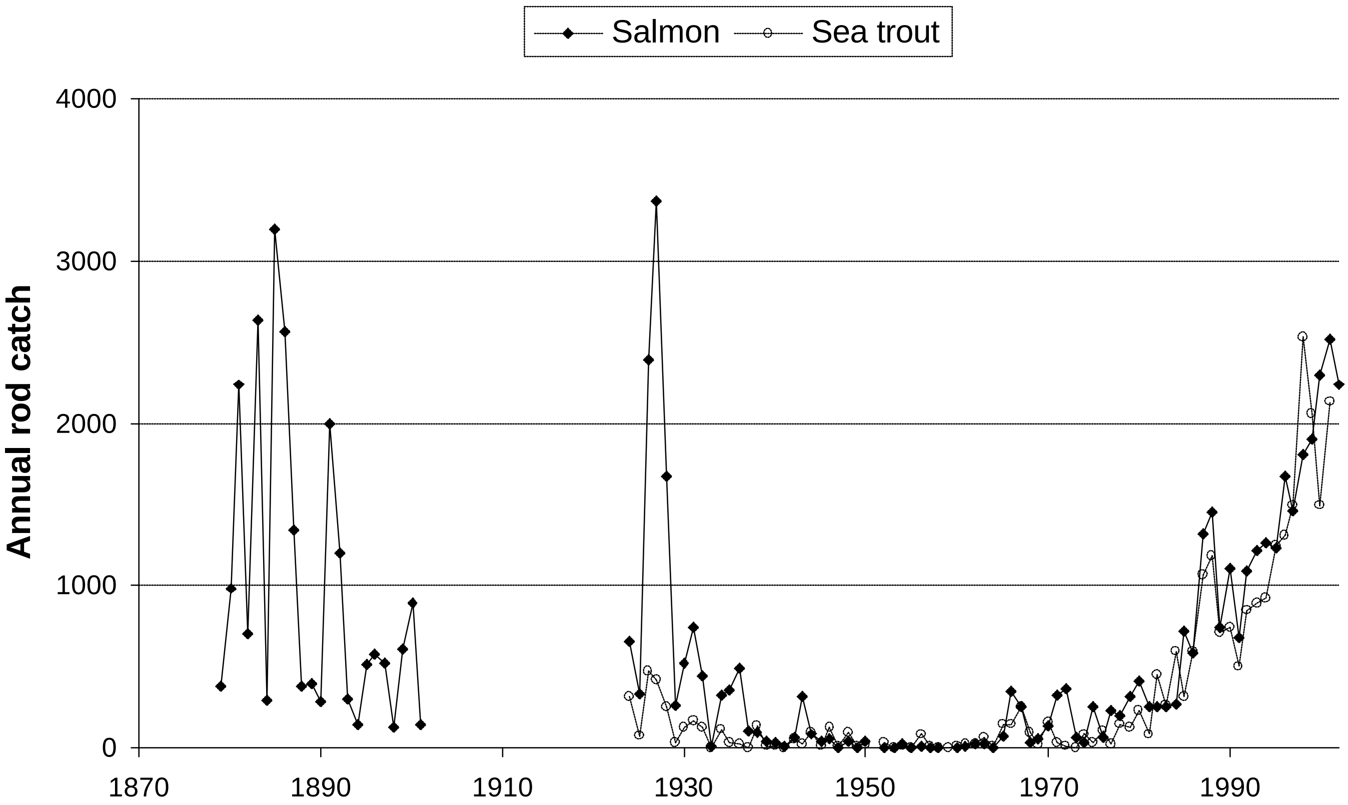

Fig 1 Salmon and sea trout declared rod catches, river Tyne. No sea trout records were available for the period before 1924.

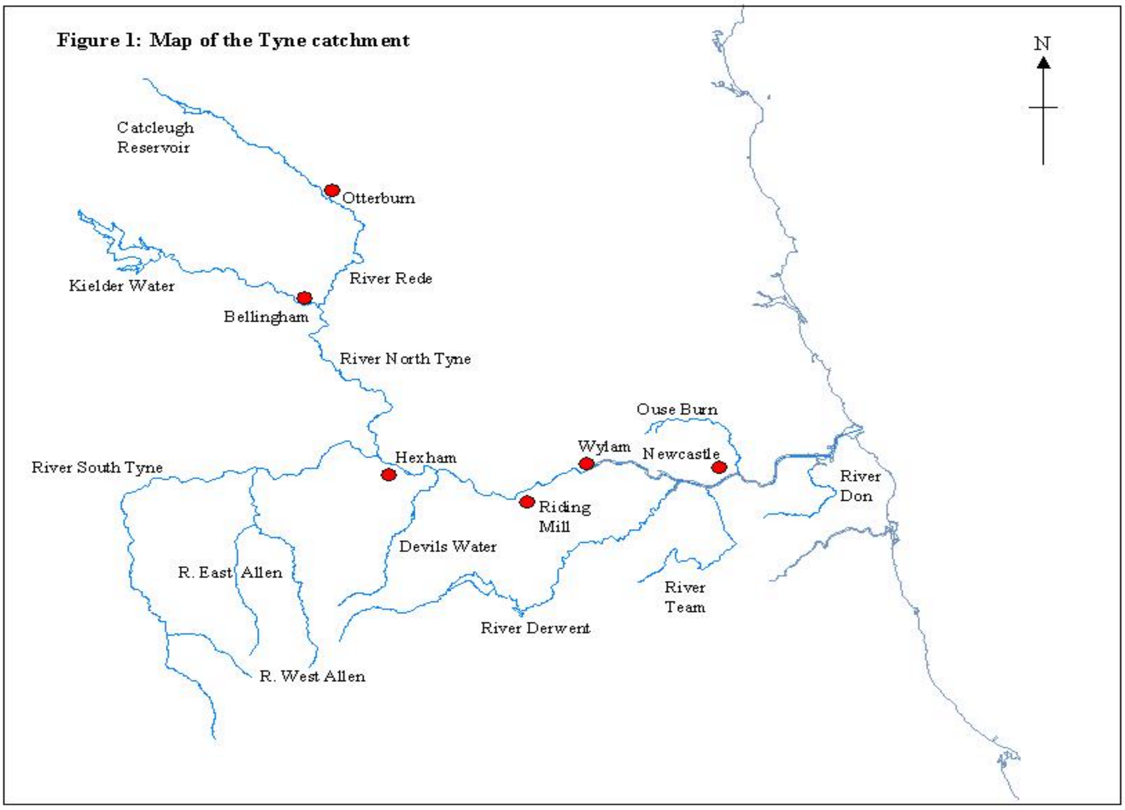

Figure 2 Map of the Tyne catchment.

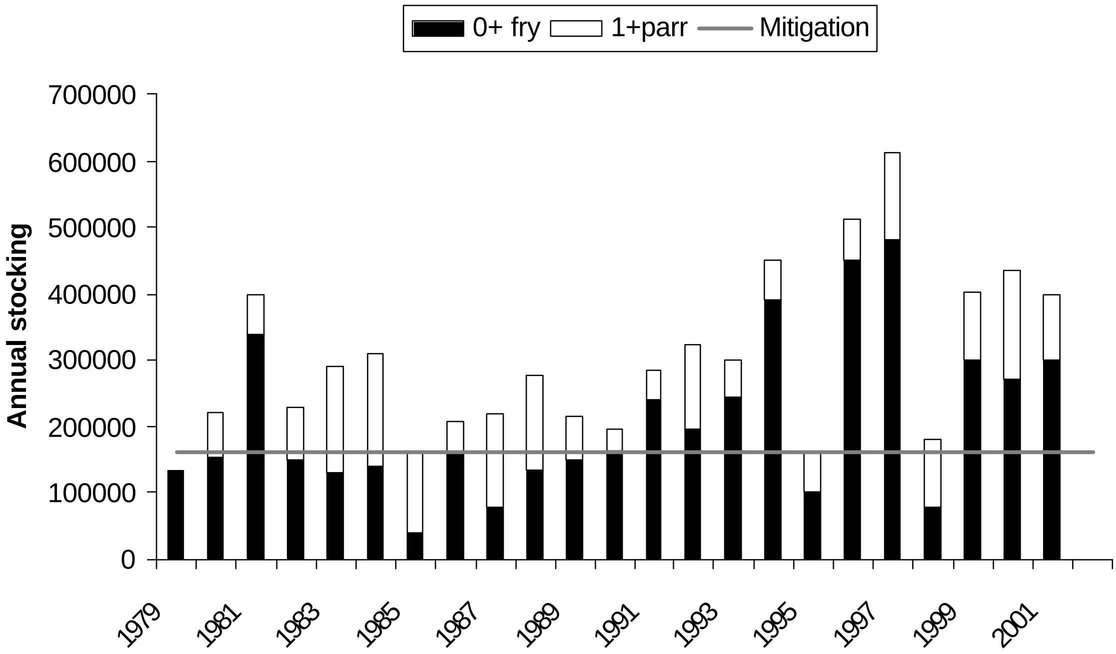

Figure 3 Salmon stocking into the River Tyne, 1979 – 2001. The mitigation level of 160,000 is shown.

