Project 152

The Impact of Land Use on Salmonids
A Study of the River Torridge Catchment

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R&D Report 30

The Impact of Land Use on Salmonids

A Study of the River Torridge Catchment

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Statement of use

This report summarizes the findings of research carried out in the River Torridge Catchment into the relationship between land use, fisheries and water quality. The information contained within this report is for use by NRA staff and others involved in the management of river catchments, particularly those catchments where land use is primarily agricultural. The report also contains valuable information for those involved in formulating land use, water quality and fisheries policies at both local and national levels.

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GLOSSARY

95%ile	95 percentile (similarly 5 percentile)
AARDVARK	Program for analysing temporal trends in water quality data
BOD	Biochemical Oxygen Demand
CEC	Council of the European Communities
CPPR	Average catch per positive licence return
CPR	Average catch per licence return
DO	Dissolved oxygen
DRA	Devon River Authority
Fry	Juvenile salmonids less than one year old
HABSCORE	Salmonid habitat assessment system
NRA	National Rivers Authority
NWC Class	Water quality class assigned using the National Water Council classification scheme
MAFF	Ministry of Agriculture, Fisheries and Food
NLO	Net Limitation Order
NO_2^-	Nitrite
NO_3^-	Nitrate
Ortho-P	Orthophosphate
Parr	Juvenile salmonids more than one year old
PDC	Proportion of returned licences declaring a non-zero catch
R&D	Research and development
RBAK	Rapid Biological Assessment Key
Redd	Gravel 'nest' created by spawning salmonid
RIVPACS II	River Invertebrate Prediction and Classification System II
RQO	River Quality Objective
Salmonid	Salmon, sea trout or brown trout
SS	Suspended solids
SWWA	South West Water Authority
T-amm.	Total ammonia
UDN	Ulcerative Dermal Necrosis (Salmon Disease)
UK	United Kingdom

EXECUTIVE SUMMARY

The intensification of agricultural activity in recent decades has led to considerable concern about the effects on river quality and salmonid fisheries in the UK, particularly from dairy and other forms of livestock farming. This report documents the findings of a three year study on the Torridge Catchment, in Devon, to investigate the circumstantial evidence linking these issues. The Torridge was selected for study because a significant decrease in salmonid rod catches and an apparent deterioration in river quality were reported in the mid-1980s. The catchment is dominated by livestock farming and, over the past 40 years, changes in farming practices have led to fewer, larger farms, supporting increased livestock densities.

Since agricultural intensification had already taken place in the catchment, the experimental component of this study comprised the comparison of current land use, water quality and wild juvenile salmonid populations between contrasting intensively and non-intensively farmed sub-catchments. Historical data from long-term routine surveys were re-assessed in order to confirm the observed environmental deterioration and to place the experimental findings in the context of both the observed long-term changes and the Torridge Catchment as a whole.

Evidence from catch statistics suggests that, despite a substantial decline in the number of rod licence returns submitted since the mid-1960s, there has been a decline in salmon and sea trout runs between the mid-1960s and the mid-1970s, coincidental with declines on other Devon rivers. Catch statistics on the Torridge throughout the late 1970s and 1980s provide no clear evidence for further systematic changes in the run size of either species, but at this time other Devon rivers were recovering, and measures were being taken on the Torridge to conserve stocks. This would suggest that there were Torridge-specific factors constraining the migratory populations during this period, the effects of which would have been even more severe had protective measures not been taken. It appears that the conditions prevailing during this investigation were less severe than those reported in the mid-1980s, and there has been some evidence that salmon and trout fry densities have improved since 1990. Available historical water quality data do not show many trends but highlight discrete periods of poor quality particularly in the mid-1980s.

In-situ salmon embryo bioassays suggest that there is an impact on embryo survival in intensively farmed sub-catchments, relating to spawning gravel quality. River-bed gravels in these areas contained fine sediment concentrations likely to be damaging to salmonid embryo survival and interstitial dissolved oxygen (DO) levels in these gravels were low enough to be lethal to embryos. However, the processes by which sediment is supplied to and deposited in watercourses are complex and it is difficult to infer whether this reflects an historical change in sediment loads.

Water quality in the non-intensively farmed River East Okement was consistently higher than that observed in the intensively farmed study catchments, particularly with respect to biochemical oxygen demand (BOD), ammonia, DO, suspended solids and nutrients. On the assumption that this reflects the wider situation in the Torridge Catchment before the period of agricultural intensification, then changes in 'land use' have caused a deterioration in water quality. Biological sampling implicates organic waste production from farms as causing a mild impact throughout the intensively farmed catchments, which is reflected in the higher BOD and ammonia concentrations observed. Deteriorations in water quality are routinely caused by flow events following rainfall, when runoff from farm buildings and fields is most likely to occur; such events are a major source of the variability in water quality observed in routine sampling.

The evidence from electrofishing surveys and *in-situ* juvenile salmon bioassays demonstrates that the survival of juvenile salmonids does not appear to have been adversely affected by water quality in the intensively farmed catchments during the study. There was evidence of localized anthropogenic impacts and the continuing occurrence of polluting discharges elsewhere in the Torridge Catchment during the study, some of which caused observable fish kills. Such evidence continues to implicate poor waste management as a possible mechanism affecting long-term degradation of stocks.

Recommendations are made for the future protection of salmonid stocks in rivers where land use change occurs. These address the need for a comprehensive national strategy that is geared to impact prevention, supported by a capability to ameliorate impacts when they arise. Within the sphere of impact amelioration, attention needs to be focused on tackling causal mechanisms and providing short- and medium-term relief whilst the fundamental problems are being addressed.

KEY WORDS

Torridge, agriculture, bioassay, fisheries, flow event, land use, rod catch, water quality

1 INTRODUCTION

1.1 General

The intensification of agricultural activity in recent decades has led to considerable concerns about impacts, particularly from dairy and livestock farming, on river quality (Schofield and Bascombe 1990, Schofield *et al.* 1990, NRA 1992) and salmonid fisheries in the UK (MAFF 1991). There has been a substantial increase in pollution incidents caused by farm waste over the past decade (NRA 1992), and a recent national study of the risk of organic pollution from livestock farming (Rutt and Mainstone 1995a) identified many catchments in the western half of England and Wales as being at high risk.

This project was initiated to investigate the circumstantial evidence linking changes in agricultural land use to deterioration in both river water quality and salmonid populations. The Torridge Catchment was chosen for the study because a significant decrease in salmonid rod catches has been reported in recent decades along with a general deterioration in river quality. A multidisciplinary environmental investigation undertaken in the mid-1980s by South West Water Authority (SWWA, 1986) concluded that, on the available evidence, there appeared to have been significant environmental deterioration within the river. Major causes were considered to be changes in agricultural land use and practices, reduced flows and the polluting load from sewage treatment works. Surveys of juvenile salmon and trout populations had shown significant decreases in distribution and abundance, whilst an apparent decline in salmon rod catches was considered to be "steeper than the national trend".

