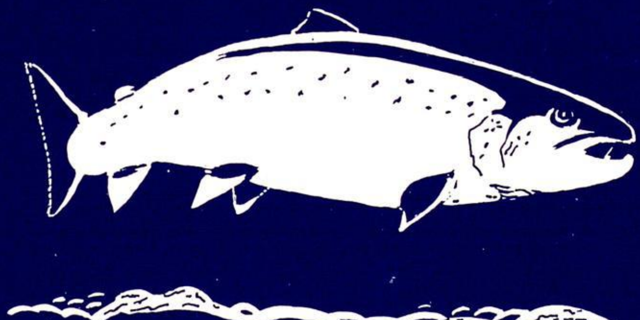
Aberdeen Research Consortium

and

The Dee Salmon Fishing Improvement Association

SALMON IN THE DEE CATCHMENT: The Scientific Basis for Management

Proceedings of a one-day meeting held at
Glen Tanar House
13 October 1994



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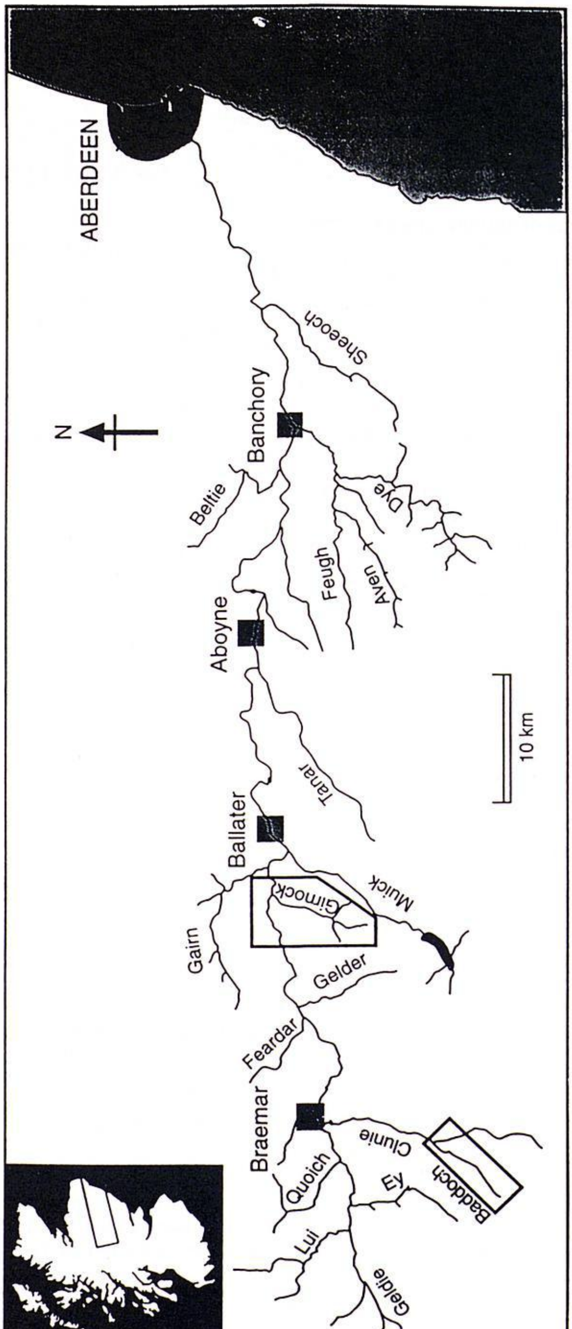
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Preface

A F Youngson

This Blue Book is based on the proceedings of a conference held at Glen Tanar House on 13 October 1994, to discuss the scientific issues relating to the Dee salmon fishery and its management. The conference was just one of a series of initiatives which started mid-way through 1992, when Grampian Enterprise, prompted by concern over the apparent decline in the fortunes of Dee salmon, commissioned a report from Coopers & Lybrand. The report reviewed the performance of the fishery and highlighted its importance to the local economy.

All the indicators point to a decline in the abundance of Dee salmon in recent years, particularly spring-run fish. The Dee's ability to offer first-class angling early in the season, long before runs have started on most rivers elsewhere in the world, is one of its most importance attributes. In the past spring salmon have dominated the annual catch from the Dee and because of this the fishery has been particularly susceptible to the effects of their recent decline.

The decline in catches of springers is not unique to the Dee fishery. The causes are not properly understood. Circumstantial evidence points to problems in the far western Atlantic Ocean. Overall, it appears that an unusually high proportion of the smolts, destined to return as springers, are failing to do so.

From the management point of view, consideration of how to resolve the problems that springers and spring fisheries face is constrained by the nature of the problem. If the root of the springer's current problems lie in the oceans, it will not be possible to address them directly. Instead, any measures which can be undertaken will have to be carried out within rivers, where springers and the habitats that support them are relatively easily accessible. A number of different management approaches can be envisaged. The Dee Salmon Fishing Improvement Association (DSFIA) and the Dee District Salmon Fishery Board have already investigated these options and, as a result, the DSFIA has produced "The Dee Salmon Action Plan".

Anyone who reads this document will appreciate that, given the short time-scale, considerable progress has been made both in identifying the problems that Dee springers face and in assessing options to improve the stock and fishery. Equally, however, many decisions remain to be made and it was in this context that the meeting at Glen Tanar House was jointly called by the DSFIA and Aberdeen Research Consortium.

The DSFIA is a long-established body with a history of support for the Dee fishery going back over 100 years. The Consortium, in contrast, is a much newer organisation. Formed in 1993 to encourage research collaboration between the universities and the scientific research institutes in the Aberdeen area, the Consortium has access to specialists in many scientific disciplines. Its members are involved in research programmes into the biology and management of salmon, physical processes within rivers and the relationships between geology, soils and land use in river catchments. It is, therefore, particularly appropriate that the expertise of the Consortium has been combined with local knowledge and brought to focus on the Dee.

Although many of the presentations to the conference relate specifically to the situation in the Dee they are also of more general relevance. Many address contemporary issues and suggest approaches to the management of salmon stocks and river catchments that are relevant everywhere.

Thanks are due to Anne McLay of SOAFD and Liz McLean of The University of Aberdeen for making the many arrangements necessary for a meeting of this kind; to Alastair Johnstone of SOAFD for acting as rapporteur and to Alastair and Caroline Thompson for their help in editing this record of the meeting; to Claire Bruce for her help in making arrangements at Glen Tanar and especially for organising the catering. I wish to acknowledge the support of Dick Shelton and Tony Hawkins of SOAFD. Dr Hawkins provided a summary of the talks presented to the meeting, as a preliminary to the discussion that followed. Finally, I wish to thank all the speakers and all those who attended the meeting for making it a success.

Introduction

Col Robert A Campbell, Dee District Salmon,
Fishery Board, Aberdeen

In recent years, catches of early-running Atlantic salmon (*Salmo salar* L.) have declined everywhere. The River Dee's pre-eminence as a spring fishery, however, makes this of particular concern in Grampian Region. The Dee's salmon stock is a valuable natural resource and its rod fisheries are an important component of the local economy. To illustrate the decline in salmon catches a review of recent catch statistics during the "spring" fishery is presented in Table 1.

Table 1. Annual average catch of salmon by all methods in the Dee from January to April

1960-1964	15,800
1980-1984	6,500
1990-1993	1,663

In the early 1980s it was recognised that the River Dee salmon angling catches were decreasing and in an effort to reduce exploitation of the stocks, the Aberdeen Harbour Board salmon nets were bought out in 1986. The problem affecting the River Dee salmon stocks of course is not just a local difficulty but reflects a broader trend of declining stocks throughout the range of the Atlantic salmon. An illustration of catch statistics from other major Scottish salmon rivers is also provided for comparison in Table 2.

Table 2. Annual average catches from January to April between 1990 and 1993 in four major rivers in Scotland

River Dee	1,663
River Tay	1,447
River Tweed	1,038
River Spey	740

Although catch statistics provide a measure of the salmon stock in the river an alternative, fishery-independent, assessment of the numbers of adult salmon in the Dee is needed to properly manage the stocks. Recognising the pressing need for an accurate assessment of the number of salmon entering the River Dee throughout the year, the Whitley Animal Preservation Trust provided funds of £300,000 to the Dee District Salmon Fisheries Board for the construction of a Crump weir and installation of an electronic fish counter at Waterside in August 1992.

The scientific papers which follow in this report include analyses of the problem of the stock decline, especially of spring fish, and lack of adequate recruitment to sustain the fishery. Various contributions attempt to identify the in-river problems and suggest action that could be taken to maximise fish production throughout the river. There is a consensus that developing a novel management approach will bring substantial benefits to the fishery in future. This has led the Dee District Salmon Fishery Board and the Dee Salmon Fishing Improvement Association to jointly develop an action plan to ensure that the Dee fishery remains vigorous. The plan is described in more detail by Michael Bruce later in this report.

Developing new management plans has brought into focus many of the scientific issues surrounding the Dee's stock, the fishery and the river catchment. Everyone has an interest in ensuring that the River Dee continues to support the world's best known spring fishery and that the catchment provides suitable habitats for a rich and varied flora and fauna. Scientific research has already contributed to our understanding of the biological background to the fishery and can make an important contribution to management and decision making in the future.

The current status of salmon stocks in the River Dee

David W Hay, SOAFD Freshwater Fisheries Laboratory, Faskally, Pitlochry

1. Introduction

The River Dee is in many ways unique. It is remarkably free from pollution from its source in the Cairngorms, to its mouth in the city of Aberdeen. It is not obstructed by dams or weirs in its lower reaches as are adjacent rivers like the River Don and the North Esk. Indeed salmon swimming upstream have uninterrupted access to the whole river as far as the Linn of Dee above Braemar. Even here, fish movement through this natural rock gorge is possible when water temperatures rise in June.

The Dee is in essence a giant stream. It is shallow for most of its length, and has an even gradient with frequent shallow riffles which are a suitable habitat for juvenile salmon. Thus, unlike some other rivers like the Tay, where the lower reaches are made up predominantly of deeper, slower stretches where mud settles out, the Dee has a shallow stony bed even near its mouth. This allows salmon parr production along its length, adding considerably to the parr produced in the tributaries, an unusually high proportion of which are high up in the catchment. Deeper slower rivers have fewer salmon parr and are favoured by trout.

2. Spring Run Salmon

The main reason for the Dee being considered unique is the composition of the adult salmon run. The River Dee has had, until recently, an excellent spring run of salmon. It is the upper part of the Dee, from Aboyne west, which contains the tributaries producing most of the spring running fish. Here the water is cooler and the growth rate of juveniles is correspondingly slower. Spring fish, available to anglers from the start of the angling season in February, are highly prized for their silvery appearance and catchability. Anglers travel great distances and pay substantial sums of money to catch these fish.

In recent years, spring run salmon have become scarce in all the rivers where they were previously abundant. In the Dee this is particularly so and rod catches have fallen substantially. Any substantial and continuing shortage of these fish would cause concern and reduce the attraction of the Dee to anglers. Despite this decline, the Dee remains, if only by a small margin, the best spring salmon river in Scotland.

The Freshwater Fisheries Laboratory operates fish trapping facilities on two tributaries of the Dee. These facilities have provided a wealth of useful information over the years. The Girnock Burn has been a study site since 1966 and the Baddoch Burn became one more recently, in 1988. Both the Girnock and Baddoch stocks of salmon are predominantly spring-running multi-sea-winter fish. In addition, a small proportion are early running grilse, predominately male, which make up on average 10-20% of the spawners and are an integral part of the upper catchment adult population.

3. River Mouth Nets

Until 1986 salmon were intercepted at the mouth of the Dee by nets. However at the end of that season the netting rights were bought out by the Atlantic Salmon Conservation Trust (Scotland), a charity dedicated to reducing fishing pressure on salmon populations, especially outside the river of origin. Many people felt that the removal of the river mouth nets would result in increased catches by rod and line which, by virtue of being a less efficient method of exploitation than netting, would allow more salmon to escape and spawn.

In 1987, following the removal of the river mouth nets, the adult fish trap on the Girnock Burn caught 293 salmon entering in the autumn to spawn. This was the highest total since trapping began in 1966. However late in the 1980s and in the early 1990s the number of spawners in the Girnock Burn fell until, in some years at least, too few salmon spawned to fully stock the stream with juveniles. In the six years from 1988 to 1993 the minimum required number of adults spawning, equivalent to the escapement of 40 female salmon, was not reached on three occasions. On the Baddoch Burn the minimum spawning escapement was not reached in two of the last six years.

4. Spawning

The Girnock Burn contains spawning grounds which extend all the way up to high altitudes (600 m) allowing fish to spawn in most areas of the stream. There are pockets, or more extensive fords of suitably sized spawning gravel at regular intervals. Good spawning areas are resistant to washout out in winter floods, yet sufficiently loose to allow fish to move the stones relatively easily while spawning. A good percolating flow of water through the gravel is important to allow adequate oxygenation of the eggs. This flow can be reduced when silt clogs the spaces in the stream bed during floods. Developing embryos will die in silted redds when their oxygen demand increases in spring as the pace of their development accelerates with rising water temperature.

Research has shown that a single salmon redd can stock around one kilometre of stream with juveniles, mainly downstream of the redd. Provided spawning gravel is distributed at intervals of no more than one kilometre throughout the length of a stream, the downstream dispersal of juveniles will ensure an even distribution in the stretches between spawning sites.

On the Baddoch, however, suitable spawning gravel is limited to the lower and middle reaches. Further upstream, although the stream is accessible to adult salmon, the gradient is too steep to allow the accumulation of spawning gravel. Thus the upper part of the stream can remain almost empty of young salmon and potential juvenile production is lost. This is one of the areas where man can intervene to advantage. It is possible to promote the creation of suitable spawning conditions and redistribute the eggs of local broodstock to utilise these areas.

5. Trapping and Tagging

Juvenile salmon which enter the Girnock or Baddoch smolt traps on their way to the sea are tagged with tiny stainless steel microtags which are inserted in the nasal cartilage. As the tags are not visible to any captors the adipose fin (between the dorsal fin and the tail) is cut off as a marker. Extensive publicity in angling huts and tackle shops has alerted most ghillies and anglers to this situation. A substantial number of microtag recaptures have been made by anglers since microtagged adult salmon first returned to the Dee in 1988. Surviving adults, tagged as smolts, enter the Girnock or Baddoch Burns in autumn to spawn. So far no Girnock tagged fish has entered the Baddoch or vice versa indicating the precision of their homing.

Fish trap catches are a source of crucial information. Fish are individually counted by hand and can be sexed and measured and their age determined from scale samples. An index of the long term variation in spawning stocks can be obtained from sites like the Girnock where a 28 year data set now exists.

6. Dee Stock Status

The data available to measure the overall status of Dee salmon stocks is more limited. River mouth net catches have not been available since the closure of the fishery in 1986. Rod catches are collected each year, but are not thought to be a precise indicator of stock size because catches vary according to the suitability of angling conditions.

Although anglers feel that the rod catch is the most important indicator of salmon abundance, biologists prefer to measure spawning escapement as this directly controls the size of the next generation of salmon. The exploitation of any resource is only possible in the long term if no more than the surplus is cropped. Sustainable angling and netting requires an adequate spawning stock to be left in the river at the end of each season.

When an electric fishing survey was carried out at twenty sites on tributaries of the upper Dee in the summer of 1994, the numbers of salmon fry produced by the 1993 spawners were similar to those recorded in a survey of the same sites in 1988 and 1989 before the most recent phase of stock decline. This suggested that although the number of spawners was marginally below the estimated minimum required, they had in fact managed to stock the upper tributaries to adequate levels. However the older parr populations were found to be only 30% of their size five years previously. This could have been caused by inadequate spawning in 1991 and 1992, poor subsequent survival, or a combination of both.

7. Fish Counter

Another method of estimating the size of the Dee salmon stock became available in 1992 when a fish counter was installed near the mouth of the Dee. All fish larger than about 500 mm travelling upstream or downstream should be counted. In 1993 the estimates obtained from the fish counter suggested a poor stock of spring fish crossing the counter from December to May. After subtracting the number caught by anglers between the start of the season in February and the end of May, it was estimated that around 5,000 of the 7,500 entrants remained in the river to spawn. Calculations of the minimum number of spawners needed to stock the upper Dee above Aboyne, suggested that around 6,000 fish would be necessary.

The estimate by the fish counter of the size of the spring run in 1994 was around one third of that recorded in 1993 at less than 2,500. The apparent seriousness of this situation provoked interest at a national level and spurred on efforts to address the Dee's problems. Estimates of only 500 spring salmon escaping to spawn in 1994, only a tenth the barely adequate number of the previous year, were regarded as gravely worrying.

Although it is recognised that an accurate fish counter can be a very useful tool for fishery management, the accuracy of the Dee counter in 1994 came under scrutiny. It is possible to compare numbers of spring fish estimated by the counter with subsequent spawning numbers in the Girnock and Baddoch Burns. As the 1994 escapement of spring fish was estimated by the fish counter to be approximately 10% of that in 1993, the number of fish entering the Girnock and Baddoch traps should show a similar reduction in 1994.

In the autumn of 1994 counts of spawners were made at the Girnock and Baddoch Burns. The number of two sea-winter fish entering the Girnock trap rose from 28 in 1993 to 49 in 1994. In the Baddoch trap the number of two sea-winter fish entering rose from 50 in 1993 to 70 in 1994. A total of 37 female salmon of all sea ages entered the Girnock and 40 entered the Baddoch in 1994. If the Girnock and Baddoch are representative of other upper catchment tributaries and these other tributaries also showed increases in the number of spawners in 1994, it is likely that the fish counter underestimated the size of the spring run of salmon in the Dee in 1994 by a substantial margin.