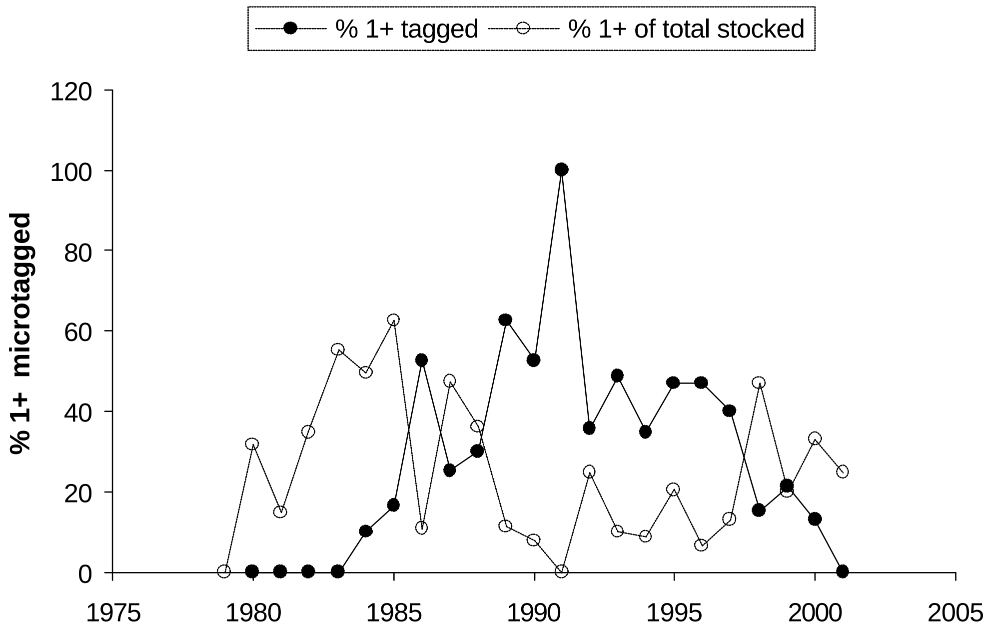

Figure 4 1+ salmon as percentage of total salmon numbers stocked into the Tyne and proportion of those 1+ that were microtagged.

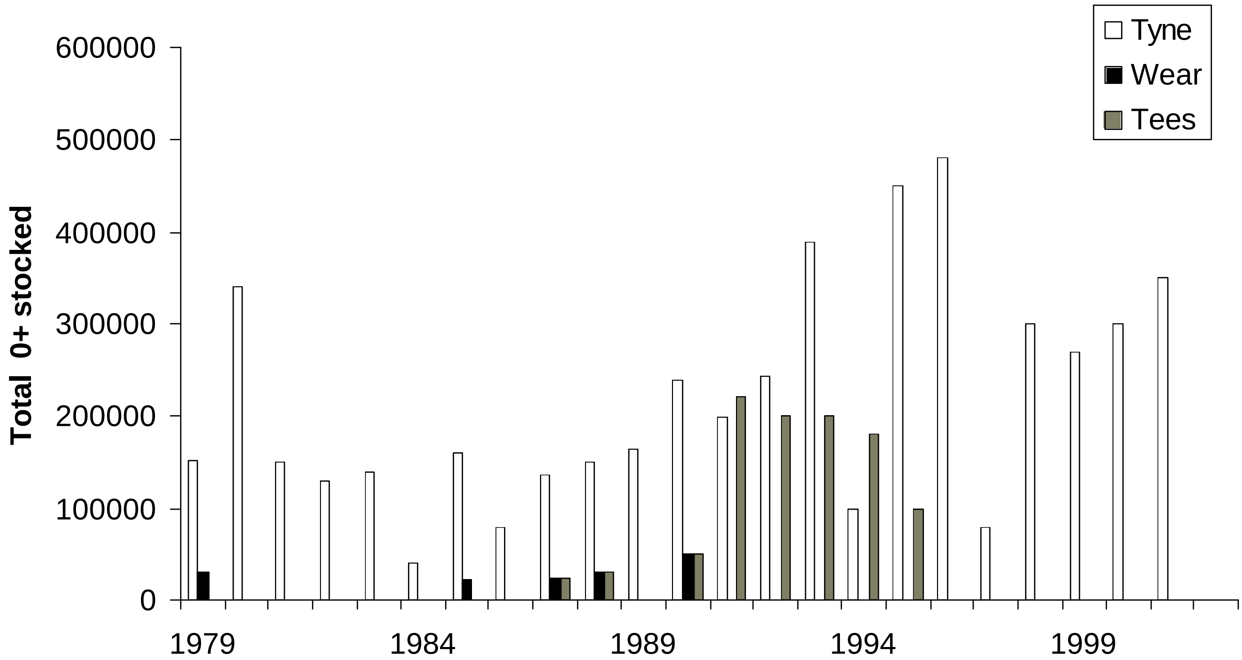

Fig 5a

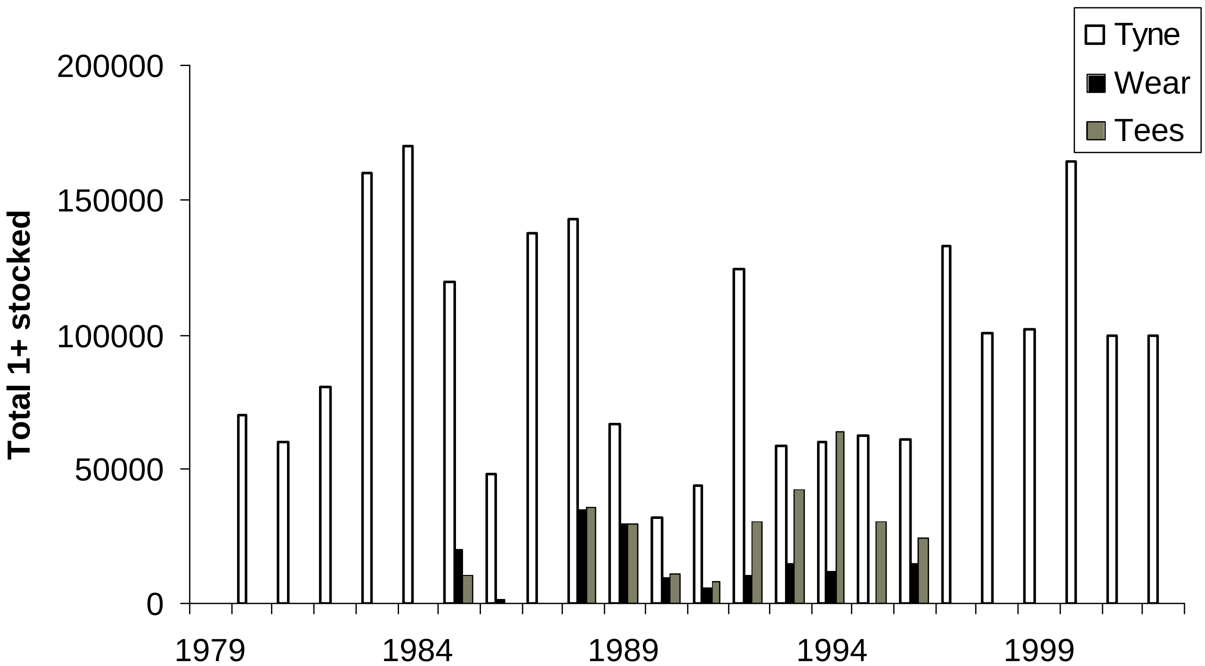

Fig 5b

Fig 5 Comparison of salmon stocking levels in rivers Tyne, Tees and Wear; a) of 0+ fish , b) of 1+ fish.

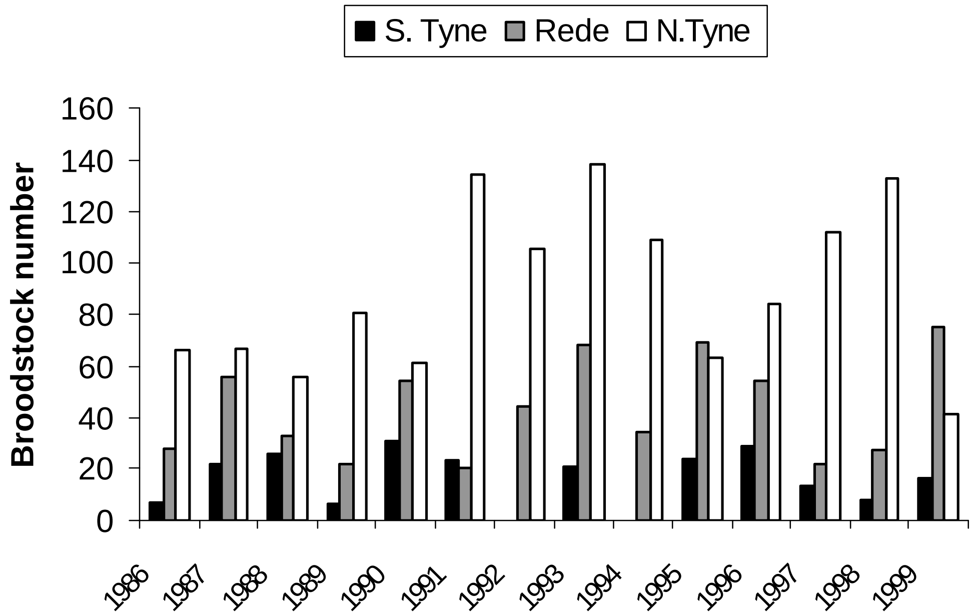

Fig 6 Sources of broodstock collection from three Tyne tributaries, for Kielder hatchery.