This report summarizes the main findings of the project. The full results and a more detailed discussion can be found in "Changes in agricultural land use in the Torridge Catchment 1952 to 1988" (Naismith and Cullum 1996), "Studies of historical water quality in the Torridge Catchment and comparisons of current water and biological quality in intensively and non-intensively farmed sub-catchments" (Naismith 1996a), "*In-situ* salmon embryo experiments, sedimentological surveys and juvenile salmon bioassay experiments in the Torridge Catchment" (Naismith 1996b) and "Studies of adult salmonid catches and juvenile salmonid populations in the Torridge Catchment" (Naismith and Wyatt 1996).

The work was jointly funded from the Research and Development (R&D) programmes of the National Rivers Authority (NRA) and the Ministry of Agriculture Fisheries and Food (MAFF), and was undertaken between April 1990 and April 1993.

1.2 The Torridge Catchment

The River Torridge (Figure 1.1) drains 857 km^2 of north-west Devon. Major tributaries include the River Waldon (78 km^2), the River Lew (117 km^2) and the River Okement, (141 km^2), the latter rising on Dartmoor. Its outer estuary is shared with the River Taw, lying to the east of the Torridge Catchment.

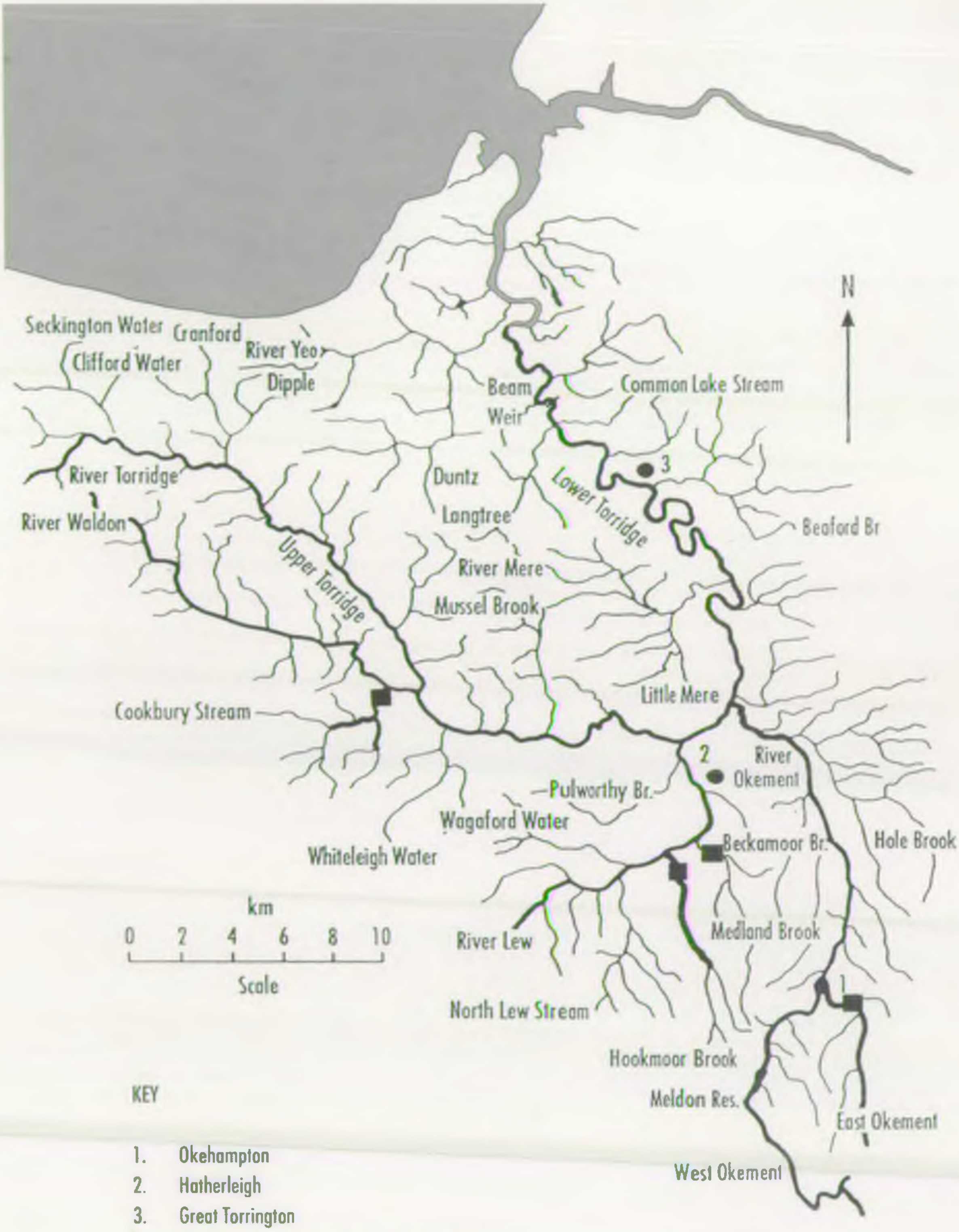
The Torridge rises at an altitude of about 200 m (above Ordnance Datum), and has a gradient of 2.95 m km^{-1} where it joins the River Waldon, decreasing to 1.2 m km^{-1} down to the tidal limit. The River Okement in contrast, rises at 560 m and falls 34 m km^{-1} over the first 3.2 km, increasing to 80 m km^{-1} as it descends the northern flank of Dartmoor. The climate is typical of Atlantic Britain with a limited temperature range and high winter rainfall. Most of the catchment is underlain by rocks with generally low permeability and porosity which is reflected by a generally flashy river flow response to rainfall and low groundwater storage availability (NRA 1990).

The catchment is sparsely populated (30 persons km^{-2}) with isolated farmsteads, hamlets, villages and a few small towns. The primary land use in the Torridge Catchment is grassland supporting dairy and other livestock farming. Industry within the catchment is primarily associated with agriculture, consisting of dairy product factories and abattoirs. Quarrying for ballast is undertaken in the West Okement Catchment and for ball clay in the Mere Catchment. Light industry is found in the major population centres of Okehampton, Hatherleigh and Great Torrington.

Fishing in freshwater is mainly for salmon, sea trout and brown trout; eels and other freshwater fish are lightly exploited. A net fishery for salmon and sea trout in the joint Taw/Torridge Estuary was suspended between 1990 to 1995 inclusive to conserve stocks.

1.3 Overall Approach

The study was established with the overall objective of identifying the factors responsible for the observed



KEY

1. Okehampton
2. Hatherleigh
3. Great Torrington

■ Monitoring stations on the study catchments

Figure 1.1 Map of the Torridge Catchment deterioration in both salmonid populations and river quality in the River Torridge. Specific objectives were:

- to determine what effects changing land use and other environmental factors have on salmonid fisheries and to identify mechanisms and quantify effects; and

- to produce recommendations and guidelines for the future management of salmon and trout stocks in rivers where land use change occurs.

The basic approach adopted for the experimental component of this study was the comparison of current land use, water quality and wild juvenile salmonid populations between contrasting intensively and non-intensively farmed sub-catchments (Chapter 3), to gain an insight into the possible catchment-wide effects of the land use change over recent decades. An inventory of the Torridge Catchment identified the River East Okement as the only suitable non-intensively farmed catchment remaining. The Hookmoor Brook and Medland Brook, tributaries of the River Lew containing a high proportion of dairy farms, and the Cookbury Stream, a tributary of the River Waldon with predominantly beef and sheep farms, were selected as representative intensively farmed study catchments.

