NRA Wales 63
(28)

A REVIEW OF FACTORS AFFECTING THE ABUNDANCE AND CATCH OF SPRING SALMON FROM THE RIVER WYE AND ELSEWHERE, AND PROPOSALS FOR STOCK MAINTENANCE AND ENHANCEMENT

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MARCH 1992
REF. HQF/1/92

NATIONAL RIVERS AUTHORITY
WELSH REGION
ST. MELLONS
CARDIFF

SUMMARY

The River Wye is the premier salmon river in England and Wales with a long term average annual rod catch of over 3,000 salmon, a high proportion of which are spring fish i.e. fish caught before the 1st May.

Over the past 20 years or so there has been a decline in the numbers and proportion of spring salmon in the catch, a phenomenon which has been observed throughout the North Atlantic range of the salmon.

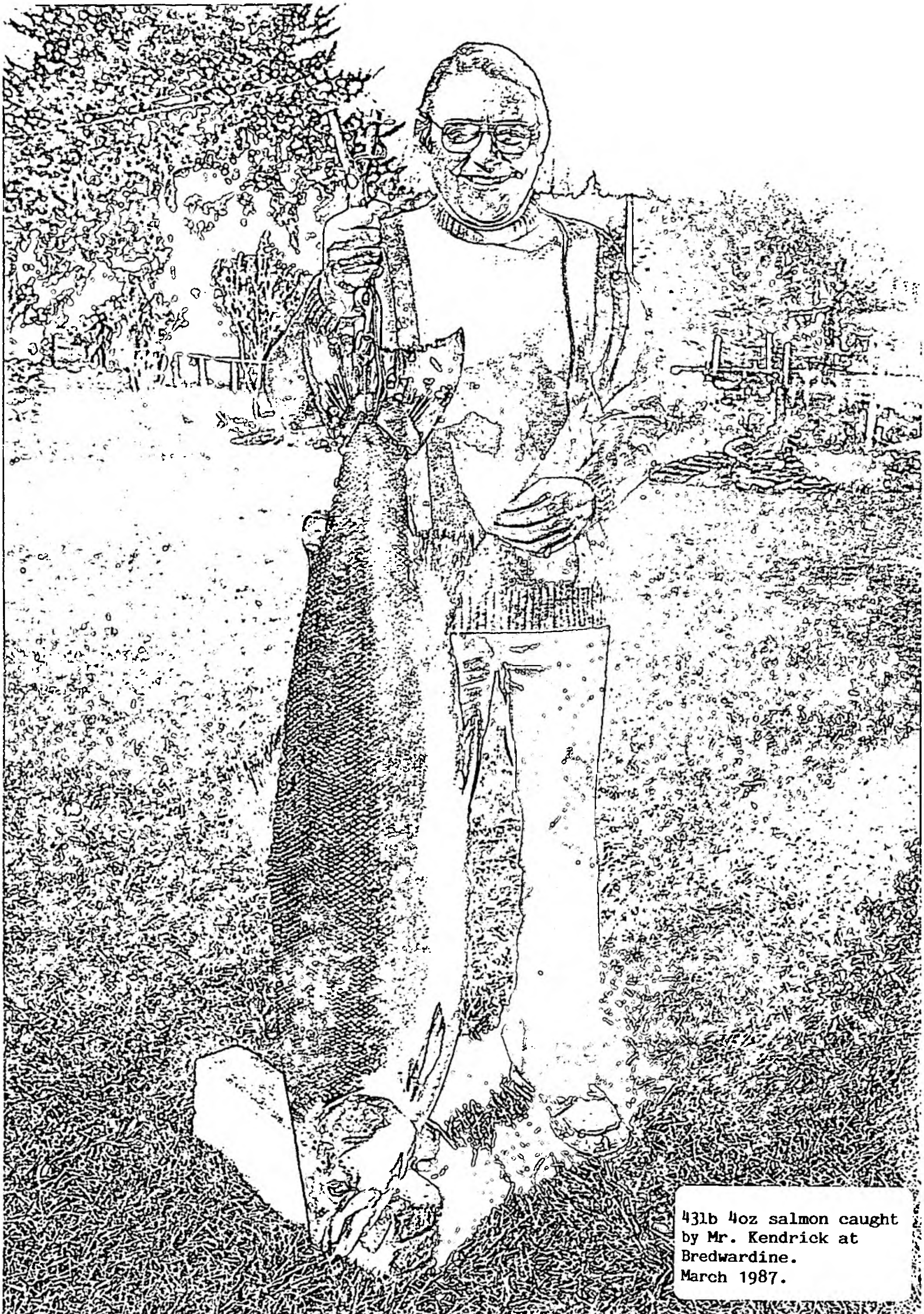
This report examines the pattern of spring salmon abundance on the River Wye and other rivers and the factors influencing their status. These include marine and freshwater environmental factors, exploitation in both distant and homewater fisheries and the role of genetics in determining sea absence.

The available evidence indicates that the spring salmon component in the River Wye is under significant pressure from over-exploitation, principally from rod fisheries. In addition recent environmental conditions, both in freshwater and at sea, appear to have favoured short sea absence and the dominance of grilse. The role of genetics and its interaction with environmental factors is crucial though in need of clarification. This report also highlights many gaps in our knowledge of the behaviour and life history strategy which constrain effective management of spring salmon.

The options for enhancing spring salmon stocks, including exploitation control and artificial propagation, are examined in detail. A strategy is proposed involving 10 main recommendations over a 5 year period at a total estimated cost of £482K. The recommendations include:

- Byelaw changes to protect spring salmon.
- A genetic survey of Wye salmon stocks and a study of genetic implications of various enhancement strategies.
- A radio-tracking programme of spring salmon to obtain information on post-release survival of angled salmon and movements and distribution of MSW salmon in the catchment.
- A feasibility study on the application of hydro-acoustic fish counting equipment on the Wye.
- A survey to identify those parts of the Wye catchment at risk from acidification and land use change.
- An investigation of potential hatchery and rearing sites in the Wye catchment.
- Trials on broodstock holding and kelt re-conditioning.
- An investigation of the genetic and cost implications of captive breeding and a contracted out rearing programme.

The financing of and priorities given to these recommendations are not addressed in this report and will need to be given further consideration.



431b 4oz salmon caught
by Mr. Kendrick at
Bredwardine.
March 1987.

CONTENTS

1. INTRODUCTION

The River Wye has long been recognised as the premier salmon river in England and Wales, not only in terms of the number of salmon caught by anglers (around 30% of the total reported catch), but also for the high proportion of large, spring-running salmon within the catch.

Over the past 20 years or so there has been a decline in the number of spring salmon (defined in this report as a fish which enters freshwater and is available for capture prior to 1st May in any year) caught in the River Wye, a phenomenon that is not unique to the Wye but has also been observed throughout the North Atlantic range of the salmon. In the Wye the majority of these spring fish have spent 3 winters at sea (3SW), with relatively small numbers of 2SW and 4SW fish making up the remainder of this component. At the same time there has been an increase in the numbers and proportion of later-running grilse (1SW salmon) whilst numbers of 2SW fish have remained relatively stable. Available data on juvenile salmon densities and overall catches do not indicate a general decline in the status of salmon in the catchment.

The existence of multi-sea winter (MSW) salmon is a demonstration of one aspect of the life-history plasticity of Atlantic salmon, which results in selection pressure for large fish. Thorpe and Mitchell (1981) postulate that increased energetic demands for upstream migration occur in larger rivers and result in selection for larger fish. Several studies have shown a correlation between the harshness of a river, for example the length or flow, and the tendancy for it to produce spring and other MSW salmon.

Both 2SW and 3SW salmon are predominantly female and characteristically produce larger numbers of ova than grilse. These ova are themselves larger and more viable than the smaller ova of younger fish, and the fry on hatching are larger. This confers advantages on the fry which may be sustained throughout the period of freshwater life.

Larger spawners are able to compete more aggressively for limited spawning sites, and are also able to select under-exploited sites for spawning, perhaps in the main river or in locations in deeper water. In the latter cases their progeny emerge to occupy under-utilised habitat at relatively low density, and thus experience conditions which are perhaps more favourable for survival. Also large females are able to construct larger redds and deposit their eggs deeper in the gravel, protecting them from wash-out during flood conditions.

The advantages of large size are clear, however it is also apparent that many factors can exert considerable selection pressure. Dominant amongst these are the influences of the environment, both in freshwater and at sea, and of genetic factors.

Two major factors are thought to have contributed to the current, and perhaps past, changes in age composition of adult stocks. Recent theories have indicated that climatic change in the North Atlantic, where most marine feeding grounds are located, has caused variations in ocean surface temperatures and this has resulted in the favouring of short-absence grilse. It is also clear that stocks are under considerably increased pressure from fisheries. Although the larger marine fisheries did not commence until the decline in MSW salmon had started, they may have contributed to further decline. Homewater estuarine commercial fisheries generally do not commence operations until the majority of spring salmon have entered their rivers, and are thought therefore not to be a major factor. In contrast rods preferentially exploit spring salmon which are the most desired and sought-after component of the stock. They are vulnerable to capture and thought to be very highly, if not totally, exploited. If this is so, then clearly only a small fraction of the spring fish survive to spawn.

The second principle factor involved in the decline of spring fish abundance is brought about by over-exploitation which has depleted the frequency of occurrence of the genetic trait which determines spring entry to the river. Fewer MSW salmon spawning together is thought to further contribute to the decline through dilution of the trait. Grilse crosses will still result in the production of spring-run salmon but only at a very low rate, as shown by several breeding trials. It may be this mechanism which is responsible for the remaining small nuclei of spring salmon in some rivers.

This report examines the status of spring salmon in the River Wye, the factors affecting their abundance and possible strategies for enhancement. It must be noted that much of the published literature on the sea age of return of Atlantic salmon relates to 1SW and 2SW fish only rather than older age classes and so there is a significant gap in our knowledge which will limit effective management of MSW salmon. Therefore recommendations are put forward to improve our understanding of this stock component to enable robust and effective measures to be taken for their maintenance and improvement.

The River Wye at
Aber Pool,
Builth Wells.

2. TERMS OF REFERENCE

The following terms of reference will be addressed in this report:

2.1 Determine from available data the status of spring salmon in the River Wye and elsewhere, and examine the factors affecting their abundance.

2.2 Examine the options for enhancing spring salmon abundance.

2.3 Determine a strategy, with targets and timescales, for increasing the abundance of spring salmon and evaluate the most important associated factors.

2.4 Make recommendations on the phasing and timescales for a proposed strategy with estimated costs.

51lb & 42½lb Salmon
caught on 30th Mar.1941
by Mr. J.Wyndham Smith
at Aramstone.

3. STATUS OF SPRING SALMON

3.1 Patterns of Spring Salmon Abundance In The River Wye

The rod catches of salmon in the River Wye have been compiled by various organisations since 1903, and probably form a data set not equalled in this country. They have been the subject of an analysis by Gee and Milner (1980), and subsequently an examination of more recent rod catches has been undertaken by the N.R.A. (1991). Figure 1 shows the overall catch by rods of all age-groups since 1909.

When statistics were first collected early this century, rod catches were relatively low (<1000) and about half of the total catch was reported by nets. Catches by both methods increased steadily until the early 1920's when they were approximately equal (both at about 4,000) and then followed a similar pattern until about 1940 (Gee and Milner,1980). Within this period catches fluctuated widely from year to year, with three distinct peaks when the total annual catch reached about 10,000 fish. After 1940, rod and net catches diverged with rods taking an increasing proportion of the catch. This pattern continued until the licenced commercial fishery in the lower Wye was closed in 1984.

The long term average rod catch of salmon (1915-1989) is 3,208, and this total has been equalled or exceeded continually by the 5-year average catch over the past 40 years. Against this however must be considered the fishing effort expended to achieve this catch. After remaining relatively constant between 1913 and 1945, effort steadily increased from 200 rods (although this was almost certainly an under-estimate due to the general licence system: effort at this time was probably closer to 400 rods) to nearly 1400 rods in 1975 (Gee and Milner,1980), and in 1982, 1,529 season licences were sold. The latter figures do not include either short-term or general licences and so are under-estimates of the true angling pressure. After 1982 the method of issuing rod licences changed, and the number of season licence holders fishing the Wye is not known. It is, however, likely to have increased further.

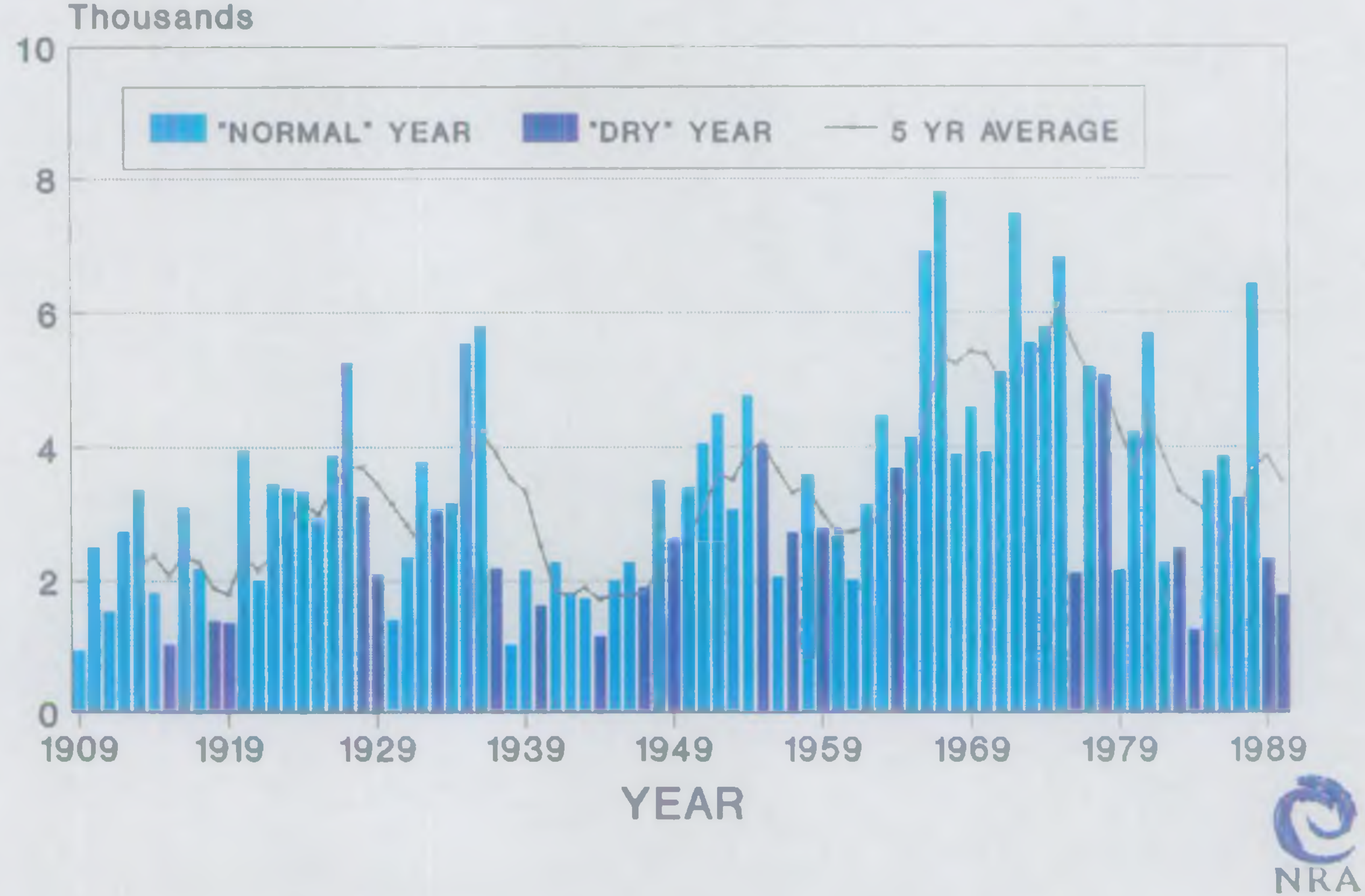
Whilst the overall catch of salmon has remained relatively constant over this time (Figure 1), the catch per licence has shown a gradual decline from about 10 in 1940 to 4 in 1975 (Gee and Milner, 1980). This figure masks the patterns for specific age-groups within the run. The catch per licence of 4SW salmon was never high, but showed a decline in this period to very low levels. That for 3SW salmon similarly declined from values of around 5 in 1940 to values between 1 and 2 in the mid-1970's. In contrast to this are the patterns for 2SW and 1SW fish : no trend is observed for the former, whereas a slight increasing trend is apparent for the latter.

Assuming that the catchability of salmon in each group had remained unchanged in this period, the reduced catch of 4SW and 3SW salmon can be explained by the increased exploitation of a diminishing stock. In fact the great improvements in fishing tackle and presumably in angling skill together with more intensive fishing and greater demand for fishing may have increased the vulnerability of these fish to capture. Furthermore it has been reported in several independant studies that the catchability of salmonids actually increases as stock size decreases (Peterman and Steer, 1981; Mills et al, 1986; Beaumont et al, 1991).It is clearly important to understand whether the stock, at the current size, can continue to support the present level of exploitation.

In contrast to the older salmon, the catch per licence of 2SW and 1SW fish did not decrease, and in the case of the 1SW component may even have increased. This suggests that the available stock of these fish may either have increased, or the rate of exploitation of them increased.

The temporal distribution of the overall run has changed as a result of a shift in the age composition, with trends away from MSW salmon towards younger fish.

FIGURE 1. RIVER WYE ROD CATCH OF SALMON 1909-1990



This is reflected in a decline in the overall average weight of angled fish, although the mean weights of each individual age-class have not changed. Many fish are now caught towards the end of the angling season (Figure 2) and there is also evidence from several studies nationally that increasing proportions of the annual run, principally grilse, enter rivers after the end of the angling season.

Not all rivers have significant runs of spring fish. Gardner (1976) noted that rivers producing spring runs are often larger than those which produce only younger fish, and Thorpe and Mitchell (1981) found significant positive correlations between mean weights of salmon and river length. Kallio-Nyberg and Pruuki (1990) found that the sea-age of female spawners in a Finnish river increased slightly with the length of the upstream migration. Jonsson et al (1991) have more recently reported increased sea-age at maturity in Norwegian rivers with greater mean discharge (in the range 1-300 cumecs), and also in rivers with greater accessible length.