Problems with the fish counter in 1994 included damage to the electrodes in the main channels which was first noticed in April and June and repaired in August. However after the figures from the Girnock and Baddoch Burns became available in late 1994 it became possible to make independent estimates of the spring run. At that time, further examination of the fish counting will revealed a standing wave situated over the downstream electrodes which could potentially reduce counting accuracy especially at elevated flow levels. The standing wave was probably caused by gravel movements in the winter of 1993 damming up the exit from the pool downstream of the counter weir, thus raising the water level below the counter.

The size and success of the 1994 spawning will be scrutinised in 1995 when another electric fishing survey of the upper catchment sampling sites will be carried out. A uniform density of 0+ salmon parr would confirm that the situation recorded in the Girnock and Baddoch Burns was typical of the upper catchment as a whole.

8. The Future

Even if the status of the 1994 spring run was better than originally feared, there are potential problems ahead for the Dee salmon in the next few years. Although the spawning in 1992 was thought to be adequate, the 1994 juvenile survey revealed older parr populations had fallen to one third of those recorded in 1989. One possibility for the poor survival could be the serious flooding experienced in the Dee catchment in January 1993. In the Baddoch Burn the flooding was so severe that the fish trap was swept away. Salmon eggs developing in artificial redds in the Baddoch suffered over 80% mortality. The stage of development reached by the dead embryos examined suggested that most had died around January. If this phenomenon was repeated in the other upper Dee tributaries it could explain the poor performance of progeny of the 1992 spawners.

This is the reason that target figures for minimum spawning escapement contain a safety margin. Populations operating at, or around minimum, replacement levels are very vulnerable to occasional setbacks. Salmon populations have no, or very little, capacity to compensate at subsequent life stages for reduced survival early in the life cycle.

At present the smolt runs from the Girnock and Baddoch Burns are around 50% of the long term average. It is possible to predict, based on parr densities found in the 1994 survey, that the smolts run from the upper tributaries in 1995 is likely to be only around 30% of the norm. By 1996 and 1997 smolt runs from the upper tributaries could be close to normal again as the 0+ parr measured in the 1994 survey leave for the sea at two or three years of age. If a survey in 1995 confirms adequate 0+ densities in the upper tributaries this will probably consolidate the smolt runs at average levels for the following year.

Further investigation into the structure and behaviour of Dee salmon, combined with well considered management of their environment will ensure the unique characteristics of the Dee salmon stock are conserved for future generations.

Adult salmon in the River Dee: patterns of migration, distribution and spawning

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The varying fortunes of the salmon resource are often reflected in the catches of commercial and recreational fisheries. While some variation in annual salmon production is normal, severe depressions are usually symptoms of either biological, environmental or manmade stress. Increasingly, in the face of a apparent decline in many stocks of Atlantic salmon there is a requirement for the management of juvenile and adult spawning populations. This is particularly important for stocks whose adult numbers at spawning are not sufficient to fully stock juvenile rearing areas with eggs (Pepper and Oliver, 1986). Management of salmon populations in various guises has been carried out on many of Scotland's largest rivers for many years. Although the scientific basis of many of these schemes have often been far from clear (Maitland, 1986). However, the past 10 years has seen increasing amount of research into the structure of salmon populations and the promotion of an increasing level of awareness of the potential damage that can be caused to existing stocks if management protocols or introductions are of the wrong type.

The decline in the angling catch during the early months of the Dee fishery has raised concerns about the status of the river's salmon populations. It is therefore timely to review the findings of the research carried out so far and discuss briefly how some of the results may impinge on a fisheries management plan for the river.

1. The Characteristics of the Dee Salmon

The Dee is one of the most productive Atlantic salmon rivers in Western Europe and has a unrivalled reputation as a early spring salmon fishing river. Between 1952 and 1992 the Dee's spring rod fishery yielded an average 39% of the total reported Scottish rod catch of MSW salmon landed before the end of April (Anon, 1993). Despite this distinction, the Dee like many of the larger rivers on the east coast of Scotland is characterised by the return of runs of fresh salmon over the whole year (Shearer, 1992).

1.1 Adult Dee salmon

There are three main runs of fish that enter the river. These are the spring and summer runs of salmon and summer runs of grilse. In part these runs of river entrants correspond to the main sea age-classes of adult fish that return to the river. These groups are the one sea-winter salmon or grilse, and the older, larger salmon that have spent either two (2SW) or three (3SW) years at sea. Among the true MSW salmon returning to the Dee, fish that have spent two winters at sea (2SW) are the most common group. The generally larger and older 3SW salmon rarely exceed 4-6% of the catches or the spawning population.

Perhaps the most famous run of MSW salmon that enters the Dee is the spring run. Despite their name, springers begin to enter the river in the late autumn and over the following winter months prior to the opening of the new season in early February. However, the main spring run does not occur until February and it peaks in late March and into early April. Most of the 2SW fish entering the river over these early months of the year are quite small, weighing on average 7-9½ lbs. A few larger 3SW fish, weighing between 13 and 25 lbs are usually also present.

The end of April sees the gradual tailing off in the numbers of spring fish entering the river and the beginning of the arrival of summer salmon. Most of the salmon that enter the Dee during the summer months have also spent two years at sea feeding but are distinct from the spring salmon in that they have resumed relatively fast body growth ("plus growth") prior to river entry. They are therefore distinguished from spring salmon by their scale growth patterns. The transition is a gradual one between late April and May. Over this period "spring" and "summer" salmon come into the river "side by side" though by late May relatively few true springers are among the fresh run entrants. The larger late summer and early autumn salmon (15-27 lb) arrive from late August onwards.

The month of May also sees the arrival of the first grilse. However, the largest runs of grilse usually enter the Dee later in the summer in July, August and September - though the precise timing of their movement upstream from the estuary may depend upon flow levels. Grilse and a smaller proportion of salmon continue to enter the river until spawning.

1.2 The size of salmon and grilse entering the Dee

The average size of grilse and salmon increases through the summer (see Table 1). Typically, within each sea-age class of returning adults, the later running fish of each group tend to be larger having spent an increasingly longer time feeding at sea. This pattern is particularly evident among the grilse, which as fresh entrants in late May and early June often weigh less that 4 lb. By late summer some of the fresh-run grilse may have attained weights often in excess of 10 lbs. As a general rule, most grilse are smaller than the 2SW salmon entering the river at the same time having spent a year less at sea.

The same pattern of increasing weight is repeated among the 2SW salmon - but interestingly not so clearly among the rarer 3SW fish. Consequently, fresh run fish that enter the River Dee in the late summer and early autumn tend to be the largest of their class.

Therefore despite its reputation, the Dee is not just a "spring" salmon river. Instead the Dee supports a wide range of adult migrant classes that return at different ages and at different times of the year. In this respect the Dee is typical of many of the larger rivers on the east coast of Scotland. Nevertheless, its historical capacity to produce large numbers of very early running salmon is unique and particularly valuable.

Table 1. Variation in the mean weight (kg) of salmon and grilse entering the Dee between February and August 1983 (Shearer, 1985)

	Grilse	**Salmon**	
	1 SW	2 SW	3 SW
February	-	-	-
March	-	3.9	7.7
April	-	4.1	8.0
May	1.7	4.2	8.2
June	1.9	4.9	9.8
July	2.4	5.5	7.8
August	2.9	6.1	-

1.3 The behaviour of adult salmon in the Dee

For many years, anglers, biologists and fishery managers alike have speculated about the likely patterns of distribution and destinations of the wide range of salmon and grilse that enter larger river systems like the Dee. Perhaps the commonest questions posed are - do the returning adult fish distribute themselves at random in a large river like the Dee or is there some sort of order? Does the river simply fill up with adult fish from the top down?

The development of small, reliable radio transmitting tags in the early 1980s has enabled scientists to monitor the movements of adult salmon and grilse tagged at or just after river entry in considerable detail. A number of such studies have been undertaken on the Dee. Between 1985 and 1989, 109 adult salmon and grilse returning to the river were radiotagged and released into the estuary at Aberdeen. In addition, during the early spring of 1988 a further nine rod-caught fish were tagged and released at Park.

The behaviour of many of the radiotagged fish was monitored up to spawning. The studies focused on two particular areas of interest: the patterns of movement in the river of different classes of river entrants and the relationship between date of entry to the river and the final spawning position. Detailed accounts of this research are given by Hawkins and Smith (1986), Hawkins *et al.* (1990) and Laughton and Smith (1994). Their findings are summarised as follows:

1.4 Patterns of movement

For many entrants, four phases can be identified during river migration. The first consists of a rapid movement upstream from the tidal reaches. This may continue for 24-36 hrs after river entry. This activity is evident over a range of seasonal flows and times of day. The second phase, comprises of a period of discontinuous movement upstream. Over this period, fish generally move at night and remain in many of the recognised holding pools during the day. However, when spate conditions prevail, daylight movements are often evident. It is during this period that many fish complete most of their upstream progress. The third phase is associated with fish spending up to three months in a single pool, exhibiting little or no movement over a wide range of flows - although minor relocations up or downstream, may take place over this time. The final phase, sees the resumption of upstream movement that usually coincides with autumn spates, as the fish move to their final spawning positions. Similar patterns of behaviour have been recorded during the course of different studies on other rivers in Scotland.

Among most migrants, the precise pattern of movement among salmon and grilse in the Dee appears to be associated with the time at which fish enter the river and the location of the place where they will spawn. Spring salmon, and early running grilse tend to exhibit extended forms of all four phases of movement described. In contrast, late running salmon and grilse may move upstream to within a few kilometres of their spawning position on completion of the first movement up from the tide.

Early in the season the underlying patterns of migration of spring salmon are obscured by the effects of low water temperatures. Low water temperatures delay the movement of fish from the lower reaches of the river to areas further upstream. Later in the spring and summer, this constraint is removed and entrants can run upstream more quickly. Flow-limited tributary access and the presence of waterfalls (eg on the Feugh) may also disrupt movements.

Differences in the behaviour of fish returning to the river at different times of the year determine the character of the fishery. Susceptibility to capture with rod and line appears to be related to levels of migratory activity (Milner, 1990; Laughton, 1991), migrants being most susceptible to capture by anglers during the second and fourth phases of activity described earlier. In contrast, relatively few fish are captured with sporting methods during phase one or three. Consequently, patterns of migratory behaviour of different groups of fish entering the river at different times of the year determine where catchable fish will occur.

1.5 The relationship between date of entry to the river and spawning position

In general, within each sea-age class of adult fish, the earlier in the season that a salmon or grilse enters the Dee the further upstream it migrates before spawning. For example, spring salmon returning to the Dee before the end of April migrate upstream through most of the angling beats on the river and spawn in the upper reaches of the main stem (ie from Ballater upstream) or in upper spawning tributaries like the Clunie, Geldie, Girnock, Gairn and Muick. Early running summer salmon (entering the river between May and July) migrate upstream to the middle reaches of the river, and some enter tributaries like the Tanar, Cattie, Beltie and Feugh. Later running summer salmon (entering the river from August onwards) limit their penetration of the river system to the large spawning beds in the lower reaches of the main stem below Banchory - with a few of these quite large fish entering the Crathes and Sheeoch burns.

Given suitable river flow conditions during the summer months, this structured pattern of behaviour is repeated by the grilse. However, among this group the relationship between the date of river entry and their final spawning designation upstream is necessarily compressed by the comparatively shorter period of the year over which they enter the river (May-December). Early running grilse that enter the Dee in May and June migrate to areas in the upper part of the river. In contrast, many of the later running grilse (late July-December) tend not to move further upstream than the Feugh and the lower reaches of the main stem.

The relationship between the date of river entry and spawning location is therefore more or less definable among each seasonal and sea-age group of fish entering the river.

The time of return to the river is therefore associated with the position of the final spawning location. Consequently, it is possible to predict that those fish that spawn in for example the very highest areas of the Dee watershed - above Ballater or Braemar, are the very earliest of their sea-age class to return to the river (spring salmon and early grilse). Furthermore, at the other end of the watershed, many of the fish that spawn below Banchory downstream to the outskirts of Aberdeen are fish that enter the river from late June to the end of the year. Different areas of the Dee and its main tributaries are therefore used for spawning by salmon and grilse that enter the river at different and definable times of the year.

1.6 The salmon of the Girnock Burn

The Girnock Burn is a small spawning tributary near Ballater - in the upper part of the Dee watershed. Many of the juvenile salmon that have left the Girnock Burn over the past 27 years have been tagged. In each year, prior to spawning in the autumn, the pattern of recaptures of adult salmon bearing Girnock tags have then been monitored and recorded.

Most of the Girnock salmon that have been recaptured by anglers have been reported between the first day of the fishing season in early February to the end of May - as clean spring salmon. Most of the recaptures are of the 2SW class with a few larger 3SW fish. Typically, many of the earliest recaptures reported each season are confined to the lower and middle reaches of the main river - below Potarch bridge. However, by May and early June there is a shift to areas of the river further upstream - between Aboyne and the Ballater. By this time, the recaptures may also include a few tagged grilse. By the end of June, few tagged salmon or grilse from the Girnock have been reported to been recaptured anywhere in the river.

All these findings therefore suggest that the Girnock Burn is a spawning tributary that generates migrant juveniles that return to the river almost exclusively as early running MSW salmon or early running grilse. The Girnock is probably typical of many of the other juvenile rearing areas in the upper reaches of the river.

2. Homing behaviour of source populations: the basis for adult return migration structuring and distribution

The tendency of salmon and grilse to return to their native rivers to spawn by homing is well documented. However, perhaps less well known is that homing is also used by many adult fish to return to their own streams at spawning. Among the adult spawners that return to the Girnock each autumn, about 50% were tagged there (Youngson *et al.*, 1994).

Salmon returning to the Dee therefore tend not only return to their river of origin, but to the more or less precise area of the watershed where they spent their freshwater lives as parr. Migratory behaviour within the river is therefore directed and not random. This homing combined with the tendency of different areas of the river to produce fish that return to the river at different times of the year combine to produce the patterns of migratory behaviour previously described.

2.1 Patterns of migratory behaviour: a determinant of fishery character

During their upstream migration, salmon and grilse are exposed to exploitation by anglers fishing on different beats along the river. Consequently, in view of the behavioural structuring described above the various classes of adult fish returning to the river over the year are exploited differentially by anglers fishing on different stretches of the river. The upper, middle and lower beats therefore exploit different combinations of the various seasonal groups of returning adults. Fish returning to the river early in the year migrate upstream to natal rearing areas in the upper reaches of the river and pass through nearly every beat on the main stem.

Spring fish returning the river early in the year are also exposed to the pressures of fishing effort by anglers for a longer period than fish entering the river later in the year. Consequently, the spring salmon are probably the most susceptible migrant group to exploitation by anglers and predation and poaching. In contrast, fish entering the river later in the year are exposed to fishing pressure for a lesser period as many (excluding "early" grilse) home to the lower reaches and are therefore not available to fisheries operating upstream.

2.2 Distribution and behaviour at spawning

The common aim of all the adult salmon that return to the Dee is to locate gravel beds near to where they lived as juveniles (via homing) and spawn. In many of the smaller salmon rivers in Scotland, spawning is often restricted to the upper reaches where the spawning and juvenile rearing habitat are concentrated.

However, in the Dee, the distribution of spawning and juvenile rearing habitat is more extensive; spanning a range of altitude of nearly 400 m - from the main river above the Linn of Dee near Braemar downstream to just above the tidal limit at Aberdeen.

4

Spawning also takes place in nearly all of the river's accessible tributaries. Spawning and subsequent juvenile rearing in the Dee therefore takes place throughout a wide range of river environments that span more than several hundred kilometres of river and stream bed.

2.3 Timing of spawning

Though fresh salmon enter the Dee all the year round, most spawning usually occurs during the late autumn and winter months between October and early January. Late September and early October sees adults of various sea-ages regrouping near their natal rearing areas. Spawning date is dictated by the timing of ovulation among the gravid females. Spawning begins first in mid-October among the spring salmon and early grilse in the upper reaches of the river. However, the season is short and spawning is more or less is complete by mid November. In contrast, the fish that have returned to areas further downstream begin to spawn in late November onwards and may continue well into January and early February of the following year.

The variation in the timing of spawning by fish in the upper reaches compared with the lower reaches is such that there is little or no overlap. The differences are probably controlled by both genetic and environmental factors. The rates at which eggs develop during the incubation period to hatch and then on to emergence is dictated by local water temperature. Eggs spawned in higher altitude (and therefore colder) streams in the upper part of the watershed tend therefore to take a longer time to incubate to the emergence stage than eggs deposited in lower altitude streams further downstream. However, the differences in spawning date do not reflect a drive among all groups of eggs towards a common hatch date. Despite spawning occurring in the Clunie about a month before the Sheeoch, the timing of the hatch date of the eggs is reversed in favour of the Sheeoch by about a month (Webb and McLay, in prep.). The reason for this pattern probably reflects the time at which conditions become suitable for the young fry to survive the first few weeks of early life. Spring, (and therefore the availability of suitable food) comes later to the upper catchment than areas further downstream.