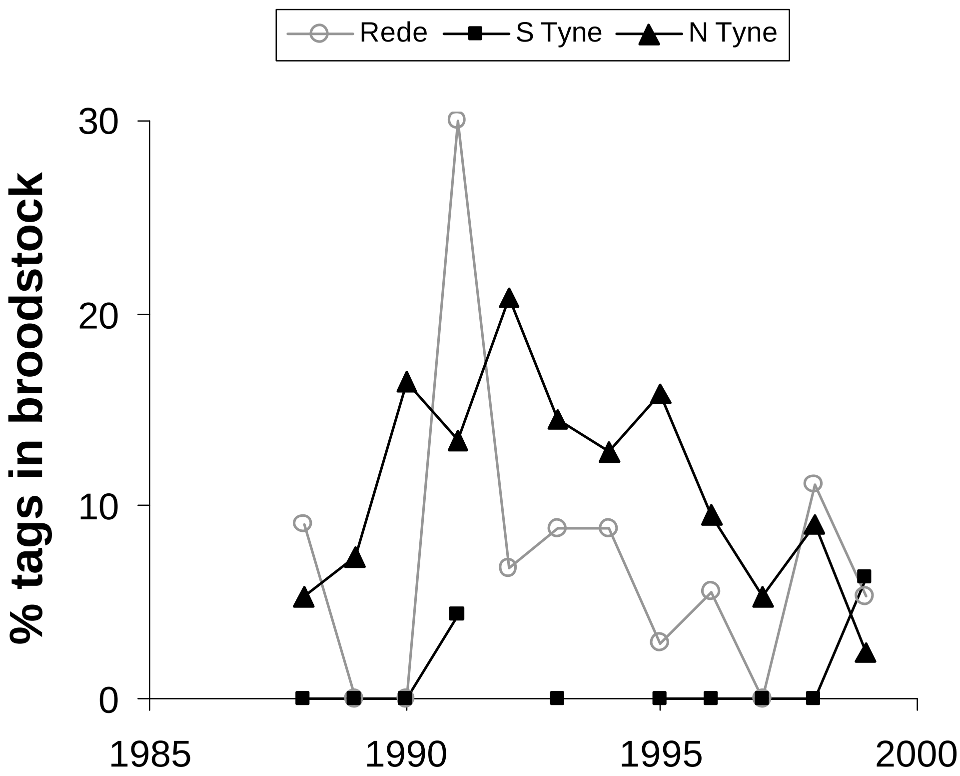

Fig 7 The incidence (%) of microtags in broodstock collected from the North Tyne, Rede and South Tyne.

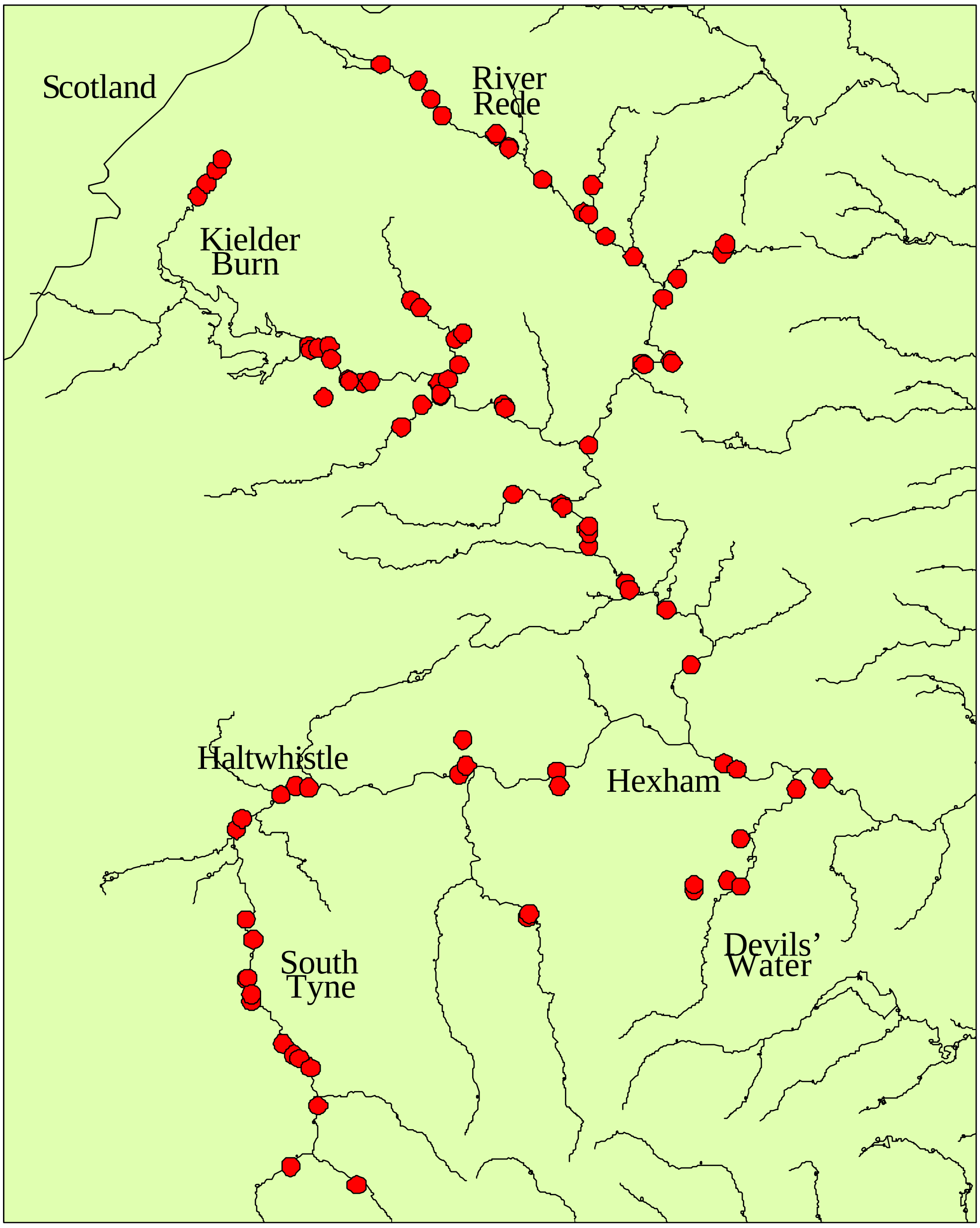

Fig 8 Salmon stocking locations, upper River Tyne.

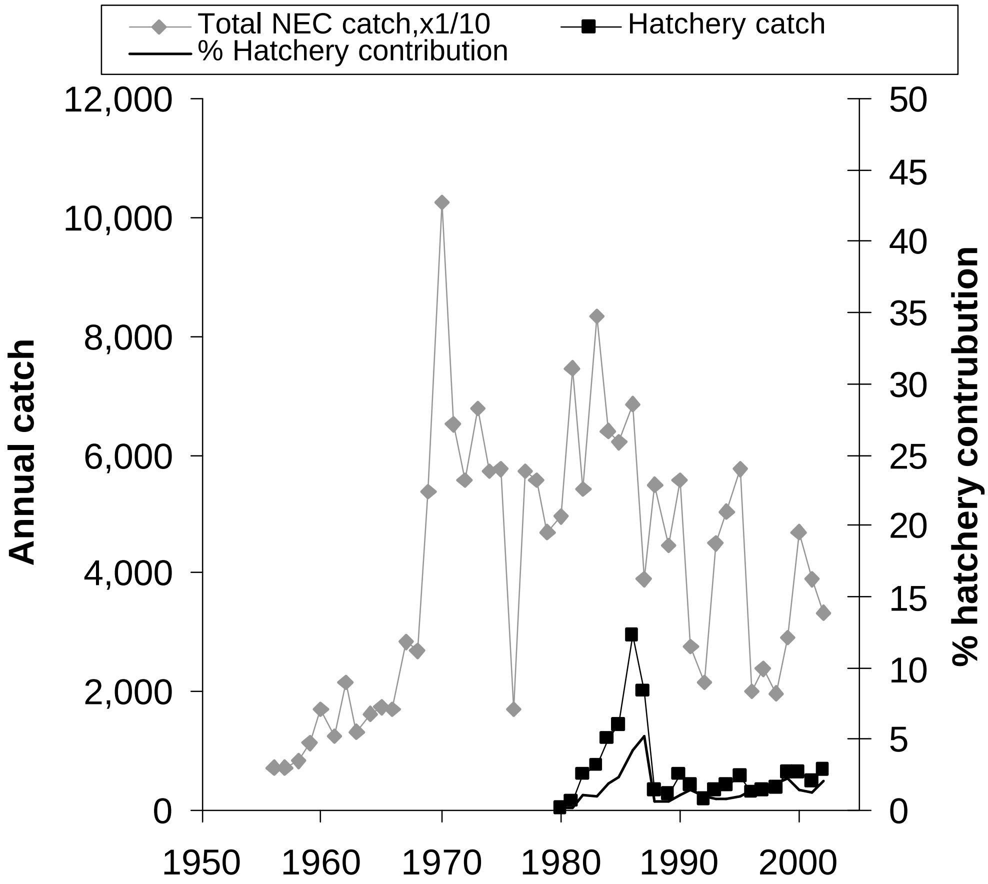

Fig 9 Adjusted salmon net catch in North East Coast Fishery and hatchery contribution.