Such relationships are clearly applicable to the River Wye (Figure 3) which at 250 kilometres in length and with a long-term average daily flow in the order of 72 cubic metres per second, is amongst the largest rivers in the United Kingdom.

Examination of the 5-year average spring catch over the past 40 years (Figure 4) shows an initial slight decline in the late 1950's after which the catch starts to rise and doubles to approximately 2400 in the late 1960's. Within this period annual catches of spring salmon peaked in 1967 when over 4,000 were reported, however in only four subsequent years was the catch in excess of 2,000 fish. The 5-year average started to decline in 1969, and except for a three year period up to 1975 has continued to decline to date.

The last three years from 1988 until 1991 have apparently shown a bottoming out of the annual catch at a level of approximately 300 to 500 spring salmon a year. This may represent the entire annual stock of spring fish in the Wye as Gee and Milner (1980) estimated that the exploitation rate of 4SW and 3SW fish is very high compared to that of youger fish, and that most of them are probably taken by rods.

3.2 Patterns of Spring Salmon Abundance Elsewhere

Changes in the age composition of exploited stocks of salmon have been widely reported. Discrete periods of varying length in which fish of a specific sea-age dominate the stock numerically or by biomass have been observed throughout the European and North American range of the species. The reasons for these fluctuations are widely perceived to be either genetic or environmental in origin. In the Wye as elsewhere the principal components of the stock which vary in abundance are the grilse and the early running 4SW and 3SW spring salmon.

Declines in the abundance of spring salmon have been reported throughout the entire range of the species. Of 40 major salmon rivers in England and Wales, 6 were considered by Harris (1988) to be notable for spring fish with significant proportions of their rod catches occurring before May. Three of these rivers are in Wales, and the two other than the Wye have also seen substantial reductions in their spring catches. On the River Usk the pattern of rod catch of spring salmon is remarkably similar to that of the River Wye (Figure 5). Annual catches fell in the 1950's before rising to a peak of nearly 600 in 1966. The 5-year average also peaked in that year at over 300 salmon. Both measures of catch have since shown an overall decline and the 5-year average catch has been less than 100 in every year except four since 1976. Annual catches of spring salmon from the Usk have frequently been in the order of only 50 in this period. On the River Dee recent catches of spring salmon peaked at over 1200 in 1954 but have since shown a clear overall decline (Figure 6). The 5-year average catch has with few exceptions followed a downwards trend and has now been below 200 and falling further still since 1978.

FIGURE 2. MONTHLY ROD CATCH ON R.WYE - PROPORTION CAUGHT PER MONTH

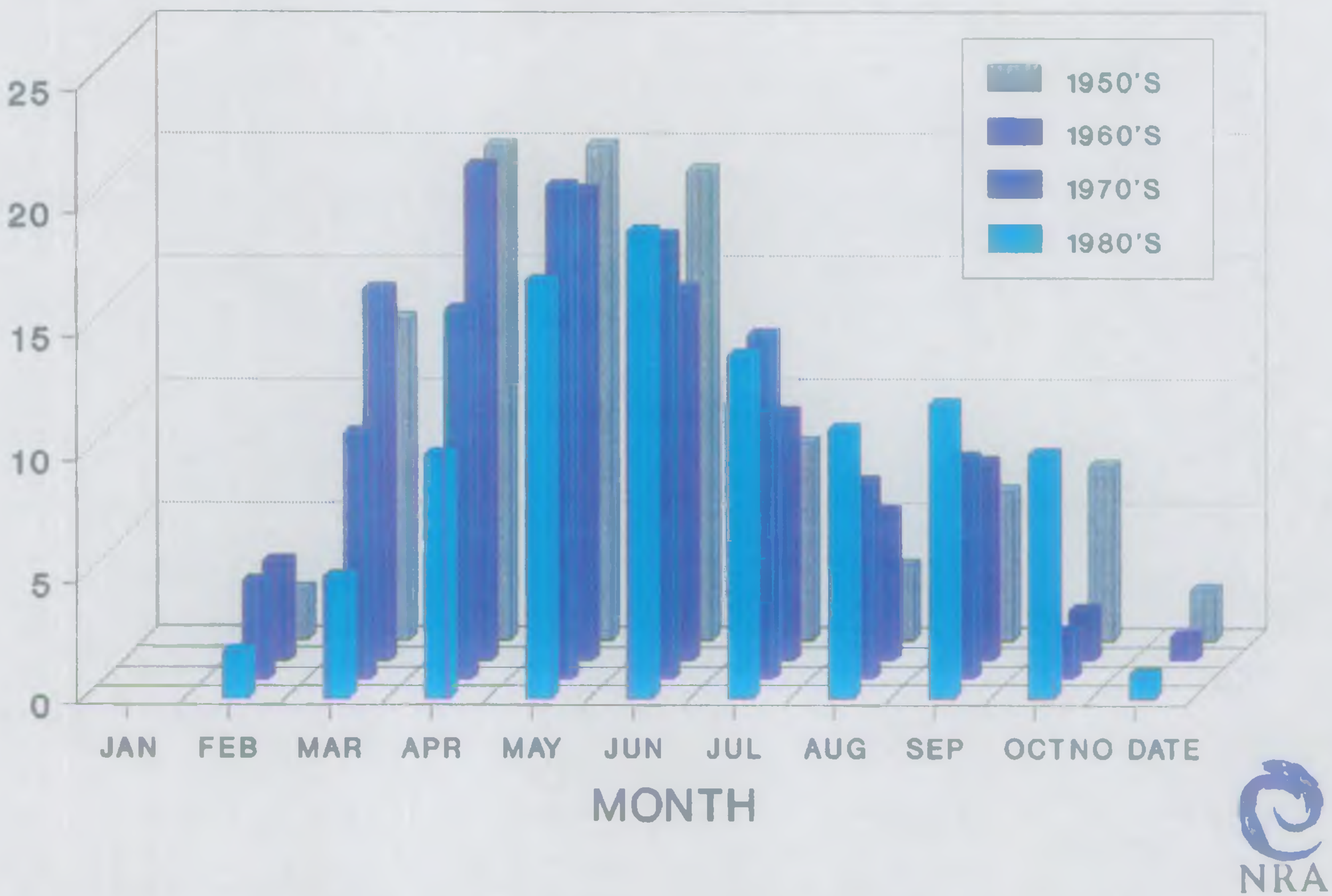


FIGURE 3

MAP OF RIVER WYE AND THE SEVERN ESTUARY

FIGURE 4.

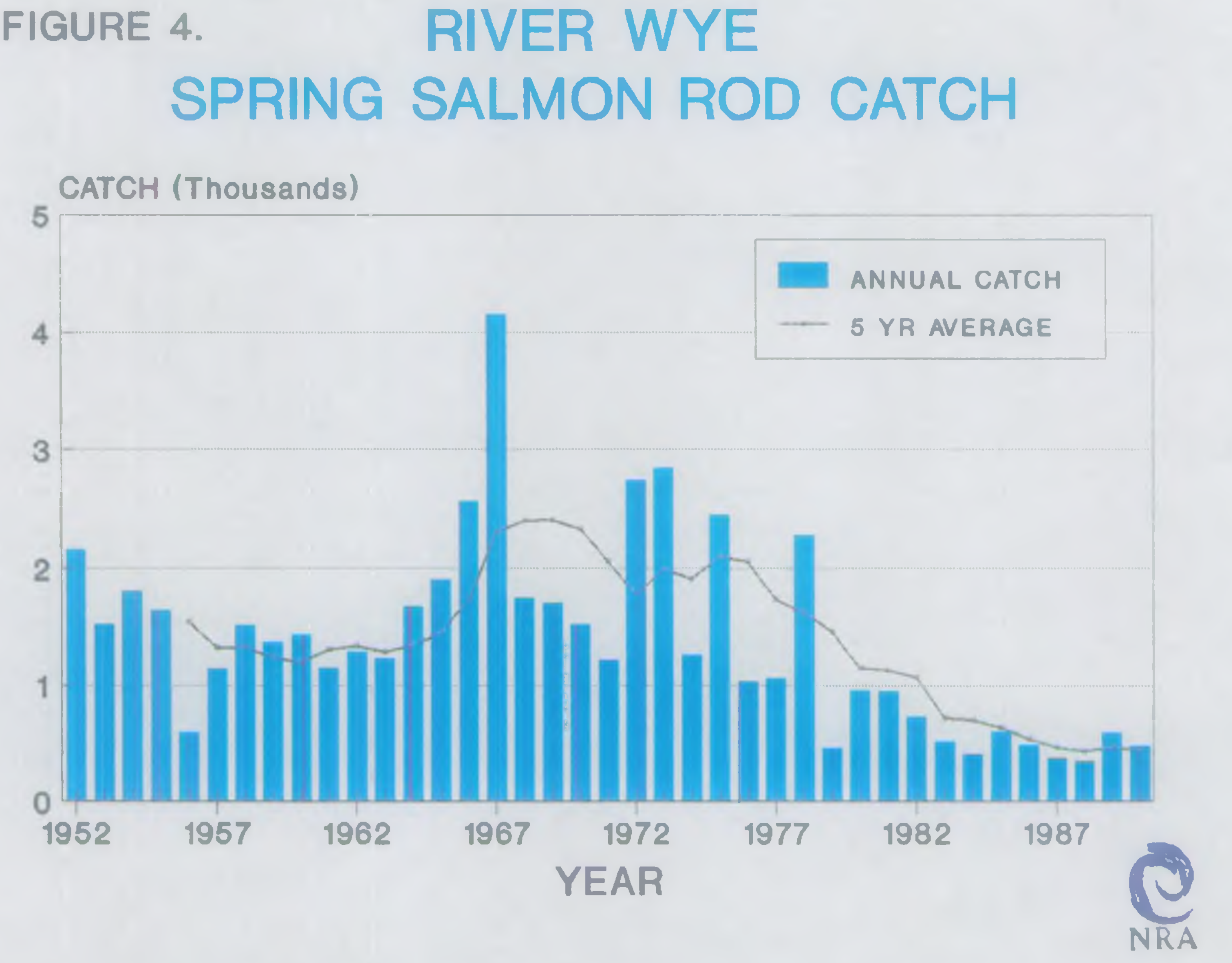

RIVER WYE
SPRING SALMON ROD CATCH
CATCH (Thousands)
5
4
3
2
1
0
ANNUAL CATCH
5 YR AVERAGE
1952
1957
1962
1967
1972
1977
1982
1987
YEAR
NRA

FIGURE 5. RIVER USK SPRING SALMON ROD CATCH 1952 - 1990

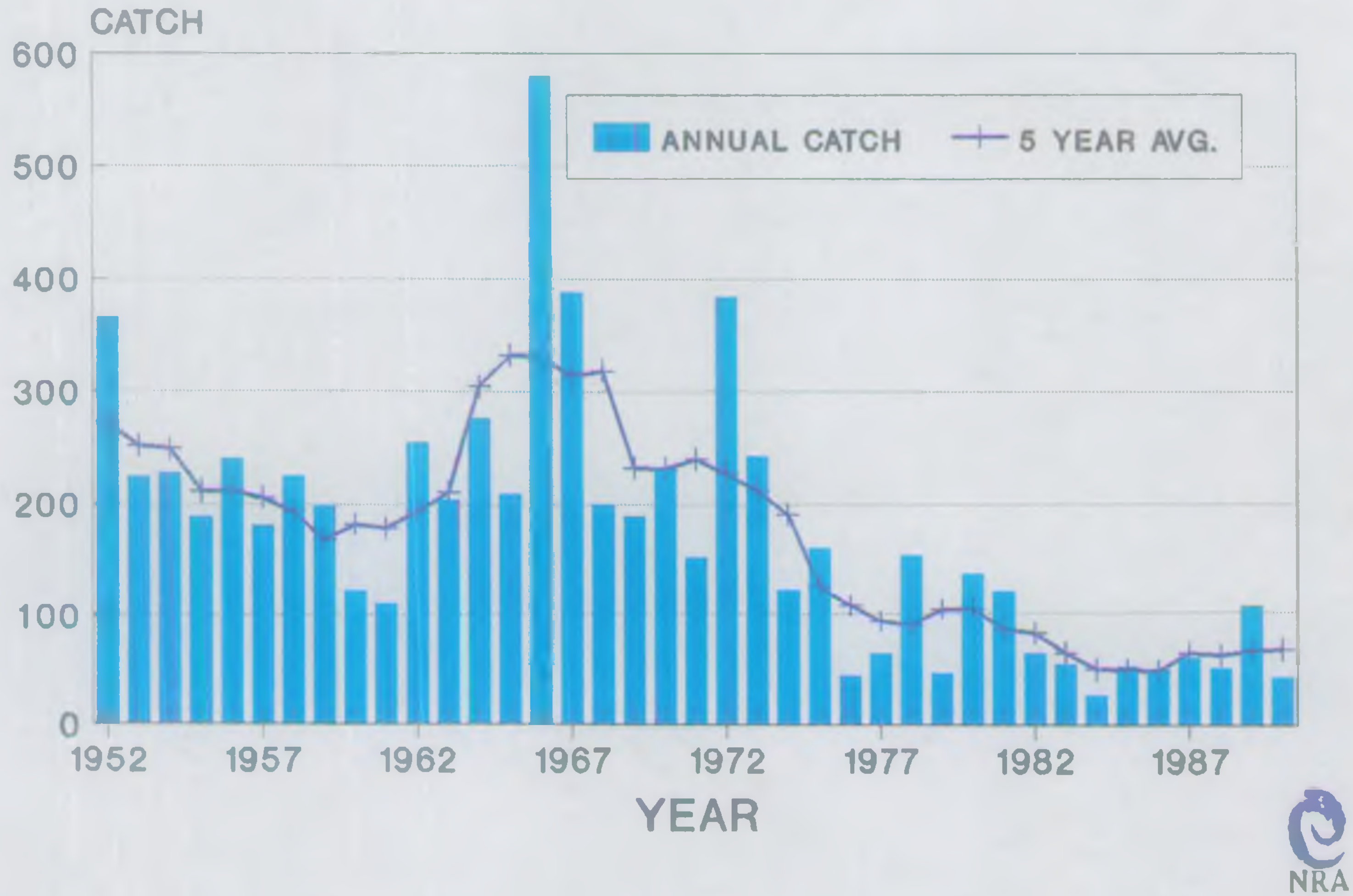
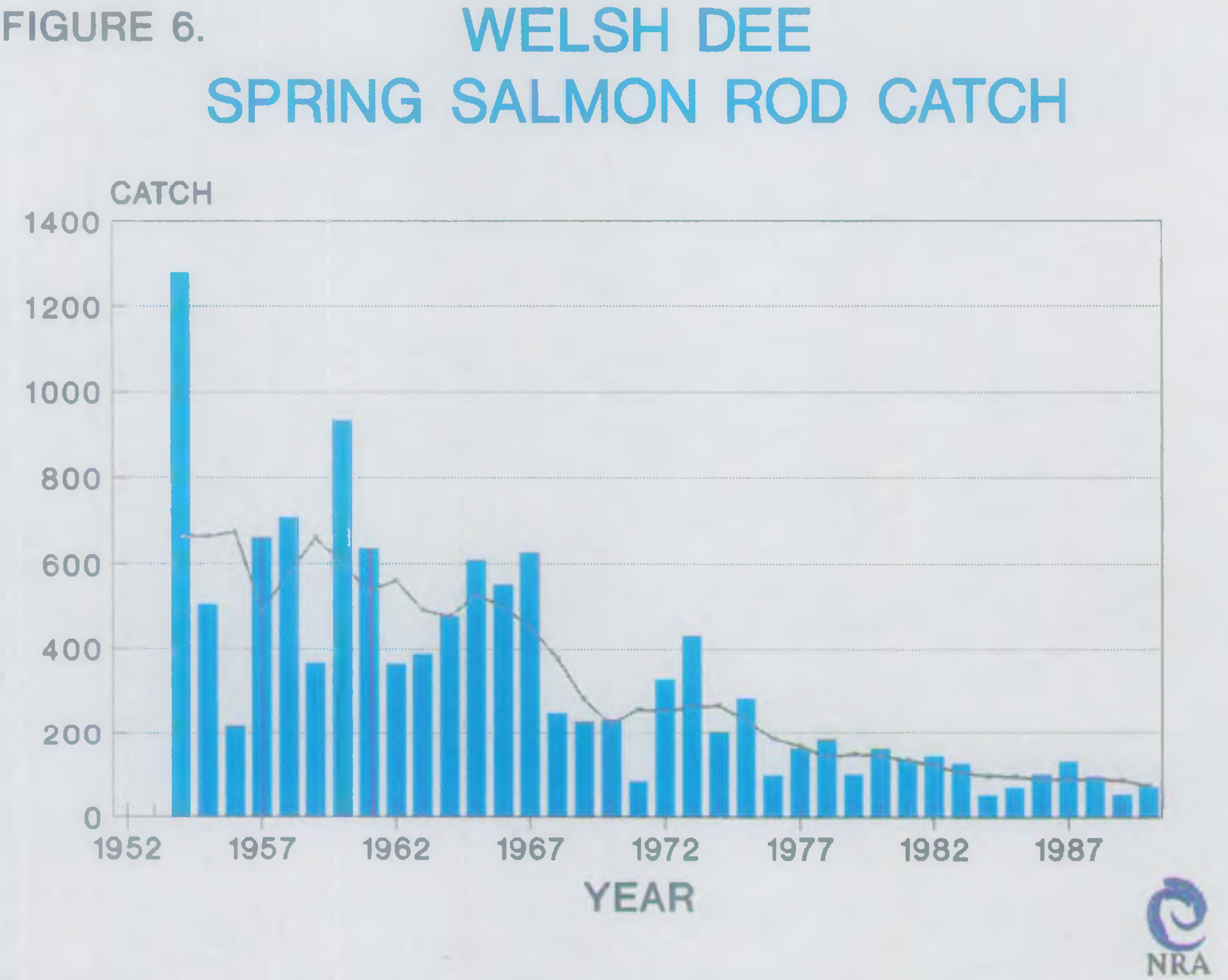


FIGURE 6.