From this work it is clear that differences exist in the timing of spawning of adults returning to different areas of the river system. These differences, together with the differences in the thermal regimes during the incubation period associated with different areas of the river combine to optimise the time of hatch and emergence in streams with different thermal regimes. These differences are probably adaptive and serve to maximise the survival of the emerging fry.

3. Changes in "run timing" in the Dee: A Spawning Tributary Perspective

The past 30 years has seen variations in the strength and sea-age composition of the various seasonal groups of adult salmon returning to the Dee: with the relative seasonal numbers of salmon and grilse entering the Dee changing from periods of comparatively high spring salmon numbers towards a preponderance of fish entering the river in the late summer. These and other changes have, in turn, affected the seasonal pattern of exploitation of salmon and grilse by both net and angling fisheries within the fishery district over much of the same period (see George, 1982; Martin and Mitchell, 1985, Shearer, 1985). In this respect however, the Dee is probably not unique, as similar changes are also been reported to have taken place in many other rivers in the UK over the same period (SAC, 1994).

However, in the Dee, despite these very obvious changes, characterisation of tagged recaptures and adult Girnock trap catches since the late 1960s has shown that the Girnock Burn has more or less consistently generated adult salmon that have returned to the river as early running spring salmon (83%) together with only a small number of early running grilse (17%). Larger, later running 2SW salmon bearing plus growth on their scales (suggesting river entry after late April - as summer salmon) have not been recorded in significant numbers at the Girnock trap site at any stage.

There is therefore no evidence to suggest that Girnock salmon and grilse are returning to the Dee any earlier or later in the year than they did in the late 1960s and 1970s - when the numbers of early running salmon entering the river were probably much higher than today. Furthermore, despite a gradual reduction in the number of female MSW spawners returning to the stream since 1967, there appears to have not been a truly compensatory increase in the numbers of female grilse to indicate a significant shift in the average sea-age of the population. The slightly larger numbers of grilse that have returned to the stream in recent years have not been consistently above what might be normally be expected with the removal of the Aberdeen Harbour Board nets in 1987 (D Hay, pers. comm.).

Dunkley (1985) describes an apparently similar phenomenon associated with many of the seasonal stock components of the North Esk. Though there has been an increase in the grilse:salmon ratio in recent years there has not been an absolute increase in grilse numbers. Consequently, the author proposed that rather than fish returning at a earlier sea age (ie grilse) the fish that would have returned as MSW salmon are being lost due to mortality. Despite the changes in the Dee's stocks and its fisheries, over the past 30 years, the characteristics of all three main sea-age groups of tagged adults that have returned to spawn in the Girnock since 1967 have appeared to have remained more or less fixed. Girnock salmon and grilse are returning to the river at the same time as when records began. If this is typical of many of the other source populations of fish in the Dee, then it is possible to explain the well documented changes in the river's stock.

In view of the population structure previously described, the research that has been undertaken at the Girnock since 1967 strongly suggests that the annual and longer term variations in the strength of seasonal runs of adult fish returning to the River Dee are unlikely to have been the result of inherent changes in the return times and migratory patterns of fish. Rather, the situation probably reflects more wider scale variations in the juvenile rearing production and subsequent sea-survival of smolts derived from broadly different areas (ie upper, middle and lower) of the river system. At present, juvenile migrants reared in upper parts of the catchment; a group that are generally predisposed to return as early spring running salmon and early grilse, are probably performing less well than they did when the Dee was at its height as a spring fishery. Indeed, smolts from the upper reaches may be performing less well than juveniles derived from rearing areas in the lower reaches of the river - areas known to generate fish that return to the river as later running summer salmon and grilse. These effects are probably being driven by the consequences of differential sea-mortality and may in part explain the imbalance in the numbers of adult fish of different sea-ages returning to different areas of the river system at the current time.

4. Conclusions

The Dee's salmon populations have been defined in terms of behavioural structuring of returning adults. The patterns probably reflect broad adaptations of the various juvenile source populations.

The structuring of the salmon populations in the River Dee is evidently complex. Though not exhaustive, the objective of this brief review has been to outline some of the main behavioural characteristics of the salmon that enter the Dee and how these characteristics determine the performance of the various fisheries on the river.

Adult salmon and grilse return to native streams or main river areas supporting source populations of juveniles. This behaviour is directed by homing. Homing, provides the mechanism by which the behavioural and genetic (see Eric Verspoor in this volume) structures have evolved. Behavioural structuring among homing adults destined for different areas of the watershed of the type found in the Dee has potentially different consequences for the susceptibility of each seasonal class of migrants to commercial netting and angling exploitation and other losses. In this respect, spring salmon in particular have been identified as a group that is particularly vulnerable to high levels of exploitation. Homing may also serve to perpetuate deficiencies in local egg deposition by restricting the possibility of compensatory spawning by members of populations derived from elsewhere.

Nevertheless, the structuring in the Dee does allow juvenile populations known to generate parr and smolts that are predisposed to produce particularly valuable classes of returning adults (eg spring salmon) to be identified within geographically definable areas of the river system. This in turn allows managers and biologists to target scarce resources towards the protection and enhancement of these populations.

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Population structure: what genetics tells us

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1. Introduction

Is the run of salmon in the River Dee composed of fish from one, or more than one, reproductively discrete population? The answer to this question is important in deciding what actions are best for the conservation and enhancement of the stock. In general population structuring within a river will be expected to contribute to a river's productivity. Thus management action must serve to maintain the integrity of any population structure. Furthermore, the factors threatening or limiting single populations may differ and management, to be most effective, must be targeted specifically to meet each population's needs.

The existence of multiple populations within rivers is made possible by the strong tendency of Atlantic salmon to home back to their natal streams to spawn. Homing to different river systems is widely documented. Only recently has microtagging of salmon passing through the Girnock Burn trap on the Dee shown strong homing to occur even within a river. As a result, fish born in one part of the Dee are more likely to interbreed with fish from the same area than with fish from other parts of the system. Thus, mating among fish is not random and this allows salmon in the river to divide into a number of distinct reproductive groups among which interbreeding is more or less absent.

Direct evidence that salmon in the Dee are divided into a number of distinct reproductive groups or populations is difficult to obtain. The existence of population structure in fish is sometimes easy to identify because of physical barriers to interbreeding. For example, brown trout above and below an impassable falls will be reproductively isolated from each other and will they will belong to more or less distinct populations. For salmon in the River Dee, there is no clear spatial or seasonal isolation of groups of spawning fish.

Gaining understanding of population structure from behavioural observations is problematical. To do so it is necessary to establish that salmon born in one area or during one time period, when they return to the river, consistently spawn with other salmon spawned in the same area or period, and not with other salmon. It would be a logistical nightmare to try to collect this information, even over one generation, using direct observations of physically tagged fish. To provide the necessary connection between observations on parents and offspring over two or more generations is impossible. Thus to gain the necessary understanding, one must look at the distribution of biological variables which are passed on from parent to offspring and whose distribution among salmon is influenced by population structure. Only one type of biological variable meets the need - inherited (ie genetic) variation.

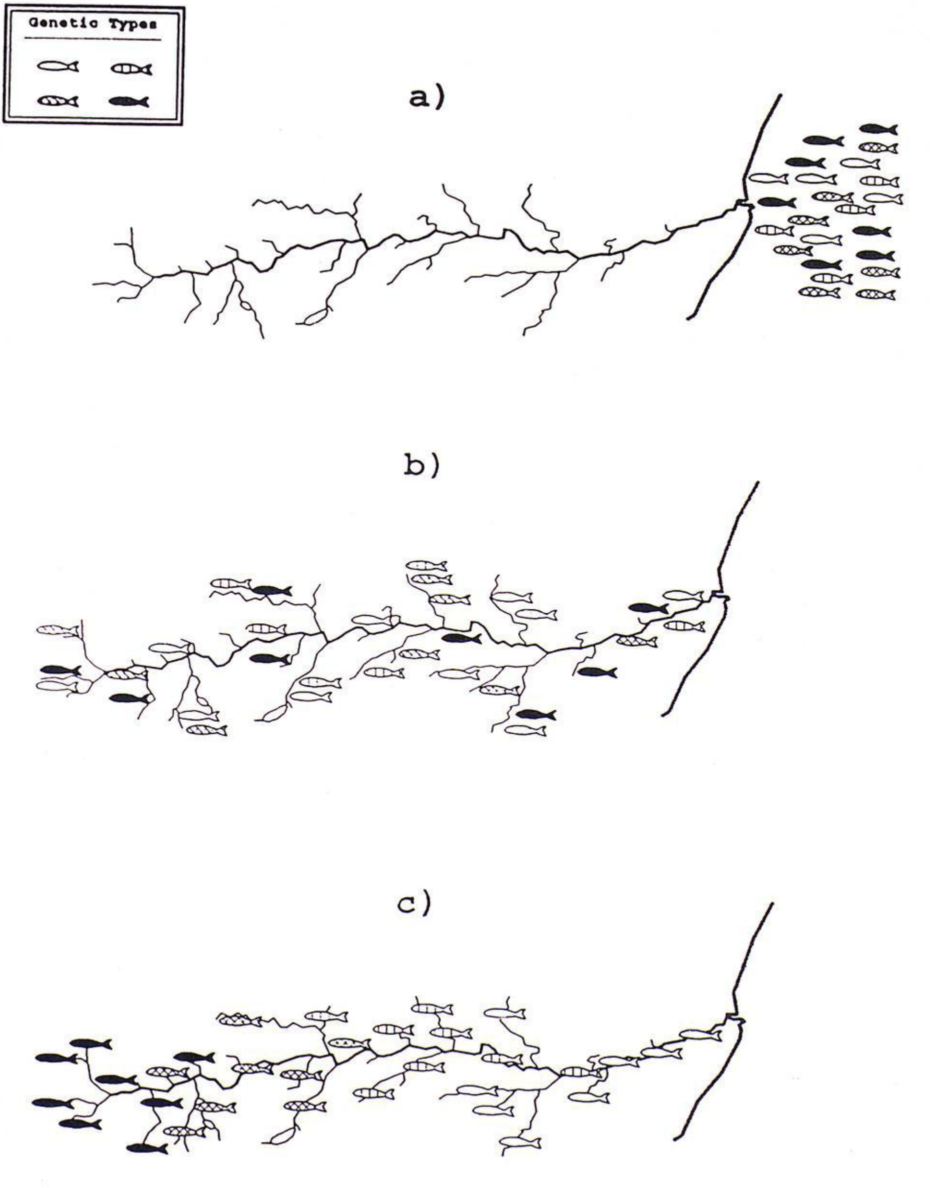
2. The Distribution of Genetic Variation

Individuals salmon are the product of the interaction of in the order of 100,000 genes with their environment. The genes are sections of cellular DNA which control particular biochemical functions. Each salmon has two types of genes. One type is found in the nucleus of the cell in chromosomes and for which there are two copies - one inherited from the mother and one from the father. The two copies are usually different. The other type is found in the mitochondria, cellular organelles responsible for energy production. There are many copies of each mitochondrial gene but they are all the same in each salmon as they derive only from the mother. However, individuals will often have different variants of the same mitochondrial gene. For either type, when all salmon are considered, there may be anywhere from two to twenty or more different variant types for each gene.

Genetic variation is useful in determining the reproductive discreteness of different groups of salmon in the following way. Assume that the fish in Figure 1a represent all the fish entering the River Dee and that each pattern represents a different genetic type of salmon. If the salmon run is composed of fish from a single population, it would be expected that the genetic types would distribute themselves at random throughout the system at spawning time eg Figure 1b. The differences in the proportions of genetic types spawning in various parts of the river should be no greater than expected on the basis of chance alone. If the situation is more like that shown in Figure 1c, and if the difference among spawners in the various tributaries is stable from one generation to the next, then chance is an unlikely explanation. In this case, the more likely explanation is that the salmon belong to a number of genetic populations that are geographically distinct.

Consistent differences in the proportions of genetic types among different groups of salmon can only result where reproductive mixing between the groups of fish is limited or absent. Where this is the case, the groups are considered to belong to separate populations. A small amount of mixing can occur but the probability that an individual from a particular population spawns with another individual from the same population will be much greater than that of spawning with a fish from another population. This means that the study of

Figure 1 Schematic of hypothetical situation of a) different genetic types of salmon running up into the River Dee, b) the distribution of those salmon types expected if there is no population structuring in the river, and c) the distribution which might occur if there was population structuring.



levels of genetic differentiation among salmon from different parts of a river system is a powerful tool for understanding salmon behaviour and population structuring.

3. Genetic Studies in the River Dee

Research has been carried out by the Freshwater Fisheries Laboratory at Pitlochry into the distribution of gene variants among salmon from different tributaries in the River Dee catchment (see map at front of report). The work has focused on variants at mitochondrial genes and at nuclear genes coding for enzymatic proteins. More recently, however, studies have been extended to include nuclear genes similar to those used for DNA fingerprinting in humans.

No absolute differences are found in the genetic variants present among the salmon from the different Dee tributaries and most genetic variants occur in most tributaries. However, the differences in the proportions of the different genetic types for the two types of genes in the tributaries are too large to be the result of chance differences within a single population (Table 1a). This conclusion is supported by a more specific comparison of the proportions of genetic types in Baddoch and Girnock Burns (Table 1b). The observations strongly support the idea that salmon in most of the main tributaries of the River Dee belong to separate breeding populations. It follows from this that the Dee stock is a composite of the contributions from a large number of reproductively distinct populations.

Table 1. The odds against the differences in the proportions of different genetic types among juveniles in the Dee tributaries sampled being the result of chance differences in the genetic make-up of spawners from a single reproductive population moving into these tributaries to spawn

a) Sheeoch, Girnock, Gairn, Baddoch, Geldie	
Protein genes	less than in 1,000,000
Mitochondrial genes	less than two in 1,000,000
b) Girnock, Baddoch	
Proteins	less than two in 10,000
Mitochondrial genes	less than one in 4
Fingerprinting genes	less than one in 1,000,000

The genetic studies undertaken, as yet, are limited in their extent. At most, variation at only 40 genes has been examined, out of the many thousands that exist, and over a relatively limited geographical scope. This makes it difficult to say anything conclusive about the total number of distinct populations there might be in the Dee, the geographical limits for each tributary population, or what structuring occurs in the main river. Nevertheless, it is clear that multiple populations exist and that these utilise different parts of the river. This insight is crucial. It means that population structuring is an important variable in the biology and dynamics of the Dee salmon stock.

Further genetic studies will continue to add to our understanding of the nature and extent of population structuring in the River Dee. Studies of the highly variable genes such as those used for DNA fingerprinting should be particularly informative as they can be used to estimate the degree of relatedness of individual fish and to uniquely identify the offspring of particular salmon parents. This genetic tagging, when used in combination with physical microtags, will make possible the monitoring of the reproductive behaviour of salmon and their offspring in the wild. The outcome will be a clearer picture of the precision with which salmon home and of the number and geographical boundaries of the Dee stock's constituent populations.

Some work using DNA fingerprint genes is underway on the Girnock and Baddock Burns and should extend our understanding of salmon populations in the Dee. This work has already, for example, revealed that up to 60% of eggs in an individual salmon redd in the Girnock Burn are fertilised by "precocious" male parr and that up to 14 different precocious parr may be involved in fertilising the eggs in a single redd. That precocious parr could make such a substantial genetic contribution to subsequent generations was previously not appreciated. This means that they also have a role to play in enhancement schemes based on artificial spawning.

4. The Biological Implications of Population Structuring

Given multiple populations, the total production of salmon in the River Dee will be the sum of the salmon produced by each individual population. Changes in the size of the run may reflect changes in one, a few or all the populations. The contributions made to the fishery by each population will vary, with some large and some small.

The different populations are associated with distinct spawning and juvenile rearing areas. This means that reductions in numbers in one population will not be compensated for by an increase in production by another. Thus to maintain the maximum natural run of salmon in the river, all populations need to be vigorous, producing fish to their full natural capacity.

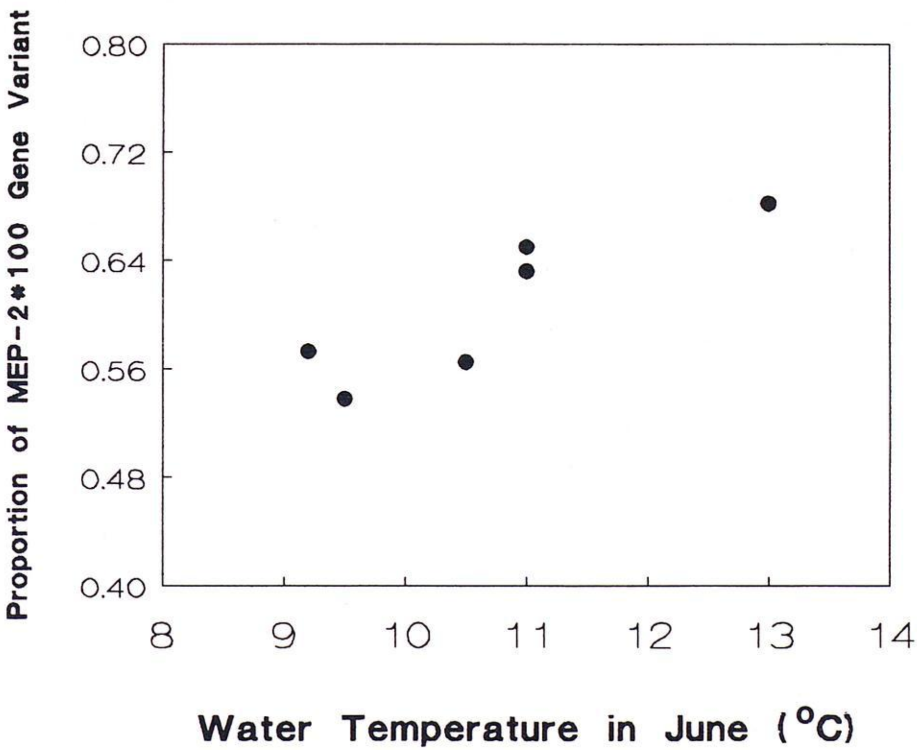
The rules governing productivity will be different for each population as each will have a unique biology. This will particularly be the case with respect to environmental differences and to factors contributing to their reproductive separation. Differences include areas utilised for spawning, juvenile rearing or marine feeding, run and spawning timing, size, fecundity, and age of maturity as well as level of exploitation. The factors limiting the production of one population may be quite different from those limiting another.