Initial fieldwork (in 1990/91) concentrated on the basic characterization of the land use, water quality and salmonid populations of these study catchments. On the basis of the results, the strategy for the remaining fieldwork (up to late 1992) was developed to consider three primary areas:

- the influence of land use on river quality;

- the influence of river quality on individual salmonids (bioassays); and

- the consequences of observed ecotoxicological effects for the wild salmonid population.

In addition, the historical data from long-term routine surveys were re-assessed in the light of data collected since the SWWA (1986) study, in order to confirm the observed deterioration and to place the findings from the study catchments in the context of long-term changes and the rest of the Torridge Catchment.

Recommendations for the future management of salmon and trout stocks are made on the basis of the findings of the research.

2 HISTORICAL CHANGES IN THE RIVER TORRIDGE

2.1 Introduction

Historical data for the River Torridge span different time periods, as shown in Table 2.1. Particular attention was paid to data pertaining to the Rivers Waldon, Lew and Okement, in which the study catchments (Cookbury Stream, Hookmoor Brook and East Okement respectively) were located (Chapter 3).

2.2 Changes in Land Use and Farm Waste Management

2.2.1 Methods

Changes in land use and livestock density in the intensively farmed Waldon and Lew Catchments, and the non-intensively farmed East Okement Catchment were examined using MAFF Parish Summaries of annual census returns for agricultural holdings, for selected years between 1952 and 1988 (Naismith and Cullum 1996). Changes in field drainage were examined using MAFF records of annual grant payments for completed drainage works.

2.2.2 Silage

Over the past 40 years there has been a continuous process of change, particularly in cropping practices and animal husbandry in the late 1960s and 1970s, which has resulted in fewer, but larger, farms supporting increased livestock densities (Figure 2.1). A key factor in the intensification of livestock production has been the introduction of silage as a winter feed since the late 1960s. This reduced reliance on arable rotations of fodder/cereal crops for animal winter feed has resulted in a substantial increase in permanent improved pasture, from the 1970s (Figure 2.2). A by-product of silage production is the liquor produced during grass fermentation which has a Biochemical Oxygen Demand (BOD) up to 60 000 mg l^{-1}. The widespread production of silage has created a problem of safe containment and disposal of the liquor, which has caused numerous organic pollution incidents (NRA 1992). This is exacerbated by the fact that much silage production occurs during the summer months when dilution and dissolved oxygen (DO) in the river network are relatively low, and water temperatures are high.

Table 2.1 Summary of long-term data for the River Torridge

Note: Shaded areas show years for which data are available

Figure 2.1
Changes in the density ($N\ km^{-2}$) of cattle in sub-catchments of the Torridge

- ▲ Dairy cattle
- △ Total cattle
- ○ Other cattle

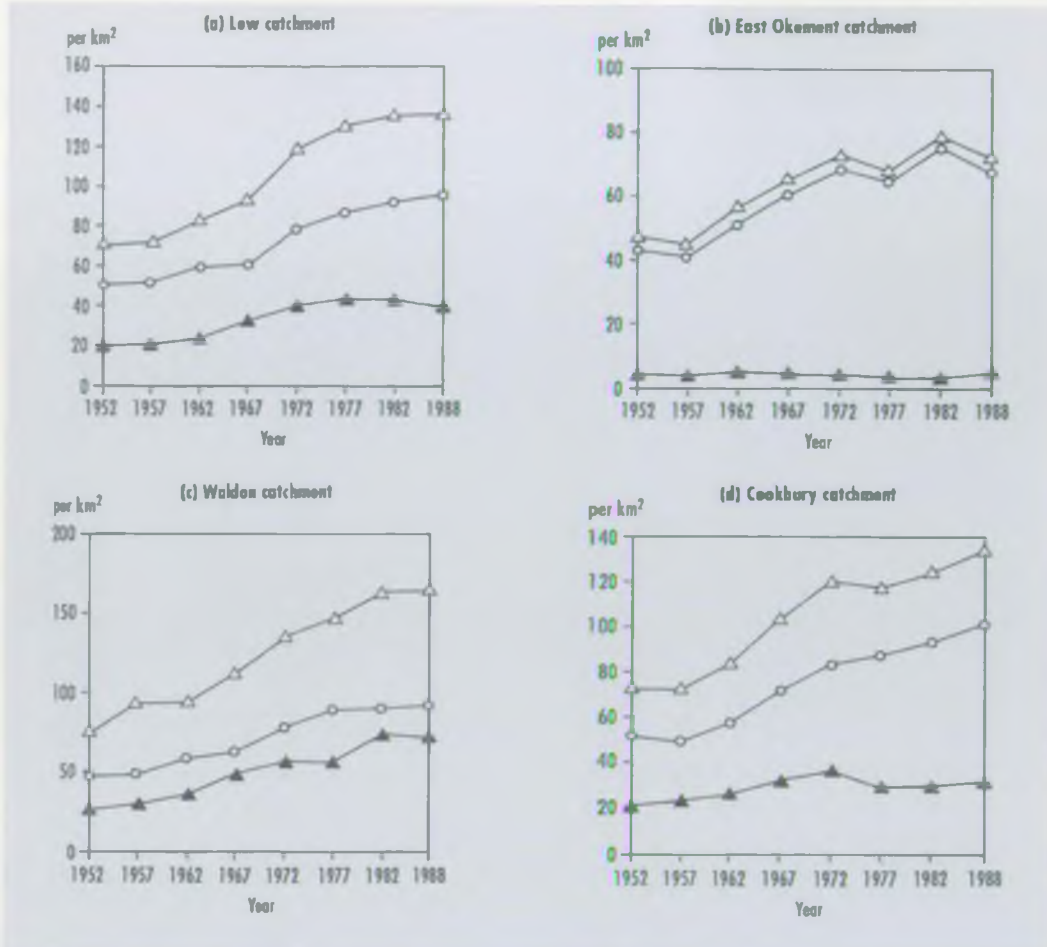
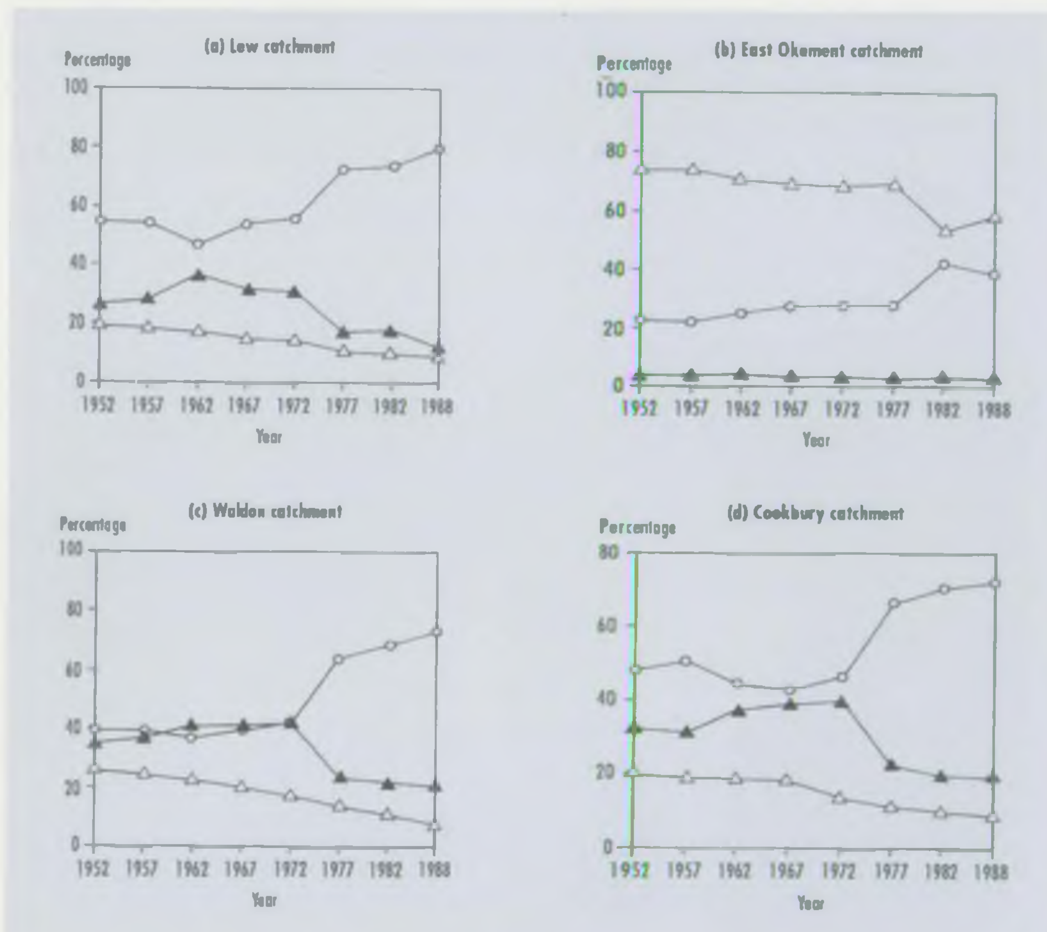