WELSH DEE
SPRING SALMON ROD CATCH
CATCH
1400
1200
1000
800
600
400
200
0
1952
1957
1962
1967
1972
1977
1982
1987
YEAR
NRA

In English rivers similar changes in stock composition have occurred on the Rivers Avon, Exe, Frome and Severn, and apparently also on others for which accurate data is not available. Churchward and Hickley (1991) report decreased contributions of 4SW and 3SW salmon on the Severn, whereas the numbers of 2SW fish are essentially unchanged and the numbers, and particularly percentage contribution of 1SW fish, are substantially increased.

Very similar observations have been reported for the Rivers Avon and Frome in Hampshire (Anon.,1986) where 4SW salmon are reported to have virtually disappeared from the rivers and 3SW numbers have fallen considerably. These age classes have until recently predominated in the spring catch but have recently declined and been replaced by the small proportion of 2SW salmon which enter during the spring. In the middle 1950's the annual catch of spring salmon on the Avon was over 600 but since 1970 the catch has exceeded 200 only twice, and has now fallen to only about 30 fish annually since 1987 (Figure 7).

The River Exe in Devon has also seen a decline in spring runs (Figure 8). The fishery, which once yielded a majority of 2SW spring salmon, has changed substantially on a similar time-scale to the changes elsewhere, and is now dominated by grilse (Reader, pers. comm.).

In two North-West rivers, the Eden and the Lune, similar patterns are again evident (Aprahamian, pers. comm.). In the case of the Eden, catches of spring fish have fallen from a peak of over 1500 fish in 1966 to less than 200 in most years since 1974 (Figure 9). The five-year average has been consistent since 1980, unlike that for the River Lune which seems to indicate a gradual recovery in this period (Figure 10). The numbers of fish on this river are, however, very small with a peak in the last seventeen years of only 45 salmon.

In Scotland similar patterns of changes have been noted. Williamson (1988) reported an overall decline in spring fish numbers in both the rod and net catches, with that in the latter being more marked. He also reported a change in the overall age composition of the stock with a shift in the salmon-grilse ratio in favour of the grilse. Shearer (1986) also noted a decline in Scottish catches of spring salmon, reporting a fall in the overall mean 5-year catch from 88,000 in 1952 to 28,000 in 1983. He observed that the rate of decline of the spring fish was faster in the first half of this period, and that the decline in the net fishery was greater than that in the rod catch (80% compared with 45%). Williamson had suggested that consequent reductions in fishing effort for spring salmon had occurred after the beginning of their decline in abundance and that this had made the decline more marked. Shearer (1989) however notes that decreased catches of spring salmon are actually real and not simply a result of changes in fishing effort. He reports that the situation in the 1950's when the catch of spring fish in February-April was sometimes more than 50% of the whole annual catch changed rapidly over the next two decades such that throughout the 1980's the spring catch had slumped to only 7% of the total. During this time catches during September to November rose dramatically from just 19% during the 1950's to 70% of the annual catch during the 1980's.

Similar patterns of declining spring salmon abundance have been seen in other major Scottish salmon rivers and reported for the North Esk (Shelton and Dunkley,1991) and for the Tweed district (Shearer,1989). The pattern for the latter (Figure 11) is broadly similar to that seen in the River Wye (Figure 3).

Data from elsewhere in Europe also reveals changes in stock composition. In France, Prouzet (1990) reports increasing or steady proportions of 1SW and 2SW fish, but generally declining or depleted stocks of 4SW and 3SW salmon in the rivers of the Loire-Allier and Adour-Gaves-Nive basins. Ventura (1988) observes a substantial change in the stocks of Asturias, Spain, where spring salmon have declined in abundance and the 3SW salmon component of the stock has declined from 36% to 3% of catches.

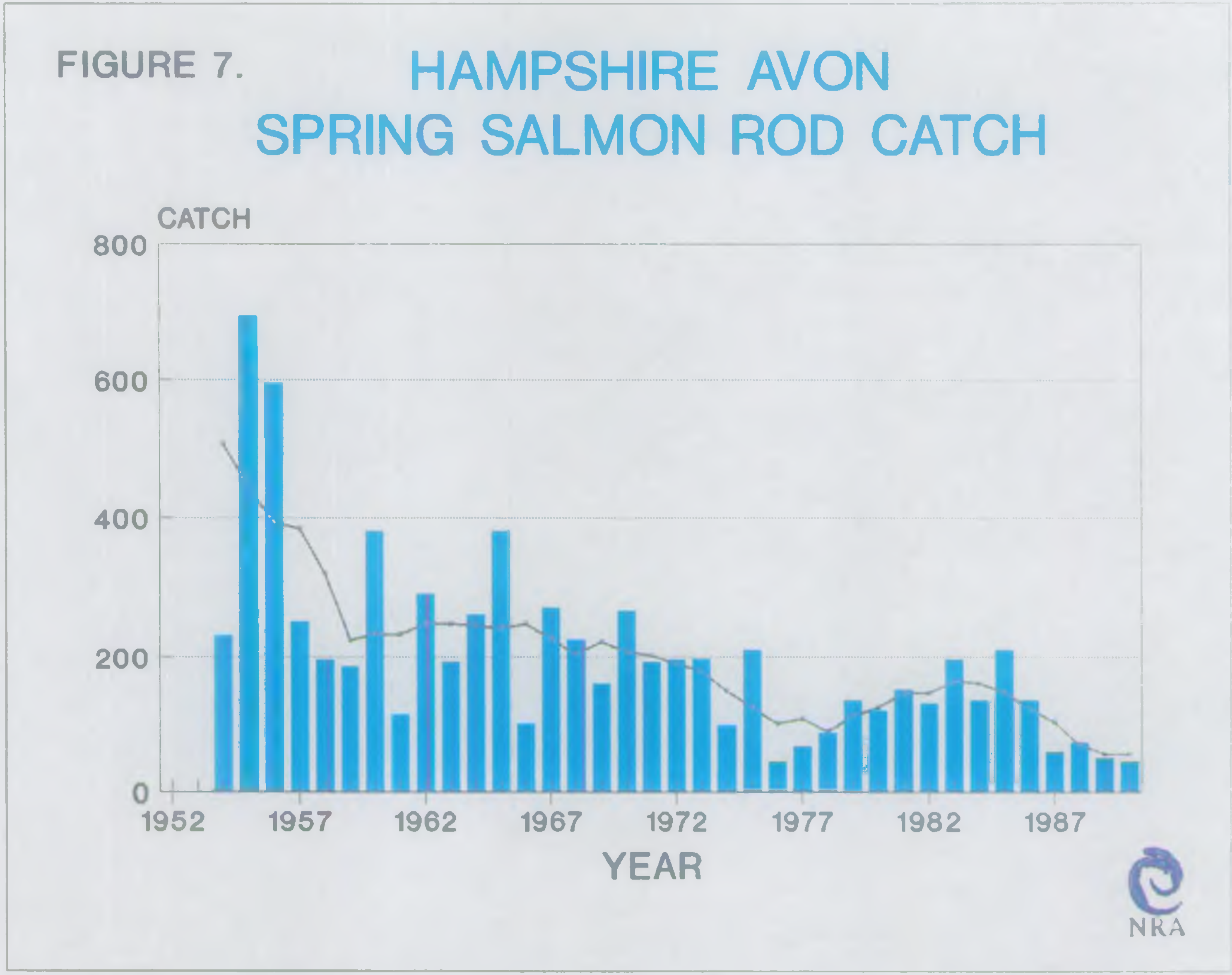


FIGURE 7.
HAMPSHIRE AVON
SPRING SALMON ROD CATCH
CATCH
800
600
400
200
0
1952
1957
1962
1967
1972
1977
1982
1987
YEAR
NRA

FIGURE 8.

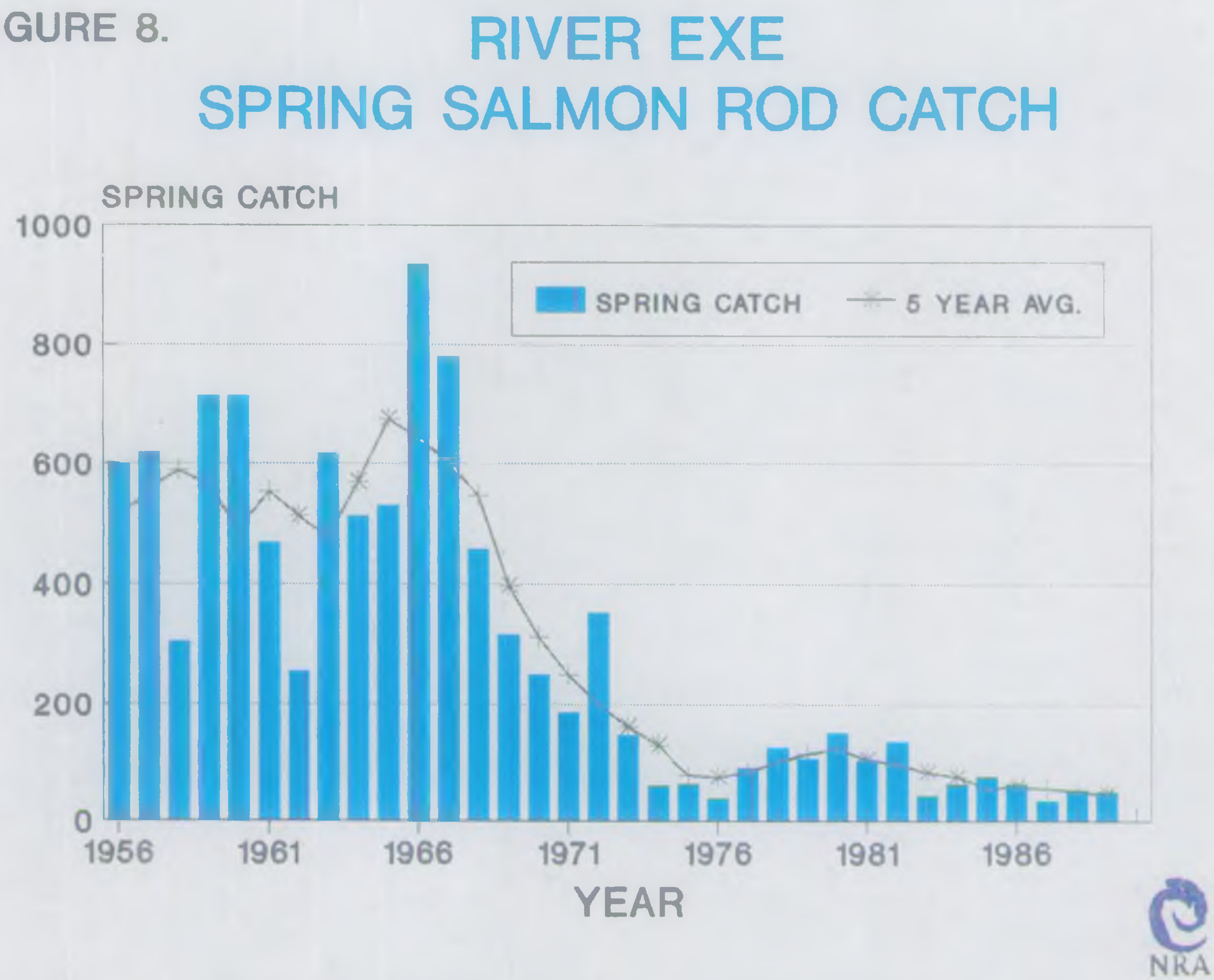
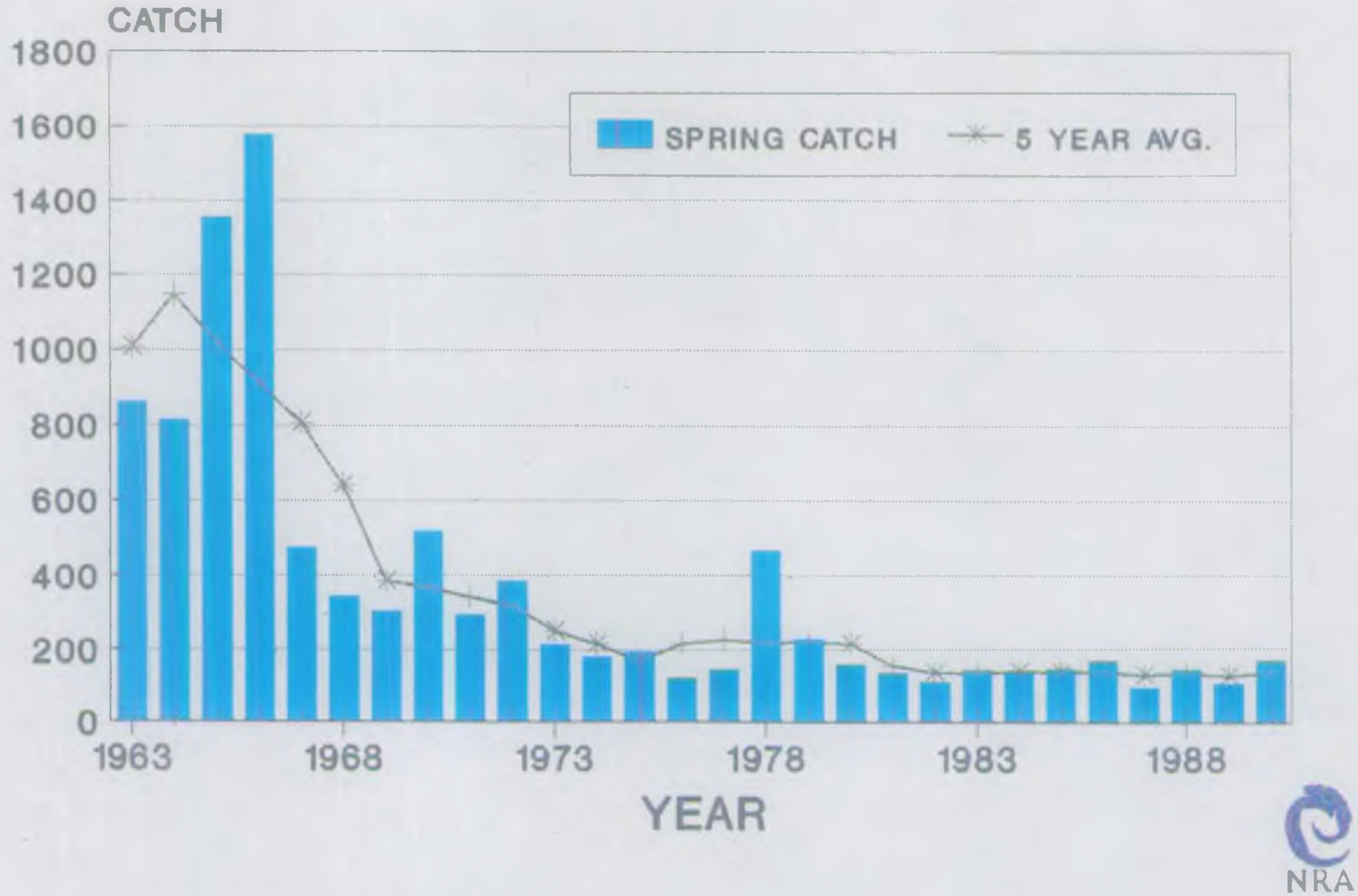

RIVER EXE
SPRING SALMON ROD CATCH
SPRING CATCH
1000
800
600
400
200
0
SPRING CATCH
5 YEAR AVG.
1956
1961
1966
1971
1976
1981
1986
YEAR
NRA

FIGURE 9.