Biological differences among populations may be caused by the environment. Habitats may differ in ways which affect survival, growth, maturation and behavioural characteristics such as run-timing. This may be true for the marine phase as well as the river environment. Nothing is known about the migrations of salmon from different Dee tributaries in the ocean but it is known that different river populations and salmon of different sea ages habitually feed in different marine areas. If tributary populations behave in the same way, this would have implications for growth, exposure to exploitation, predation risk, timing of movements, etc.

Biological differences among populations may also arise from innate genetic differences. Population structuring provides the opportunity for natural selection to adjust the proportions of genetic types present in an area. This means the types present are best suited to survive and reproduce successfully. This local adaptation has two implications. The first is that population structuring by its very existence maximises the overall productivity of a river. The second is that each population has the opportunity to continue to evolve genetic differences which are passed on from one generation to the next. Individually, these may be minor but together they may affect exploitation rates or alter susceptibility to environmental changes. Furthermore, these genetic differences may affect aspects of the salmon such as size, sea age, run timing and body shape. Indeed, population structuring may well be the basis of the existence of different run components such as spring fish or multi-sea winter fish.

There is some direct evidence of local genetic adaptation of populations in the Dee. The clearest case is the association of the proportion of genetic variants of the enzymatic protein MEP-2 in the tributary populations with water temperature (Fig. 2). However, other characteristics may also be locally adaptive. For example, the incidence of multi-sea winter fish in a population is in part under genetic control and differences in the relative numbers of grilse and salmon spawning in different parts of the Dee may reflect genetic

Figure 2



differences among populations. Run-timing may be another case in point as may body morphology. A study on salmon from different tributaries of the Miramichi River in eastern Canada, found strong evidence for adaptive genetic differences in body shape associated with differences in flow conditions. A tributary with fast water was found to have juveniles with larger fins and more stream-lined bodies than a slow flowing tributary. The differences in body shape were found to be inherited from one generation to the next.

In summary, population structure is a necessary condition for local adaptation and an important factor in determining both the productivity and character of a river's run of salmon. Local adaptation increases juvenile survival, smolt production, adult survival and reproductive success within each population unit and, thus, in the river overall. Local adaptation can also give populations unique characteristics which may be reflected in variation in the size, age, or time of entry among salmon entering the river.

5. Management Implications

The biological implications of population structuring within the River Dee are important to the development of management initiatives to conserve and enhance the river's run. Management, to be most effective, must be targeted at the problems and opportunities presented by the individual populations, rather than treating all salmon in the river the same. It must also ensure that the population structuring in the system is not eroded.

Management initiatives can be directed towards the individual populations in the Dee, even though the exact number of populations and their geographical boundaries cannot, as yet, be defined. This approach can be achieved by the practical expedient of treating the salmon in each tributary as belonging to a separate population. It would also be prudent to assume that salmon in different parts of the main river, say the lower, middle and upper reaches also comprise different populations. Management can then examine what threats, are faced by the salmon in each area and target actions to deal most effectively with each. Conservation resources are limited and this practical approach will lead to the greatest improvement in the river's run from the available funds.

The effectiveness of management actions will also be compromised if the actions taken erode population structure. Population structuring will be adversely affected if salmon native to one tributary or part of the main river are used to supplement numbers of salmon in other parts of the river with an existing population. Instead, enhancement activities should focus on actions which enhance the survival of offspring of local wild spawners within each tributary or section of the main river.

Potentially useful approaches which could be considered in this regard are the redistribution of eggs or fry to produce a more even distribution of juveniles and better use of available juvenile habitat. This will increase survival by reducing density dependent mortality associated with factors such as local food shortages caused by excessive local densities of fry immediately post emergence. Improvements to local habitat would increase space for juveniles and the production of the creatures they feed on.

Where habitat improvement or redistribution of fry is not an option, juvenile production might be increased by the use of satellite tanks. These are tanks constructed next to a stream with a flow of water from the stream in which young salmon are supplementally fed so increasing survival. Provided the fry are derived from local spawners this offers the possibility of increasing juvenile production beyond the natural capacity of the stream without posing a substantive threat to the integrity of the local population.

Although initiatives like these will not guarantee vigorous populations they satisfy some of the necessary conditions and are ones amenable to action. At the same time other factors beyond our control, such as conditions at sea, may be limiting productivity and affecting some populations more than others. However, this should not be viewed as an excuse for inaction. While we cannot control to any great extent a salmon's habitat at sea, we can ensure that conditions in the rivers are optimal.

6. Conclusion

The run of salmon in the River Dee is composed of salmon from a number of distinct reproductive populations. Unless management focuses on the problems faced by the component populations of the river's run of salmon and acts to preserve the population structuring which exists in the river, conservation and enhancement initiatives are unlikely to be fully effective and they may even fail. However, while taking population structuring into account is a necessary condition for success, it is not the only one. Conserving population structure is just one part of a well-considered conservation and enhancement programme.

Habitat requirements of salmon in the river

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1. Introduction

Salmon are particularly well adapted to life in fast-flowing water and dominate the fish fauna of many Scottish rivers including the Aberdeenshire Dee. The life cycle of Atlantic salmon starts with the fertilisation of eggs that are deposited and buried in gravel reaches. After hatching, salmon grow in the river, where they are known as parr, and a proportion of the male fish mature, some of which may never migrate to sea. However, after reaching a length of approximately 9 cm, many salmon parr become adapted to sea water during the following spring in a process termed "smolting" and then go to sea. Survivors return as adults to the river after one or more years at sea. They may then spend many months in pools before the final stage of the migration to spawning areas. After spawning, most anadromous adult salmon die, but some, mainly females, survive to spawn a second time.

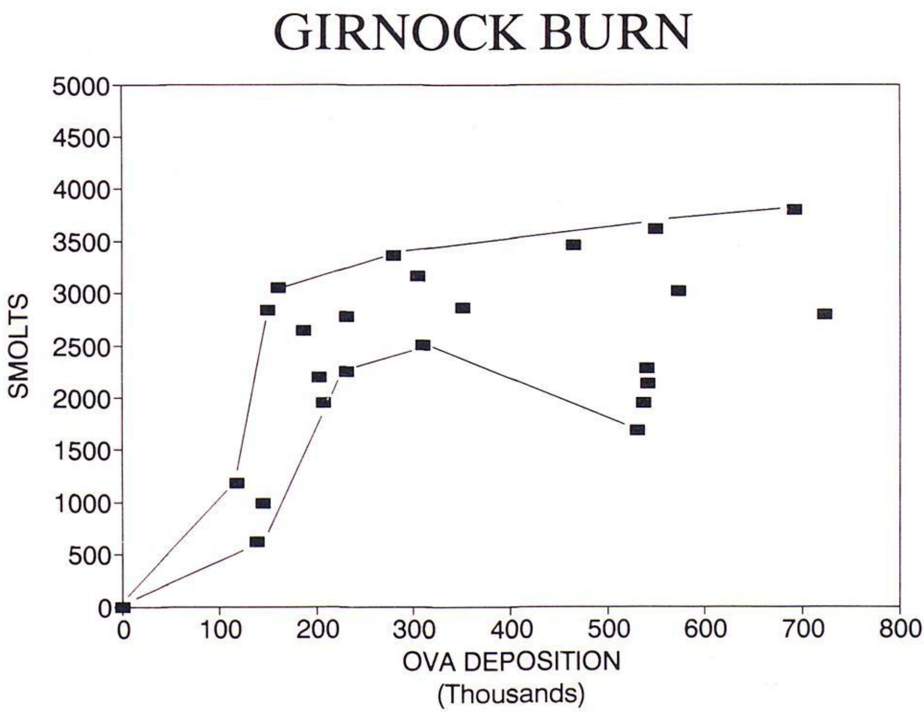
From this brief résumé of the life cycle it can readily be appreciated that the biological requirements of salmon will change throughout their development and the ideal river must be capable of coping with the demands of successive life stages. This paper provides an outline of some of the major biological and physical factors which relate to the production of juvenile Atlantic salmon.

2. Some Principles of Population Dynamics

To put the importance of good river management into perspective, it is useful to consider some basic features of the population dynamics of salmon. Maximising the production of smolts is particularly important because there is thought to be little, if any, "density-dependence" of growth and mortality after salmon leave rivers. Density-dependence is a term used frequently by biologists to describe the situation where a population is so crowded that growth is stunted and/or some fish die as a consequence of the high density. It is easy to visualise the difference in population density as salmon smolts leave rivers where they may be extremely abundant, and enter the ocean where, once they disperse, they can be regarded as rare. The important point here, is that even though the overall population mortality at sea can vary substantially, the proportion of a smolt year-class that returns as adults would be the same, regardless of how many smolts left the river, as density-dependence is not likely to be a factor in marine mortality. So, for example, if the production of a river could be increased from 100,000 to 200,000 smolts, then roughly twice as many adults would be expected to return. When sea mortality is low, this might be an increase from 10,000 to 20,000 adults; and when it is high the gain might be from 5,000 to 10,000 adults. Under either scenario, the benefit of a two-fold smolt output is a two-fold increase in the numbers of returning adults. This summary example illustrates the basis for management models although, in reality, a number of other factors must be accounted for when evaluating more precisely the benefits of smolt enhancement.

Salmon grow much faster at sea than in the river. A unique set of data collected from the Girnock Burn, a tributary of the River Dee, illustrates clearly the importance of density-dependence in the river. Above a critical level of spawning adults, any further egg deposition does not result in an increase in smolt production (Fig. 1). On a gross scale the

Figure 1



burn is at "carrying" capacity when this plateau level is reached. In reality the situation is rather more complicated than this simple model suggests. Nevertheless, it can be seen that there is a limit to the number of smolts that can be produced unless the carrying capacity is increased. There is some scientific debate over the capacity of salmon populations to balance losses after the first year of growth. However, it is clear that at very low spawning levels a carrying capacity is never reached and the only ways of then improving natural smolt production are to ensure that egg deposition is increased, and to reduce natural mortality.

Often the carrying capacity is considered in terms of the "biomass" that a burn can support. Overall numerical production of smolts will be highest if this biomass is turning over rapidly and comprises mainly fast growing parr that leave as young smolts. However, an issue of particular relevance here is the question of whether changes in the development rate of young salmon may ultimately affect their characteristics as returning adults. More research is needed in this area to establish the relative contributions of genetic and environmental factors in determining the characteristics of adults especially sea age and season of return.

3. Basic Chemical and Thermal Regimes

Salmon are influenced throughout their lives by the chemical composition and thermal energy of the water in which they live. There are direct effects, such as the influence of acidity on the hatching of eggs and of temperature on metabolism and growth. Indirect effects are also important and include the effects of nutrient input on the production of food organisms. Water chemistry and thermal regimes vary throughout the Dee catchment and this is reflected by local variations in productivity of salmon. Areas enriched by basic rocks and/or agricultural development support the highest densities of salmon parr.

4. Juvenile Development

4.1 Early life

Female salmon deposit their eggs in redds (nests) which they excavate in gravel runs. A good supply of oxygen is essential for the eggs to develop successfully and this is facilitated by a suitable flow of water through the gravel bed. Clogging with fine sediment, which reduces water flow, can result in egg mortality. However, the process of redd cutting may dislodge some of the entrained fine material. Wash-out during winter spates is thought to be the most serious factor in destroying redds. This is a function of the stability of the river bed, the dynamics of water flow, and the weather.

During the first few weeks after hatching (the exact time depends on temperature), salmon obtain nutrition from their yolk sac, but must then switch to feeding on other organisms. After emergence, fry may occur locally at very high densities and competition for space and food is intense. Subsequently they disperse away from the redd, but if suitable spawning areas are distributed patchily, then clumping of juveniles may reduce production of smolts in a burn to below the level that would have been achieved with a more even distribution of eggs. The relationships between movements, growth rates and mortality of parr are complex, and are crucial determinants of the productive capacity of burns.

4.2 Food, oxygen, and mortality risks

Salmon parr require food and oxygen for maintenance of body tissues and growth. Parr feed on a wide range of invertebrates, some of these are produced within the stream and others are of terrestrial origin. Factors which increase food availability tend to increase smolt production. The level of nutrients within burns can influence the abundance of invertebrates. The presence of bank-side vegetation may enhance smolt production both through supplying food directly and by the input of organic material from fallen leaves which will subsequently be broken down and used as food by invertebrates. Excessive tree cover may have an adverse effect by shading out light. So vegetation, while potentially advantageous in some circumstances, may require continued management. Much of the salmon production on the River Dee is from the main stem, and it is not clear whether changes in bank-side vegetation would be expected to enhance salmon production significantly in such wide river sections.

Feeding by parr usually necessitates a degree of competition with other salmon, and also increases the level of exposure to predators. So, in effect, growth incurs the risk of death, and the interplay between the advantages of rapid development and the need to survive probably influences the life of salmon throughout their time in the river prior to migration to sea.

Oxygen is abundant in most healthy upland rivers, and fish extract it by passing water almost continuously over their delicate gills. The capacity to exchange respiratory gases (oxygen and carbon dioxide) and ions creates the problem that other less desirable chemicals might also move freely between the fish and the environment. Salmon can maintain the levels of naturally-occurring chemicals at the correct levels in body tissues, but are particularly vulnerable to a range of pollutants which may act internally or may damage the gills and interfere with oxygen uptake.

4.3 Habitat preferences

Habitat use by salmon is determined to some extent by interactions with other fishes, particularly brown trout, and probably also by the abundance and distribution of other predators. For salmon parr living in riffle areas, the water depth that is utilised increases as they grow, partly due to interactions between year-classes. Consequently, while the "optimum" depths are fairly similar (typically 15-20 cm for fry and 15-25 cm for parr) parr are much more common than fry in deeper water. There is also some indication that the preferred substrate size increases with parr size. High densities of salmon parr are associated with in-stream cover which provides protection from predators and a degree of visual isolation which reduces competitive interactions between fish. Many salmon parr are strongly site-attached for periods of months or even years, although redistribution over the winter period is common. The long periods of population stability facilitate the development of complex social structures with fish being territorial or forming a dominance hierarchy. The detailed structures of salmon populations are not understood easily and may appear often to be merely the subject of academic debate. However, the behaviour of fish on a local scale ultimately determines the overall productivity of streams and rivers and should not be ignored.

There is little information on the effects of destabilising events such as extreme spates and drought on population production, however, some recent evidence suggests that the capacity for juvenile salmon in the River Dee to redistribute during catastrophic events is rather limited. A stable water flow may therefore be particularly important for maximising the production of parr.

The behaviour of salmon changes in winter. As temperature falls they become largely nocturnal and may tend to move to deeper water. Suitable shelter is probably of particular importance during winter as protection from extremes of water flow, freezing, and predators. Over-winter mortality may be a major factor limiting the production of smolts.

5. Migratory Stages

5.1 Parr

Some salmon parr migrate over extensive distances in fresh water during early summer and autumn. The autumn migration includes fish leaving upper tributaries at the start of the smolt run and also male parr that have matured and are seeking females. Little is known about the specific habitat requirements of these fish.

5.2 Smolts

As salmon change from parr to smolts, they start to shoal and migrate downstream. At this time changes occur in their body-form, colour and physiology, and they move through unfamiliar areas. This is probably a period of increased vulnerability to predators and free access to the sea is important to facilitate rapid exit from the river.

5.3 Anadromous adults

Returning adult salmon require suitable water flows, clear access up river, and the availability of resting pools (see "Adult Salmon in the Dee" by John Webb in this report for details).

6. Salmon Within the Ecosystem

Salmon exist within a large and complex community of animals. Some of these provide food, compete for resources, or are predators of salmon. Others do not interact directly with salmon but influence the populations of those animals that do affect salmon. Many animals within the community depend on the components of the same habitat used by salmon at least for part of their lives. Therefore, any change in the habitat that affects salmon populations in one particular way, may have ramifications for other components of the community. These, in turn, may further affect salmon populations. The consequence of this is that while a good understanding of biological mechanisms may guide management, it is difficult to arrive at general rules that will apply to all situations. This is not to say that sound management practices are ineffective, but that their effects may be difficult to quantify and predict.

7. Habitat Management

From this summary of factors that may affect salmon populations, it is clear that there are a number of possible options for increasing the production of salmon. For example, higher smolt numbers may be achieved by changing the food supply, shelter, flow stability, sediment type, populations of predators, and egg deposition. In reality only some of these factors can be modified on a sustained basis over a large scale, and in seeking to increase salmon production it is important to consider whether the costs and benefits of any actions give a positive nett gain. When considering the possible enhancement of smolt production it is important to address the question: what is limiting the productivity of the river/burn? If the population is at carrying capacity, then introducing additional eggs or juveniles will have no benefit. If the population is well below carrying capacity, then habitat enhancement may have little benefit, at least in the short term.