Figure 2.2
Changes in the percentage composition of grassland types in sub-catchments of the Torridge

- ▲ Temporary grass
- △ Rough grazing
- ○ Permanent grass



2.2.3 Fertilizers and pesticides

Fertilizers and pesticides are widely used in both grassland and arable husbandry, and both are potentially damaging to the aquatic environment. National data (NRA 1992) show an increase in fertilizer usage in recent decades and runoff from land has been shown to be an important source of nitrate and phosphate in water in the Torridge (SWWA 1986).

In addition to treatments applied to crops and grassland, sheep dipping is a major activity in the catchment that may cause pesticide contamination. This may arise from runoff from fleeces, disposal of unused dip and leaking or overtopping by rainfall of dippers that have not been emptied (Blackmore and Clark 1994). Its usage is likely to have increased along with the substantial increase in sheep densities that has occurred in the catchment (Naismith and Cullum 1996).

2.2.4 Animal waste

The increase in livestock densities (Figure 2.1) sustained by improvements in husbandry and food production has resulted in a steady increase in organic waste production, with consequent implications for its management and safe disposal. An increased use of indoor overwintering of livestock since the late 1960s has had the effect of concentrating waste in the vicinity of farm buildings, whilst a more sparing usage of bedding material and the use of silage as a winter feed has increased slurry production.

Buildings and concrete yards intercept rainfall and, in the absence of proper separation of clean water from dirty water, this can increase the volume of waste. Spreading of organic animal waste to land as a means of disposal may additionally cause organic contamination of watercourses through runoff from fields. Furthermore, land close to rivers which tends to be flatter are favoured places for spreading.

2.2.5 Field drainage

On the naturally waterlogged soils of the Torridge Catchment, field drainage and the development of arterial drainage networks has been an essential part of grassland improvement. There was an increase in such activity from the 1950s to the mid-1980s (when grant-in-aid from MAFF for drainage work ceased nationally) in all parts of the Torridge Catchment, but particularly in some headwater areas (Table 2.2). The development of arterial drainage networks can cause more rapid responses of river flow to rainfall events and higher flood peaks (Robinson 1990), which in turn are likely to affect the process of sediment supply and deposition within watercourses. However, analysis of annual flow data collected since 1963 from the gauging station at Beam Wear, near the estuary, revealed no significant trends in peak flows in the Torridge.

2.2.6 The Torridge Farm Campaign

The Torridge Catchment has been the subject of a pioneering "Farm Campaign", started in 1983 in response to SWWA concerns about the effects of farm waste disposal on water quality. All 989 farms in the catchment were inspected and extensive evidence of inadequate farm waste management was found (NRA 1990), with up to 50% of farms in sub-catchments "polluting" or "at risk of polluting" watercourses (Section 3.2) with waste from buildings or silage clamps.

Remedial advice was provided, and follow-up inspections to polluting farms found a substantial reduction in the number considered still to be polluting (Table 2.3). This campaign has since been reinforced by the introduction of the Control of Pollution (Slurry, Silage and Agricultural Fuel Oil) Regulations (HMSO 1991), which set minimum standards for agricultural storage facilities. Farmers have, with financial help from the Farm and Conservation Grant Scheme, made considerable investment in storage facilities within the catchment. Any proposal to build new

Table 2.2 The extent of field drainage in parishes of the Torridge Catchment between 1971 and 1984 (after SWWA 1986)

Region of the Torridge Catchment	Number of parishes within the region	Mean area of each parish drained (per cent)	Range (per cent)
Upper Torridge/Waldon	18	6.7	2.9 - 14.3
Lew/Okement	15	6.2	2.8 - 15.6
Lower Torridge	13	2.6	0.2 - 6.4
Yeo/estuary	10	3.9	0.8 - 7.0

ion of

Table 2.3 Polluting farms identified at first, second and third visits during the Torridge Farm Campaign (1984 to 1989)

	Number of polluting farms	Percentage of all farms
First visit (all farms)	232	23
Second visit (to those polluting at first visit)	113	11
Third visit (to those polluting at second visit)	21	2

stores, or to substantially alter existing facilities with less than four months storage capacity, must now satisfy the NRA that they can spread to land without causing pollution. Farmers are also encouraged to produce farm waste management plans, which are considered essential to combat problems associated with land runoff. Consequently, the impacts from such point sources may be less severe now in the Torridge than in the mid-1980s, and also less severe than in other livestock farming catchments that have not been the subject of a farm campaign.

2.3 Changes in Water Quality

2.3.1 Introduction

Surface water quality in the Torridge Catchment has been routinely monitored by spot sampling since 1967. Initially this was confined to the main River Torridge, and major tributaries were added in 1978 and minor tributaries in 1990; the routine programme now comprises some 75 sites. The results which comprise four to 12 samples per year have been used by the SWWA/NRA primarily to assess compliance with River Quality Objectives (RQOs) using the National Water Council (NWC) classification system.

When RQOs were applied to the Torridge Catchment in 1978, it was already considered that the river was suffering water quality problems relating to diffuse runoff throughout the catchment and that, as this is potentially difficult to control, the highest 1A Class was difficult to achieve (SWWA 1986). RQOs of 1A were confined to the Okement Catchment draining Dartmoor, and the Yeo Catchment; the majority of the catchment was assigned an RQO of 1B. However, both classes 1A and 1B are considered suitable for salmonids (NRA 1992).