RIVER EDEN SPRING SALMON ROD CATCH



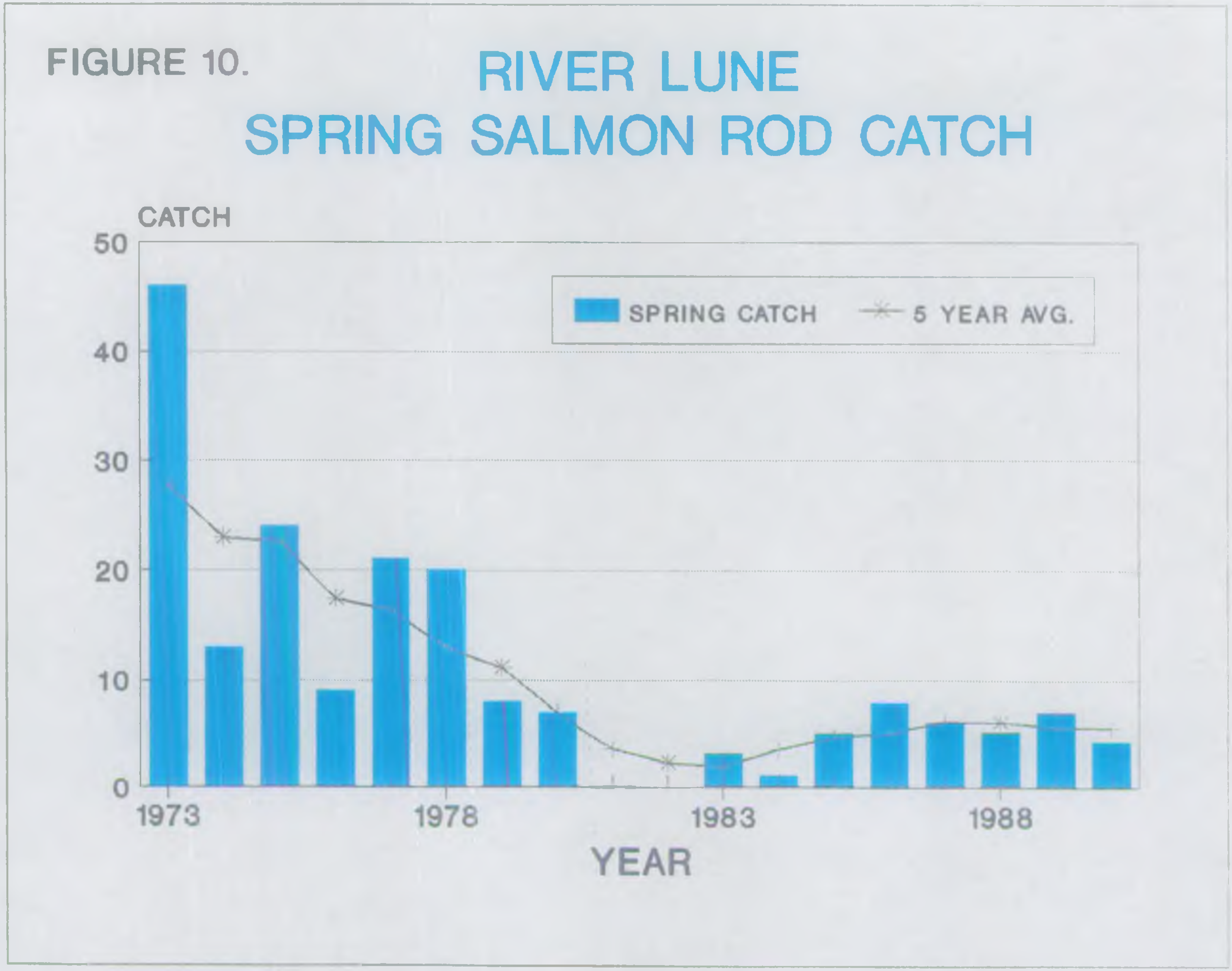


FIGURE 10.
RIVER LUNE
SPRING SALMON ROD CATCH
CATCH
50
40
30
20
10
0
SPRING CATCH
5 YEAR AVG.
1973
1978
1983
1988
YEAR

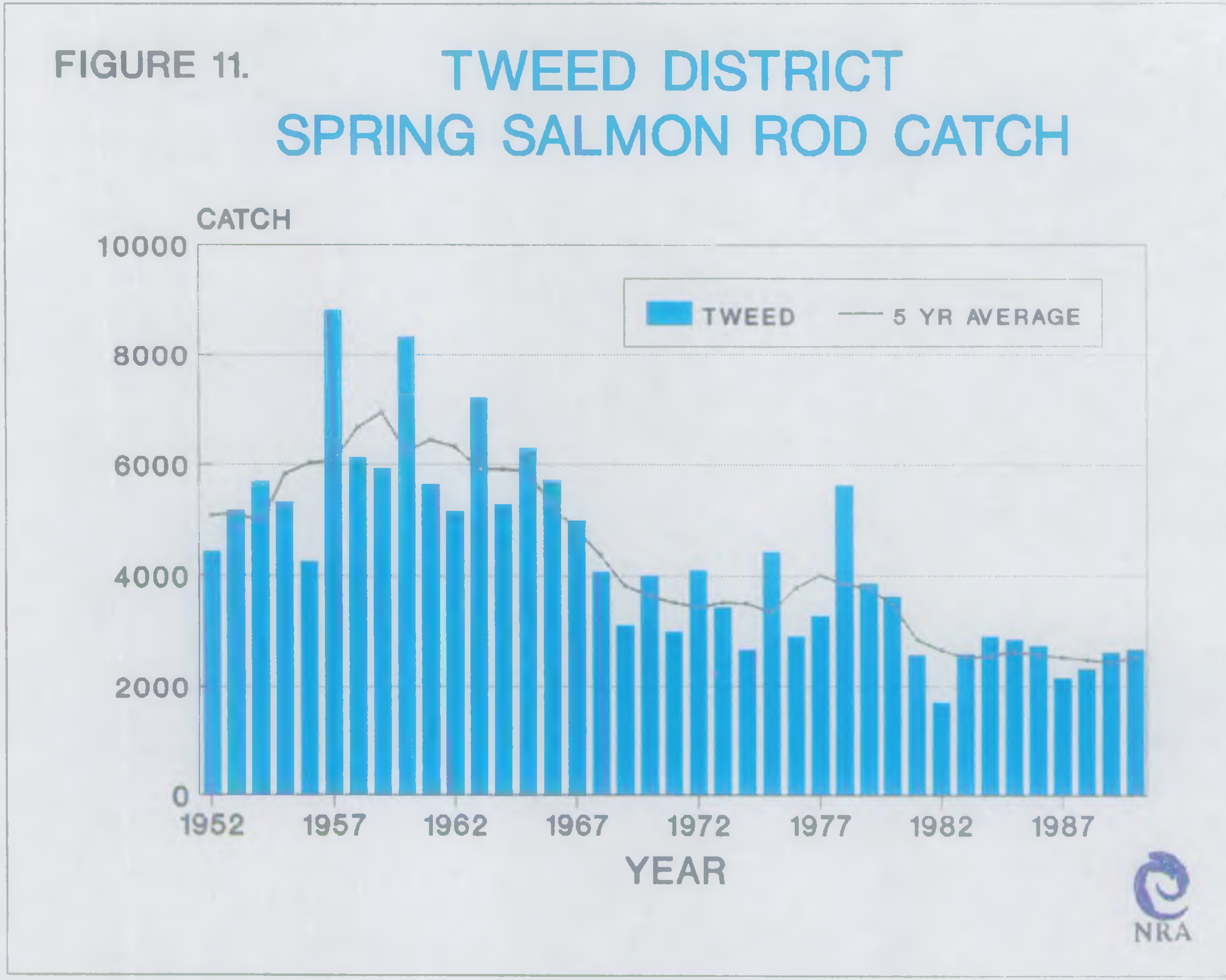
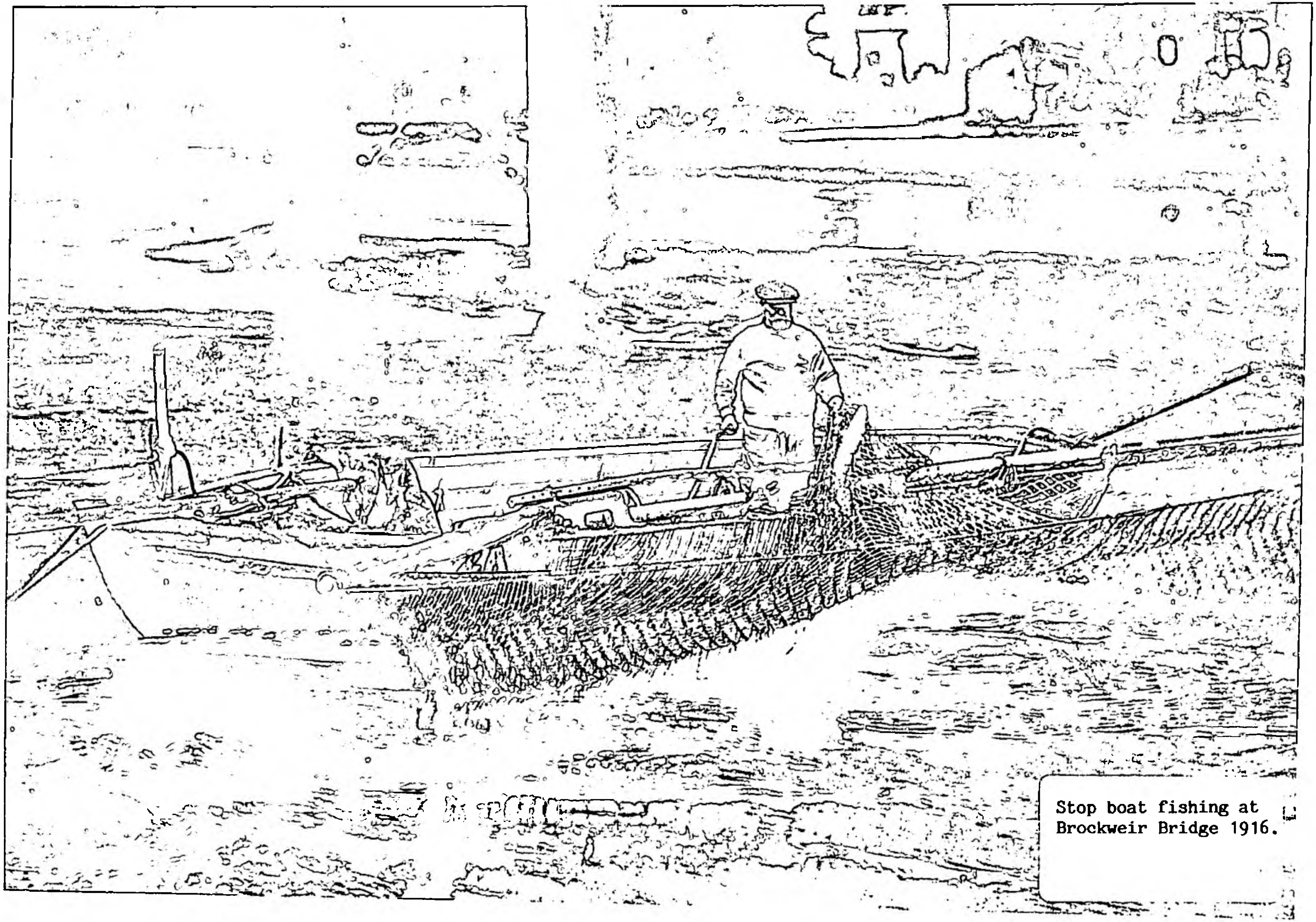


FIGURE 11.
TWEED DISTRICT
SPRING SALMON ROD CATCH
CATCH
10000
8000
6000
4000
2000
0
TWEED
5 YR AVERAGE
1952
1957
1962
1967
1972
1977
1982
1987
YEAR
NRA

Similar stock composition changes have occurred in Canada. Porter et al (1986) review patterns of decreasing abundance of MSW salmon and concurrant increases in the proportion of grilse in the spawning stock in many rivers including the Miramichi, Restigouche, Matamek rivers and several others in Newfoundland. Saunders (1969) noted that more than 90% of Miramichi MSW salmon were selectively removed from the fishery by exploitation and that the spawning stock thus consisted principally of 1SW fish. Whereas the fishery showed a grilse:MSW ratio of 2:1, the ratio amongst the spawners was 28:1.

Variations in the numbers of MSW salmon and in the ratio of 1SW to MSW salmon have been observed throughout the range of the Atlantic salmon. In many cases these may be short-term trends relating to temporary variations in either the freshwater or marine environments. Additionally however, the existence of long-term trends seems now to be accepted. These may come about as a result of long-term, and perhaps subtle environmental change, or as a result of genetic influences. The two might of course interact. Patterns in various rivers appear to be broadly similar (Figures 4 - 11).



Stop boat fishing at
Brockweir Bridge 1916.

4. FACTORS AFFECTING SPRING SALMON

A large number of factors can potentially influence the spring salmon abundance ranging from widescale climatic factors to more localised effects of exploitation and freshwater habitat. This range of factors is likely to interact with the underlying genetic basis of sea absence to form a complex pattern of changes in stock status.

4.1 Exploitation

The Wye salmon stock contains temporally distinct runs of fish. The 4SW and 3SW spring fish are known to be present in the river at the commencement of the angling season in January, and the catches of both age-groups peaks in April. The peak catch of 2SW spring fish occurs a little later in May. Gee and Milner (1980) reported that older spring fish tend to be caught earlier than younger ones, and that median dates of spring fish capture were becoming gradually later.

Spring salmon are the component of the Wye stocks most valued by anglers. Their value to the fishery is thus disproportionate to their abundance, and the relatively recent decline in catches is hence a cause of great concern. In common with other age-groups of salmon, spring fish are exploited both legally and illegally at all adult stages of their life-cycle between marine feeding and spawning in their natal rivers. In contrast to grilse however, MSW salmon have been preferentially exploited at sea by fisheries specific for that sea-age, and in freshwater by relatively high levels of angling effort. The residence of spring salmon in freshwater is considerably longer than that of other fish, and this can also result in higher rates of exploitation, or mortality.

Of considerable concern is the fact that specific over-exploitation of the spring stocks will result in depletion of the spawning stock of such fish. It seems most likely that sea-age at maturity, and hence the season of return to the river, is a heritable trait (Saunders, 1986). Thus reduction by specific exploitation of one part of the genetic complement, for example that determining return as spring salmon, will subsequently result in further depletion. Continued excessive exploitation could therefore drive a particular trait, and hence that component of the stock, towards extinction.

4.1.1 Homewater Exploitation

Most information on the homewater exploitation (within the juridstiction of the N.R.A.-Welsh Region, and the Severn Estuary) of salmon has come from tagging experiments and particularly from relatively recent widescale use of microtagging. This technique involves the implantation of an inert coded wire tag around 1mm long in the nasal cartilage of smolts. The tag is used in conjunction with an adipose fin-clip to provide a visual indication that the fish is tagged. Such fish may then be scanned to detect the presence of a tag, but must be sacrificed for extraction and decoding of the tag to determine the origin of the fish.

The scanning of catches from homewater fisheries is problematical because of their diffuse nature. Large scale publicity, together with the incentive of a tag reward scheme, and the purchase of tagged salmon from commercial fisherman has provided results however it is unclear what proportion of the true catch these represent.

Wild smolts were caught in the Wye each year between 1985 and 1989 and microtagged. Of the total of 7689 smolts tagged, most (4084) were released in 1987. Data from these studies have shown that equal numbers of the adult recaptures have been taken by the rods and by Severn Estuary commercial fisheries. These recaptures each represent 0.18% of the tagged smolts, and 26%

of the total numbers recaptured, with the remaining recaptures (48%) reported by distant water fisheries.

Rod and net recaptures of mictotagged Wye fish in homewaters have comprised 68% 1SW fish and 28% 2SW fish whilst only one 3SW salmon has been recorded. Swain (1982) reported sea-age composition of recaptured Carlin-tagged Wye smolts as 33% 1SW, 50% 2SW, 16% 3SW and 1% 4SW for the period 1960-1967. These earlier data indicate, when compared with more recent microtagging data, that there may have been a real shift towards younger sea-age groups.

4.1.1.1 Exploitation By Rods

There is some evidence to suggest that salmon are most vulnerable to capture during a period of around 20 to 30 days following entry to the river (Clarke et al,1991). In the case of spring salmon it has been suggested that this period is longer, perhaps being a function of the lower water temperatures. This together with greater angling effort may result in a higher rate of exploitation of spring salmon rather than any variation in behaviour between different age groups.

Several studies have demonstrated that the rate of exploitation of MSW salmon exceeds that of 1SW salmon. On the River Wye, Gee and Milner (1980) examined the exploitation rates of different weight categories of fish and found that large salmon were probably fully exploited, and that only the category of fish less than 3.2 Kg (predominately grilse) was lightly exploited. They suggested therefore that very few salmon heavier than 9.1 Kg (3SW or older) survived to spawn and that the spawning stock therefore consists of those 2SW and 1SW salmon which survive angling exploitation together with grilse entering the river after the angling season has closed. This is likely to have significant implications for the genetic composition of the stock.

Since 1910 the catch per licence of Wye 3SW spring salmon has shown an overall decline, and by 1977 was little more than 1 (Gee and Milner,1980). The catch of 4SW spring salmon also declined in this period, and very few such fish have been reported since 1960. To date, no microtag returns of 4SW or 3SW salmon from the Wye rod fishery have been recorded. The reported catch of 13 microtagged salmon has consisted of 46% 2SW salmon, the remainder being grilse.

Similar patterns are seen elsewhere. Overall stock exploitation on the Rivers Avon, Piddle, and Frome were considered to be very variable at 72%, 10% and 30-40% respectively (Anon.,1986). More recently Beaumont et al (1991) examined data for different sea-age groups and reported that the exploitation rate of early season MSW Frome salmon was 32% whereas that of later season grilse was considerably less at 11%. On the River Severn, although not quantified, Churchward and Hickley (1991) consider that both 4SW and 3SW salmon are over exploited whilst grilse are under exploited. Similar findings have also been reported for the Elorn River in France where Prouzet (1990) has estimated that exploitation by rod of MSW salmon was 30% whereas that of grilse was less than 5%.

Angling exploits only those fish present in the river during the open season. Increasing numbers of salmon, almost all of which are grilse, are known to be entering rivers after the end of the season and they are therefore forming an increasing proportion of the spawning stock. The trait for such late running behaviour is therefore presumably increasing in frequency, and will continue to do so unless environmental selection operates to reverse the trend.

4.1.1.2 Exploitation By Net And Fixed Engine

The commercial salmon fishery on the lower River Wye and Severn Estuary at one time consisted of drift nets, and also methods such as stop-boat fishing, putts and putchers, and lave nets. These are generally techniques peculiar to the Rivers Wye, Usk and Severn which have developed in response to the particularly high tidal range encountered. Fishing by drift-net and stop-boat ended in 1984 marking the end to commercial fishing within the River Wye itself and in the immediate vicinity of the estuary. Most of the other techniques persist, although at a reduced rate, in the Severn Estuary.

Salmon from the River Wye together with fish from other south Wales rivers are known from earlier tagging studies (Swain,1982) and more recent microtagging studies to be caught throughout the Severn Estuary. Of the total homewater recaptures of microtagged Wye salmon, 14% were caught in commercial fisheries operating upstream of the Severn Bridge. Only 13% of Severn Estuary recaptures were MSW, principally 2SW salmon, with the majority being grilse. It is of interest that the only tagged Wye 3SW salmon reported came from a commercial putcher fishery. Although this demonstrates that exploitation of this component of the stock is occurring here, it is likely to be only at a very low rate.

The relative proportions of the sea-age groups taken by the rod and net fisheries were observed by Gee and Milner (1980) to be different. This has since been found also to occur in Severn fisheries by Churchward and Hickley (1991). The net fisheries catch higher proportions of the 1SW and 2SW stocks and far smaller proportions of the MSW stock, and particularly the spring-run component, than the rods.

Towards the end of the operation of the Wye drift-netting and stop-boat fishery, the catch of 3SW salmon had declined to just 3% of the total catch. Notwithstanding the value of spring fish, it is likely that their relative scarcity and the frequently difficult fishing conditions at that time of the year resulted in correspondingly light fishing effort.

Selection by age still occurs in the remnant putcher fishery. Churchward and Hickley (1991) report that these take relatively more grilse and 2SW salmon than the rods, whereas the rods were biased towards 3SW spring salmon. This selection is largely a result of the putcher season, which does not commence until 17th April.