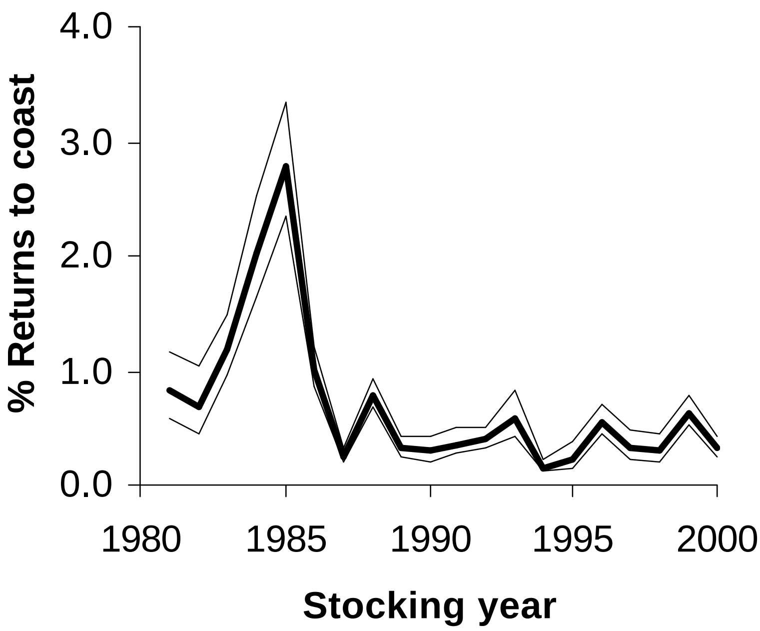

Fig 10 Estimated return rates of stocked Tyne salmon to the coast, pre-North east Coast fishery. Upper middle and lower lines are MAX, BEST and MIN estimates, respectively.

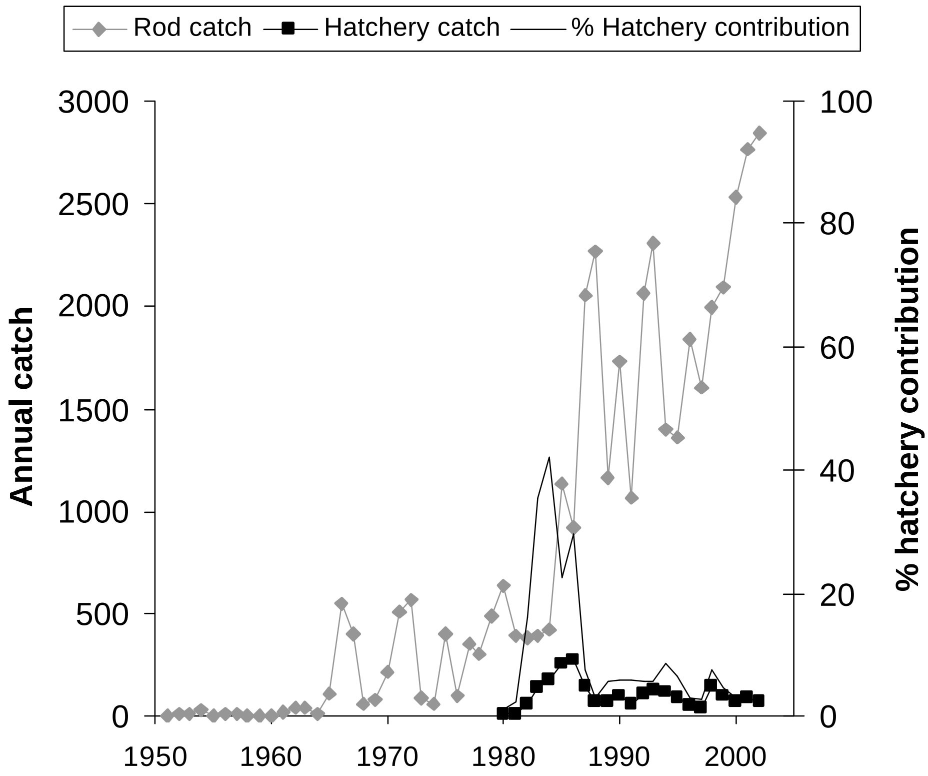

Fig 11 Adjusted salmon rod catch and hatchery contribution.

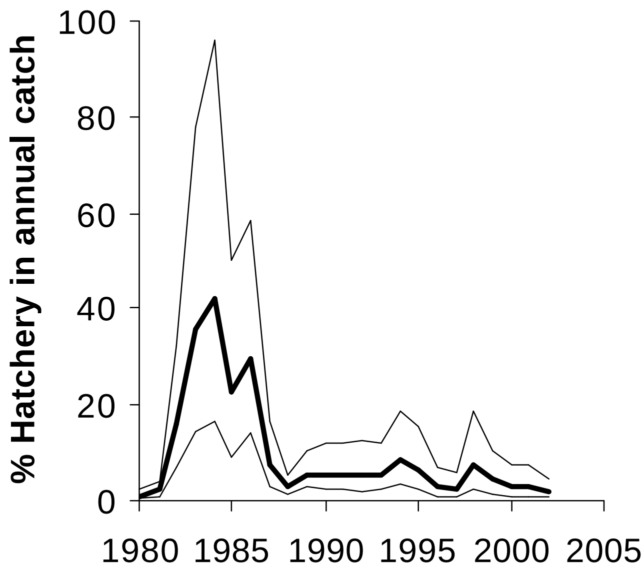

Fig 12 BEST, MIN and MAX estimates of % hatchery contribution to annual rod catch.

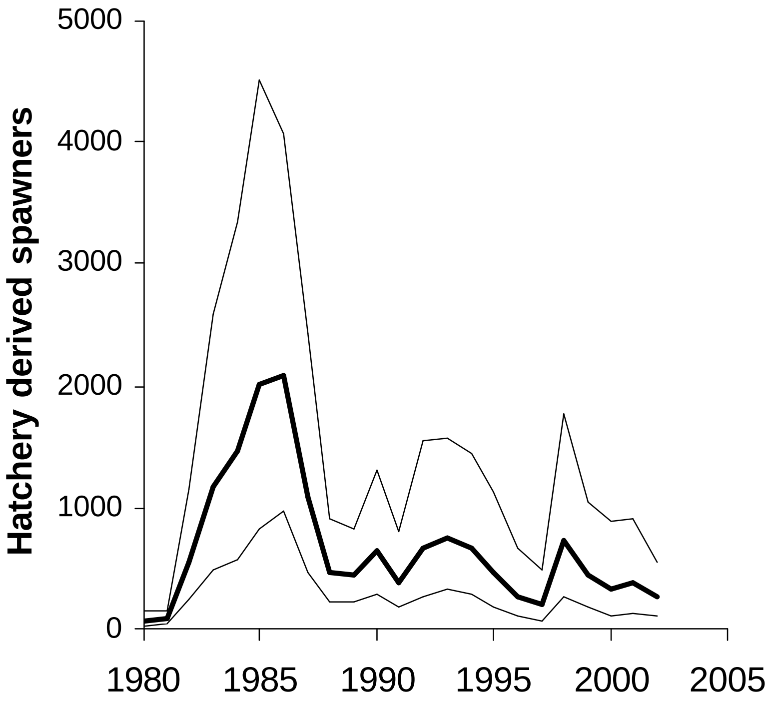

Fig 13 Estimates (MIN, BEST and MAX) of hatchery origin spawners.