Historical water quality data were examined using two methods: raw data from six sites were examined for overall temporal trends; and annual NWC class at all sites were examined for overall trends (Naismith 1996a).

2.3.2 Trends in raw data

Data for eight determinands from six sites (upper, middle and lower Torridge, and the tributaries Waldon, Lew and East Okement) for the period 1974 to 1992 were examined for trends in concentrations using "cusum" (cumulative sum) analysis of seasonally corrected data using the AARDVARK program (WRc 1989).

Of the three tributaries, levels of BOD and concentrations of ammonia (indicators of organic contamination), suspended solids, nitrate, nitrite and orthophosphate were highest in the intensively farmed River Waldon, and lowest in the non-intensively farmed River East Okement (Table 2.4). The converse pattern was observed for DO, with the highest concentrations found in the East Okement.

Whilst significant step changes were present for DO, BOD and pH (Table 2.5), there were no clear trends apparent over the period 1974 to 1992. Nutrient data provide conflicting evidence since there are indications of an increase in nitrate concentration at some sites whilst concentrations of nitrite species and of orthophosphate show downward trends in the 1980s. No significant changes in the mean concentration of ammonia were detected at any site.

Determinand concentrations at individual sites were highly variable and this, together with the relatively small number of samples (four to 12) taken annually, limits the power to detect trends in the data. In addition, such infrequent sampling is likely to miss any transient poor water quality events which can be caused by accidental, deliberate or rainfall-induced discharges.

2.3.3 Water quality classification

Since the 1970s there have been changes in both the determinands used and the methods of calculation employed to assess NWC class. These made the identification of long-term temporal changes in water quality from existing classification reports difficult.

Table 2.4 Water quality in Torridge sub-catchments, 1974 to 1992

River		DO % sat	T-amm $mg\ l^{-1}N$	BOD $mg\ l^{-1}O_2$	pH	SS $mg\ l^{-1}$	NO_3^- $mg\ l^{-1}N$	NO_2^- $mg\ l^{-1}N$	ortho-P $mg\ l^{-1}P$
Upper Torridge	95%ile	-	0.442	3.50	7.78	24.0	3.77	0.0675	0.139
	Mean	90.6	0.134	1.66	7.07	8.9	2.42	0.0321	0.053
	5% ile	82.0	-	-	6.52	-	-	-	-
Middle Torridge	95%ile	-	0.274	3.80	8.21	67.2	3.83	0.0465	0.172
	Mean	97.4	0.073	1.87	7.39	20.7	2.34	0.0229	0.081
	5% ile	86.0	-	-	6.80	-	-	-	-
Lower Torridge	95%ile	-	0.240	4.28	8.60	62.0	4.11	0.0580	0.339
	Mean	98.9	0.079	1.98	7.52	15.5	2.57	0.0240	0.122
	5% ile	80.8	-	-	6.90	-	-	-	-
Waldon *	95%ile	-	0.358	4.72	7.70	63.0	4.34	0.0915	0.185
	Mean	93.8	0.093	1.93	7.28	16.5	2.78	0.0312	0.084
	5% ile	82.0	-	-	6.71	-	-	-	-
Lew **	95%ile	-	0.218	3.23	7.80	35.4	2.90	0.0515	0.100
	Mean	94.1	0.067	1.60	7.35	13.2	1.77	0.0204	0.041
	5% ile	76.6	-	-	6.87	-	-	-	-
East Okement	95%ile	-	0.060	1.80	7.50	12.0	1.20	0.0162	0.050
	Mean	98.4	0.021	0.98	6.77	5.9	0.64	0.0084	0.021
	5% ile	90.6	-	-	6.00	-	-	-	-

Notes:

*	downstream from Cookbury Stream
**	downstream from Hookmoor Brook
BOD	biochemical oxygen demand
DO	dissolved oxygen
NO_2^-	nitrite
NO_3^-	nitrate
ortho-P	orthophosphate
SS	suspended solids
T-amm.	total ammonia

Table 2.5 Significant step changes in water quality, 1974 to 1992

River	DO	BOD	pH	SS	NO_3^-	NO_2^-	Ortho-P
Upper Torridge	↘ 82	↗ 79	↘↗↘↗ 79,82,89,91	–	↗↗↗ 76,83,90	–	↘↘ 83,89
Middle Torridge	↗↘↘ 82,84,87	↗↘ 84,85	↘↗↘ 78,82,84	–	–	↘ 87	↘↗↘ 84,88,90
Lower Torridge	↗↘↗↘ 82,86,87,87	↗↘↗↘ 83,84,86,86	↘↗↘↗↘ 78,82,84,86,87	↗↘ 86,87	↗↘↗ 84,88,90	↘ 87	↗↘↗↘ 84,84,89,90
Waldon	↘ 89	–	↘↗↗ 80,82,91	↗↘ 89,90	↗ 76	↘ 84	↘ 84
Lew	↘↗↘ 79,84,87	–	↘↗↗ 79,82,91	–	↗↘ 76,88	↘ 88	↗ 78
East Okement	↘ 77	90	↘↗↘↗↘↗ 78,84,84,86,89,91	–	↘↗↘	– 84,84,87	–

↘ Mean shows a significant step decrease in year shown.
↗ Mean shows a significant step increase in year shown.
– No significant step changes present.

Consequently, in this study annual water quality classifications for the period 1974 to 1992 were re-calculated for individual determinands (temperature, DO, BOD, ammonia, un-ionized ammonia and suspended solids) using a standard method (Naismith 1996a). Classification criteria are generally based on 95%iles, which ideally requires a minimum of 20 samples to be taken annually. In practice this has rarely been achieved and therefore the common practice of using data from three consecutive years in a rolling programme was followed; the first year of classification in the analysis is therefore 1976.

These classifications (example in Table 2.6) have revealed temporal and spatial changes in water quality class designation, and periods of widespread failure to comply with the 1B RQO. However, for individual determinands and sites these generally highlight discrete periods of differing quality, rather than continuous trends of improvement or decline over the 18 years examined, as observed with the raw data presented in the previous section.

The most frequent and widespread failures to meet RQOs concern BOD and ammonia which are both indicative of organic contamination. One result of high BOD levels that can affect fish is a reduction in DO concentration, but in these data the frequent and widespread failures to comply with BOD criteria (below Class 1B) were not found to translate into failures for DO. Similarly, whilst failures for total ammonia were common, failures for un-ionized ammonia, the toxic species, have been rare and localized. This can be linked to the high reoxygenation capacity of upland streams and rivers, compensating for enhanced oxygen consumption and oxidizing ammonia to nitrite and nitrate. Consequently, despite the evidence for widespread organic contamination, the available data indicate that the occurrence of instances likely to severely stress salmonids have been rare. However, as previously stated, routine sampling programmes may miss transient events.

Compliance failures for BOD and ammonia were particularly severe in the mid-1980s during the time of the SWWA environmental investigation (SWWA 1986), when there were strong indications of a deterioration in river quality. SWWA concluded that low river flows, giving low dilution capacity, were an important factor affecting water quality in the drought summers of 1983/1984. High levels of ammonia and BOD during low summer flows suggest continuous discharges of waste. It is therefore notable that similar, widespread failures are not apparent during the preceding droughts of 1975 and 1976, or in the subsequent 1989/1990 droughts, suggesting that organic contamination may not have been as severe at these times.