Whilst our understanding of the mechanisms that underlie production of salmon has increased steadily, there have been few case studies of the impacts of large scale management exercises in Scotland. The development of management strategies for Atlantic salmon will benefit from careful monitoring of the effects of any imposed changes, such as development of bank-side habitat, and stocking of normally inaccessible burns. Due to the flexibility of the salmon life cycle, the complexities of ecosystem dynamics, and the widely fluctuating environment, the development of management theory and practice is likely to be an on-going process over many years. The River Dee has already played a central role in providing much of the large scale field data that underpins our understanding of salmon biology. It is important that this continues into the future, particularly as the salmon population fluctuates through periods of high and low production.

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The hydrology and fluvial geomorphology of the Dee catchment: The physical habitat of Atlantic salmon

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1. Introduction

The River Dee transfers water and sediment from its catchment area to the sea. This inexorable flux intimately connects the river to its 2,100 km^2 drainage area. In addition, the morphological characteristics of the river channel that are important salmon habitats (pools, riffles, margins etc) are formed by these transfer processes, particularly during large floods. Fluxes of water and sediments are highly dynamic with substantial movements occurring in short periods of time. Despite this, the consequences of these relatively infrequent events may be important over prolonged periods. Understanding the hydrology and geomorphology of river systems is therefore critical to understanding and managing in a sustainable manner the processes which create salmon habitats.

2. Hydrology of the River Dee

The lowest gauging point on the river Dee is at Park (NGR NO798983), where the mean daily flow of the river is 45 cubic metres per second (m^3s^{-1}). However the flow is highly variable and may drop below 10 m^3s^{-1} in summer low flows and can exceed 1,000 m^3s^{-1} in flood events. Flows are strongly influenced by precipitation in the western and southern headwaters of the catchment where mean annual precipitation may exceed 2,000 mm each year (in the Cairngorms) compared to only 800 mm yr^{-1} in the lower parts of the catchment (Warren, 1985). Snow can constitute a large proportion of the precipitation in the headwaters and snowmelt can be important in generating large spring floods (thus giving the river an Alpine-like flow regime) and contributing to baseflows during the early summer months. The Dee occupies a steep catchment and the geology is dominated by impermeable schists and granites, thus the river responds rapidly to precipitation in the headwaters and floods can rapidly travel downstream. The valley of the river and its main tributaries are filled with extensive glacial and fluvioglacial deposits which act as important stores of groundwater that sustain summer baseflows (Maizels, 1985).

The river floods as a result of heavy rainfall and/or snowmelt in the catchment headwaters. As well as inundating land and causing damage to property, floods are important from a fisheries management point of view; the turbulent flows are able to mobilise, transport and subsequently deposit sediments of a wide range of sizes. This can lead to "washing out" of redds and substantial juvenile mortalities may occur in the most extreme floods. In addition, the deposition of fine sediment in redds can suppress oxygen supply to eggs and result in significant mortalities.

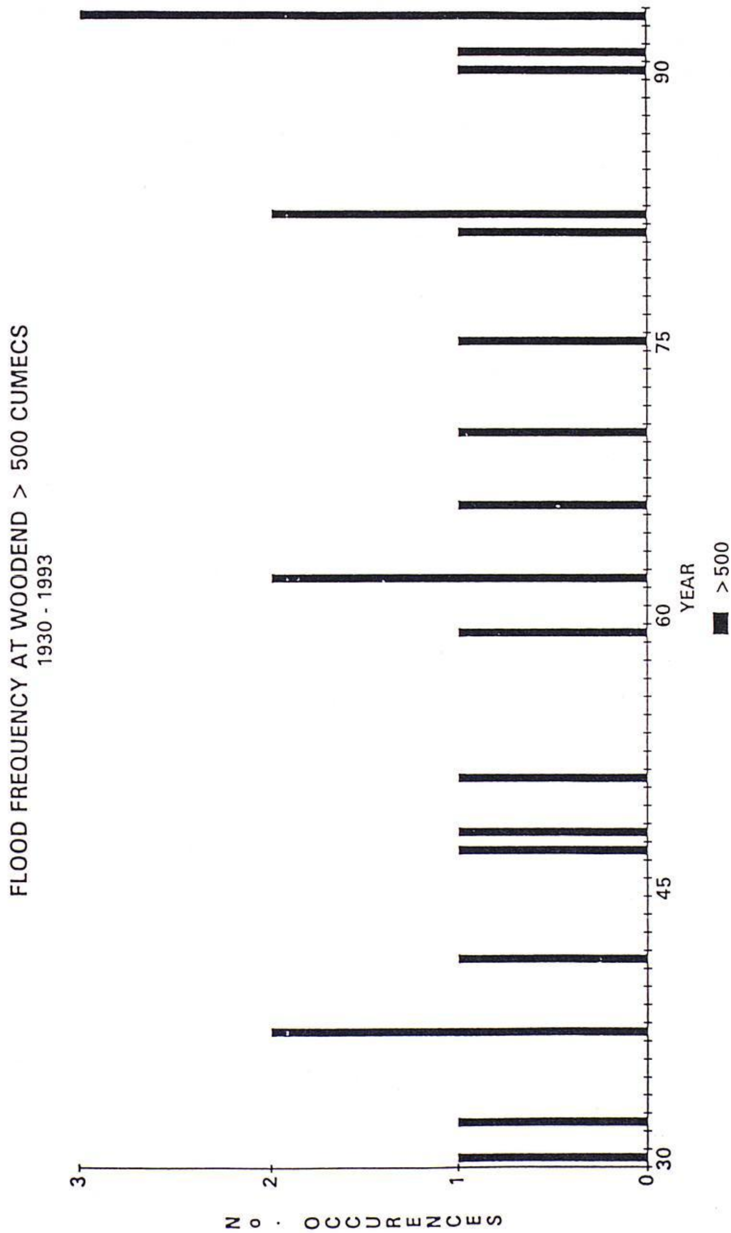
A view shared by many users of the Dee, is that in the last few years floods have become more frequent, larger in magnitude and more rapid in their propagation through the river system. Certainly, there has been an increased frequency of larger floods in the early 1990s (Fig. 1), however, these floods have been relatively modest compared to some of the larger historic floods (Table 1). For example the major flood of January 1993 had a discharge at Woodend gauging station (just upstream of Banchory, NGR NO645964) of 680 m^3s^{-1}, only the fourth largest flood measured at this location since recording began in 1929. The famous Muckle Spate flood of 1829 is estimated to have had a peak discharge of up to 1,900 m^3s^{-1}, and floods in both 1937 and 1951 had flows exceeding 1,000 m^3s^{-1}. It is difficult to assess the accuracy of claims that changing catchment land use (eg increased afforestation, moor gripping etc.) has led to more rapid rises in flood levels. Resolution of this issue would require detailed analysis of historic hydrological data that has not, as yet, been undertaken.

Table 1. The five highest flood flows (m^3s^{-1}) recorded at Woodend gauging station 1929-1993

Rank	Year	Flow
1	1937	1,133
2	1951	1,020
3	1982	720
4	1993	690
5	1990	620

Unlike many other upland rivers, the Dee is not regulated by any major reservoirs in its headwaters. Consequently, summer flows are dependent on groundwater seepage and melting of snowpacks. Moreover, the water supply for Aberdeen and many of the surrounding towns and villages is abstracted from the river Dee at Cairnton (70 mega litres per day [Mld]) and Cults (75 Mld). During summer low flows, water abstractions must stop

Figure 1 Occurrence of major floods (with flows greater than 500 cubic metres per second) at Woodend gauging station between 1930-1993.



for six hours if the flow at Park gauging station falls below 640 Mld, at which point abstractions would constitute almost 25% of the river flow. This measure is intended to aid fish access into the river. There has been an increased tendency to drier summers in eastern Scotland and three of the five lowest flows recorded at Woodend since 1929 occurred in the 1980s (Table 2). This, together with increasing expansion of Aberdeen's population may lead to a future conflict between fisheries management in the Dee and the water supply industry. The lowest flows generally occur in July or August. However, if low flows continue into the start of the spawning period some potential spawning sites may not be accessible either due to their being dry or to physical restrictions on fish moving upstream. Preliminary analysis of data for the Girnock Burn, for example, indicates that the upper reaches of the burn are only utilised for spawning once a certain flow threshold has been exceeded.

Table 2. The five lowest mean daily flows (m^3s^{-1}) recorded at Woodend gauging station 1929-1993

Rank	Year	Flow
1	1976	3.5
2	1984	3.8
3	1983	4.3
4	1972	4.5
5	1989	5.1

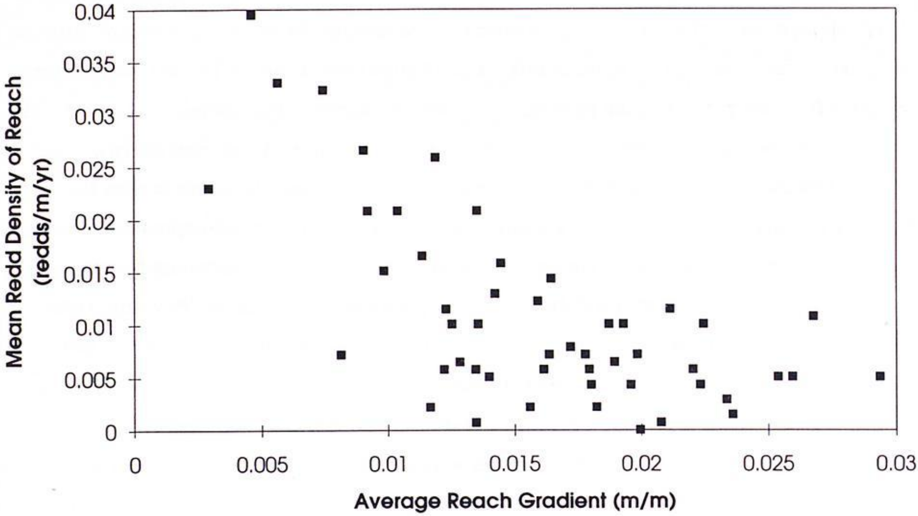
3. Fluvial Geomorphology and Salmon Habitats

Three distinct channel patterns exist on the River Dee: straight reaches characterised by alternating pools and riffles or bars; meandering reaches; and braided reaches where the river splits into more than one channel as it flows around mid-channel islands or bars (Maizels, 1985). Straight reaches are relatively uncommon, 30 have been identified which occupy only 16% of the rivers length in reaches like that at Inver. More common are meandering reaches which provide such a distinct feature of the rivers appearance in sections such as that between Dinnet and Aboyne. This characteristic of the river reflects the coarse, "armoured" bed over most of the Dee which exhibits a strong intermeshed structure and erodes only in the largest floods. This "armouring" results from fine sediment being flushed from the river during spates leaving only coarse sediments on the bed. In contrast the river banks commonly consist of unconsolidated glacial and fluvioglacial deposits or unstable material deposited after floods. Such materials are easily eroded on the outer bends of meanders where the main line of current is directed. Maizels (1985) compared series of maps and aerial photographs to estimate erosion rates on meanders. The average rate of bank retreat at 14 sites studied was 0.7 m per year and rose to over 2.3 m per year on some particularly active meander bends such as that at Murtle. These rates are high compared to most British rivers and reflect the high energy that the Dee possesses during floods (Newson, 1986). Braided reaches also occur where the river banks are susceptible to erosion. Usually the river will split around deposited sediment such as mid-channel bars or at confluences with tributaries. The bars may be temporary storage zones of sediment that will be reworked in subsequent floods or they may vegetate to become stable islands. Thirty-eight such features have been identified on the Dee.

These differences in river morphology provide a diverse range of habitats that salmon can exploit. Shallow, fast-flowing water running over deposited gravel in bars and riffles usually creates conditions that are suitable for spawning. Figure 2 shows that redd densities in the Girnock Burn are highest in the reaches of the river where gradients are low, thus encouraging the accumulation of suitable spawning gravels. Such shallow zones often additionally contain suitable juvenile habitat, whilst slower flowing water in deeper pools provides resting places for salmon during their movement upstream.

The morphological characteristics of the river channel (shape, width, depth, slope and velocity) at any particular point reflect the interaction of the controlling factors of discharge. These include sediment load, bed and bank material, riparian vegetation and the valley slope (Hey, 1994). It is now recognised that channel morphology is very finely adjusted to the interaction of these elements and any changes may result in instability and produce major changes to the patterns of erosion and deposition. This is particularly the case during floods as the river channel becomes sculpted to facilitate the efficient movement of water and sediments during high flows. Consequently, major channel changes occur during the larger flood events where natural controls such as discharge and sediment load change very rapidly and need to be accommodated. McEwen (1989) examined a series of historic maps of the upper Dee to examine when major channel changes have occurred in the period since 1755. It was noted that the Muckle Spate of 1829 produced widespread instability in the catchment. However, other larger floods, particularly when occurring in rapid succession, such as those in the 1870s and 1890s, also caused major changes. The period in the early 1990s may be a comparable period of successive large floods which have

Figure 2



destabilised parts of the river system. There is certainly extensive evidence throughout the Dee catchment that the recent increase in flood frequency has resulted in an upturn in erosion and sediment transport rates. Increased rates of erosion are being reported from a number of river banks, together with observations that sediment is being deposited in the lower reaches of the river where numerous pools are being reported as silting up.

It is important to view such phenomena from a long-term perspective. Periods of increased flooding and sediment transport tend to be punctuated by periods of lower activity where only small or moderate floods occur. The 1970s were a recent example of such quiescence in the catchment. During these periods, smaller and moderate floods rework sediments mobilised and deposited in the larger floods, and the channel again re-adjusts. Hence, sediment deposited in pools can begin to scour and accumulated sediment in bars can be re-sorted and transported downstream. Thus in the longer term the river reestablishes a quasi-equilibrium and the whole cycle is repeated when flood activity picks up again.

4. Channel and Catchment Management

The hydrology and geomorphology of the river Dee make it a dynamic high energy river. As a result the Dee is an excellent example of an upland river system that remains in a semi-natural state. It also causes problems to riparian owners and fisheries managers where natural processes cause the river to flood, erode river banks or deposit sediment at inconvenient locations, including salmon habitats. Thus, there is much evidence of human attempts to manage the river so as to prevent erosion and flooding, and to remove sediment when it is deposited in locations where it is deemed to be unsuitable. Consequently, revetments, rip-rap and other engineering structures have been placed to protect eroding river banks in certain locations and flood banks have been constructed in places to prevent the river from inundating its floodplain.

Although such features are often successful in treating the local problem of concern, they disturb the natural equilibrium of the river over an often extensive, but usually unknown, distance. Thus if the river is prevented from dissipating energy by eroding a specific river bank, this energy may be used to erode a river bank downstream, or to scour bed sediments. Willetts (1985) points out that it is very difficult, if not impossible, to predict the impacts of river engineering on active, gravel-bed rivers like the Dee. From a geomorphological perspective it is certainly desirable to restrict engineering to sites where it is essential, for example when a village or town is subject to a substantial flood risk. From a conservation perspective, features like eroding river cliffs and zones of sediment erosion and deposition add to the habitat diversity of the river system. Moreover, some bank erosion is essential to supply sediment that will create spawning gravels. Unlike the Dee, many rivers have a reduced diversity of habitats due to an excess of heavy engineering. In addition, it is worth remembering that engineering can never afford full protection against flooding and erosion. A flood of the magnitude of the Muckle Spate for example (which could happen at any time!) would top all but the most expensive flood defence structures, and cause extensive damage to many currently protected river banks.

The natural state of the River Dee certainly provides a strong argument for applying management techniques that are sensitive to the natural ecology of the river. Much sediment erosion that is filling in salmon pools in the main river, probably occurs in headwater tributaries where inappropriate land management practices may promote erosion. Forest management, for example increases erosion when land is ploughed and drained for planting and subsequently when heavy machinery disturbs the soil during thinning and felling operations. Fine sediment from such operations can degrade the quality of spawning gravels and fill downstream pools. The land management techniques described in the Forestry Commission's Forest and Water Guidelines would minimise such problems, but there is ample evidence in the Dee catchment that such advice is not always followed by individual forest managers. Construction of upland tracks for sporting access, overgrazing by livestock and recreational activities also contribute to erosion in the steep mountainous headwaters where natural erosion rates are already high. Excavating sediment from rivers, whether for fisheries management or gravel extraction, is also a potentially hazardous perturbation that can destabilise river systems by removing the armour layer on the bed and changing the in-channel hydraulics. It is unfortunate that channel management in Scotland is undertaken by a variety of authorities ranging from individual fishery owners to Local Authorities, with no coordination of such activities. Individual managers would do well to remember that sediment is a pollutant and once mobilised by de-stabilising river systems, it is very difficult to control. Those intending the sustainable management of salmon habitats in rivers such as the Dee would do well to minimise any intervention in the river, and when intervention is absolutely essential, to ensure that any changes to the channel are made within the context of the river's natural hydrology and geomorphology.