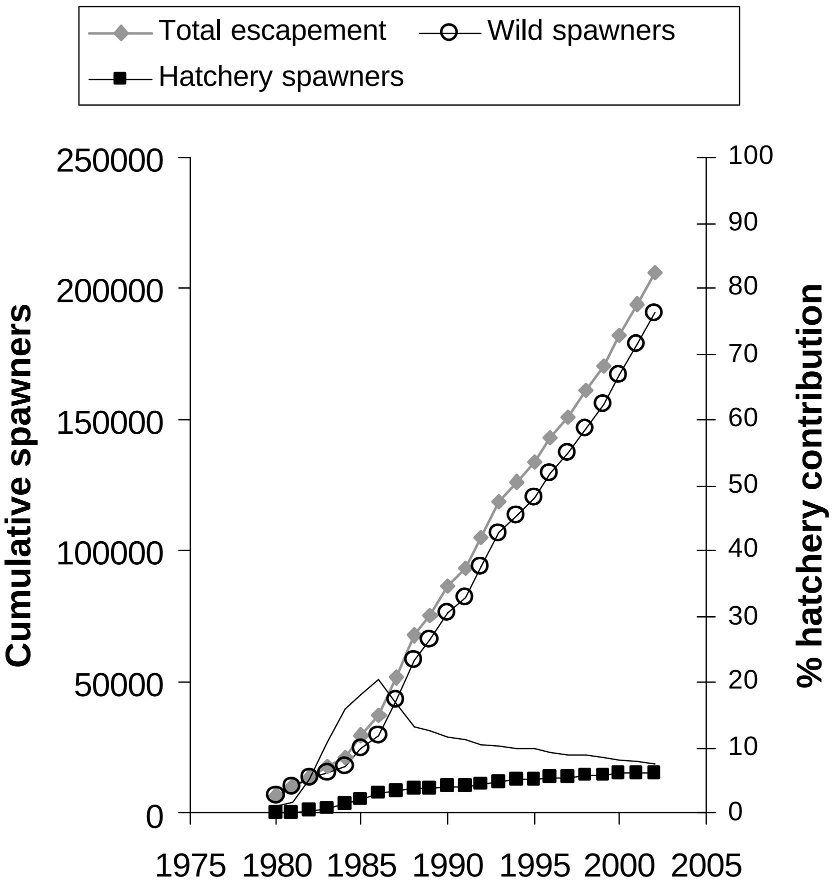

Fig 14 Cumulative spawning , Hatchery, wild and total, BEST parameters

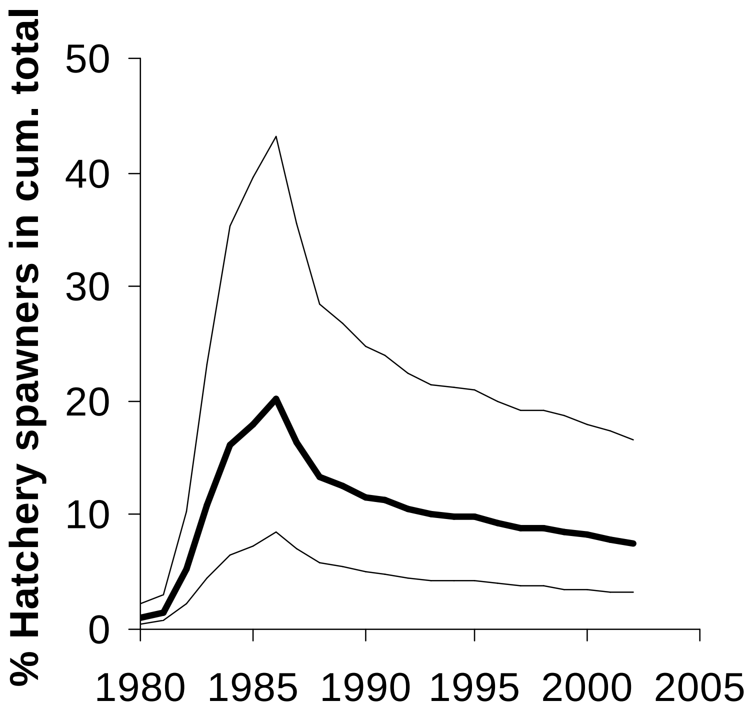

Fig 15 Estimates (MIN, BEST, MAX) of percentage hatchery contribution to total cumulative spawners.

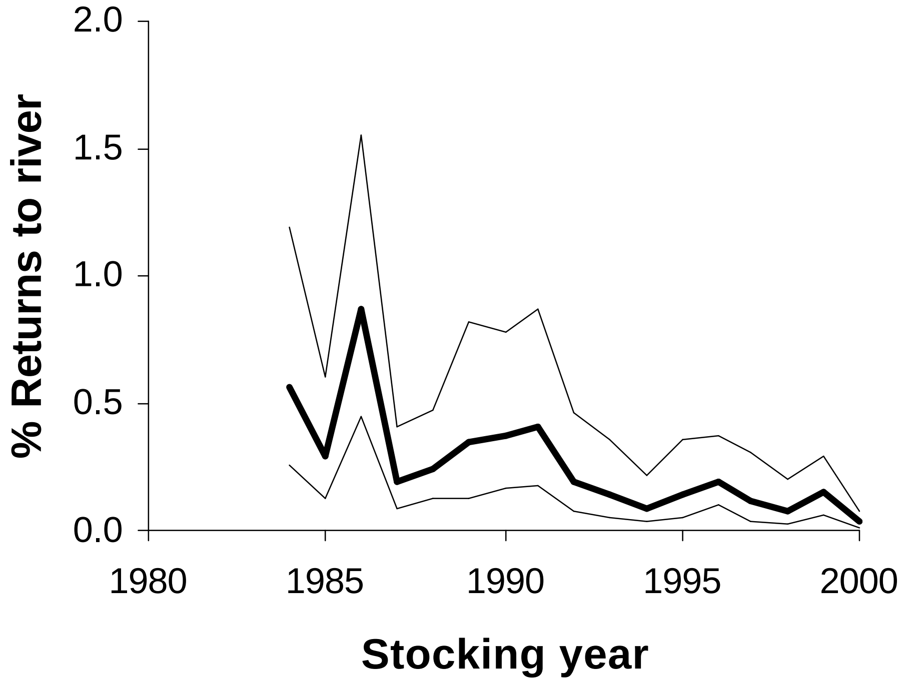

Fig 16 Estimated (MIN, BEST, MAX) percentage returns of hatchery salmon to the Rive Tyne (after coastal fishery, before rod fishery).

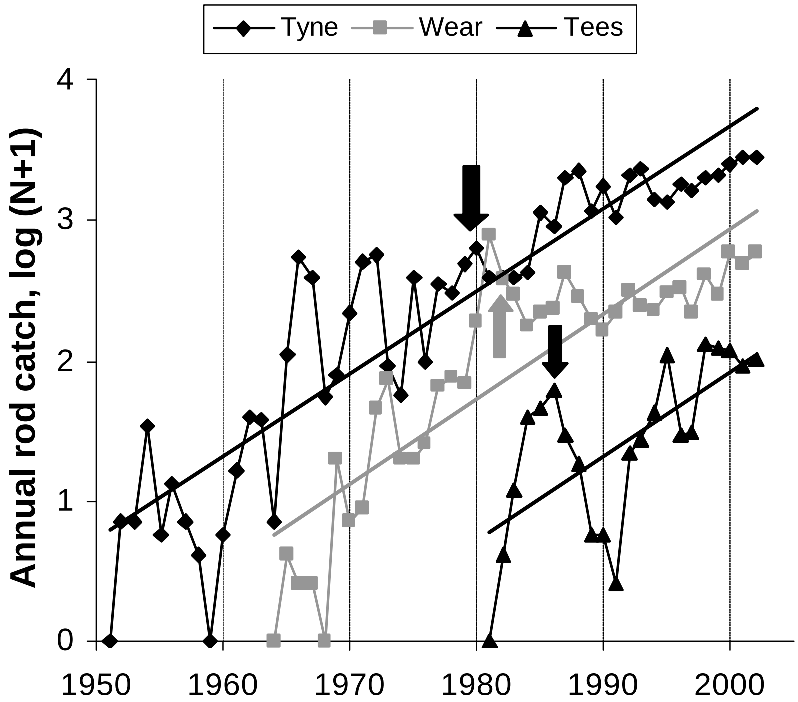

Fig 17 Change in rod catches, adjusted for return rate as log10 (N+1) in three North East recovering rivers. Arrows show start of stocking returns, 1980, 1981 and 1986. Slopes fitted by linear regression.

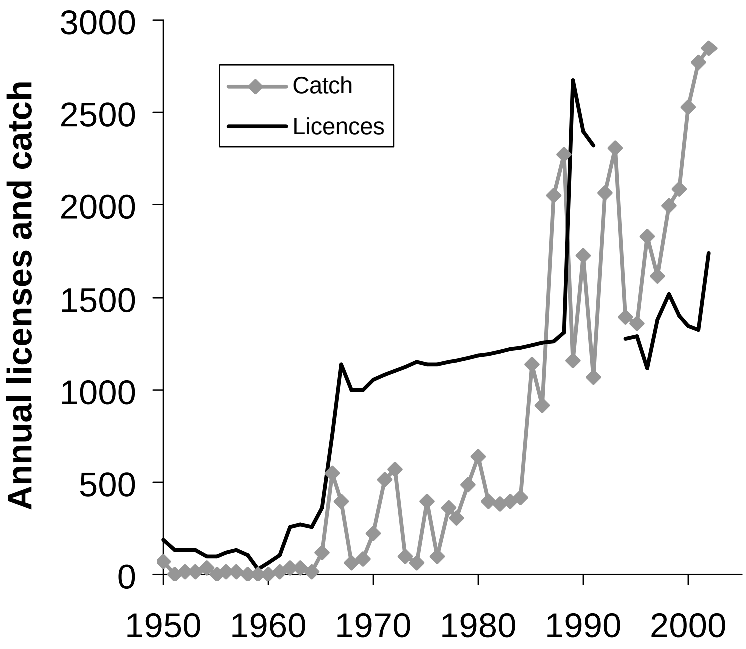

Fig 18 Annual licence sales (from Marshall, 1992) and adjusted rod catch for River Tyne. NB between 1969 and 1986, no licence data, these values were estimated in Marshall (1992).