4.1.1.3 Illegal Fishery

For many years Wye salmon have been taken illegally during the spawning season by individuals using gaffs and spears. This practice has now virtually ceased in the Wye catchment with the number of apprehensions declining throughout the 1980's to the point where there were no arrests for illegal use of these instruments in 1990 or 1991. This method of illegal fishing is not considered to be a threat to large spring salmon.

In the absence of significant barriers to fish migration there is little or no illegal use of rod and line such as snatching. In addition snaring is rarely seen and there is no history of poaching using poisons. Therefore the principal threat to salmon stocks in the Wye from illegal fishing is the use of nets both in the Severn Estuary and within the river itself.

All the salmon destined for the Wye pass through the Severn Estuary. These fish are one component of the mixed stocks within the estuary which also includes salmon from the Rivers Usk, Severn and Taff although the proportion from each river is not known. Eight licenced salmon netting boats operate in the Severn Estuary off Uskmouth whilst a number of other boats also use drift nets, ostensibly for sea fish in the estuary.

In the Wye Estuary, the NRA owns the fishing rights, and indeed the Welsh Water Authority operated a commercial netting station at Chepstow until 1984. This ownership has meant that there is no tradition of illegal netting for salmon in the Severn Estuary immediately off the mouth of the Wye. Also because the sea fishing rights (as well as the salmon fishing rights) are owned by the NRA, enforcement is relatively straightforward. There is no evidence that the cessation of the Wye commercial fishery has led to any increase in illegal activity which remains at a very low level centered around a few individuals using gaffs and hoop nets in the Chepstow area.

Few large spring salmon are caught in estuary nets, legal or illegal, as this fishery principally operates from May onwards. Since 1987, data have been collected on the low catches of sea fish by netsmen to support the promotion of byelaws under the Salmon Act 1986. These byelaws will, if approved by the Welsh Office, prohibit drift netting for sea fish and hence the legal loophole allowing the taking of salmon by unlicenced nets would be closed. However it is envisaged that the current intensive enforcement effort will have to continue for some time once the byelaws are in place to reduce the illegal salmon netting in the estuary to an insignificant level.

In the River Wye itself illegal netting activity began to increase in the early 1980's and reached a peak between 1985 and 1987 as more local individuals became involved. It is generally believed that it was poachers from the Bridport area that started this method of fishing on the Wye after their initial success on Devon rivers. Illegal netting in the river takes place whenever river conditions permit.

The use of gill nets strung across the river was first seen on the Wye in the late 1970's, and was identified by bailiffs as a problem affecting the lower river from Hay to Chepstow (approximately 160km in length). More recently since 1987/88, and in response to the detection of such nets by boat patrols using grappling hooks, the use of shorter peg nets fished from croys has increased. Peg nets are used mostly during low summer flows and whilst more salmon are taken illegally during the summer than during the spring, some spring fish are certainly netted. The advantage of the peg net to the poacher is that it can be set quickly by one man without the use of a dinghy. The peg net is very much less effective than longer nets, with only around half of the nets detected over the past three years having caught fish with an overall average catch rate of 1.2 salmon per net. Clearly these figures have to be treated with caution however they do indicate their relatively low efficiency.

In addition to direct enforcement there has also been a concerted campaign to reduce the sale of illegally caught fish. Several hundred fish dealers, hotels and restaurants have been sent, by recorded delivery, leaflets explaining how to recognise illegally caught fish and what measures to take to verify their legality. These have been followed-up with visits by enforcement staff in many cases.

In summary, the approach to combat illegal fishing in the River Wye in recent years has been river patrols targeted at the poachers and a campaign to reduce the market for illegally caught salmon.

4.1.2 Distant Water Exploitation

Fisheries for mixed stocks of salmon occur at a number of well defined locations in the North Atlantic. The relative and absolute contribution of fish from each country of origin is the subject of ongoing study, however general patterns of exploitation are now known. Techniques to identify the origin of fish have included the examination of scale characteristics and the use of a number of biochemical and genetic techniques. These are often able to discriminate salmon from different continents, or of different race, but are not able to reliably identify river or even country of origin.

Scanning of landed catches at Faroes and West Greenland for tagged fish has been organised in conjunction with market sampling programmes to collect biological samples and other fisheries data. A proportion of the landings in both fisheries have been routinely scanned since 1985. The results of these have been reported to ICES (International Council for the Exploration of the Sea) and, together with corresponding data from Irish and North-East coast scanning programmes, have been collated by the Ministry of Agriculture Fisheries and Food.

4.1.2.1 Greenland

High seas fisheries for salmon at West Greenland commenced in the first half of this century, but remained at a relatively low level until 1960. From then until 1964 the quantity of salmon landed increased dramatically from 50 to 1,539 tonnes annually (Jensen,1988). From 1965, boats of non-Greenlandic origin also exploited the resource, however the annual landings did not increase further. From 1976 controls were introduced and the fishery was restricted by quota to between 1,100 and 1,191 tonnes, depending on the start of the season. This has since been reduced further to 850 tonnes, but in the past three years this has not been achieved.

The fishery operates during the summer months and consists mostly of drift nets. It exploits MSW salmon stocks, the majority of which are females, from throughout the range of the species, with the main contribution coming from Scottish and Canadian stocks.

Since 1987 a total of 9 microtagged Welsh salmon have been returned from the fishery. Only 1 of these was derived from the River Wye stock, representing 2% of the total recaptures of this stock.

4.1.2.2 Faroes

This fishery developed after the establishment of the West Greenland fishery, and up until 1979 relatively small quantities of fish were landed. Catches increased from an early peak of 40 tonnes to 119 tonnes in 1979 and a peak of 1,025 tonnes in 1981 (Jakupsstovu,1988). After that date a quota arrangement was initiated and catches have since declined to about 60 tonnes.

The fishery operates principally in the winter months, and like that of Greenland it exploits MSW salmon from a number of countries, but principally those from Scandinavia. A total of 8 microtagged Welsh salmon have been reported in this fishery since 1987, and again only 1 of these proved to be a Wye fish.

It has recently been reported that this fishery has ceased following a buy-out scheme, due initially to last three years, and the last season of operation was 1990/91.

4.1.2.3 North-East Coast

This is a drift net fishery operating off the coasts of Northumbria and Yorkshire. Although the catch here has increased considerably from a 5-year average of 6,033 salmon in 1952-1956 to 48,680 in 1986-1990, it consists almost entirely of Scottish and Northumbrian fish.

Only 1 tagged Wye salmon has been reported from this fishery, and it is therefore not likely to represent a significant level of exploitation on Wye stocks.

A recent Government assessment (Anon.,1991) has proposed the phasing-out of the fishery, and the movement of fishing effort close inshore so that local river stocks are predominately exploited.

4.1.2.4 Irish Fisheries

Significant drift-net fisheries operate in both Northern and Southern Ireland. Both exploit principally 1SW fish, with only about 10% of the catch being MSW salmon. Returns from each fishery since 1987 have included Wye fish with 1 reported from the North and 21 from the South. The latter is the most significant of the distant water fisheries and has accounted for 40% of the recaptures of Wye fish. No MSW salmon have been amongst these however.

4.1.3 Overview of Exploitation

Many factors appear to be combining to bring pressure on the MSW component of salmon stocks and thus to reduce their abundance. The widespread observations of the present decline throughout the range of the species, together with data on fluctuating cycles of abundance in the past, point strongly to an overall climatic effect. This clearly cannot be influenced by man however there are other factors, particularly genetics, which are also capable of influencing this facet of the life-history strategy.

Factors operating in freshwater might be significant. Riddell (1986) for example considers that fishing mortality, representing as it does a minor proportion of the total mortality within the life-cycle, is not likely to be sufficiently selective to cause sea-age composition changes. He notes that life-history models developed to predict age at maturity are much more sensitive to variations in the rate of juvenile mortality in freshwater than to variations in adult mortality.

The major marine fisheries, particularly West Greenland, which selectively exploit MSW salmon almost certainly did not initiate the decline in spring salmon stocks, as reductions in abundance were clear before they commenced significant operation. Following their inception and growth however, they have presumably contributed to the specific pressure on this component of the stock. MSW salmon remain at sea for between many months and up to three years longer than grilse, and therefore experience greater rates of both natural and fishing marine mortality. Catches in these fisheries over the past few years have, however, been poor. This may reflect overall poor marine survival rates, or changes in migration patterns.

In freshwater, selective exploitation continues. MSW spring salmon are available for exploitation by angling for much of the year, unlike proportions of the grilse stock which might never be available for legal exploitation. Furthermore MSW salmon attract greater levels of fishing effort and, being more vulnerable to angling, are more heavily exploited by anglers. Long residence in freshwater prior to spawning in itself might not further increase their vulnerability to angling (although there is some evidence that they once again might become vulnerable to angling in the Autumn), however it increases their exposure to predation, disease and illegal fishing.

As the available stock of spring salmon diminishes, both during the course of the spring and from year to year, the catchability of fish is likely to increase, as suggested by Peterman and Steer (1981), Mills et al (1986) and Anon. (1991). Beaumont et al (1991) also noted this phenomenon, and attributed it to ordered selection by the small numbers of fish of preferred lies which are well known to anglers and thus selectively fished.

The result of such deliberate and selective exploitation is that a potential spawning stock of spring salmon, perhaps already reduced by climatic influence, is further reduced or perhaps even completely depleted, as implied by Saunders (1969) and Gee and Milner (1980). This pattern of exploitation results in reduced age and size of the stock of spawners, which increasingly contains those in-season fish which have escaped capture or are under exploited (especially 1SW fish) and those which enter the system after the end of the season. This effect is cumulative over successive generations and, if the genetic theory of inheritance of specific sea-age traits is correct, will result in strong pressure against MSW salmon and in favour of 1SW fish in subsequent generations. The work of Ryman (1991) amongst others suggests that such selection, or gene-flow, can become significant after only a few generations. Although it does seem that grilse spawners could continue to yield small numbers of MSW salmon (S.R.T.I.,1982), even this might cease after several years of selective exploitation.

4.2 Genetics

The importance of genetics in determining the sea age of return of Atlantic salmon has received much attention in recent years. This is mainly attributable to the dramatic increase in salmon farming and the desire to control growth rate to provide fish of the required size for marketing. There has also been an increasing realisation of the importance of genetic factors by fisheries managers and the need to conserve genetic integrity and variability of wild stocks.

Numerous studies have shown that local salmon populations are typically genetically distinct (e.g. Hindar et al 1991, McElligott and Cross 1991). These differences can occur both between river catchments and between different tributaries within a river catchment. The relationship between geographical genetic variation and age of maturity of salmon has also received some attention. Evidence continues to accumulate that sea-age at maturity is influenced by the genetics of the stock (Gardner,1976; Saunders,1986; Hansen and Jonsson,1991) however much evidence also strongly implicates important environmental influences which may over-ride genetic factors.

Breeding studies using parents of differing sea ages have demonstrated that a genetic component is involved in determining the sea age of return of the progeny. For example Piggins has reported work undertaken in Ireland (S.R.T.I.,1982) in which 1SW and 2SW parents were used in a number of crosses :-

Smolt Parentage	% Return as:	
	1SW	2SW
2SW x 2SW	87.0	13.0
2SW x 1SW	96.1	3.9
1SW x 1SW	98.4	1.6

Although the pure 2SW cross yielded more 2SW offspring than the other crosses, it still produced predominately grilse.

Similarly in the course of selective breeding experiments on the Miramichi River in Canada it was observed that of the progeny of grilse x grilse matings, 73% of the tagged offspring returned as grilse; conversely of the offspring of 2SW x 2SW matings, 84% of the returning offspring were 2SW fish (Schaffer and Elson 1975). In farmed salmon, Laird and Needham (1986) reported the following percentages of grilse at two rearing sites (C and D) in the same year:

Male	Female	C	D
Salmon	Salmon	4	7
Grilse	Salmon	20	18
Grilse	Grilse	43	44

Two sea winter fish produced offspring with a low grilsing potential and the use of a grilse male with a salmon female produced around half as many grilse as from a crossing between two grilse. They also found that there were substantial annual variations in the proportions of grilse produced by such crosses, perhaps reflecting the effects of variable environmental conditions.

Thorpe and Mitchell (1981) quote a Canadian study in which hatchery reared smolts derived from large, long sea-absence Restigouche River fish were stocked into the Apple River, whose indigenous stocks are dominated by grilse. The great majority of the resultant adults returned to the Apple River as 1SW fish. Saunders (1981) noted that MSW spawners from the St. John River yielded as many 1SW as MSW offspring, and contrasted this with work reported by Elson (1973 - quoted in Saunders,1981) who had concluded that age at first spawning was a heritable trait. In other Canadian trials Sutterlin et al (1981) released half of a batch of hatchery smolts in a river as part of a ranching trial, and reared the others in sea cages. The great majority of the former returned to the river as grilse, however the caged fish showed a grilse rate of less than 1%. Although this seems to be clear evidence of an environmental effect, it might be more related to the inability of the caged fish to escape conditions which they may otherwise have avoided. It seems therefore that overall the characteristic age at which individuals become sexually mature is, to a varying extent between stocks, genetically heritable. It is not clear however in what way environmental factors can over-ride this.

Variation in the two alleles (alternative forms of a specified gene) which code for the protein known as MEP-2 (malic enzyme-2*) in Atlantic salmon has been used extensively in descriptions of the species population structure (Jordan et al 1990, Jordan and Youngson 1991). It has been found that the different allele frequencies vary with latitude and is therefore likely to be associated with environmental temperature. Differences can be demonstrated even within a single river catchment, and are similarly correlated with water temperatures experienced. In addition differences in the performance of individual fish have been shown to be associated with the different pairings of MEP-2 alleles (genotypes). These different genotypes differ with respect to growth and age at sexual maturity with the frequency of heterozygotes (in which the two genes are different) being generally significantly higher in grilse than in salmon from the same hatch year class (Jordan et al 1990). Although the exact nature of the link between the genotypes and performance is not known, the findings do suggest that geographic genetic differences may be associated with variation in the environment and with differences in performance with respect to adaptively important characters such as age at maturity and growth rate.

Although these recent advances in our understanding of the genetic basis of salmon life history characteristics suggest that there may be potential for breeding programmes to select for traits such as spring running, there are also dangers. Whereas there is a potential gain in hatchery production of offspring compared with wild production, due to enhanced hatchery survival rates, there is a simultaneous reduction in the effective size of the total breeding population that may result in a loss of genetic variability (Ryman 1991). For hatchery programmes, Cross (1989) recommends using at least 40 parents of each sex to avoid problems with inbreeding.

RECOMMENDATION. It is recommended that a full genetic survey of Wye salmon stocks is undertaken, in order that fish of different sea-age classes, and spawners from different locations within the catchment may be characterised.

4.3 Marine Factors

Atlantic salmon are able to utilise differing reproductive strategies which optimise recruitment from a given spawning stock. It has been suggested (Reddin and Shearer 1987) that older, larger salmon which have a higher fecundity are better able to utilise large river systems, whereas grilse, which mature after one winter at sea, have a higher marine survival rate than older salmon as a consequence of their earlier maturity. These alternative strategies have a genetic basis that can be modified by interaction with environmental factors.

Saunders et al (1983) provide evidence of a major environmental component in the determination of the grilse:large salmon ratio. They found that marine temperatures had a strong influence on the timing of sexual maturity with low water temperatures leading to more MSW salmon in caged reared fish compared to wild fish. Saunders (1986) considers that there is a genetic influence in the capability for expression of grilse or MSW traits, and that this influence is itself governed by both long-term climatic and short-term physiological -biochemical factors at sea (such as growth rate or migratory pattern).

Reddin and Shearer (1987) concluded that the distribution of salmon varied seasonally in the NW Atlantic with fish altering their movements in response to water temperature. Growing salmon were commonly found in water from 4C to 8C. Similarly, Martin and Mitchell (1985) hypophesised that the temperature of the sub-Artic influences the migratory pattern. Salmon travel further north into the Artic/sub-Artic only during those years when the minimum temperature remains above 2C. Lower temperatures increase the number of returning grilse and reduce the number of returning MSW salmon. This difference between the results of Saunders et al (1983) and Martin and Mitchell (1985) can be explained since the former caged fish were forced to endure cold water temperatures, whilst the latter wild fish were able to avoid such conditions.

The widespread decline of MSW, and in particular spring salmon, now observed appears to be the most recent of several changes in the relative abundance of different sea-ages in the past 200 years or more. Evidence for cyclical fluctuations since 1790 amongst Scottish stocks has been examined by George (eg. George,1984) who has concluded that climatic variation dictates the changes in duration of sea-absence of salmon. A summary of these cycles of abundance reveals two previous periods in which overall stocks of salmon were poor, and George (1991) considers that the current situation is a third such poor period following the recent decline of the latest grilse cycle:-

Period	Dominant Group	
1792-1812	Salmon	
1812-1849	Grilse	
1849-1855	-	Low Overall Abundance
1855-1884	Salmon	
1881-1896	Grilse	
1896-1920	-	Low Overall Abundance
1920-1963	Salmon	
1960-1990	Grilse	
NOW	-	Low Overall Abundance

George theorises that sea temperature is the principal factor controlling sea-absence, with cold conditions favouring returns of salmon as grilse and warmer conditions encouraging longer sea-absence, and subsequent return as MSW salmon. In contrast to this however, and demonstrating that the relationship between sea-age and the environment is not fully understood, is the work by Dempson et al (1986). They found no correlation between sea temperatures and the age at maturity of salmon returning to North American rivers. They also reported that marine growth rates of both 1SW and MSW salmon in their first year at sea were not different, and was not therefore a factor in determining sea absence. Subsequent work has shown that differential marine growth is not apparent until after the first winter at sea, with those fish accelerating their growth remaining at sea to become MSW salmon and those which do not being destined to return as grilse.

The current trend in the North Atlantic is one of warming, and George (1991) considers that this is the reason for the declining abundance of grilse seen in recent years. In the past such a period has been characterised by overall low abundance of fish with the following MSW-dominant cycle taking up to 20 years to become established.