Bankside management throughout the main river and its tributaries affords a long-term ecological option in controlling erosion on the Dee. Gravel-bed river channels with wooded banks are, on average, 30% narrower than channels where banks are clear. This is due to the binding effects of tree roots and the hydraulic resistance of the vegetation on stream banks. It is important that fisheries managers note this point where bank side trees are cleared to allow increased fishing access and increased scope for casting. Whilst riparian planting will not prevent erosion on river cliffs that are already actively retreating, it will minimise future erosion by protecting areas that may be vulnerable. The current grant scheme for riparian set-a-side, stock fencing and tree planting in the upper Dee is therefore to be welcomed and it is hoped that more of the catchment, particularly in the headwaters will be eligible for such schemes in future allowing the rehabilitation of riparian zones in sediment source areas.

6. Conclusions

Although the hydrology and geomorphology of the Dee catchment and river system provide the physical habitat for salmon, their importance has often been overlooked in the past. Any attempts to manage the Dee must work within the constraints and opportunities that the river naturally affords. The fact that the river is dynamic and mobile but adheres to a quasi-equilibrium state over longer periods needs to be recognised, as does the interaction between the river and its entire catchment area. Institutional frameworks for river management in Scotland are fragmented and sectoralised and there may be a need for a single agency to be given the responsibility for coordinating management activities in integrated physical systems like the River Dee.

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The importance of river banks

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1. Introduction

It is intuitively obvious to most people that the characteristics of the soils and the land use immediately adjacent to a stream, river or lake may directly or indirectly influence the water quality. In Scottish rivers, much of the water is equilibrated with adjacent soils immediately prior to entering the main water course, and thus a direct link between soil physicochemical characteristics and the solute composition of the drainage water is to be expected. Equally relevant in the present context is the influence of river banks upon the nature of sediment in the rivers. The river bank vegetation influences both the amount of soluble and the amount of particulate organic matter entering the river. It may also directly influence the shading of the river, although shading effects vary with the dimensions of the river channel.

Prediction of the precise effects of particular land management strategies for river banks is not a simple task, because of the complexity of interactions between the components in any individual ecosystem. Thus it is essential to take an overview which incorporates information from soil science, biogeochemistry, hydrology, biology and pollution science. This can only be done in depth on a catchment-by-catchment basis. The situation is further complicated by the dynamic nature of river systems, which means that they need to be considered over a range of time scales from changes such as individual storm events through seasonal trends to longer term trends (years to decades or longer). Moreover the possible effects of ultra-severe episodes, occurring perhaps once in ten or even once in a hundred years, may need to be borne in mind. However, in spite of the above limitations, it is possible to present some general observations on the effects of river banks on water quality, and to identify potential problems and management options that are best avoided under particular circumstances.

2. Effects of River Bank Soils on Water Chemical Quality

The author's interest in the link between soils and water quality evolved in the late 1970s, when involved in attempts to estimate the biogeochemical weathering rates of soil minerals using catchment balance studies. Although the work was conducted to satisfy academic curiosity, a luxury rarely acceptable in the 1990's, the results have become very relevant today, because weathering rates provide a direct measure of the capacity of soils in a catchment to buffer against natural acidification, or acidification induced by atmospheric pollutants, or by the growth of trees. In other words, the work provides a quantitative measure of key aspects of the sustainability of both soils and of land management strategies being applied to them. Studies involve precise measurement of the annual movement of chemical elements entering the catchment in precipitation or as dry deposition, and of the annual movement of the same elements leaving the catchment in the river. The difference is assumed to be the result of mineral inputs derived from weathering of soils.

Initial interest focused upon the catchments of the River Dye, which eventually drains into the River Dee (Reid *et al.*, 1981a,b), and a smaller catchment at Peatfold, Glenbuchat, where the stream drains into the River Don (Edwards *et al.*, 1984). Development of a sampling strategy to quantify the movement of chemicals in flowing water soon pointed to a need to understand the dramatic changes in stream water chemical composition which occur during storm episodes (Cresser *et al.*, 1984; Cresser and Edwards, 1987, 1988a,b).

During normal conditions, water quality is governed by water draining from sub-surface soils. This water contains relatively high concentrations of silicate and of ions such as calcium, magnesium and sodium, compared with river water at high discharge conditions. Sub-surface water contains a relatively low concentration of dissolved organic matter and tends to be relatively alkaline. Even where the soil parent material adjacent to the stream is an acidification-sensitive till such as that derived from granite, the water pH is often around neutrality at pH 7.0 to 7.5. This comes as a surprise to the uninitiated, since the mineral soils themselves may have a more acid pH value of around 5.5. However, the water pH is less acid because carbon dioxide, originating from the soil atmosphere and dissolved in the drainage water, outgasses when the water drains into the river channel (Cresser and Edwards, 1987). This reduces the contribution of carbonic acid to the water acidity.

During high flow conditions, there is a much greater input of water draining from and through the more acidic surface soils. As these organic soils, have lower concentrations of calcium, magnesium, sodium and silicate, concentrations in river water fall during storms, so consequentially water pH drops and becomes more acidic. The concentration of soluble organic matter, on the other hand, tends to increase during theses events, often quite markedly.

Water with an excessively acid pH is potentially damaging to salmon, especially when it contains a low calcium concentration, because the water dissolves aluminium and may result in a very unfavourable calcium:aluminium ratio. Rivers in north east Scotland generally contain calcium at between 0.2 and 20 thousandths of a gram per litre (mgL^{-1}), and there is a close relationship between mean acidity and calcium concentration values, high acidity being associated with a low calcium concentration, as shown in Figure 1 (Cresser *et al.*, 1987).

The concentration of calcium which passes from soil into drainage water in the short term depends upon the proportion of the negatively charged ion exchange sites in the soil which are occupied by calcium in preference to other positively charged ions, a parameter termed the % calcium saturation. The higher this percentage occupancy, the more readily the calcium will pass into solution, other factors being equal. Billett and Cresser (1992) used data from soil surveys and analyses from a two year study of river water quality in 10 catchments in north east Scotland to show that there were excellent relationships between concentrations of river water calcium and river bank soil calcium (Fig. 2). They showed that it was thus possible to model water quality parameters from riverside soil characteristics, provided the approximate route of the water from where it fell to the river channel could be estimated from soil and topographic maps.

The above observation has far-reaching consequences in the present context. It implies that it is possible to predict precisely what practical measures can be taken to maintain or restore a desired calcium concentration in the water of a particular river. Results for prediction of water acidity were also encouraging (Billet and Cresser, 1992). It also follows that data on the effects of tree growth of particular tree species upon key soil chemical parameters (Billett *et al.*, 1988, 1990) may be used to predict the effects of changes in land use and tree planting upon important water quality parameters.

3. Pollution, Land Use and Soil and Water Change

As discussed above, the mobility of individual ionic species, including hydrogen ions (acidic) and base ions such as calcium (alkaline) from river-side soils into rivers depends upon the relative abundance of those ions on ion exchange sites in the soil. This abundance depends upon the relative sizes of the sources and sinks of the ion of interest. In unmanaged ecosystems, inputs come primarily from biogeochemical weathering of soil minerals and from the atmosphere, for example as dry deposited dust, or in rain or snow. Plant litter also provides inputs, although these may just involve element recycling. On

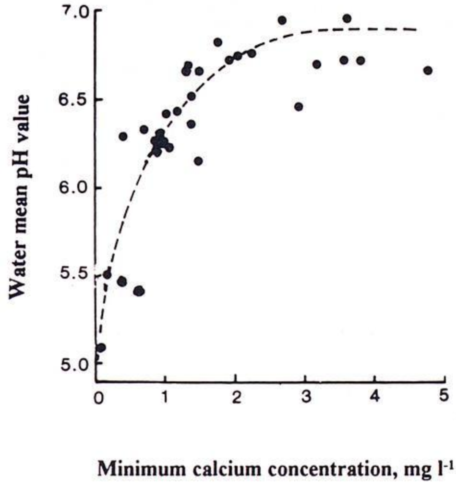

Fig. 1. Relationship between river water mean water pH values and the minimum calcium concentrations observed in a set of monthly samples from 30 rivers taken over a 12-month period

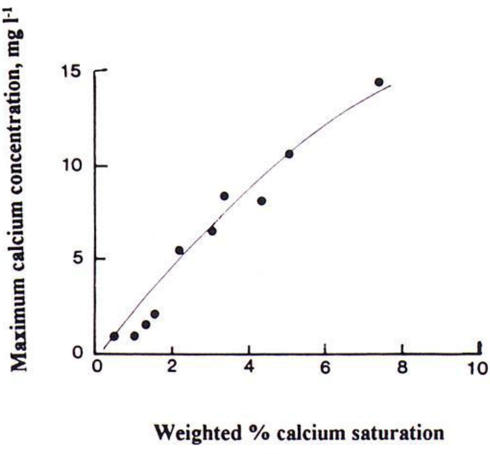

Fig.2. Relationship between maximum river water (low baseflow) calcium concentration observed for weekly samples from ten catchments over two years and flow pathway weighted % calcium saturation of the riverside soils.

typical upland sloping sites, inputs may also come in drainage water. Outputs are associated primarily with drainage water losses, although removal by plant uptake is also sometimes substantial, especially in the case of trees. Thus tree growth may reduce soil base ion concentration and cause acidification of both soil and associated drainage water.

Whether tree growth does or does not cause soil and water acidification has been a bone of contention between some foresters and some conservationists for years. A recent review by Alexander and Cresser (1995) has helped to clarify this situation. They pointed out that if soil mineral weathering is capable of replenishing the ions lost by tree uptake, the soil base saturation will not necessarily fall and the soil will not normally acidify to any great extent. In sensitive soils, such as those derived from quartzites, some old sandstones and granites (Barton *et al.*, 1994), afforestation is eventually likely to lead to soil acidification, unless ameliorative steps are taken at planting or during the early forest growth period. These might include, for example, a fertiliser dressing with a ground rock with an adequate content of weatherable minerals to replenish base ion losses caused by tree uptake.

Acid pollution in deposits from the atmosphere may also cause acidification of soils and associated drainage waters (Skiba and Cresser, 1989). For example, in Scotland there is a significant positive correlation between rainfall acidity and soil acidity for moorland soils derived from granites (Barton *et al.*, 1994). Potential adverse effects of tree growth and pollution deposition in combination have been a cause of particular concern over recent years. However precise prediction of effects is complex because of the dynamic nature of ecosystems, and because tree growth may influence the amounts of pollutants deposited, the amount of organic matter in the underlying soils, and the local hydrological behaviour of the catchment. It is, nevertheless, not advisable in a long-term perspective to plant trees adjacent to rivers if the soils are evolved from acid sensitive materials without taking additional management steps to combat potential acidification. On sloping sites, however, in a shorter perspective, no adverse effects may be seen for several years, or even decades, because of the beneficial effect in the interim of enhanced base ion leaching from up slope.

A factor which should be considered briefly in the present context is the possible differences in impacts of various tree species. Species effects may occur via a number of mechanisms (Alexander and Cresser, 1995). In winter, evergreen coniferous species clearly are likely to have more effect on pollutant trapping and upon catchment hydrological pathways and snow melt than deciduous species. Moreover, they tend to produce more acidic litter layers than most deciduous species, and this difference tends to become more marked as litter decomposition proceeds. However, heather litter is also highly acidic. Effects restricted to surface litter and superficial organic soils are likely to have most effect upon water quality during acid episodes. Unfortunately little quantitative information is available upon the effects of acid episodes on fish at different times of the year.

4. River Banks and Sediments

There is much opposition from the fishing community to afforestation of the catchments of good fishing rivers arising from fears of serious mineral soil erosion following ploughing and planting, and of the associated adverse effects of high sediment loads on the freshwater system ecology. The extent to which this may be a problem depends upon the extent to which planting guidelines are adhered to and interpreted sympathetically on a catchment-by-catchment basis.

River bank vegetation also contributes substantially to the sediment load carried by a river. In the case of river bank trees, there may be marked seasonal differences in the monthly litter loads deposited. The table below summarises the origins of organic load at any point in a stream. It must be realised that organic litter entering rivers may be either beneficial, in terms of its contribution to the food of freshwater species that feed fish, or potentially damaging. Where a small stream passes through a densely wooded catchment, the organic matter load may be effectively all derived from outside the stream itself. For a lightly wooded area, on the other hand, the more modest input from the trees may enhance production in the stream itself, and be of benefit to the fish prey species. An excessive input of woody litter is likely to be more damaging than a more leafy litter input.

5. Sources of Organic Matter Inputs to Fresh Water Streams

Type	Source
From outside the stream:	
Meteorological	
1. Litter fall	Terrestrial
2. Blown litter	Terrestrial
3. Throughfall	Terrestrial
Geological	
4. Sub-surface seepage	Terrestrial
5. Stream flow	Upstream
From inside the stream:	
Biological	
6. Primary production	*In situ*

The decomposition rate of woody litter in streams depends upon the nature of the woody material to a large degree. Woody litter from species such as spruces and firs generally has a higher lignin content and a lower nitrogen concentration than woody litter from species such as birch and alder, and as a consequence tends to decompose more slowly.

So far, organic inputs have been considered in terms of plant-derived material only. However riverside trees also may contribute directly to the aquatic species food chain via insects falling into the water from overhanging vegetation. In this respect hardwoods are generally regarded as being likely to make a greater contribution than conifers (Alexander and Cresser, 1995).

6. Riverbanks and Shading

Both because of direct effects of excessive shade, and because of the adverse effects on in-stream productivity, it is apparent that relatively open canopies adjacent to rivers are likely to be beneficial, whereas dense canopies may be injurious. To some extent, of course, the optimal canopy density must be related to the stream channel width.

7. Conclusions

The control of the chemistry of soils adjacent to rivers provides a method for regulation of water chemical quality, especially for avoiding excessively acidic pH and low calcium concentrations. Planting appropriate trees along river banks may be beneficial in terms of providing food for freshwater food species, provided excessive shading is avoided, and provided the soils being planted are not highly susceptible to acidification. If they are, compensatory additions of suitable fertiliser, capable of releasing sufficient base ions to offset additional demands resulting from afforestation, should be applied.

8. Acknowledgements

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Water Quality in the Dee Catchment

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1. Introduction

The Dee and its tributaries support a world renowned salmon fishery, riverine habitats of great diversity and naturalness, and an indigenous wildlife of major importance. These waters are used for potable supply, recreation, angling and are a great asset for public amenity and the local economy. The waters of the whole Dee catchment are designated as salmonid under the terms of the European Freshwater Fisheries Directive which provides statutory protection for the fishery.

As the statutory authority with regard to the control of pollution in the Dee catchment the North East River Purification Board (NERPB) has developed an extensive water quality monitoring network. Breaches of effluent standards and impacts on water quality from licensed discharges or, indeed, pollution from any unauthorised discharges can be detected by this network.

The waters of the Dee catchment are generally regarded as being of excellent quality and suitable for supporting a healthy salmonid fishery but there are pressures on this resource. The urbanised areas in and around Aberdeen give rise to various industrial discharges and towns and villages discharge treated sewage effluents into the catchment watercourses. These point sources of effluents are strictly controlled by consent conditions so that the rivers and streams remain in prime quality and enforcement action is taken against any breaches of effluent quality standards.

There are also a number of diffuse sources of pollution which are more difficult to control. One intensively agricultural sub-catchment shows symptoms of excessive nutrient enrichment of standing waters and some montane areas clearly exhibit acidification of watercourses. It is vitally important to continue to manage the catchment for best water quality so that the character and uses of the river can be maintained.

The apparent decline in the salmon fishery naturally begs the question of whether water quality might be a contributory factor. Future potential developments, such as large scale afforestation, also need to be judged carefully for their possible water quality effects.

2. Habitat and Water Quality Requirements of Salmonid Fish

The standards of habitat quality required to support a healthy salmonid fishery are well known (Table 1) (Forestry Commission, 1993). Water quality criteria are laid down by the EC Freshwater Fisheries Directive (Table 2) and the NERPB is obliged to return data to show compliance with the Directive.

Table 1. Water quality requirements of salmonid fish

Cool Range	5-15°C, not greater than 21°C
Oxygenated dissolved oxygen	Always greater than 60%
pH	Ideally between 6 and 9
Clean gravel	Low suspended solids and silt
Clarity	Very dark colour hinders feeding
Cover	In-stream shelter, deep water, overhanging vegetation, undercut banks
Food	High abundances of invertebrates

Table 2. Mandatory requirements of water quality for salmonids in the fresh water fisheries directive

Temperature	< 21.5°C
Dissolved oxygen	> 9.0 for 50% time (mg/l) > 7.0 for 100% time
pH	6 - 9
Non-ionised ammonia	< 0.025 (mg/l NH_3)
Total ammonia	< 1.00 (mg/l NH_4)
Residual chlorine	< 0.05 (mg/l HOCI)
Total zinc	< 0.3 (mg/l Zn)

3. Water Quality Trends

The NERPB monitoring network comprises some 162 sites on rivers at which regular environmental (chemical and biological) information is recorded. In addition, there are 112 licensed discharges sampled for consent compliance. The environmental monitoring sites include both strategic sites, where overall background information is collected, and impact sites, which are specifically located to detect the effects of particular discharges. The Board also operates nine primary gauging stations in the catchment which supply flow information. Water quality data is available for at least the past 15 years for many sites while flow information has been collected from Cairnton, for example, since 1929.