Other compliance failures have been generated by exceptional "transient" events rather than underlying changes in mean concentration. For example, failures to comply with RQOs due to suspended solids are associated with exceptional flood events, and failures due to temperature were only associated with the exceptionally warm summer of 1976.

Table 2.6 Example of NWC classification results: lower Torridge

Determinand	Year																
	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
Temperature	2	2	2	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A
DO	1A	1A	1A	1A	1A	1A	1A	1B	1B	1A	1A	1B	1B	1B	1B	1A	1A
BOD			1B	1B	1B	1A	1A	2	2	2	2	2	1B	1B	1B	1B	1B
Ammonia	1A	1A	1A	1A	1A	1B	1B	3	3	2	1A	1A	1A	1A	1A		1A
Un-ionized ammonia									1A		1A	1A	1A	1A	1A	1A	1A
Suspended solids	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A	1A
Overall	2	2	2	1B	1B	1B	1B	3	3	2	2	2	1B	1B	1B	1B	1B

All parts of the catchment appear to have been affected by organic inputs, with the notable exception of the upper Okement Catchment which has consistently been classified 1A. Currently the worst problems are localized in a few minor tributaries, but these have only been sampled since the late 1980s. The data indicate some specific impacts, notably suspended solids in the Mere Catchment, which contains ball clay workings, and a compliance problem due to BOD and ammonia in the Okement Catchment associated with a sewage treatment works.

2.3.4 Pollution incidents and fish kills

Compiled records of pollution incidents and fish kills in the Torridge Catchment were available from 1980 to 1985 and from 1976 to 1984 respectively. A computer database was established for both pollution incidents and fish kills in 1987; data for the mid-1980s were not available in a readily accessible form. A rapid rise in the reported number of incidents associated with sewage (including storm drains and tips), farms and "others" (including unknown) is apparent since the early 1980s (Figure 2.3); the numbers of trade waste incidents have remained relatively constant. Farms have remained the largest single source of incidents over the period, representing around 45% of all incidents.

It is not certain whether the increase in reported incidents reflects an increase in actual incidents, or merely an increase in public awareness and reporting. Irrefutable evidence of transient water quality problems is provided in fish-kill records (Table 2.7). In particular, two slurry spills in 1983 were estimated to have killed 15 000 juvenile salmonids in the River Waldon and 35 000 in the upper River Torridge. Of those with a known cause, 80% resulted from farm waste, and 82% of all fish kills occurred between April and September.

2.4 Changes in Adult Salmonid Populations

2.4.1 Introduction

Declared net catches for the combined Taw and Torridge Estuary have been recorded since 1928, however, records of the number of nets licensed each year have only been recorded since 1951. Since 1951, 36 nets were licensed to fish on the estuary, but in 1981, the Net Limitation Order (NLO) was reduced to 14 nets to improve spawning escapement. To prevent the additional fish entering the Torridge being exploited by the rod fishery, a voluntary bag limit was also introduced in 1981. In 1982, the number of net licences was raised on appeal to 22, but by 1987 had fallen back to 14. In 1988, 11 of these nets accepted compensation payments to suspend their netting activity and from 1990 all the netsmen accepted this arrangement.

Until 1973, the Devon River Authority (DRA) was responsible for issuing rod licences for the area, and each river was licensed separately. From 1974 SWWA issued licences covering the whole of the South West Region

Figure 2.3
Number and type of pollution incidents reported in the Torridge Catchment from 1980 to 1992

Note: Data for 1980 includes the months May to December only and data for 1986 were not available in a summarized form

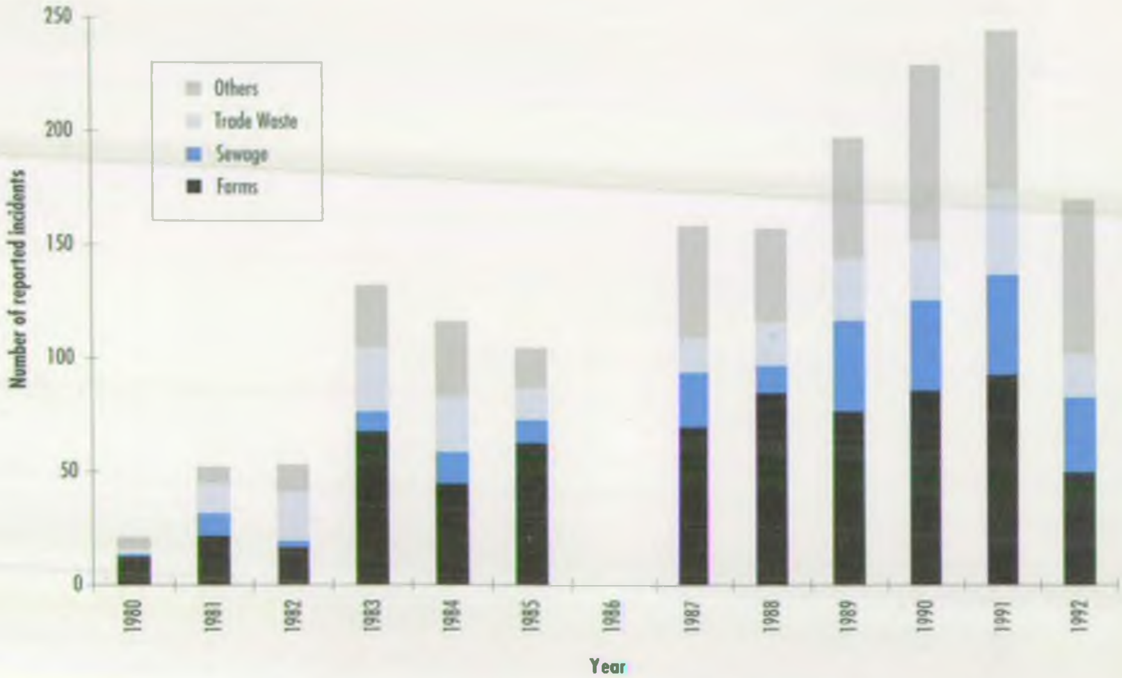


Table 2.7 Number and cause of fish kills reported in the Torridge Catchment in the periods 1976 to 1984 and 1987 to 1992

Cause	Year														
	76	77	78	79	80	81	82	83	84	87	88	89	90	91	92
Farm waste	3	0	0	0	0	0	0	3	1	6	1	1	0	1	3
Dairy washings	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Abattoir	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Industry	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0
Quarry	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
Natural	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0
Other	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0
Unknown	0	0	0	0	0	0	0	0	2	2	0	0	0	1	1
Total	4	0	1	0	1	0	1	4	6	10	2	2	0	4	4
Estimated no. salmonids killed by farm waste (k)	4.5							50	<0.1	0.6	<0.1	<0.1		0.5	0.2

only and not for specific rivers. At the end of every fishing season, anglers who have used a day, week or season licence for salmon or migratory trout are required to make a return declaring the rivers fished and the numbers (including nil returns) of salmon and sea trout caught. These rod-licence returns have been archived on microfilm since 1962. However, information on the numbers of licence returns for the Torridge have not been routinely collated.