The influence of the marine environment is almost certainly more complex than a temperature effect alone. Temperature itself is probably a manifestation of some other factors such as prevailing currents (both water and wind) and upwelling water bodies. In the case of Pacific salmon (principally coho salmon, Onchorhynchus kisutch) the role of upwelling water seems clear, and Scarnecchia

(1981) estimates that variations in the magnitude of the upwelling effect accounts for 34% of the variation in commercial landings of wild fish. The role of temperature alone in this fishery is noted by Nickelson (1986) who reported that higher surface temperatures caused a deepening of the thermocline and a concommitant decline in oceanic productivity.

4.4 Freshwater Factors

Generally there is a critical minimum size that young salmon must reach at a certain time of year in order to smoltify. If a fish fails to reach this size it will remain in freshwater for another year. Growth conditions in the river will therefore have a major influence on the age at which a salmon parr becomes a smolt. Long term studies on several rivers have recorded changes in the average smolt age of salmon over time. In Quebec, Bielak and Power (1985) suggested that commercial fisheries have affected spawning stocks of salmon in several rivers resulting in decreased egg deposition, lower parr densities and a tendency towards younger smolts. Dunkley (1985) reported that on the River North Esk in Scotland, the older smolt age groups in any particular sea age group tend to return to freshwater earlier in the run. Also there was a significant negative relationship between smolt age and the percentage of adults which returned as 1SW salmon, suggesting that there was a tendency for younger smolts to return as grilse rather than salmon.

These studies suggest that there may be a relationship between freshwater growth conditions and the age of return of adults. Data from smolt netting excercises on the River Wye in recent years indicates that in the upper catchment (upstream of Glasbury) the majority of smolts (>95%) are two years old. However, sampling lower in the catchment (downstream of Hereford) showed that around 40% of smolts were one year old. Data from scale sampling of adult salmon caught in the rod fishery shows that over 90% of fish migrated to sea as two year old smolts. Therefore, it would appear that the one year old smolts, which comprise a large proportion of smolts sampled from the lower river, contribute comparatively little to rod catches which may be related to their age and timing of return to the river as adults reducing their availability to the rod fishery.

There is also evidence that adult salmon return to spawn to the same areas of a river where they were hatched and subsequently became smolts. In the River Alta in Norway correlations between growth differences in young and adult salmon suggest that pre-smolts that have lived their first years in the upper section of the river apparently return there after having been at sea (Heggberget et al 1986). On the Northwest Miramichi River, smolt tagging experiments at two counting fences have shown a higher proportion of smolts tagged at the upper fence returning as adults to the upper section of the river (Saunders 1967).

If particular areas of a river system are more important than others for the production of MSW salmon then any degradation of these areas may have a significant effect on the abundance of this stock component. There is evidence of substantial acidification in parts of the upper Wye catchment however it is not clear to what extent this is currently affecting recruitment of juvenile salmon, or to what extent it will in future. It is further unclear as to the impact on salmon recruitment of land-use changes, such as afforestation and land drainage, and concommitant alterations in the patterns of run-off.

Future changes in seasonal patterns of rainfall and discharge may occur due to climate change, and the potential impact of this on juvenile salmonids and migratory behaviour is not fully understood.

RECOMMENDATION. It is recommended that a survey is undertaken to identify those parts of the Wye catchment at risk from acidification, and from land-use change. It is further recommended that research is undertaken to establish the critical flows for various stages of the salmon life-cycle.

5. ENHANCEMENT OPTIONS

5.1 Exploitation Control

5.1.1 Legislation

The extent to which angling pressure has contributed to the decline of spring salmon is not known. It is clear however, that a reduction in the exploitation of these fish is necessary if further decline is to be prevented. Extinction of the spring-run component is unlikely as the genetic potential to produce MSW salmon apparently exists, although probably at a lower level, amongst other age groups. If environmental factors are currently favouring smaller and younger fish, protection of the residual stock of spring fish is vital if early recovery is to occur when environmental conditions once more favour the early running salmon.

Two legislative methods to control and reduce exploitation are considered below.

5.1.1.1 Delayed Start To The Angling Season

Earlier studies (N.R.A.,1991) have revealed that a salmon captured before the end of April is more likely to be a large spring fish, irrespective of capture location or method. A delay to the start of the season until 1st May would therefore protect the majority of these fish which would be unlikely to remain vulnerable to angling during the rest of the season. They would however remain vulnerable to poaching throughout the year.

Although there is little evidence that large fish are caught in significant numbers by anglers towards the end of the season, this may become a problem if larger numbers are available for capture. In particular large male fish are known to become vulnerable once again to capture. Future control over exploitation of such fish, present only because of protection earlier in the season, might then be required.

A deferred season would clearly have considerable implications for many Wye fisheries which depend largely on spring salmon and the anglers which they attract.

5.1.1.2 Angling Method Restrictions

The use of spinners and worm baits accounts for most of the large salmon caught in the Wye, particularly in the lower river. Spinning is permitted throughout the season although the use of bait, including worm, is restricted to the period 15th April to 31st August. To afford protection to spring fish some restriction on the use of techniques to which the fish are most vulnerable is necessary. This could best be achieved by a ban on the use of these methods in the critical period up until 1st May

Clearly method restrictions could also be deployed in conjunction with season restrictions. An option which may be of benefit is a restriction to the use of fly only in the important period from the start of the season until 1st May. This would protect spring fish from excessive exploitation by spinning and bait fishing whilst allowing fisheries to operate. Careful monitoring to ensure that protected salmon are not simply being caught by other permitted techniques would of course be needed.

5.1.2 Catch And Release

A method which is now in widespread use for salmonids in North America, and is traditionally used for coarse fish in this country, is catch and release. Adoption of this could relieve the necessity for a deferred season and could also, together with the setting of a size limit, protect the target size category of salmon throughout the entire season. It remains unclear however whether this would be a suitable technique for large and possibly delicate spring salmon.

The release of angled salmonids as a conservation measure was first promoted on a large scale in North America. Ever increasing demand from anglers for quality fishing resulted in great pressure on stocks which subsequently declined to dangerously low levels. Although the practice was accepted reluctantly in the first instance, it quickly became the 'thing to do' for conservation-minded anglers, and has since helped to protect and conserve stocks (see Anon.,1977).

In Canada bans on the retention of MSW salmon were introduced as part of a wide-ranging package of measures to cease the decline in stock levels, and in particular of the MSW component. This resulted in increased proportions of the returning MSW fish surviving to spawn (Marshall,1988). The technique now appears to be widely accepted, and O'Neil et al (1987) report that over 20,000 large angled salmon have been returned in some years to rivers in the Maritime Provinces alone. Bielak (1987 - quoted in Walker and Walker, 1991) notes that the package of measures taken by the Canadians has resulted in an apparent recovery of stocks, and that this has enhanced further the acceptance of catch and release.

In this country catch and release has been adopted on a voluntary basis by some fisheries. More widely, salmon caught late in the season (particularly females) are released in the belief that they will survive to spawn. It is clear that if they are to do so they must be in good condition, and thus the techniques used for capture and the methods used to handle them must be carefully considered.

The vulnerability of salmon to poor handling is well known. Damage may be immediately obvious, eg. by bad hooking, but delayed mortality due to the cumulative effect of capture, exhaustion and handling can also occur. Any stressor, whether caused by angling or environmental factors, will initiate changes in blood chemistry which often take days to revert and can themselves predispose the fish to delayed mortality, disease and fungal invasions. Handling can cause physical damage such as mucus,scale and skin loss, bruising, and damage to fins, eyes and delicate internal organs. All of these contribute to the overall stress caused by angling.

The very delicate nature of salmon cannot be emphasised enough. Even careful handling of fish later in the season during broodstock collection can lead to mortalities, which often only occur after many days of retention and despite careful prophylactic treatments. It is only during the retention of fish that the full impact of the damage unwittingly caused by capture and handling become apparent. Anglers may return fish to the river assuming that they will survive and contribute to the spawning stock, only for them to die unseen later.

The method of capture of the fish is clearly important, with some techniques causing far more harm to the fish than others. Wydoski (1977) has reported that hooking mortality is greatest in salmonids caught on baits and least for fly-caught fish with those taken on lures showing intermediate levels of mortality. He further notes that single hooks improve the chances of survival in all techniques. The location of hooking is also important with those fish hooked in the gill or throat being less likely to survive than those more conventionally hooked in the scissors of the jaw. Barbless hooks surprisingly did not necessarily result in lower mortality, however they allowed fish to be unhooked far more quickly and this reduced loss rates.

The time of capture is also significant, and Wydoski (1977) found that rainbow trout caught during warmer temperatures showed lower rates of survival.

A recent study has been carried out on the Little Gruinard River in Scotland by Walker and Walker (1991). They observed that over 50% of the 25 radio-tagged grilse, caught by angling and released, survived until spawning time.

In conclusion it is clear that catch and release is a viable management technique in some cases, however it is yet to be proved that it will protect large MSW and spring stock. The ethics of catch and release have also been questioned, involving as it does a fundamental shift away from angling for food to angling simply for recreation.

RECOMMENDATION

It is recommended that a programme to examine the survival of angled spring salmon after release and during the remainder of the year, and the proportion which survive until the spawning season is initiated. This could be achieved by radio-tracking techniques with the co-operation of fishery owners and anglers.

5.2 Artificial Propagation

5.2.1 Introduction

Before artificial propagation as a solution for the decline in abundance of a stock or stock component is adopted, it is essential that full understanding of the constraints and the potential harmful impacts of stocking is gained. It is also most important that a method for adequate monitoring of the results of the exercise is available.

Restocking with hatchery-reared smolts is frequently proposed as a remedial measure for the enhancement or rehabilitation of salmon stocks. It offers potential for the rapid initiation of runs of fish and has been used with varying levels of success in Wales (eg. Rivers Taff, Tawe), England (eg. Rivers Tyne, Thames,) and elsewhere (eg. Penobscot and Connecticut Rivers in the U.S.A., and rivers in Newfoundland and Nova Scotia). Success has not always been achieved however and it is clear that careful planning is vital if the goal of sustainable stock enhancement at no risk to the native stock is to be attained.

Considerable advances in the techniques and technology of hatchery operation have been made since the beginning of commercial salmon production, and the procedures for large-scale smolt production are now well understood. Notwithstanding this however there are still many problems associated with the artificial propagation of fish destined to be released into the wild. Hatchery smolts are known to be less viable in the wild than natural smolts, and more particularly there is little or no data on the level of success of the specific enhancement of one component of a stock.

The rate of return of hatchery smolts as adult fish is consistantly lower than that of wild smolts. On the Burrishoole River in Ireland for example, 10-year average rates of return of hatchery and wild smolts as grilse of 1.7% and 8.6% respectively have been recorded (S.R.T.I.1982). Rates of return of MSW salmon in this grilse-dominated system were much lower (range 0 - 0.06%) but might of course be higher elsewhere where MSW salmon form a larger component of the stock.

Lower return rates might be a reflection of the naivety of hatchery smolts, which are known to be more susceptible to predation (eg. by cormorants - Kennedy and Greer,1988) and to marine exploitation (Crozier and Kennedy,1991). Hatchery smolts are also known to differ from wild smolts in the timing of their migrations. Reduced rates of return of smolts as MSW salmon might of course be more a reflection of prolonged exposure to both natural and fishing mortality at sea.

In addition to problems associated with biolgical factors, hatchery rearing programmes involve considerable capital and revenue costs. Clearly it is most important to fully understand all factors involved before embarking on a costly enterprise. It must be accepted also that the adoption of a hatchery programme addresses only the symptoms of a perceived problem, and not the problem itself.

The fact remains of course that even if all practical problems can be overcome, and that smolts destined to become MSW salmon are successfully produced, environmental factors may dominate and prevent the expression of the genome. Many problems associated with a propagation programme exist, and these are summarised below.

5.2.2 Genetics

Available evidence indicates that environmental factors can over-ride potential genetic factors which would otherwise exert control over such traits as age at maturity. The production of smolts from spring fish parents and their release into a historic spring salmon river would probably not in itself guarantee successful enhancement, and this was clearly appreciated by an anonymous source in Jones (1959) who knew "of no authentic case where a spring run of salmon has been induced by the planting of spring fish eggs".

An important point which would have to be considered if a programme of spring fish broodstock collection were started would be the impact of the removal of these potential very valuable spawners from the river. In addition to the significant practical problems of location and capture of sufficient brood fish, the genetic implications of removing what might be a significant proportion of the spring salmon spawners are not understood and may be damaging.

Artificial propagation to supplement a wild stock has been termed 'supportive breeding' by Ryman (1991) who stresses the potential loss of genetic variability which can result, and the importance of thoroughly evaluating and monitoring such a programme. Empirically it is considered that the hatchery production of relatively large numbers of smolts destined to be spring salmon would result in them substantially dominating numerically the natural production of such fish. Thus the gene pool for spring-running traits within subsequent generations would be dominated by spawners derived from a small, and perhaps not wholly representative proportion of the stock. Even within one generation considerable damage may be inflicted on the genetic identity of the stock.

The genetic implications of hatchery rearing and the potential for both genetic damage and even irretrievable damage to the gene pool would all have to be carefully considered. Additionally the production of hatchery smolts must be balanced against the lost natural production of more viable smolts which would have occurred if the brood fish had been left in the river.

Ryman (1991) stresses the great importance of deriving guide-lines for the adoption of hatchery support for wild stocks whilst ensuring genetic conservation. He quotes recent Swedish legislation that limits the contribution of hatchery smolts to the total stock (or specific contribution to one stock component) to 10%, but adds that even this could severely affect the indigenous stock within just a few generations.

5.2.3 Broodstock Capture

The philosophy of enhancement by artificial propagation depends on the theory that the specific genome for long sea-absence and for the spring-run trait is heritable. Further, if this is accepted then it would also be accepted that crosses involving such fish would result in the production of juveniles with a large proportion inheriting the trait and destined to be MSW salmon themselves.

The collection of MSW salmon, and more preferably spring fish broodstock, is therefore a vital part of any propagation programme although this is likely to be extremely difficult to achieve. Potential techniques include trapping, electrofishing and possibly angling, however each has inherent problems. The number of potential broodstock available in the river is low, particularly at the end of the season, and the location of them and their capture is likely to be very problematical. Current electrofishing programmes catch very few 3SW salmon, whilst the construction and operation of a main river trap or partial trap is likely to be very expensive. The possibility of obtaining angled spring fish exists, however it is not known whether such fish could be successfully maintained in good condition until maturation occurs. These options are considered in more detail later.

5.2.4 Broodstock Retention

5.2.4.1 Tanks And Raceways

Salmon have been retained safely in both circular tanks and raceways of various sizes. Hendrix (1989) reports that up to 230 fish have been safely held for three to six months prior to maturation in a circular tank of just 6m diameter with a flow of 400l/min at a maximum temperature of 17C. Similar success has been achieved with salmon held at Kielder hatchery. Kennedy and Johnston (1986) successfully held up to 800 principally grilse brood fish within four enclosed 25m sections of a gravel-bottomed layde less than 2m wide with about 1m depth of water. In all cases the importance of covering the tanks to prevent fish leaping out was stressed.

The success of these operations is contrasted by many others in which very high or even complete mortalities have occurred. It seems clear that the safe retention of fish is totally dependant on careful management of both fish health and the environment in which they are held.

5.2.4.2 Cages

Little information is available on the use of cages to hold broodstock, as the technique is clearly dependant on the availability of a suitable site. Over the past few years salmon captured in the River Thames have been successfully held in standard fish farm cages (floating collar 6m X 6m, depth of net about 6m). Up to 70 fish have been retained per cage, and it was considered that segregation by sex would maximise survival. The site used was a large water supply reservoir of about 20m depth at the cage location, in which the water body was moved continually by jetting to maintain good quality. Fish captured by both trapping and electrofishing were held for up to four months and overall mortalities of less than 10% of the females were generally observed.

In Ireland, S.R.T.I. retain 1SW brood fish each year but have experienced great difficulties in maintaining 2SW fish from their capture in about April until stripping time, principally because of disease problems. They recommend holding such fish in cages (S.R.T.I.,1987).

The main problem with cage retention is that routine surveillance of the fish is not possible unless the whole cage net is hauled. This is clearly essential when the fish are examined at spawning time, but potentially can be damaging for the fish.

5.2.5 Broodstock Maintenance

Many brood collection and maintenance programmes in this country and elsewhere have in the past failed because insufficient care was taken of the fish. It is vital that the fish are in good condition at the outset, that their condition is fully monitored during retention, and that all possible steps are taken to minimise the risk of infection. Adult salmon are extremely vulnerable to fungal infection, and the occurrence of this is always higher when fish have been handled.

Wherever the fish are kept, they should be left as undisturbed as possible in a covered, dark location. This should reduce the danger of them leaping, and minimise stress. Although some handling of the fish is essential, particularly as the time for stripping approaches or when medication is to be administered, it should be kept to an absolute minimum.

Following capture from the wild, intensive care of the fish should start. In all situations after initial capture the salmon must only be captured in and moved using smooth polythene or rubber tubes or slings to reduce abrasion damage. The use of nets should be avoided.

The fish should be moved with a minimum of delay to a large transportation tank equipped with aeration or oxygenation equipment. River water should be used and the temperature and dissolved oxygen content monitored. The use of anaesthetics and initial fungicides in the tank water should be considered, and transit time kept to a minimum.

Many workers recommend the administration of general antibiotics (Minta et al,1981; Hendrix,1989) to control pathogenic bacteria. This only protects the fish for the first few days, however it is important to help overcome the severe stress experienced during initial capture and handling. Further protection against furunculosis, the pathogen of particular concern, could be acheived through specific vaccination using one of the recently introduced commercial products. The fish should be anaestetised during injections to ensure that the medication is accurately administered intraperitoneally, avoiding damage to internal organs.

Of particular concern also is the susceptibility of salmon to invasion by the fungus Saprolegnia, whether by secondary infection of a wound or by primary infection. It is known that any stressor can predispose salmon to susceptibility to fungal attack. The probability of this occurring is so great that regular biweekly prophylactic treatment with fungicides is recommended, in addition to treatment of individual salmon when necessary. In some instances infection may not recur, although often continued treatments throughout the holding time are needed. In comparison with Furunculosis and Saprolegnia other diseases or parasitic attack are of less consequence.

5.2.6 Rearing Procedures

The potential effects of environmental factors on the sea-age of fish have been implicated by many studies. In many cases however, this work has been undertaken with hatchery-reared smolts, and it is clear that their environmental experiences within the hatchery itself might, in fact, be a dominant factor.