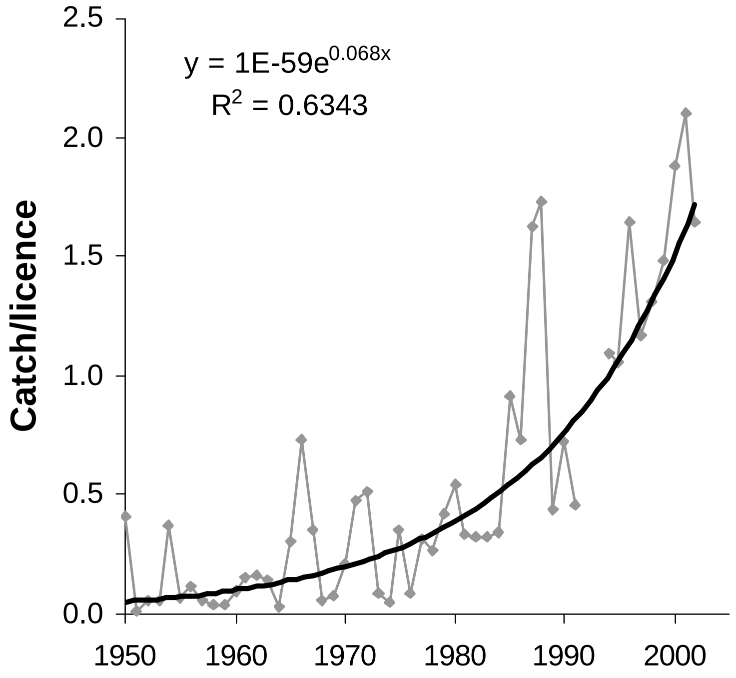

Fig 19 Showing exponential curve fitted to Tyne catch per licence data.

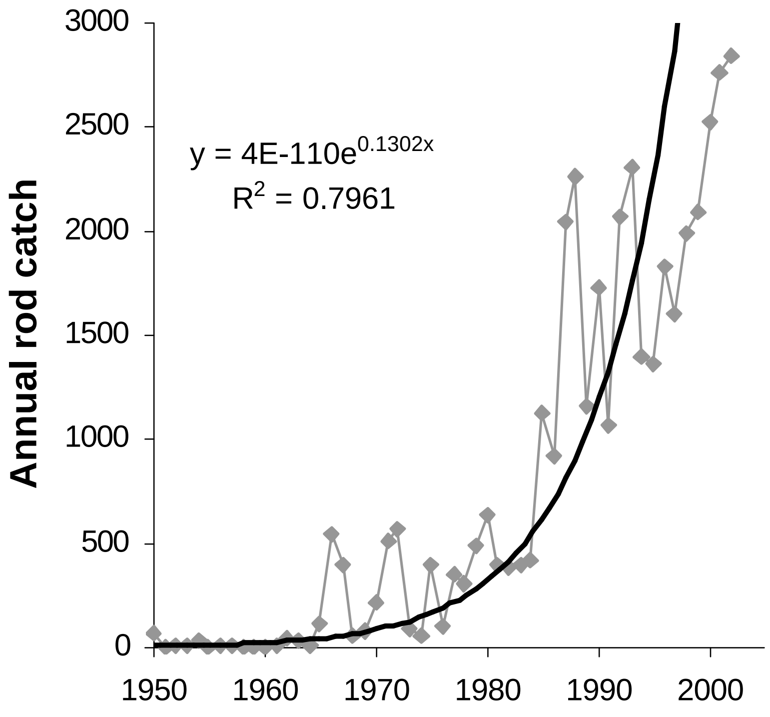

Fig 20 Exponential fit of adjusted Tyne rod catch data

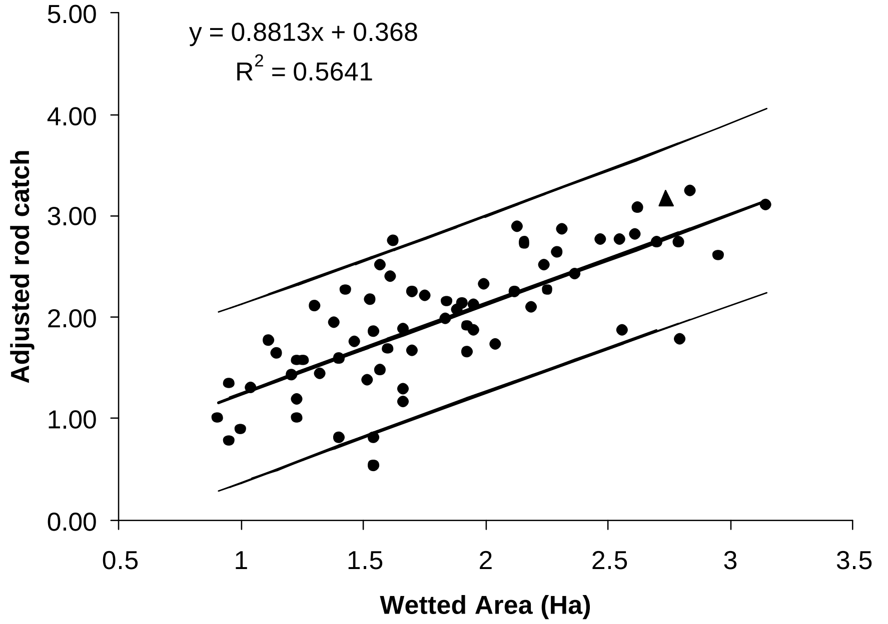

Fig 21 Comparison of five year (1994 to 1998) mean annual salmon rod catches in 66 English and Welsh rivers (regression excluding the Tyne), against wetted area, showing the position of the River Tyne (▲) and 95% prediction limits.

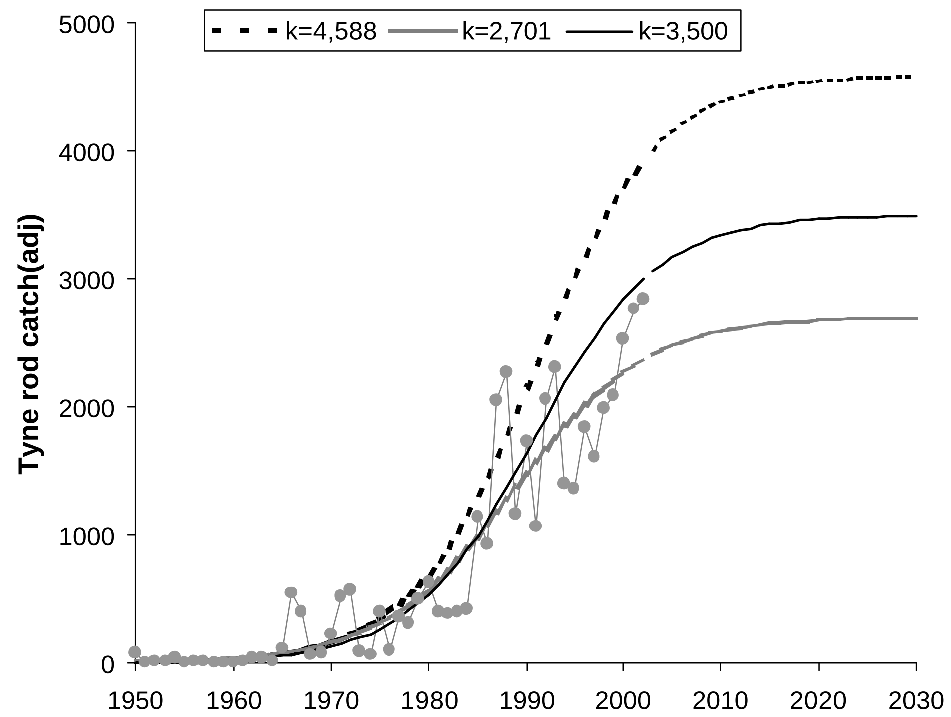

Fig 22 Tyne adjusted catch data fitted to a logistic growth curve, with alternative values of k, the upper limit to catch (see text).