4. Chemistry

A useful comparison can be made between the Dee, the Don and the Ythan, which are all north east of Scotland rivers but with quite different catchment pressures reflected by their quality of waters. Data has been collected monthly over the past 10 years which clearly indicates the superior quality of the Dee. Concentrations of phosphorus and nitrogen are good markers of general enrichment through agriculture and sewage disposal and on both counts the Dee is much less influenced by these than the Don or the Ythan. Biochemical Oxygen Demand is a measure of the organic load received by a watercourse and the low (< 2 mg/l) long term mean and especially the relatively low maximum concentrations for the Dee demonstrate only slight organic loading at Milltimber.

A number of other chemical parameters are regularly measured at the monitored sites which are useful for the detection of different pollutants. As a general indication of water quality it is helpful to summarise this data into a single index. The NERPB uses a Water Quality Index (WQI) which combines information from nine chemical determinants (Table 3) and the resulting index gives values between 0, worst possible quality, and 100, best possible quality. Comparing the WQI of the same three rivers at their lowest sites clearly demonstrates the excellent quality of the Dee.

Table 3. Parameters combined in the water quality index

Dissolved oxygen	Soluble reactive phosphorus
Biochemical oxygen demand	Suspended solids
Ammonia	Conductivity
pH	Temperature
Total oxidised nitrogen	

This excellent chemical water quality is recorded at the great majority of monitored sites, including all the major tributaries. However, there are a few watercourses with significant quality problems in the lower part of the catchment. Even in these cases, however, the quality of the main stem of the Dee remains unaffected.

5. Biology

The ultimate damaging effects of any pollutant are on the organisms that live in that environment and the health of the ecosystem can only be finally judged by biological examination. These methods will detect pollutants not normally monitored by chemistry and those that are intermittent. Biological information also provides an overall view of background quality, for example, with regard to diffuse sources of pollution.

The analysis of bottom-living freshwater invertebrates (eg insects, molluscs and crustacea) at the monitored sites is a very useful technique and the interpretation of such data has been refined in recent years so that very reliable water quality information can be derived. The BMWP Score places a value between 1 and 10 on particular groups of invertebrates depending on their tolerance to pollution. An average score can then be calculated and both the total and average scores provide a good indication of water quality over the preceding period. Figure 1 compares the BMWP Average Scores as annual means over the past 10 years for the Dee and the Don at their lowest sites.

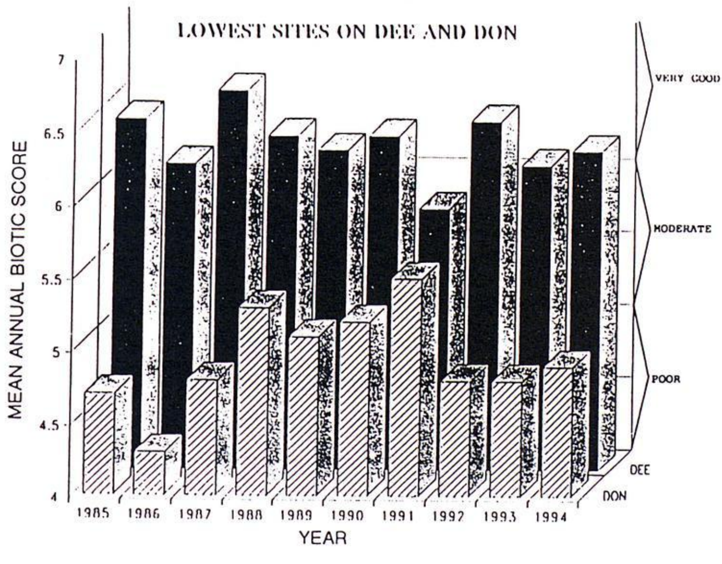
In general any score over 6.0 represents a healthy, diverse population of invertebrates showing little or no stress from organic pollution. Any score below 5.0 can be taken as indicating a modified pollution-stressed population. Clearly, the Dee has an excellent record of biological health in contrast to the Don at its lowest monitored site in Aberdeen. Similar high biological class pertains, with very few exceptions, at the other Dee catchment sites. While the long-term water quality of the Don has shown remarkable variation as pollutant loads have changed over the past 10 years that of the Dee has remained consistently high.

6. Current Catchment Pressures

6.1 Sewage discharges

Each town and village within the Dee catchment discharges domestic sewage to watercourses. In general, these effluents are well treated to remove most of their organic load and the conditions of discharge ensure that their receiving waters can cope with and assimilate the remaining material. A few small waste water treatment plants do have a detectable impact on the immediate receiving water but even here adverse effects on biological health are negligible. Occasional failures of treatment plants or the unauthorised

Figure 1



LOWEST SITES ON DEE AND DON
MEAN ANNUAL BIOTIC SCORE
7
6.5
6
5.5
5
4.5
4
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
YEAR
DEE
DON
VERY GOOD
MODERATE
POOR

discharge of wastes have led to pollutions which are vigorously pursued by NERPB staff. It is vitally important that anglers and other river users report such incidents immediately.

Two large discharges of untreated sewage are made to the Dee Estuary within Aberdeen Harbour. Grampian Regional Council has committed a capital programme to the removal of these discharges by 1997. Since these discharges have been present for many years it is not considered that they present a significant threat to the passage of salmon through the estuary and there is no evidence of any recent adverse effects on migratory fish.

6.2 Acidification

The NERPB became aware of growing concerns on the potential adverse effects of the widespread atmospheric deposition of acid pollutants derived from power generation and other sources in the early 1980s. To determine the extent of acidified waters and thereafter to monitor trends in acidification a special network of sites was established in 1983. The network included sites in the upper Dee catchment and both chemical and biological monitoring was employed to detect acidification.

The initial single survey in 1983 covered some 82 sites in the Cairngorms and other upland areas in the Dee and Spey catchments. It was immediately seen that a proportion of smaller watercourses, on the more sensitive rock types and soils, were already acidified. These included some streams in the Muick catchment where Lochnagar granites predominate. It was also noted that many other streams were not acidified, even those at high altitudes, and a few others could be said to be sensitive to acidification but not yet acidified. The distribution of sensitive and non-sensitive streams could be related mainly to underlying geology. Table 4 shows the proportions of these stream types in the initial survey.

Table 4. Alkalinity of headwater streams in the Spey and Dee catchment, August 1993

Alkalinity (mg/l)	Description	No of sites	%
<10	Sensitive	15	18
11-29	Intermediate	45	55
>30	Not sensitive	22	27
Total		82	100

It should be remembered that the initial survey was biased towards upland streams, for the most part in the montane regions of these catchments, and that these proportions are not representative of the Dee catchment as a whole. It is very likely that the percentage of sensitive streams is very much lower for the whole Dee catchment.

It is interesting now to see what the trends in acidification have been at some of the 17 sites selected for long term monitoring. Figure 2 shows monthly pH data, a simple measure of acidity, at an acidified site (Glas Allt in the Muick sub-catchment) and at an intermediate site (Quoich Water).

Despite the differences in means and ranges of pH between the sites there is no detectable trend towards increasing acidification. The same inference can be made at all other acidification monitoring sites. The detailed chemical data accords with that from other sources which suggests that there is an overall decrease in sulphur deposition (from power generation) but an increase in nitrogen oxides (from vehicle emissions).

A drawback of this long term programme is the relative infrequency of the regular monthly measurements for chemistry which must miss many of the extreme acid events. Nevertheless it is considered that the data set is good enough (at 120 data points for each site over 10 years) to be able to come to reasonably firm conclusions. To obtain further information on acid episodes the NERPB is currently considering, with the Dee Salmon Fishery Board, the deployment of continuous pH monitoring equipment at a site on the upper Dee.

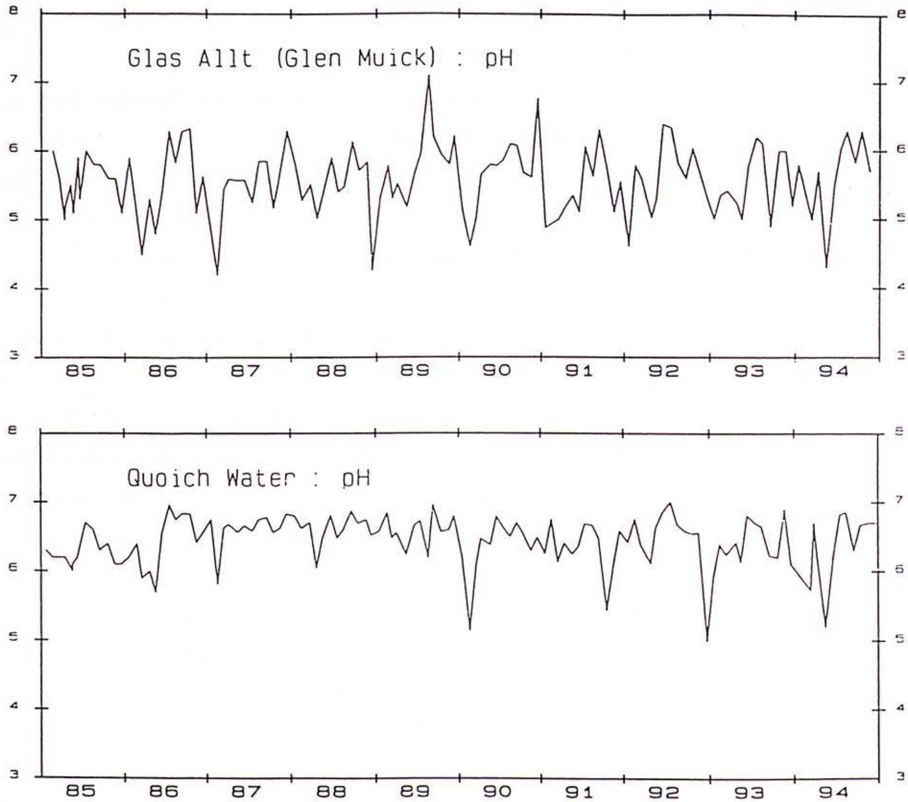
6.3 Eutrophication

The River Dee and most of its tributaries are some of the best examples of large, nutrient poor, running waters in the UK. This reflects the upland nature of the catchment with relatively little intensive agriculture. Nevertheless, there are a few areas where the effects of nutrient enrichment are discernible. The sub-catchment containing the Loch of Skene is particularly affected by enrichment with phosphorus. The resulting eutrophication of the loch has led to the annual production of very large quantities of floating blue-green algae in the summer months. These algal blooms are often of species which are potentially toxic to fish, livestock and people.

In these circumstances it is important to manage effluent discharges in the sub-catchment to minimise the phosphorus loads from point sources. Consideration has been given to removal of phosphorus-rich bottom mud in the loch, to the use of barley straw as an algal inhibitor and to bankside management techniques. However, effective remedial

Figure 2

A 10 Year Comparison of pH in a Sensitive and an Intermediate Stream in the Dee Catchment



measures are difficult to achieve where agricultural activities are the dominant source of nutrients. The enriched waters of this sub-catchment do not appear to affect the main stem of the Dee markedly or to obstruct salmon migration.

7. Potential Future Pressures

7.1 Afforestation

Forestry and woodland is already part of the landscape and character of Deeside and it is true to say that there is potential to plant or regenerate on much of the currently unforested land. A recommendation of the Cairngorm Working Party (1992) was the consideration of a Forest of Mar which would include large areas of naturally regenerated pine forest and of commercial forestry. This forest would extend over large areas of upper and middle Deeside and provide landscape, recreational and economic benefits.

While the mosaic of habitats associated with natural pine forests would very likely benefit the fishery there are a number of potential adverse effects on watercourses from widespread commercial activities. Water yields and summer base flows are generally reduced in catchments under mature commercial forest. Initial ploughing and drainage, especially in peaty or wet areas, has often led to increases in peak flows and to the transport of large quantities of sediment. High turbidity adversely affects fish feeding and deposited silt may swamp good spawning gravels. Fertilisation programmes certainly increase the concentrations of nutrients in afforested catchments and can lead to excessive algal growths smothering out the diverse habitat required for fish food organisms. On the other hand, over-shading through closed tree canopies will drastically reduce plant production and affect the food chain. The afforestation of catchments sensitive to acidification can seriously exacerbate these effects and lead to major problems for the fishery.

All of these effects can be mitigated through careful forestry management practices which protect watercourses (Forests and Water Guidelines, 1993) and their ability to support healthy fish populations. The regulatory authorities would, however, need to ensure that fisheries-sensitive management was strictly enforced on Deeside. The assessment of catchments liable to acidification has now been refined to the point where sensible decisions can be made on where to avoid afforestation.

7.2 Abstraction

The River Dee has a long history of abstraction for water supply and the current water abstraction order operated by the supply authority is for a maximum of 0.810 m^3 per second (m^3s^{-1}) at Invercannie and for 0.868 m^3s^{-1} at Inchgarth when river flow allows. The Dye sub-catchment is also abstracted at a maximum allowable limit of 52.62 litres/second provided the river flow downstream is at a minimum of 78.9 ls^{-1}. These abstractions are made with regard to protecting river flows in drought conditions. Other smaller abstractions are made for water supply and for crop irrigation throughout Deeside. Unfortunately, the NERPB has no powers to control these demands for water and under current proposals nor will the new Scottish Environmental Protection Agency to be formed in 1996. Any significant increase in the demand for water supply could pose a threat to the well being of the salmon fishery.

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Soils, Land Use and Water Quality

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1. Introduction

Understanding the relationships between the water in a river and the land which the river drains involves examining the physical resources of the catchment, their relationship with the river, and their interaction with land management and land use. This develops a view of the river and its catchment as an integrated whole - a system of interrelated components that interact to produce the whole environment - and requires a view of the subject from a wide range of scientific and management perspectives. This multi-disciplinary approach is increasingly necessary as awareness grows of the interdependence of environmental and socio-economic potential, options and impacts.

Catchments provide a coherent geographic region for management and planning of resource use and also are a natural unit for analysis of relationships between physical resources, land use practices, and river water quality as well as socio-economic and cultural factors. A wide range of issues operate in, and effects, catchments. Land use decisions, management practices and policy constraints and opportunities, operating at a range of geo-political scales, interact with the biophysical and socio-economic resources of a catchment to produce diverse responses in different, related components of the catchment environment. This complex, interactive environment of human and physical components is increasingly being considered using an holistic approach that incorporates systems theory, exploratory models and information technologies to integrate planning, management, development and conservation. Increasingly, an integrated approach to catchment management combines these methodologies with individual and community participation.

Interaction between physical properties of the catchment, land use and water quality of the river has been carried out using a variety of techniques. These include field measurement and survey, laboratory analysis and experimentation, as well as physical, mathematical and computer-based simulation modelling. Data for these studies comes from field measurement and sample collection, laboratory analysis and remote sensing (air photographs and satellite imagery) and maps. Modelling is necessary to understand the information provided by these different data sources. Generally, different aspects of a catchment are studied in some isolation. Examples of components of catchment chemistry are described below. The ability to relate these different issues and aspects, to make predictions using models, and to combine very different disciplinary perspectives is one of the emerging strengths of systems modelling and the use of computer based Geographical Information Systems (known as GIS) and these topics are briefly discussed later in this paper.

2. Acidification

Analysis of acidification provides an example of the importance of climate, soil, land cover, and water quality interactions to water quality aspects of catchments. Understanding these interactions is the subject of scientific research using two approaches, so-called "critical loads" mapping and field-sampling linked with modelling, and reveals the way in which different approaches to the same issue can provide information for land use planning and management.

Soils are naturally acidic in areas with high rainfall and base-deficient rocks and soils. These conditions are found in much of upland Scotland. Soil acidity is also influenced, however, by human activity through atmospheric inputs (acid deposition) and by the effects of different land uses on environmental chemistry. Acid pollutants derived from fossil fuel combustion are transported through the atmosphere and deposited in rainfall or as dry deposition. The "critical load" approach (Bull, 1991) uses information on the geographical extent of vegetation, soils and waters to assess areas with different sensitivities to pollutants (Langan and Wilson, 1994). A critical load is an assessment of the level of pollutant that can be tolerated without significant harmful effects on a specified element of the environment. Assessments of the critical loads of acid deposition on Scottish soils (Langan and Wilson, 1994) and surface waters (Langan and Wilson, 1992) have been made using geology, soils and land use data. These maps can be combined with maps showing the geographical variation in atmospheric acid deposition to identify areas where critical loads are being exceeded. This information can be used for strategic planning and helps relate within-catchment acidification issues to wider concerns about the state of the environment on a regional and national scale.

Critical loads analysis currently provides a detailed regional-scale assessment of potential impacts of acidification although it has potential for extension to more local scales. For local scales of analysis, however, an approach based on field survey and monitoring linked to modelling is more usually used. The model MAGIC (Model of Acidification of Groundwater in Catchments) is a process-oriented intermediate-complexity dynamic model that constructs and predicts long-term trends in soil and water acidification at a catchment scale (Cosby *et al.*, 1985a,b). The model uses a series of equations to describe the processes that influence water chemistry as water drains through the vegetation and soils in a catchment and into rivers. Descriptions of soil conditions and properties, as well as land cover in the catchment are used in the model. Including land cover in any analysis has obvious relevance given the influence of forestry in exacerbating acid deposition as trees scavenge acidic pollutants from the air (Miller *et al.*, 1991). Work carried out jointly by MLURI and the Institute of Hydrology has shown that MAGIC can be used to predict the effects on soil and water chemistry of land use changes in a catchment under different scenarios of acid deposition (Ferrier *et al.*, 1993). The link between water chemistry and fish stocks also allows a modelling approach to be used to evaluate the economic impact of acidification.