This is most clearly shown in the Canadian sea cage-rearing experiment discussed previously, however there are also a number of freshwater environmental factors which are seemingly capable of substantially changing the subsequent life-history patterns. Heritable traits such as growth rate in freshwater, the precocious maturation of male parr, and the age and size of smolts produced are amongst those reported to be directly influenced by the hatchery environment. There is information that these same traits will themselves influence the future sea-age of the progeny. For example, Jordan and Youngson (1991) have recently noted that allelic frequency of the MEP-2* enzyme locus is highly correlated with summer temperature during freshwater growth. Furthermore, differences in the level of heterozygosity at this locus are known to exist between 1SW and MSW fish, thus demonstrating the potential impact of the freshwater environment on duration of sea absence.

The potential importance of hatchery experience is thus clear, with evidence for the masking of genetic traits coming from many sources. Thorpe (1986) has noted that hatchery growth rate and the incidence of precocity are positively correlated, and points out that in nature the incidence of freshwater maturity is very low. Also, strains in which the incidence of male precocity is high typically yield high proportions of grilse when cage-reared at sea, however Glebe and Saunders (1986) have noted that such strains can yield lower grilsing rates when ranched rather than cage-reared. Generally MSW salmon are believed to yield low rates of precociously mature male parr, however scope for accelerated growth in a hatchery might encourage it. Freshwater maturity of female parr is very rare, even in hatcheries, however the opportunity for faster growth can result in greater ovarian development. Chadwick et al (1986) found that the ovarian development of smolts was inversely correlated to the sea-age of their parents, and that the sea-age of salmon was dependant upon the rate of development of their ovaries, and therefore on their growth rate in freshwater.

Bielak and Power (1986), and Randall et al (1986) also considered the effect of freshwater growth on subsequent sea-age : the former found no relationship between sea-age and smolt age, and the latter reported a negative correlation with size at smolting. Ritter et al (1986) have concluded that salmon farmers have the opportunity to regulate sea-age at maturity through brood selection and hatchery practices (ie. both genetic and environmental impacts). The implications of this for enhancement of wild stocks are clearly that great care must be taken in the hatchery environment to prevent the masking of desired genetic traits.

There has been much contradictory information published with some reports of correlations (positive or negative) between both smolt size and smolt age with sea-age at maturity. Such manifestations could of course be catchment, or race-specific.

Overall it seems that the optimum hatchery approach would be to produce relatively small smolts, restricted by careful ration-control to limit scope for male precocity or advanced ovarian development. The production of one year old smolts would minimise hatchery and feed costs. Alternatively hatchery conditions could be manipulated to ensure that growth rates similar to those found naturally are attained.

5.2.6.1 Captive Breeding

In many enhancement and rehabilitation programmes, a fundamental problem of broodstock scarcity and a requirement to stock large numbers of fish exists. Artificial propagation realises the potential of broodfish, however captive breeding offers the possibility to greatly optimise stock fish production from a relatively small initial number of adult salmon.

Captive breeding involves a complete life-cycle entirely in captivity. Adult fish are captured from the wild and stripped, and their progeny reared to the smolt stage. At this point a proportion of the stock is selected and retained, and the remainder stocked. Those retained are then transferred to sea-cages and grown-on until they mature, and are themselves stripped. It is then their progeny which are used in a stocking programme. The potential scale of such a programme is great, for example if 1,000 smolts from just 1 adult female were successfully matured they could subsequently yield over 1,000,000 smolts in the following generation.

Many problems are associated with such a scheme, not the least of which are considerable doubts regarding the genetic implications for the stock. Initiation of such a programme would clearly be dependant on the outcome of a full consideration of these implications, and on expert genetic advice. The programme would also be dependant on access to a sea-cage rearing site, perhaps on a contract-rearing basis, the cost implications of which are unknown.

5.2.7 Kelt Reconditioning

The effort and expense associated with capture and maintenance of adult salmon broodstock is considerable, and has resulted in attempts to recondition kelts. Reconditioning involves the retention of spawners, principally females, after stripping and encouraging them to resume feeding and ultimately re-mature. Success in this field has the potential to greatly increase the productivity of valuable female brood fish, and reduce the requirement to obtain wild broodstock. Gray (1980) recognised that the technique had the potential to significantly contribute to the Atlantic salmon enhancement programme in Canada.

Reconditioning has been successfully achieved in both saltwater (Gray et al,1987) and freshwater (eg. Hill,1978; Gough,1991; Dumas et al,1991). Johnston et al (1987) have reported that the length of a resting period following spawning may be genetically determined, and that all fish may not re-mature in the first year. This would of course reduce the viability of such a proposition. Hill (1978) and Dumas et al (1991) reported however,that 90% and 85% of the females in their trials became mature in the first year after spawning.

Gauthier et al (1989) also successfully reconditioned spawned salmon in freshwater, however after holding them for up to 10 months they released them into a 90m enclosure in a river. There they were all found to spawn naturally and successfully. This interesting observation demonstrates the potential success of reconditioning. It would clearly not have resulted in realisation of the full potential benefits of a reconditioning programme however.

The major problem with the reconditioning of kelts is in the nutrition of the fish, particularly pursuading them to accept food initially, and in the size and cost of the facilities required. Hendrix (1989) noted that resumption of feeding is a major problem and he and Minta et al (1981) have both reported that intensive coaxing of individual fish is necessary. Force feeding of recovering kelts has also been successfully used. Cage-held salmon usually re-commenced feeding only if other actively-feeding large salmonids were present (personal observation). Once the feeding response is well established no further problems are generally encountered, although Minta et al (1981) did notice unaccountable cycles of feeding and abstinence.

Diets designed specifically for brood salmon are now available commercially and are probably sufficient for reconditioning kelts. It is frequently advised however, that mineral and vitamin supplements are needed, and these have been incorporated into feed or injected intra-muscularly.

There is considerable scope for enhancement of the reconditioning process. Johnston et al (1990) note that the reproductive cycle of recovering kelts can be manipulated with both light and temperature. Of more significance however are the reports of Dumas et al (1991) who noted the potential benefits of optimising nutritional status, and Eales et al (1991) who concluded that thyroid hormone supplements could be used to enhance reconditioning and subsequent reproductive success.

5.2.8 Gene Banks

In situations where stocks are percieved to have declined to very low levels, the establishment of gene banks to ensure against extinction has been proposed. A gene bank is a store of the unique genetic material of a stock which can subsequently be used to enhance or re-establish the stock. The two principal methods considered to be appropriate for salmonids are cryopreservation of milt, and the establishment of specialised rearing stations to act as living gene banks. Both would entail considerable expenditure, although the use of existing commercial cryostorage and farming establishments might be possible.

It is unlikely that such a programme would be necessary for River Wye stocks unless considerable stock depletion was demonstrated although the storage of male gametes could form part of an overall rearing and enhancement programme.


1916 April 4 6 - 126½ lbs. 16¾ to 24½

6. STRATEGY FOR THE WYE

It is clear that complete cessation of exploitation of spring salmon would be the best way to protect this part of the stock, to prevent further decline, and, subject to over-riding environmental factors, encourage recovery. Any compromise to this may be favoured by fishery owners and anglers, however it will inevitably delay potential stock recovery. The more radical the measures, the more likely the chance of success within a shorter timescale.

6.1 Targets

The options described in this section depend on the adoption of targets for maintaining or increasing MSW salmon abundance within the river. The possible scenarios are firstly, maintenance, and secondly, enhancement of the stocks. In the case of maintenance, the current spring salmon stock abundance should be monitored and future exploitation controlled to guarantee no further decline in stocks. In the case of stock enhancement, the stock would again be monitored and steps taken to increase the stock to levels above those existing at the present time. A higher rod catch could then be supported, although in both cases increased escapement of MSW spawners must be the major goal. This is in anticipation that subsequent stock structure will re-adjust in favour of spring and MSW salmon abundance, or will at least guarantee a spawning nucleus of such fish as a genetic reservoir for future expression when environmental conditions permit.

The following targets for increasing the spring salmon rod catch are therefore proposed and considered further later in the report:

TARGET		INCREASE SPRING SALMON ROD CATCH
Maintenance		0
	Level 1	500
Enhancement	Level 2	1000
	Level 3	2000

To maintain these catches in the long-term, it may be necessary to control exploitation in the short-term.

6.2 Exploitation Control

6.2.1 Legislation

The most effective method to protect the spring salmon resource would be a prohibition on their capture. This could be achieved with bye-law legislation to delay the start of the season until a date when the salmon are less vulnerable to capture, or alternatively by legislation to prohibit the use of those techniques or baits to which spring salmon are most vulnerable (spring salmon are particularly susceptible to angling with spinners and worm). A combination of the two should also be considered which would also have the effect of reducing the incidental capture of kelts in the first few months of the season.

Such a proposal clearly has considerable implications for some of the Wye fisheries, and a compromise of permitting the use of fly-only up until 1st May has been suggested. Although this will obviously reduce the effectiveness of a total ban, it is likely to minimise the adverse effect on the fisheries. Any compromise to these recommendations however, such as delaying the start to the season to only 1st April or permitting the use of spinners before 1st May, will reduce the effectiveness of the measures to a considerable degree. It must also be realised that in proposing these legislative measures, many 2SW salmon will be inadvertantly protected and that the overall catch of fish will be further affected. Such an impact can only be justified if maximum protection is demonstrably afforded to the target stock, the large spring salmon.

There is little evidence that significant numbers of spring salmon are caught after 1st June, or towards the end of the angling season. It is therefore not considered necessary to introduce legislative control for this period, however this should be kept under review. Voluntary measures to return any MSW salmon that are caught at any time in the season should be encouraged.

RECOMMENDATION. It is recommended that the following bye-law changes are considered :

- **delay the start of the salmon angling season until 1st May**
- **prohibit the use of spinners until 1st May**
- **prohibit the use of worm baits until 1st June**

It is also recommended that, following implementation of such bye-law changes, careful monitoring of catch, catch-age composition and catch-effort data is undertaken to verify the effectiveness of the measures.

6.2.2 Catch And Release

Implementation of a catch and release policy could be achieved on a voluntary basis, however experience has suggested that this might not be effective. Byelaw legislation may therefore also be necessary if this option were adopted. This would also serve to assure anglers that all are obliged to return fish alive to the river.

Catch and release would need to protect the valuable spring salmon and other MSW fish whilst permitting continued retention by anglers of the grilse and 2SW salmon which are not thought to be in need of protection. If the method were to be adopted, it is suggested that it be in conjunction with a size limit, and that all salmon larger than an agreed maximum, whenever they are caught in the season, be returned alive. The limit would need to be approximately 30 inches (72cm) to ensure adequate protection. It is essential that the fish are treated very carefully to maximise the probability of their subsequent survival, and that they are returned to the river as rapidly as possible.

Such a policy should only be adopted if it is clear that a large proportion of the fish survive the capture and handling experience and subsequently spawn successfully. It is possible that recapture of the fish, or even multiple capture, will occur as has been observed in some cases. It is therefore important that a programme to assess the post-release survival and behaviour of the fish is implemented. This could best be achieved by a radio-tracking study, which would simultaneously address other recommendations made above.

Salmon for such a programme should be obtained from a small number of target fisheries where the local bailiff, ghillie and anglers have been fully briefed on the study, and on the importance of careful handling of the fish. Salmon should be landed following hooking as quickly as possible using large knot-less landing nets and carefully unhooked. Those considered to be undamaged would then have to be retained safely, perhaps in large knot-less keep-nets or in tanks provided at strategic locations. Imposition of controls on angling methods, for example the use of fly only and barbless hooks, could improve the rate of survival and condition of angled fish. Consideration should, however, be given to the future of any potential catch-release bye-law, and the possibility that not all returned salmon would necessarily have been carefully handled.

Up to 30 angled salmon would be radio-tagged and floy-tagged, perhaps by a ghillie or bailiff following adequate training or by a temporary contract scientist, and released following recovery. If immediate mortality of the fish occurred, then the tags could be retrieved for re-use. Survival of the fish would be deduced from post-release behaviour. This could be monitored preferably by the deployment of automatic listening stations at strategic locations, or by regular active tracking e.g. by light-aircraft flights along the river to record fish locations.

Such a programme has been estimated to cost in the order of £20,000 to £25,000 per year, depending on the method of monitoring:

Manpower (6 month temporary contract)	£ 5,300
Manpower oncosts (15%)	£ 795
Radio tags (30 at £100 each)	£ 3,000
Active tracking equipment	£ 500
Other (equipment, travel, subsistence etc)	£ 2,000
EITHER : 5 automatic listening stations	£14,000
OR : 10 monthly flights (approx.)	£10,000

RECOMMENDATION. It is recommended that the post release survival of angled salmon is investigated by a programme of radio-tracking.

6.3 Artificial Propagation

Specific and demonstrably successful enhancement of the spring salmon component of any salmon stock has yet to be demonstrated. Potential environmental and genetic reasons for failure have been discussed earlier. The perceived reluctance of fishery managers to embark on such enhancement strategies is due to the implicit risks and the potential, no matter how small, for irretrievably damaging the genetic integrity of the stock. Even if such concern were resolved satisfactorily, further formidable obstacles associated with practical aspects of propagation exist.

6.3.1 Broodstock Collection

The number of these fish available in the river is relatively small, particularly at the end of the angling season, because of the high rate at which they are exploited by anglers. Indeed it seems possible that the number of 3SW salmon required for a rearing programme of a significant scale may not exist in the river in some years. It would be vital however that the target number of brood fish is obtained.

6.3.1.1 Number Of Broodstock Required

Calculations based on the agreed targets (Table 1) suggest that the broodstock requirements will be :

TARGET INCREASE IN ROD CATCH	NUMBER OF BROOD FISH	
	Female	Total (male & female)
500	0 - 31	20 - 62
1000	21 - 62	42 - 124
2000	41 - 123	82 - 246

The potential methods for the capture of broodstock are trapping, electrofishing and angling. Safe and reliable capture of sufficient brood fish would be the basis of a propagation programme, and therefore vital.

Little is known of the distribution of spawning effort by salmon of different sea-age, although recent evidence from the River Spey suggests that spring salmon migrate to, and subsequently spawn in the upper reaches of the river (Laughton,1991). It is not known whether fish of similar ages preferentially spawn together. Such information would be needed to maximise the efficiency of trapping and electrofishing programmes.

RECOMMENDATION

It is recommended that a programme of radio-tracking of spring salmon is undertaken to investigate the movements of this valuable component of the stock, their spawning distribution, and the time of spawning. Salmon for the study could be obtained from anglers, and useful data on the survival of angled fish would therefore also be obtained

TABLE 1

Scenarios for Production of target levels of 3SW Salmon Rod Catch Enhancement

ROD CATCH	STOCK IN RIVER		STOCK EXPLOITED AT SEA (COMMER.)	STOCK AT SEA, MARINE MORTALITY	SMOLTS ENTERING SEA	NO. OF SMOLT EQUIVALENTS WILD	HATCHERY
			A	B	C	D	E
	2,222	[X]	2,778	4,209	5,612	26,724	164,088
2,000	3,333	[Y]	4,166	6,312	8,416	40,076	246,068
	6,667	[Z]	8,334	12,627	16,836	80,171	492,248
	1,111	[X]	1,389	2,105	2,807	13,367	82,11
1,000	1,667	[Y]	2,084	3,158	4,211	20,052	123,177
	3,333	[Z]	4,166	6,312	8,416	40,076	246,068
	556	[X]	695	1,053	1,404	6,686	41,052
500	833	[Y]	1,041	1,577	2,103	10,014	61,486
	1,667	[Z]	2,084	3,158	4,211	20,052	123,177

NOTES Rates of rod exploitation : {X} 90% ; {Y} 60% ; {Z} 30% .

A - Marine fishery exploitation rate assumed to be 20% overall.

B - Natural marine mortality rate of 0.01 for 34 months.

C - Immediate mortality rate of 25% of smolts entering the sea.

D - Smolts destined to be 3SW salmon form 21% of the total smolt run (calculated from proportions of salmon of different ages in rod catch over last 10 years).

E - Hatchery smolt viability factor of 6.14 (calculated from ratio of 10-year mean rates of return of wild and hatchery smolts to Burrishoole - S.R.T.I.,1982).

6.3.1.2 Trapping

The logistic problems and cost implications of constructing and operating a trap are considerable, and even if these are overcome the capture of sufficient broodstock could not be guaranteed.

A trap in the lower reaches of the river would have the advantage of capturing salmon before their exposure to high rates of rod exploitation. The required fish enter the river during the spring however, a time of year in which high flows frequently occur, and the trap would therefore have to be capable of withstanding very high flows. Fish caught early in the season would need to be held for many months before the spawning season, and this in itself is likely to be extremely problematical.

A trap further up the catchment, or in one of the principle tributaries, could be smaller and operated later in the year when the salmon undertake their spawning migration. It would still have to be capable of withstanding seasonal high flows, although captured fish would not have to be held as long. The main problems would be the choice of location, and the availability of fish. Exploitation of MSW salmon is known to be high and the numbers remaining after the rod season may be very low. Furthermore the distribution of these fish within the river is not known, as no sections of the river are known to be favoured by large fish.

Whichever location might be favoured, it is clear that a functional trap would have to be a substantial structure. The design would have to be carefully considered and the structure built to withstand the extreme flow conditions which occur in the catchment. It would also be subject to land drainage consent. The cost of such a structure was estimated in 1991 to be in the order of £50,000 - £100,000, and the running costs to be up to £20,000 per year.

6.3.1.3 Electrofishing

Wye salmon are currently collected for use as broodstock by electrofishing in small tributaries in the Builth Wells to Glasbury area. The method is relatively labour-intensive for short periods, and is strongly dependant on suitable low flow conditions. Over the past 17 years an average of 40 hen salmon have been caught each year but virtually all of these have been grilse and salmon smaller than 12lb. It is assumed that this reflects the lack of large MSW salmon entering these small streams, and demonstrates that such a programme is not suitable for the collection of these fish.