In 1978 a fish pass was installed in Monkokehampton Weir near the foot of the River Okement, allowing access for salmon and sea trout to the River Okement and its tributaries the East and West Okement.

2.4.2 Ulcerative Dermal Necrosis

Ulcerative Dermal Necrosis (UDN or Salmon Disease) was confirmed in the River Taw at the end of April in 1968, and isolated incidents also occurred in the River Torridge from the middle of June onwards. This disease affects both salmon and trout in freshwater, and according to the DRA (1969) "Losses in both rivers were heavy in November, December and January [1968/1969] and many fish died before spawning had been successfully completed". UDN particularly affected spring fish which predominated the rod catches at the time.

2.4.3 Methods for analysis of rod-catch data

All rod-licence returns that reported fishing activity on the Torridge, even if no fish had been caught, were re-examined for a subset of 11 years selected from the period 1964 to 1988 (Naismith and Wyatt 1996).

The re-examination of the original licences was extremely labour-intensive, and it was not possible to examine all years; the years were selected so that the interval between them was not greater than three years.

The raw data obtained from the licence returns are the declared catch of salmon and sea trout for each individual licence used on the Torridge. Five statistics were calculated separately for day, week and season licences to provide information on the changes in the rod fishery on the Torridge: the number of licences returned, the total declared catch (available for all years), the proportion of returned licences declaring a non-zero catch (PDC), the average catch per licence return (CPR) and the average catch per return declaring a positive (non-zero) catch (CPPR). Table 2.8 describes the theoretical relationship between possible causal factors such as the run characteristics, exploitation and reporting of a migratory fishery and these catch statistics. The response of spawning escapement, a measure of the number of fish that do not get caught by the rod fishery and reach their spawning grounds, is also shown. All of these statistics are subject to reporting biases, and trends in the declared statistics may not necessarily reflect trends in the actual statistics.

2.4.4 Number of rod-licence returns

The number of day, week and season licences on the NRA archive reporting angling effort on the River Torridge has declined markedly over the period 1964 to 1988 (Figure 2.4). This decline may reflect a reduction in the number of anglers fishing the Torridge, or a decline in the reporting rate. The drop in returns between 1968 and 1969 may have been due to a drop in licence sales across

Table 2.8 The effect of a decline in selected factors on spawning escapement and declared catch statistics (number of licences, total catch, PDC, CPR, CPPR)

Factor decreasing	Statistic					Escapement
	Licence returns	Catch	PDC	CPR	CPPR	
Run size	-	↓	↓	↓	↓	↓
Catchability	-	↓	↓	↓	↓	↑
% running in-season	-	↓	↓	↓	↓	↑
Number of anglers	↓	↓	↑*	↑*	↑*	↑
Bag limit	-	↓	-	↓	↓	↑
% of inexperienced anglers	-	↑	↑	↑	↑	↓
Reporting rate (overall)	↓	↓	-	-	-	-
Reporting rate (zero catch)	↓	-	↑	↑	-	-
Reporting rate (large catch)	↓	↓	↓	↓	↓	-

Notes:

* Particularly if exploitation rate (catch/run size) was initially high
↑ Decrease in factor will cause an increase in statistic (all other factors remaining constant)
\- There will be no response (all other factors remaining constant)
↓ Decrease in factor will cause a decrease in statistic (all other factors remaining constant)

PDC Proportion of returned licences declaring a non-zero catch
CPR Average catch per licence return
CPPR Average catch per positive licence return (i.e. excluding zero catches)

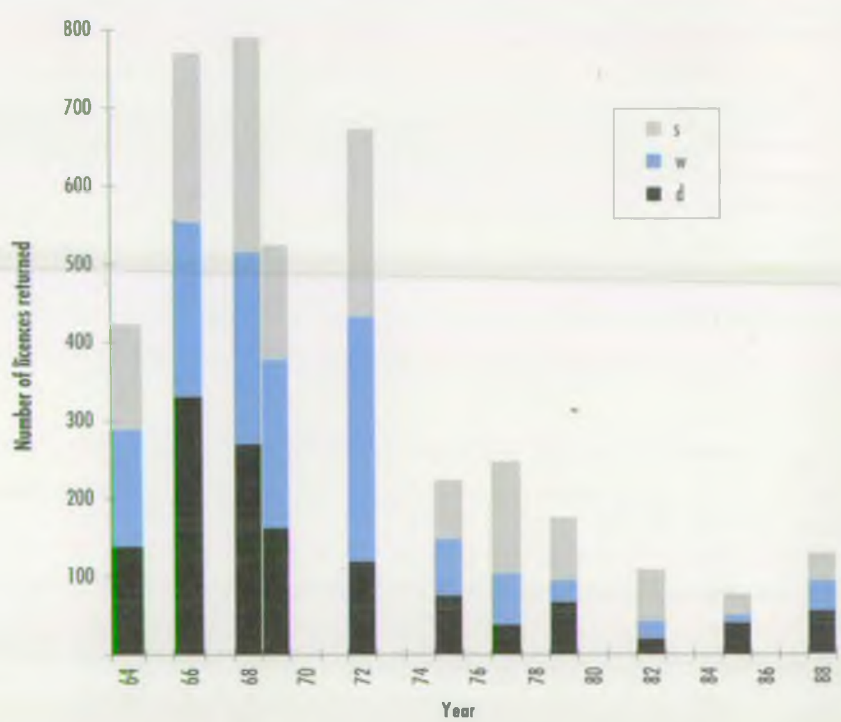


Figure 2.4
Number of archived day (d), week (w) and season (s) licences reporting angling effort on the River Torridge for selected years

the South West coincident with the incidence of UDN. Licence sales in the region picked up in the early 1970s, which is reflected in the licence returns on the Torridge in 1972. Since 1972, however, the number of returned licences declaring effort on the Torridge have continued to decline, with the greatest drop between 1972 and 1975, coincident with the change from the river-specific DRA licence to the regional SWWA licence in 1974.

The overall proportion of anglers declaring a catch (PDC) of either salmon or sea trout showed an increase after the introduction of the regional SWWA licence. Many factors could have caused a change in the PDC (Table 2.8), although the observation that the increases were less pronounced for the shorter-term licences suggests that the reporting rate for zero catches may have declined.

2.4.5 Salmon net and rod catches

Net catch on the combined Taw and Torridge estuary

From 1950 to the mid-1960s, the declared annual catch of salmon from the 36 licensed nets on the combined Taw and Torridge Estuary remained relatively constant at around 3000 salmon (Figure 2.5). From the mid-1960s through to 1980, the declared catch per licence was somewhat lower, averaging around 2300 salmon. The reduction in number of licensed nets between 1981 and 1987 reduced the annual declared catch to an average of around 1800, despite being accompanied by a marked rise in the declared catch per licence. The reduction to four nets in 1988 and 1989 resulted in a further marked decline in the total catch to around 700 fish.

Since the 1960s, there has also been a shift in the timing of the salmon catch, from over half of the catch being taken in the spring (before 1st June), to the majority of fish being caught in the summer and autumn.

Total declared rod catch on the Torridge

Salmon rod catches in the Torridge between 1954 and 1968 were variable, but showed no systematic trends (Figure 2.5). After the late 1960s, however, the rod catch showed a steady decline along with other Devon rivers, notably the Exe and the Dart, coincidental with the arrival of UDN. However, after the mid-1970s these other rivers started to recover, whereas the Torridge continued to decline. It was also in the mid-1970s that the number of rod licensees submitting catch returns on the Torridge showed the greatest decline.