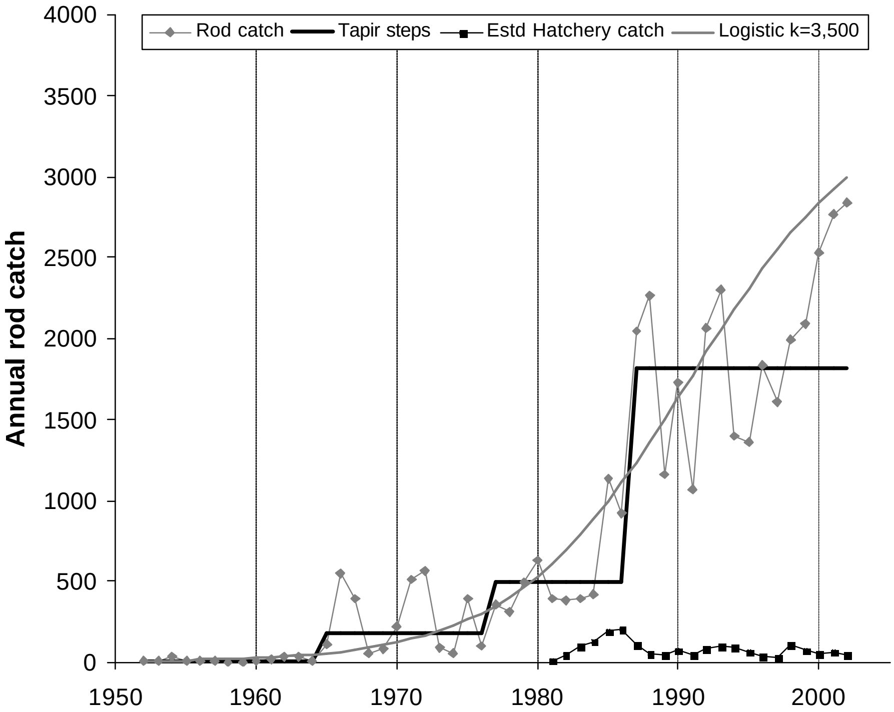

Fig 23 Comparison of stepped (TAPIR-identified steps) and logistic (k=3,500) fits to Tyne salmon adjusted rod catch data.

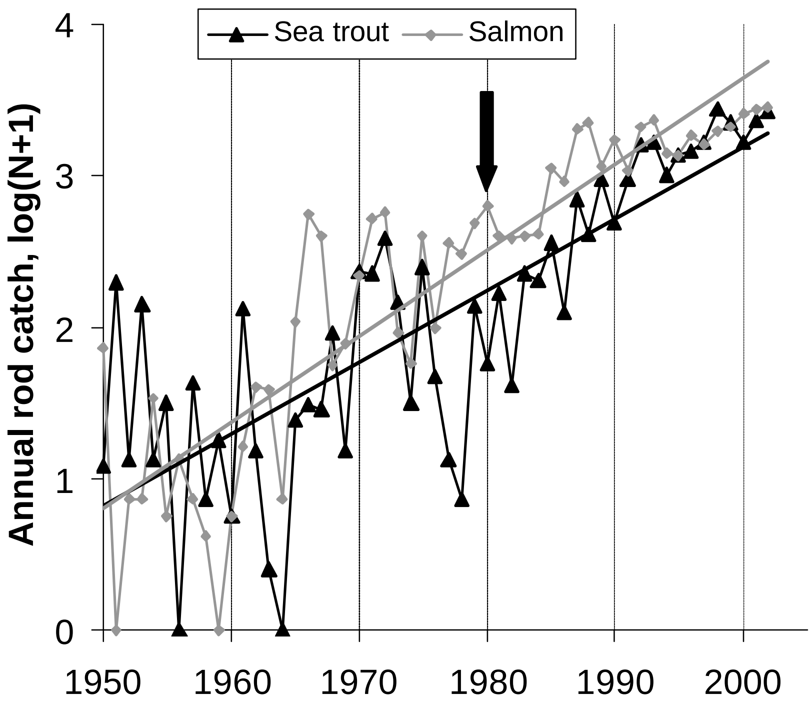

Fig 24 Comparison of salmon and sea trout catches in Tyne. Arrow marks first returns of hatchery salmon.

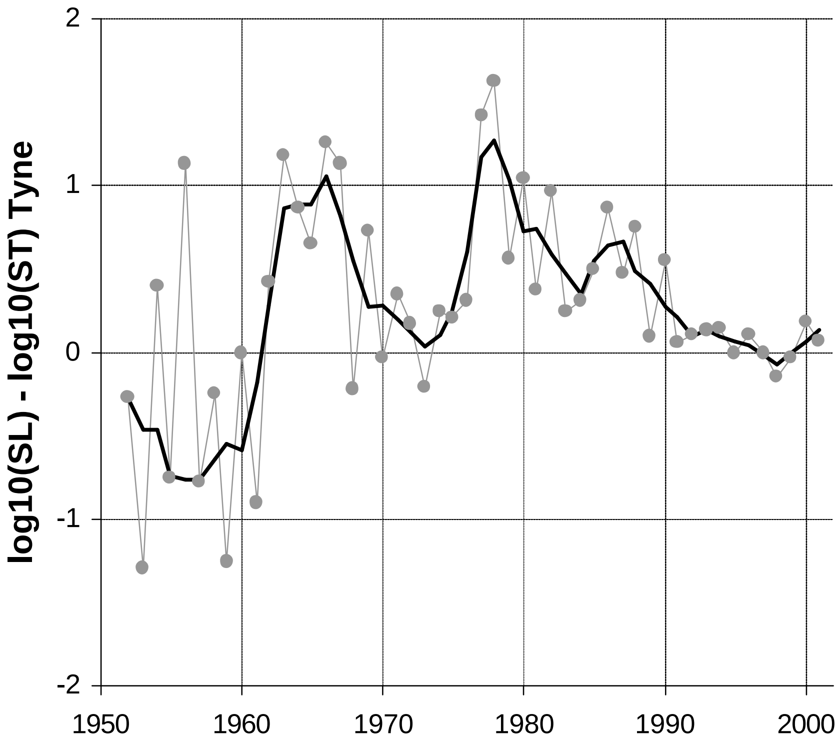

Fig 25 Difference between log-transformed Tyne salmon and sea trout annual catch, with LOWESS smoothed curve (solid line).

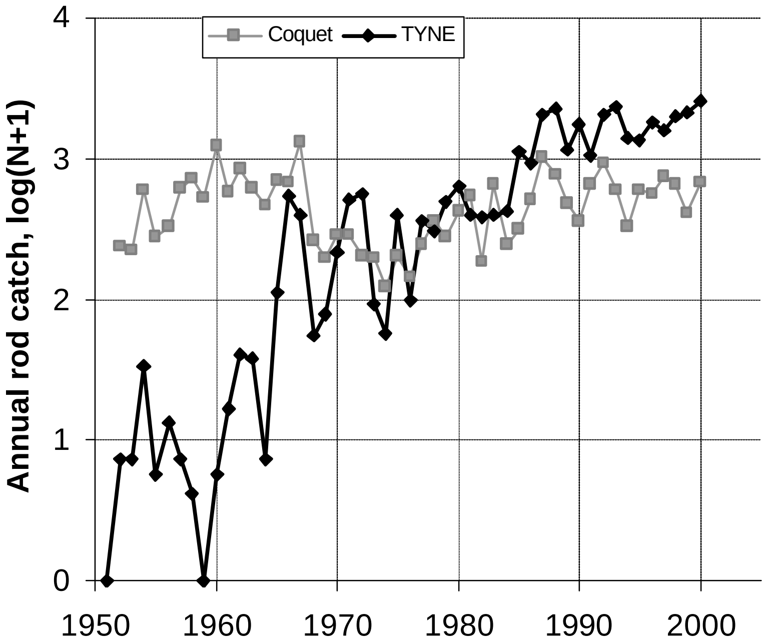

Fig 26 Comparison of Tyne and Coquet salmon adjusted rod catches.

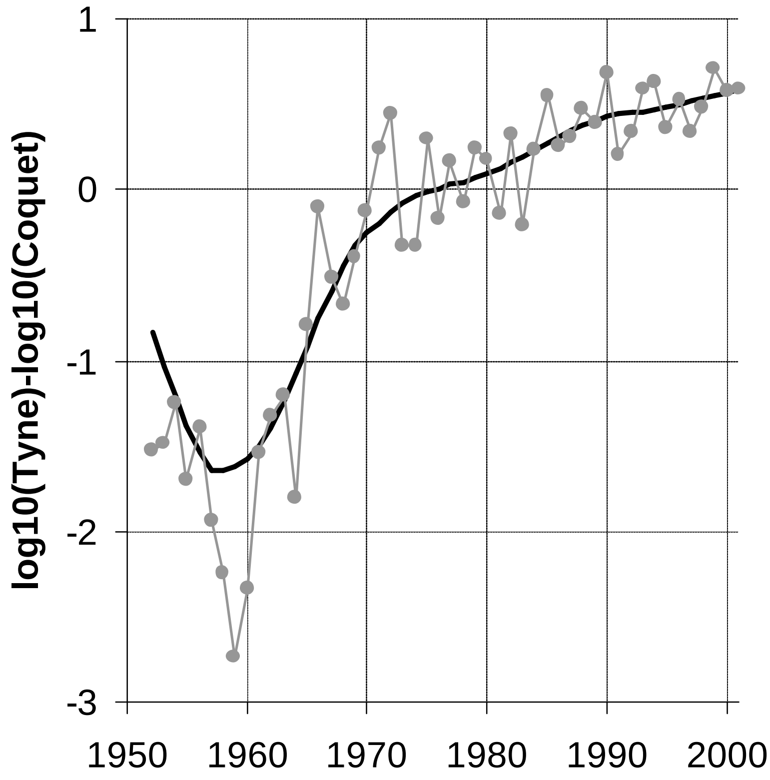

Fig 27 Change in difference between log-transformed salmon rod catches in riversTyne and Coquet, with LOWESS smoothed curve (solid line).