No locations within the river are known to regularly attract large spawning fish, however there is some anecdotal evidence that main river locations are favoured. The practicalities of electrofishing here are extremely doubtful and the implications for health and safety of operatives of great concern. Electrofishing is known to be harmful to adult salmon and mortalities almost always occur in broodstock collection programmes. Males appear to be more susceptible to damage than females, and often suffer damaged kidneys and even broken backs. Careless handling during capture and retention of the fish can substantially increase the risk of mortality.

6.3.1.4 Rod Caught Fish

The only record of spring salmon abundance in the river is provided by the annual rod catch return. The potential for catch and release of these fish as a method of controlling exploitation has been discussed above. If angled fish survive the experience of capture and handling, then they could feasibly be of use in an artificial propagation programme. This would require their safe retention for several months however, and it would need to be established whether this is possible.

An alternative might be the monitoring by radio-telemetry of the movements of MSW salmon released after capture as an aid to their re-capture nearer spawning time. The practicalities of brood fish capture have already been discussed, and it is not at all clear whether the capture of such fish would be possible, even if their location were accurately known. The fish would also be vulnerable to fishing and natural mortality in the meantime.

6.3.2 Broodstock Retention

The delicate nature of salmon and their acute sensitivity to stress, and particularly capture and handling, has already been discussed. Full account of this must be taken if brood fish are to be held safely. The cost of establishing a tank or raceway facility will depend entirely on whether an existing site could be used. If a new site is necessary the costs are likely to be up to £200,000. If it is possible to use an existing site, the cost could be lower, restricted to the purchase of tanks and pipeworks, their installation and the provision of water supplies and security systems. Up to four 6m diameter tanks would be required . The cage option would be considerably cheaper than the establishment of holding tanks. Four cages would be required for a retention programme and the cost of these would be approximately £13,000, however further costs associated with maintenance of a cage site would be incurred.

RECOMMENDATION : It is recommended that trials in the long-term holding and maintenance of salmon is initiated. These should first be undertaken with the less valuable 2SW salmon to establish the likely problems. The fish should be obtained by angling, as this is the only feasible method for reliable capture of early-season fish.

6.3.3 Kelt Reconditioning

To embark on a programme of reconditioning, considerable facilities would be required. For example, kelts from the Connecticut River, U.S.A., are held individually in circular tanks at a dedicated holding facility, minimising the risk of disease transmission and providing the opportunity for enticing the fish to feed. The cost of this is clearly substantial, however it demonstrates the high level of care which is felt necessary.

To hold the numbers of large kelts necessary for an initiative on the Wye up to four 6m diameter circular tanks would probably be needed. The fish would need almost continual supervision for feeding and monitoring of health, whilst remaining as undisturbed as possible. An alternative would be the establishment of a cage site at a local reservoir. This would prove to be cheaper, however little supervision and control of fish health would be possible. Nevertheless it remains an option, perhaps for exploration in a programme of trials. The cost of such a programme would be similar to those associated with broodstock retention (section 6.3.2), although a trial could be initiated at a lower cost.

Although a programme would concentrate on the reconditioning of females, some males would also be needed, and these would need to be kept separate from the females.

RECOMMENDATION. It is recommended that small-scale trials are initiated to examine the feasibility of reconditioning large salmon kelts.

6.3.4 Hatchery Procedures.

The technology and techniques used in modern hatcheries are well established and described elsewhere. It is beyond the scope of this report for them to be fully described here. Of particular relevance however are the questions of the number of broodstock to be used, and the genetic bases of the crosses used. This is an area of particular expertise and advice from experts in the field will be required.

RECOMMENDATION. It is recommended that expert opinion and advice on the feasibility of, and the genetic techniques associated with the specific enhancement of the spring component of the Wye stock is commissioned.

The calculations of the number of broodstock required to achieve the targets of 500, 1000, and 2000 extra rod-caught spring salmon in the river (Table 1) suggest that between 10 and 123 adult females will be needed. This range is large because of the great uncertainty about the levels of mortality at many stages of the life cycle.

A different and more important way of assessing brood numbers is proposed by geneticists. The number is selected to reduce the real risk of losing vital genetic variability and of inbreeding. There appears to be general acceptance that around 30 - 40 females would be needed to ensure that no damage is done to the stock as a whole. This is clearly a more important criterion than numbers alone, and this estimate should therefore be adopted as the absolute minimum number of female MSW salmon needed.

The broodstock requirement therefore is in the range of 30 - 123 females, and a similar number (but preferably more) of male fish. These could be held in up to 6 or 7 cages, if a suitable reservoir site could be found, or in a similar number of 6 metre circular tanks at a hatchery. The latter would clearly involve considerable investment in a site and in the services required to operate it.

To maximise genetic variability in the offspring, crosses between as many of the brood fish as possible should be carried out. Ova from one female would be divided into several fractions, and each fertilised with milt from a different male. This would also reduce the probability of full sibling crosses occurring in the next generation, whether in the hatchery or by spawning in the wild.

It is possible that surplus ova may be obtained due to the genetic requirement of minimum brood numbers. These should be reared until the early-feeding fry stage and then stocked out (see below).

In subsequent generations care will be necessary to ensure that inbreeding is avoided. Thus later broodstock should include wholly wild fish as well as some derived from artificial propagation.

6.3.4.1 Hatchery Site Requirements.

In general the following site requirements can be identified:

a) sufficient volume of surface water of acceptable quality;compensation water from an existing reservoir is often ideal

b) sufficient volume of groundwater of acceptable quality;natural resurgences or artesian springs are often ideal

c) water supply free from the risk of pollution incidents

d) gravity supply of surface water and if possible groundwater

e) freedom from the risk of flooding

f) migratory salmonids should preferably not be present upstream of the intake to reduce the risk of disease

g) sufficient gradient or an existing weir to avoid the need for long water delivery systems

h) sufficient area for the construction of hatchery and rearing facilities, buildings, settlement ponds and on-site housing

i) good access; services nearby

The calculations in Table 1 suggest that a minimum of 41,000 hatchery smolts would be required for an enhancement programme. As discussed earlier it is clear that on genetic grounds a mimimum of 30 female fish would be needed, however in this particular scenario surplus ova or fry could be removed from a hatchery facility for rearing or stocking elsewhere. The maximum number in Table 1 is 492,000 smolts. On the basis of commonly accepted assumptions on hatchery performance, such as rearing densities and flow rates, the following equipment would be needed for this range of smolt numbers :

Item	Number For :	
	41,000 Smolts	492,000 Smolts
Fry first feeding troughs	8	98
On-growing tanks	4	49
Hatchery troughs	12	138

The amount of surface water required for facilities of this size would be 2 or 7 million gallons per day, however total site stream flows would need to be four times larger than this to accommodate effluent flows at a satisfactory dilution. The total 95 percentile flow would therefore need to be a minimum of 8, and possibly as much as 28 million gallons per day.

The assumptions and calculations used here are intended only as a guide to the potential scale of an enhancement facility and does not include provisions for broodstock holding or kelt reconditioning.

The cost implications of artificial propagation are considerable and it is clear that such an approach should be fully justified. Based on the range in smolt numbers used above, the probable costs for equipment alone would be approximately £120,000 to £590,000, and the entire cost of the hatchery facility (including buildings, site services, hatchery keepers house etc.) in the order of £0.5 million to £1.2 million.

RECOMMENDATION. It is recommended that consideration is given to the investigation of potential hatchery and rearing sites within the Wye catchment, and the design and cost implications.

6.3.5 Captive Breeding Trials

The production of stock fish by artificial propagation could be considerably optimised if a programme of captive breeding were adopted. Such a programme has been initiated by the Southern Region of the N.R.A. for the depleted stocks of the Rivers Test and Itchen.

RECOMMENDATION. It is recommended that the genetic and cost implications of captive breeding is investigated, and that a contracted-out rearing programme is considered.

6.3.6 Stocking Juvenile Fish

The progeny of an artificial propagation programme are extremely valuable and it is vital that full consideration and great care be taken in the selection of locations and times of release of reared fish.

6.3.6.1 Fry And Parr Stocking

During the rearing programme, densities in rearing tanks will need to be reduced as the fish grow and demand more space and water flow. This will generate fry surplus to requirements within the hatchery, and these should be stocked back into the catchment. The principles for doing this are well established, and good rates of survival of these fry (at least 10% to the smolt stage) can be anticipated. They should be stocked if possible where fry of spring fish occur naturally, and it is therefore important to gain information on the distribution within the catchment of MSW spawners (see recommendation above). Alternatively the fry may be released into streams inaccessible to spawning salmon.

6.3.6.2 Smolt Release

To assess the success of any smolt stocking programme it would be most important for all fish to be marked . Adipose fin-clipping in conjunction with microtagging of parr and smolts would permit the adult fish to be identified in marine fisheries, and in the river by anglers. The procedure for the release of smolts is not absolutely clear as it is not certain whether the fish will specifically home to their release point, or distribute themselves naturally within the catchment. Conflicting evidence for both possibilities exists, and the situation is further confused by observations on the relative rates of survival of smolt batches released at different distances from the mouth of a river. Considerably higher returns have been noticed in batches of fish released closer to the estuary of a river in several cases, including the River Usk.

The optimum approach might be to distribute relatively small batches of fish along much of the length of the river. Spreading the fish in this way might also reduce the risk of excessive predation on the fish.

Specific homing might of course be used to advantage for the collection of the fish as broodstock in later years. This would be a particularly attractive option if a trapping facility was available in the lower river. This would effectively become a ranching operation and would have the disadvantage that returning adults might not be available for angling.

6.4 Monitoring

It is absolutely essential that a method of monitoring returning adults which is capable of quantifying the results of a programme of artificial propagation is initiated as an integral part of any enhancement programme.

6.4.1 Catch Data

Data would be available from microtag returns and these could be used in conjunction with annual catch returns to assess the results of stocking. There are many problems associated with reliance on such data however, for example, under-reporting of tagged fish captures and the failure of many anglers to make statutory catch returns.

Catch data, no matter how accurate, give an incomplete indication of the size of the salmon stock and the number of salmon surviving to spawn. Many salmon ascend their home rivers after the end of the angling season, and data on this is only available for the few rivers which have fish counters or traps. Some information is available from redd counts, however the adequacy of this is doubtful, particularly for MSW salmon which may spawn in the main river where counting efficiency may be low.

Catch-effort data such as that quoted in this report (Gee and Milner,1980) is of value and the collection of this should be resumed.

6.4.2 Remote Sensing

The absence of reliable data on salmon stock abundance is a major problem for rational fishery management. There are only two methods currently which have the potential to provide data on the numbers of salmon ascending the River Wye.

6.4.2.1 Resistivity Counters

Deployment of a resistivity counter would entail the construction of a crump weir in the lower river on which the electrodes of the counter would be installed. Salmon passing over the electrodes would be detected and enumerated, following analysis to discriminate them from spurious signals. The costs and logistics associated with a civil engineering project of this magnitude would be considerable and almost certainly prohibitive. Additionally the accuracy of such counters, particularly in a river such as the Wye which experiences frequent large flow variations, is in considerable doubt.

6.4.2.2 Hydroacoustic Counters

Modern hydroacoustic techniques have the potential to accurately count the number of upstream migrant adult salmon, and to discriminate fish of various size categories. They can therefore provide data on the abundance of different sea-ages of fish and on the temporal distribution of their migrations. It is also possible that the equipment could yield data on the abundance of downstream migrant smolts.

The technique has been developed in this country, since the first use of sonar in the second world war, for the assessment of commercially important North Sea fish stocks. More recent developments in North America have been specifically for the enumeration of salmonids, and sophisticated equipment is now in routine use for many applications. The application of hydroacoustic technology to the surveying of fish stocks in deep water is currently being investigated by the N.R.A., and a proposal for the extension of this to the enumeration of salmon runs has been submitted for consideration under the N.R.A. research and development programme.

The technique does not demand the construction of any in-river structure. A transducer array would be deployed at a site carefully selected on the basis of flow and profile characteristics. Fish passing through the ensonified zone would be detected and their size (on the basis of their target strengths) and direction of movement (upstream or downstream) deduced. The data would be available real-time, and could be summarised as daily, monthly or annual counts of fish of selected size ranges.

The potential of this technique is considerable however the equipment is expensive, costing approximately £80,000, and the annual running costs would be in the order of £30,000. Such costs compare favourably with those associated with other monitoring techniques such as trapping and the use of resitivity counters however.

RECOMMENDATION. It is recommended that a feasibility study is commissioned from an appropriate organisation regarding the deployment of hydroacoustic counting equipment on the Wye.

7. RECOMMENDATIONS

The recommendation made previously in the report have been consolidated and rationalised below. In addition a provisional timetable for implementation of the recommendations has been formulated (Table 2), together with a provisional estimate of associated costs (Table 3). At this stage these are for guideline purposes only and further consideration will need to be given to prioritising the recommendations and the financing and administration of their implementation. A total of 10 main recommendations are presented below covering a 5 year timescale at a total estimated cost of £428K.

1). It is recommended that the following bye-law changes are considered :

- delay the start of the salmon angling season until 1st May
- prohibit the use of spinners until 1st May
- prohibit the use of worm baits until 1st June

It is also recommended that, following implementation of such bye-law changes, careful monitoring of catch, catch-age composition and catch-effort data is undertaken to verify the effectiveness of the measures.

2). It is recommended that a full genetic survey of Wye salmon stocks is undertaken, in order that fish of different sea-age classes, and spawners from different locations within the catchment may be characterised.

3). It is recommended that expert opinion and advice on the feasibility of, and the genetic techniques associated with the specific enhancement of the spring component of the Wye stock is commissioned.

4). It is recommended that a programme of radio-tracking of spring salmon and MSW salmon is initiated on the River Wye. Suitable salmon could be obtained with the co-operation of fishery owners and anglers. Information obtained from such a study would include:

- the post-release survival of angled salmon
- the movements of MSW salmon and their distribution within the catchment
- the proportion of MSW salmon which survive to spawn, and the temporal and spatial distribution of spawning.

5). It is recommended that a feasibility study is commissioned from an appropriate organisation regarding the deployment of hydroacoustic counting equipment on the Wye

6). It is recommended that a survey is undertaken to identify those parts of the Wye catchment at risk from acidification, and from land-use change. It is further recommended that research is undertaken to establish the critical flows for various stages of the salmon life-cycle.

7). It is recommended that consideration is given to the investigation of potential hatchery and rearing sites within the Wye catchment.

8). It is recommended that trials in the long-term holding and maintenance of salmon is initiated. These should first be undertaken with the less valuable 2SW salmon to establish the likely problems. The fish should be obtained by angling, as this is the only feasible method for reliable capture of early-season fish.

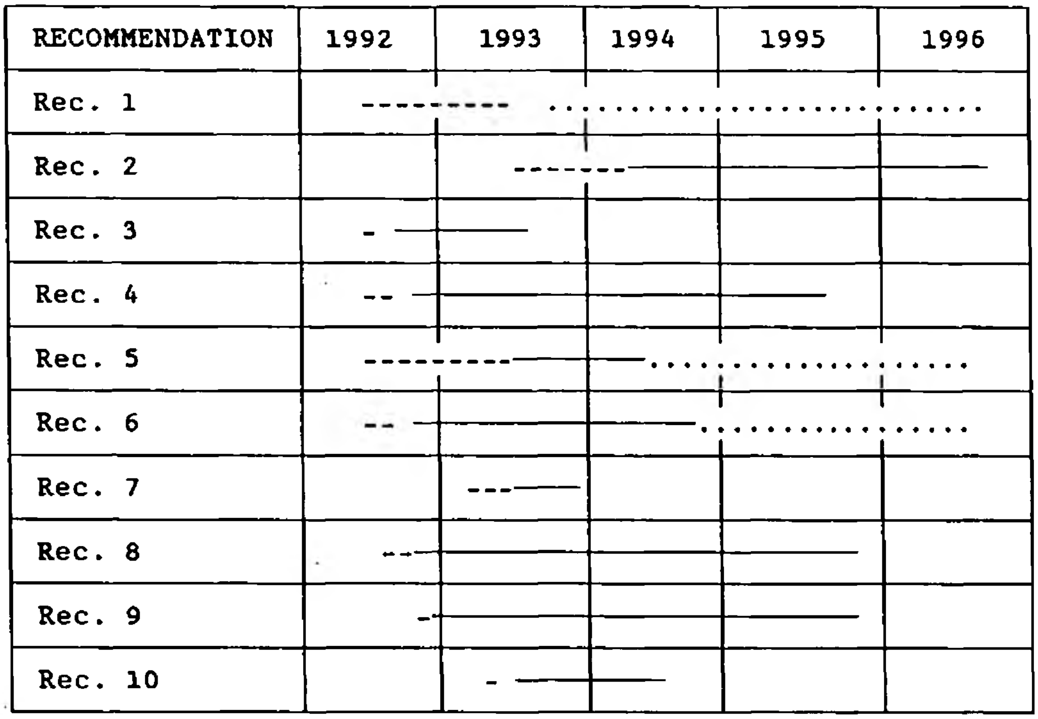
9). It is recommended that small-scale trials are initiated to examine the feasibility of reconditioning large salmon kelts.

10). It is recommended that the genetic and cost implications of captive breeding is investigated, and that a contracted-out rearing programme is considered.

Progress with these recommendations will have to be reviewed on a regular basis and where necessary appropriate adjustments made to the strategy. This may involve other areas of work not identified in this report and hence additional resources and expenditure. However, it is important that the strategy is carried out on a step by step basis and fully reviewed prior to any commitment in relation to the various enhancement options.

Table 2

Provisional Timetable for Phasing of Recommendations



---------- Initial/feasibility study period
―――――― Implementation period
.... Monitoring period

Table 3

Provisional costing of Recommendations

RECOMMENDATION	1992 £K	1993 £K	1994 £K	1995 £K	1996 £K	TOTAL £K
Rec. 1	2	5	5	5	5	22
Rec. 2		10	10	10	10	40
Rec. 3	10	5				15
Rec. 4	20	20	20	20		80
Rec. 5	10	5	80	30	30	155
Rec. 6	15	20	20	10	10	75
Rec. 7		10				10
Rec. 8	5	10	10	10		35
Rec. 9	5	10	10	10		35
Rec. 10		5	10			15
TOTAL	67	100	165	95	55	482

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