3. Nitrification

Links between water chemistry and catchment land use are also clearly shown through study of eutrophication. This is the enrichment of water by nutrients, especially by compounds of nitrogen and phosphorus, and causes accelerated growth of algae and higher plants leading to a change in the balance of organisms present in the water. A study of land use and nitrates in river water in the Dee, Don and Ythan catchments in North east Scotland has found the concentration and load of nitrate in river water to be proportional to the amount of agricultural land in the catchment (Edwards *et al.*, 1990). This link shows the result, but not the mechanism, of a wide range of hydrological and chemical processes that operate within a catchment and that link the river to the land. Further work is developing process-based models that attempt to explain and predict the impacts of land management practices on river water quality (eg Ferrier *et al.*, in press).

4. Data, Knowledge and Skills needed for Integrated Catchment Management

The use of systems modelling, information technologies and models to develop integrated analyses that support management and planning at catchment scales is at the root of current efforts towards Integrated Catchment Management. Integrated Catchment Management goes beyond consideration of single themes or properties of catchments in isolation, but rather considers the interaction of diverse themes and properties of both the cultural and physical environment.

For management of specific catchments, attention must be paid to the specific pattern of land use and other activity in relation to the full range of environmental variation in the catchment. For this, GIS offers a suitable working environment that allows descriptions of catchment resources to be managed and used for modelling and analysis. GIS also allows integration of diverse data through a common geographic referencing system and assists in coupling analysis of different components of catchments. A computer-based systems model linked to GIS which quantitatively evaluates alternative land use options and their impact on properties and processes in a catchment provides a general framework for environmental monitoring and modelling at catchment scales.

This view of rivers and their catchments as an integrated whole inevitably requires that a wide range of perspectives be brought to the complex issues it presents. This involves a range of scientific disciplines (eg biologists, ecologists, fisheries scientists, geneticists; earth and environmental scientists, hydrologists, geomorphologists, soil scientists, environmental chemists; and socio-economists) but also, importantly, includes land owners, land users (farmer, forester, fisherman and ghillie), land managers and planners.

The fusion of physical, biological, geographic and socio-economic sciences applied to practical land management and land use issues is increasingly being termed "Land Use Science" and has an obvious role in catchment management. Understanding interactions between rivers and land through catchment studies offers a powerful framework for connecting diverse land use issues and appreciating the way in which different land use practices influence one another. The methodologies and techniques needed to pursue an integrated approach to catchment management are now available as systems modelling is coupled with information technologies, especially GIS, to coordinate and couple analyses of the different components of catchments. Specific objectives of applying scientific principles and analyses to catchment land use and management issues must however, be combined with local knowledge and involvement to ensure practical solutions to catchment management issues.

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The Dee Salmon Action Plan

Michael Bruce

1. Introduction

Following the success of the "Dee Campaign" the Dee Salmon Fishing Improvement Association (DSFIA) approached Grampian Enterprise Ltd (GEL) for support to analyse a perceived marketing problem amongst fishing owners of the Dee.

As the study progressed it quickly became apparent that the marketing issues were inextricably linked with low catches ie low stock levels. The key marketing solution therefore was for owners of fishing to be seen taking action to improve the level of salmon stocks in the river.

The Dee Salmon Action Plan is the collective response of the Dee Salmon Fishing Improvement Association and the Dee District Salmon Fishery Board to this challenge.

The report analyses the drop in catches especially of the spring catch, February to May, and consequent effects on the customer base. It establishes that a significant reason for this decline has been high levels of sea mortality. It suggests a number of strategies and actions that could be taken to improve the situation.

The key strategy that the report recommends is for the industry to take both short and long term action to increase the number of smolts produced to sea. It also recommends that resources are concentrated on the upper catchment, ie west of Aboyne.

In broad terms the Dee Salmon Action Plan addresses the three elements of this overall strategy by:

a) Indicating where, how and by whom short term measures can be taken to ensure full utilisation of the existing habitat by young salmon.

b) Indicating where and how longer term environmental improvements could be made that would increase the carrying capacity of the river system by increasing the quality of stream habitats.

c) Concentrating resources on the western part of the catchment - the nursery areas for spring salmon.

2. Background

2.1 Salmon stocks and biology

The Dee is different from most of the other major salmon rivers in Scotland in that it is very heavily reliant on its stock of spring fish. Other rivers have a more significant summer and autumn run of salmon. Spring salmon stocks have fallen dramatically throughout the north Atlantic. The Dee is particularly sensitive to changes in this stock. That being said the Dee according to the latest figures available still catches more spring salmon than any other river in Scotland (Scottish Statistical Bulletin 1992).

Other studies have identified weaknesses in the sea stage of the MSW salmon's life cycle, especially in the feeding grounds off the west coast of Greenland. While at the river end of the life cycle this has been reflected in a dramatic drop in the proportion of smolts returning as adults (eg on the North Esk).

On the Dee this is manifested as low stock levels in the river system and low catches. That there is a relationship between the spring catch on the Dee and the problems off the west coast of Greenland was suggested by evidence included in the Grampian Enterprise report.

Information from the Girnock and Baddoch fish and smolt traps and the electro-fishing surveys of the Dee carried out in 1989 and 1994, when combined with estimates of available habitat, has shown that our immediate problem is a lack of broodstock.

The Dee like other major Scottish rivers has also suffered a series of massive floods since 1990, especially in 1993. There is some evidence from the 1994 electro-fishing survey that this has reduced the number of one year old salmon. This means that habitat improvement work should include stabilising silt generating areas.

2.2 Roles and Responsibilities

The DSFIA and DDSFB are the two organisations central to the achievement of the plan. The legal remit of the DDSFB is limited but as the DSFIA is an association it can undertake a very wide range of tasks to support its members interests. In general, actions which directly affect the fishery are being undertaken by the DDSFB. Everything else is the responsibility of the DSFIA.

A technical sub-committee has been formed to identify and prioritise objectives, goals and actions and to get the plan implemented. The plan is complex with many different actions and organisations identified in it. The DSFIA with its remit has taken on the task of overall coordination of the DSAP,

3. Strategies, Objectives and Actions

The DSAP is split into six sections. The main strategies and objectives for each strategy are explained below.

Section 1

Strategy

To collect sufficient information to prioritise actions within the western catchment of the Dee.

Objectives

1.1 To identify understocked areas of the western catchment.

1.2 To identify the cause of understocking.

1.3 To improve the information base to allow prioritisation of stock enhancement and habitat improvements.

Priorities Established

1. Stock conservation.
2. Stock enhancement via hatchery.
3. Improve control of predators.
4. Habitat quality improvements. Use computer derived models (GIS) to establish best areas for improvement.

Section 2

Strategy

To actively increase the number of smolts produced to sea while conserving the genetic integrity of populations.

Objectives

2.1 To improve accessibility of understocked tributaries to salmon.

2.2 To increase utilisation of all potential nursery habitat.

2.3 To reduce loss of juvenile parr and smolts from predation.

2.4 To consider changing the seasonal pattern of the fishing effort within the DDSFB area.

2.5 To consider changing the seasonal pattern of the fishing effort outwith the DDSFB area.

Section 3

Strategy

To improve the carrying capacity of the river system by increasing the quality of stream habitats.

Objectives

3.1 To improve the overall condition of the riparian zone.

3.2 To reduce sediment input.

3.3 To improve water nutrient status.

3.4 To increase food supply available to juvenile salmonids.

3.5 To reduce peak water temperatures on upper spawning tributaries.

3.6 To improve stream flow patterns.

Note: The single action that will be most effective in achieving all these objectives is the establishment of a buffer strip 10-30 metres wide; with good natural vegetation, especially native broadleaf trees, along ALL watercourses in the catchment.

Section 4

Strategy

To create a monitoring, development and research programme that supports the needs of the Dee Salmon Action Plan.

Objectives

4.1 To gain agreement among the many research organisations to collect data in a coordinated way.

4.2 To gain agreement to investigate all avenues of mutual support.

4.3 To ensure that from all future research the catchment managers gain information that is relevant to their needs.

Section 5

Strategy

To build bridges with long loyal customers to take the action plan forward together.

Objectives

5.1 To ensure that everyone connected with supplying salmon fishing is aware of the benefits that accrue from the use of customer care techniques.

5.2 To create links, including associate membership, with our loyal customers.

5.3 To ensure that the Dee is attractive to current and potential fishing clients in terms of cost and quality.

5.4 To increase information to potential customers on the availability of fishing and accommodation on Deeside.

5.5 To identify and communicate with all important target audiences, key organisations and individuals.

Section 6

Strategy

To create the motivation to have the plan resourced and implemented.

Objectives

6.1 To motivate all key players to adopt, resource and implement those parts of the plan that fit with their own organisation's objectives.

6.2 To explain to local, national and fishing publics the need for immediate positive action.

6.3 To persuade organisations to allow personnel to operate outwith their normal roles in support of the DSAP.

6.4 To persuade organisations and individuals to find additional financial resources for the DSAP.

6.5 To obtain finance from fundraising.

General Discussion

Some of the speakers were questioned after their individual presentations and a more general panel discussion was held at the end of the programme. The summary of these question and answer sessions and the open discussion has been divided into several sub-headings for clarity, but the topics are not arranged in any order of priority.

1. Juvenile Fish Habitat

The experiments investigating the movements of juvenile salmon, *Salmo salar* L., appear to presuppose that there are spare fish available to move into experimentally depleted areas. However, it has been shown that in their first year as juveniles, salmon parr suffer high levels of mortality and do not move within their particular habitat. It may be that they would be less likely to find a suitable niche if they did move and the strategy is to remain in their known habitat. There is highly likely to be variation in movement strategy, however, with fish from an unstable environment differing in behaviour from those living in a more stable habitat. Brown trout, *Salmo trutta* L., are considered to be more mobile than juvenile salmon and appear to establish larger home ranges.

The factors which trigger juvenile salmon to move between summer and winter habitats were considered. One of the major factors is probably water temperature. There is a large change in fish behaviour when water temperature falls below about 8 to 10°C. Parr switch to feeding at night at decreased temperatures to avoid predators and it is therefore likely that movement to "winter" habitat occurs when temperature declines below a certain threshold level. Temperature is also a major factor affecting growth but unfortunately temperature in the natural environment cannot be readily influenced.

2. Erosion

A view expressed at the meeting was that since there are many man made environmental impacts on river flow characteristics, such as change of land use, erosion should be controlled by bankside protection schemes. Gravel can fill pools resulting in a loss of adult salmon holding areas so it would seem to be good management practice to fortify river banks to protect against erosion. It was felt, however, that protecting river banks against erosion would only be sensible if it was possible to be sure of the "knock-on" effects of fortification works. The problem is that there may be insufficient data to accurately predict bankside erosion events subsequent to anti-erosion work. There are many examples of failure where adverse effects of upstream bank protection schemes have caused erosion further downstream. It is not yet possible to accurately predict the consequences of particular anti-erosion measures.

In relation to the impact of environmental changes, such as altered land use, it is difficult to prove the effects of changes since they are moderated further downstream. For example forest drainage increases run-off initially, but once the forest is established tree growth tends to dry up the area, with clear felling again increasing run-off and sediment transportation.

To protect valuable bankside assets, however, it is necessary to take steps to avoid erosion. In certain areas it may be sufficient to manage the bankside vegetation so that erosion is reduced or prevented by consolidating the bank structure. Grazing animals should be excluded and suitable additional vegetation planted if necessary. Other benefits accrue from such bankside management schemes and will be discussed later.

3. Acidification

There was considerable interest in the topic of acidification and several of the contributors commented on points raised. It was suggested that snow melt could reduce pH by the release of concentrated atmospheric pollutants as an acidic flush. The effect of snow melt on pH, however, depends largely on whether the sub-surface ground is frozen. When sub-surface soil is frozen the snow melt water only contacts the upper few millimetres of soil. If this is the case then acid flushes can occur and these tend to be more acidic than in previous recorded history. Such events can of course vary annually depending on climatic conditions.

It was agreed that the best method of evaluating pH at sample sites was with a continuous monitoring approach. Monthly monitoring may not be adequate to detect short-term acid flushes and problems of periodic acidification may not be registered. Reference was made to Scandinavian systems where rivers can be pure but biologically sterile because they suffer from destructive episodic acid flushes.

An extreme case of acidification in an upper tributary, the Glas Allt flowing into Loch Muick, was shown where reduced pH is attributed to the thin soil in the area and the underlying granitic bedrock, however, this tributary is impassable to salmon. Loch Muick itself and other tributaries in the area are of high quality with pH in the region of 6 to 7. The Glas Allt is the worst case from 21 monitored sites on the River Dee and there has been no trend towards increasing acidification.

In general, few of the monitored sites in the Cairngorms have been found to be acidified despite the fact that the area is a granitic catchment. Of 83 sites in the Cairngorms 15 were found to be acidified and classed as sensitive. In general terms about 5 to 10% of the Cairngorm catchment is affected by acidification.

The length of exposure to reduced pH which may cause damage to eggs or juvenile salmon was discussed. It was suggested that not all salmon eggs are equally susceptible to the effects of acidification and some stocks appear to be more resistant than others. Although environmental conditions do not appear to have altered in the Girnock Burn, acid flushes may have caused some problems for egg survival. However, the effects on eggs depends on the depth they are buried and the prevailing water flow conditions.

It was noted that during the 1970s the agricultural liming subsidy was discontinued and the reduction in lime application could have a local effect. There are two techniques which could be applied to combat acidification. Firstly, with the application of course lime on soils immediately adjacent to river banks and secondly by using a ripping plough to break up the indurated iron pan layer in the area surrounding watercourses. However, there can be problems resulting from the application of lime, with pulses of ammonia and nitrate being released into watercourses in addition to the desired elevation of pH. The use of basic ground rock should be considered to raise pH, using deep ploughing techniques to permit input from lower mineral layers but avoiding increase input of sediment.

In conclusion, it was accepted that there may be a minor acidity problem within the River Dee catchment but not sufficient to result in the apparent scale of salmon stock reduction. Although liming would alter the nature of the natural habitat the habitat was already affected by land use changes. It was recognised that there is a need to restore the balance, particularly in upland areas, in a system exposed to 150 years of acid rain resulting from air-borne industrial pollution.

4. Bankside Habitat Management

The discussion focused on ways of improving the habitat for juvenile salmon. Even small improvements to bankside habitats could have an impact on juvenile fish production but the effects of improvement schemes should be monitored effectively to evaluate them. It was suggested that with financial encouragement habitat might be improved, perhaps with a shift in grant aid policy. It was considered that there was tremendous support already from SOAFD but it will take time to convince other departments within the Scottish Office. At present the management structure was area based rather than the linear base preferred for fishery management. Local farmers deal with small environmental or habitat protection problems, but the psychology of the farmer is to maximise income and not primarily to manage the riverside land to the benefit of the fishery. The Cairngorms are currently designated as an Environmentally Sensitive Area (ESA). At present whole farm conservation plans are required to qualify for grant aid, however grants are available for water margin management.

In general there was a consensus that the exclusion of grazing livestock from the bankside is beneficial since erosion is reduced and natural vegetation can regenerate. It was recommended that any replanting along the banks should consist of broad leaved deciduous trees. The Department of Plant and Soil Science at the University of Aberdeen could comment on particular planting proposals and give advice depending on soil type on a site by site basis. However, it would be preferable to draw up an overall Deeside plan with perhaps enough information already existing to provide the planting advice required.

Guides on appropriate tree species for planting are already available from forestry authorities which provide suggestions for suitable trees for particular types of area. Unfortunately forestry has a poor reputation currently due to deep ploughing, introduction of exotic species and the use of chemicals. It was suggested that new grants could be introduced to provide incentives for the exclusion of livestock calculated as a percentage of the capital cost involved. Exclusion of grazing animals would allow natural regeneration which occurs fairly rapidly without replanting.

The buffer strip width recommended would vary depending on the different soil types and the bankside area gradient. Relatively few estate owners farm and most agricultural activity is pursued by tenant farmers. Tenants have a minimal cash flow and are therefore reluctant to enter into conservation projects. It might be better if conservation grants were managed by the ESA or the Forestry Commission. However, strategies for planting and habitat conservation still need information on the factors which limit the salmon population.

5. General Points

The effect of flood events causing erosion and silting of redds were raised during the meeting, but conversely problems can arise when low flows bar entry to spawning tributaries. Entry into tributaries under low flow conditions is a problem for adult salmon and previous research has shown the relationship between redd distribution and river flow. If flow conditions prevent entry into spawning tributaries then adults may spawn "short" in the main stem.

The previous salmon hatchery on the Dee was closed principally because of problems with water quality and supply. Sediment clogged water filters and smothered eggs but in addition hatchery produced fish tended to be released in large numbers into relatively small areas which limited subsequent survival.

The increase in marine mortality of salmon was discussed and although this was generally accepted as the principal factor causing the decline of the salmon stocks the factors involved were not clearly understood at present.

Judging the success of the Dee Action plan and the timescale for its implementation were considered. It would be the responsibility of the Dee District Salmon Fishery Board to implement and monitor the success of the measures suggested in the Action Plan. It was recognised, however, that many of the recommendations would be radical for anglers but the catch and release scheme would mean that the river could remain open as a salmon rod and line fishery. Although it could be suggested that the fishery should be closed because of the reduced state of the salmon stocks, the subsequent loss of employment and income would be unacceptable. The salmon catch and release scheme, proposed as a management measure by the DDSFB would be discussed with The Scottish Office. The situation will be reviewed regularly and further action taken in the future as required.

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