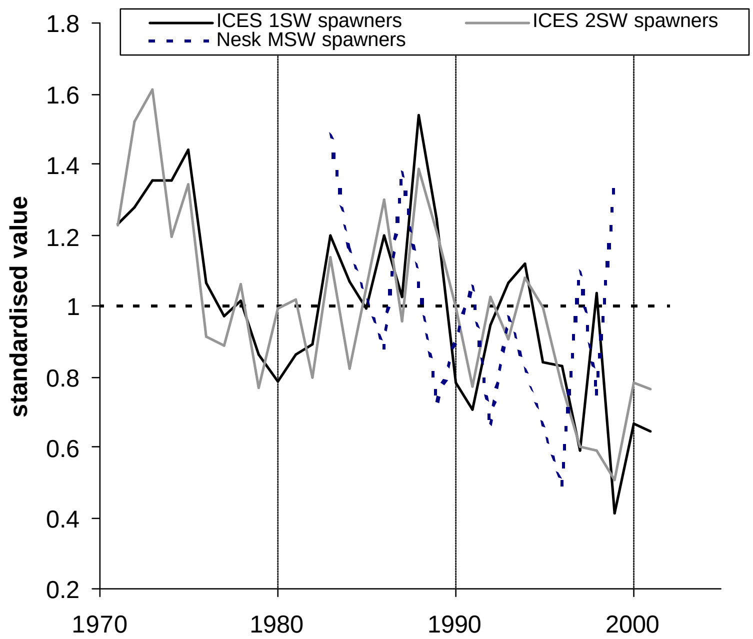

Fig 28 Standardised (values/long term mean) return rates for North Esk MSW salmon adjusted to year of return, and standardised estimates of spawners in Southern area of the North East Atlantic Commission area, showing common response during 1980s and post 1990.

APPENDIX I

Assumptions for model variables, justification and sources

1. Raising factors for Nets (Nf) and rod (Fr) tags returns

Raising factors were necessary to adjust the reported tags to estimate total returns. These were derived in different ways for the net (Fn) and rod (Fr) fisheries. Based on the catch screening programme, the total numbers of tagged fish recovered in the net fishery were estimated by scaling up the tags recovered from the fish sampled to the total declared catch using appropriate regional (Northumbria and Yorkshire Area) raising factors, as shown below. No adjustments made for non-catch fishing mortality.

Year	Northumbria			Yorkshire		
	Declared catch	Number scanned	Raising factor	Declared catch	Number scanned	Raising factor
1986	53,898	19,863	2.71	9,527	472	20.18
1987	33,064	26,100	1.27	3,079	201	15.32
1988	44,679	30,622	1.46	6,170	1,438	4.29
1989	35,169	18,988	1.85	6,284	1,750	3.59
1990	43,048	41,242	1.04	8,482	5,621	1.51
1991	22,525	13,133	1.72	2,904	2,395	1.21
1992	18,567	14,292	1.30	1,577	1,224	1.29
1993	37,097	25,569	1.45	4,698	4,403	1.07
1994	42,547	34,530	1.23	4,007	2,032	1.97
1995	49,801	35,056	1.42	3,384	2,041	1.66
1996	17,784	13,871	1.28	797	486	1.64
1997	19,828	12,994	1.53	2,094	904	2.32

In the absence of a targeted screening programme, it was not possible to derive a raising factor for the rod fishery in the same way as for the nets. Jowitt and Russell (1994) used an initial raising factor of 3, but on later analysis this was felt to be too high and was therefore reassessed.

An approach considered initially was to estimate the rod raising factor based on the proportion of tagged fish recovered in the broodstock collected on the Tyne. On the assumption that the proportion of tagged fish is representative of the whole Tyne run, this might have been used to estimate the expected number of tagged fish in the rod catch in any year. This, in turn, could have been compared with the number of tags actually reported to estimate an annual raising factor. The substantial drawback of this approach is the assumption that the proportion of tagged fish in the broodstock is representative of the Tyne as a whole. In practice, there is good reason to believe this is not the case.

River Tyne broodstock are collected from a number of locations on the North Tyne, South Tyne and Rede, and in particular from the North Tyne in the area immediately below Kielder dam. It has been common practice to release tagged parr at these broodstock recovery locations, with highest numbers being stocked in the North Tyne. Because returning hatchery fish appear to home quite precisely to their tributary of release (Russell, 1994), it is reasonable to assume that a higher proportion of tagged adult fish will be present in these areas, particularly in the area below the dam where natural recruitment is very low. This is seen in the broodstock data (Appendix Table IV), which demonstrate that adults collected from the North Tyne contained a much higher proportion of tagged fish (11.6%, on average, over the period 1986-97) than those collected on the South Tyne (1.0%) or Rede (6.3%). Applying these values might suggest rod raising factors as high as x9, or x4 if data for the North Tyne are excluded. Both these values are considered to be unrealistically high.

In years when large numbers of dead fish have been collected from the estuary, the percentage of tagged fish observed has been quite low (<1%). This might suggest a much lower rod raising factor should apply (x1.1 based on these fish mortality samples), but since these samples will include fish originating from other local rivers where little or no tagging has taken place, this will be an underestimate of the raising factor. In summary, using broodstock and fishkill data give variable results for Rf but suggest that the value lies somewhere between 1.2 and 3.

An alternative and preferable approach for deriving a rod raising factor has therefore been based on the CEFAS wild smolt trapping and tagging programme on the River Wear (1985-96). During this exercise a mark/recapture estimate was made of the size of the overall smolt run in most years. On the basis of the number of fish tagged during the trapping programme, together with an estimate of any previously tagged, Kielder-origin smolts in the run, it was possible to estimate the proportion of the outgoing smolt run that was tagged. This proportion can be assumed to reflect the proportion of tagged fish in the subsequent adult run and hence in the rod catch. In turn, this can be used to compare with the actual number of tags recovered from the rod fishery and thus provide a raising factor.

The raising factors derived for the River Wear in this way display much less variability than those from the Tyne, varying in the range from 1 to 4. Trial calculations of MAX assumptions using a value of Fr=4 showed that maximum annual hatchery contributions exceeded 100% in some years suggesting that Fr=4 was unrealistic. Taken as an average, with a small allowance for post-tagging mortality (10%), the rod raising factor for the Wear has been assessed to be x2. This value falls within the range of values estimated for the Tyne and is considered to be more representative.

The overall conclusion is that the most likely Rf = 2.0 (range 1.2 to 3.0)

<u>2. Variable *v*</u> (= survival of untagged 1+ parr compared with tagged 1+ parr)

Issue: Microtagging requires fish above a minimum size. These were selected from the hatchery population by grading. Consequently the tagged sample was larger than the remaining untagged sample. Smaller salmon survive less well than larger ones either suffering increased mortality in the river, or at smolting, or delay smolting for a further year thereby increasing the total mortality before smolting.

The overall conclusion is that the most likely *v* = 0.8 (range 0.7 to 0.9)

<u>3. Variable *w*</u> (= survival of untagged 0+ parr compared with tagged 1+ parr)

Need to correct N of 0+ autumn stocked parr to N of 1+ fish kept in hatchery and then stocked in March-April. Values for over-winter survival of stocked 0+parr (w). No direct measurements of this are available, so have referred to literature values of survival of summer 0+ parr (Aug-Oct) through to 1+ (March, where possible).

1. Baglinière et al (1994): Survival (Autumn(?) to March) of wild fish remaining in the stream was 0.298, plus 0.198 of migrants that moved out at end of first growing season. i.e in-stream S =0.298.
2. Symons (1979): Using Elson's (1975) results for summer stocked parr over-winter survival was 0.4- 0.5 (value read off his Fig 1 is 0.43).
3. River Wye, based on data used in Gee et al (1978): Sites in four tributaries samples four times/year, using density values for Aug-Oct and Mar-April. Autumn to spring S of wild 0+ salmon ranged 0.02 to 0.75, arithmetic mean 0.35 (sd= 0.195), weighted mean 0.24.

NB 1. These values are likely to overestimate the survival of freshly stocked hatchery 0+ parr, particularly because Kielder parr are comparatively small due to the low ambient rearing temperatures.

NB 2. the gravel incubators started in 1989 and were thought to bring big benefits to the growth and survival of the hatchery reared fry (Rippon and Gray, pers. comm.). Consequently the earlier fry and parr (pre-1989) will have exhibited correspondingly lower growth rate and survival, suggesting that the assumed variables may be optimistic for the critical pre-1989 period. Conversely, the reported better performance in later years may have rendered the values of *v* and *w* conservative with respect to hatchery returns, and this is discussed in the text (section 5.1.5).

The overall conclusion is that the most likely *w* = 0. 25 (range 0.1 to 0.5)