Catch of individual anglers on the Torridge

For salmon, the pattern of change in the PDC, CPR and CPPR for season licences is shown in Figure 2.6. The pattern for the PDC and CPR were similar for day and week licences, although the CPPR remains close to unity for day licences.

Over the period 1964 to 1972, all three indices show evidence of a decline, at a time when the rod catches on some other Devon rivers were declining. The CPR, for example, declines from around 2.5 salmon per season licence to around 1 salmon. The possible decline in the reporting of zero catches with the change from the DRA to SWWA licences in 1974 may have resulted in an increase in the CPR and PDC (Table 2.8), particularly for the season licences shown in Figure 2.6; the CPPR, however, will be unaffected by changes in the reporting of zeros (Table 2.8). Over the period 1975 to 1988, all three indices showed reduced values in 1979 and 1982.

Figure 2.5
Declared salmon net catch in the combined Taw and Torridge Estuary (1950 to 1990), and declared salmon rod catch in the River Torridge (1954 to 1990)

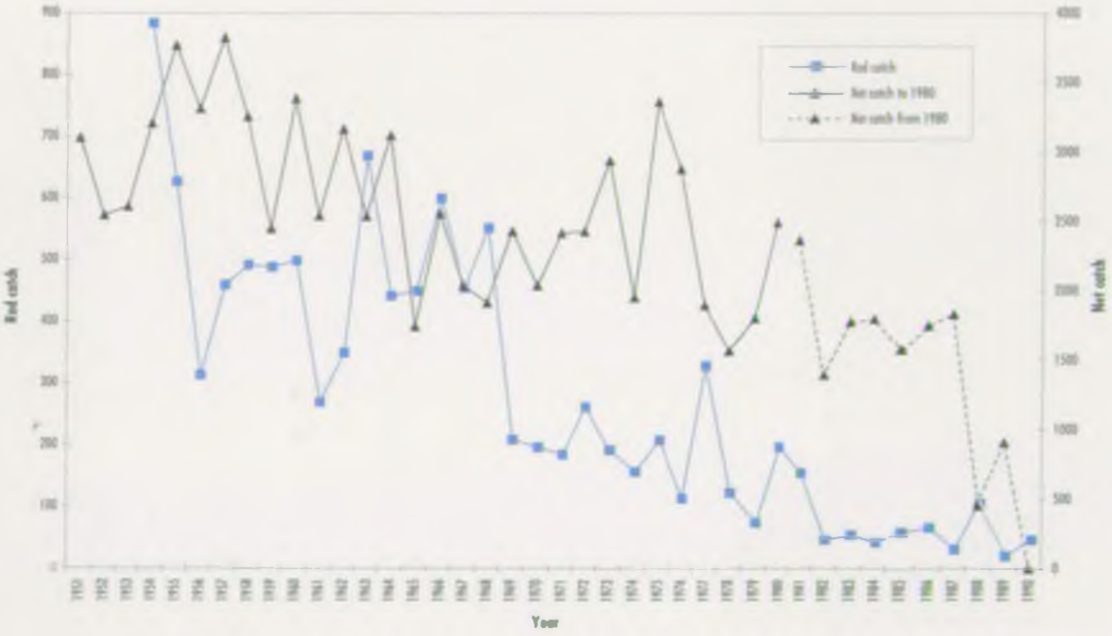
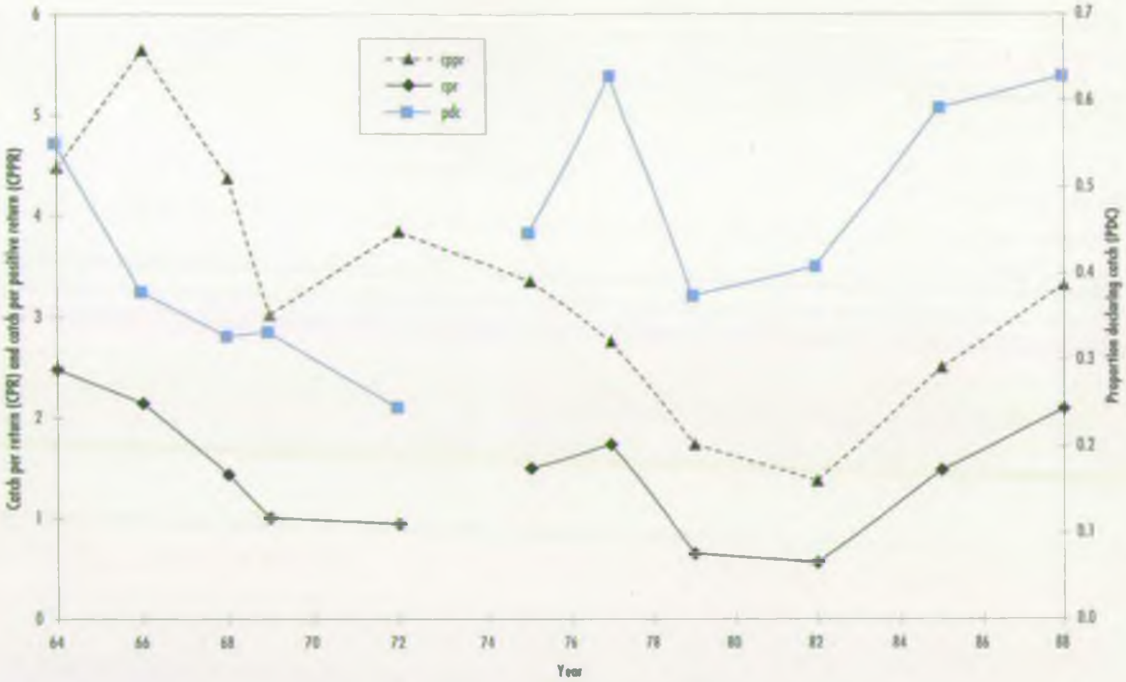


Figure 2.6
Proportion of licences declaring a catch (PDC), average declared catch per licence return (CPR) and average declared catch per positive licence return (CPPR) for salmon season licences in selected years from 1964 to 1988



2.4.6 Sea trout net and rod catches

Net catch on the combined Taw and Torridge Estuary

The total declared catch of sea trout from the combined Taw and Torridge Estuary rose from 1800 in 1951 to 7200 in 1967, followed by a rapid decline to 1700 in 1970 (Figure 2.7). The catches then improved and averaged around 4500 throughout the 1970s. The pattern of high sea trout net catches in the 1960s and a collapse in the early 1970s was similar to other Devon rivers such as the Dart, Teign, Tavy and Tamar (suggesting regional influences), although the recovery in the 1970s was somewhat less pronounced on the Torridge compared to the Dart and the Teign. As with salmon, the reduction in number of licensed nets between 1981 and 1987 was accompanied by a marked rise in the declared sea trout catch per licence, and the annual catch was reduced to an average of around 4100. The partial suspension of netting in 1988 and 1989 resulted in a further increase in the catch per licence, but successfully reduced the annual catch to an average of around 1000.

Total declared rod catch on the Torridge

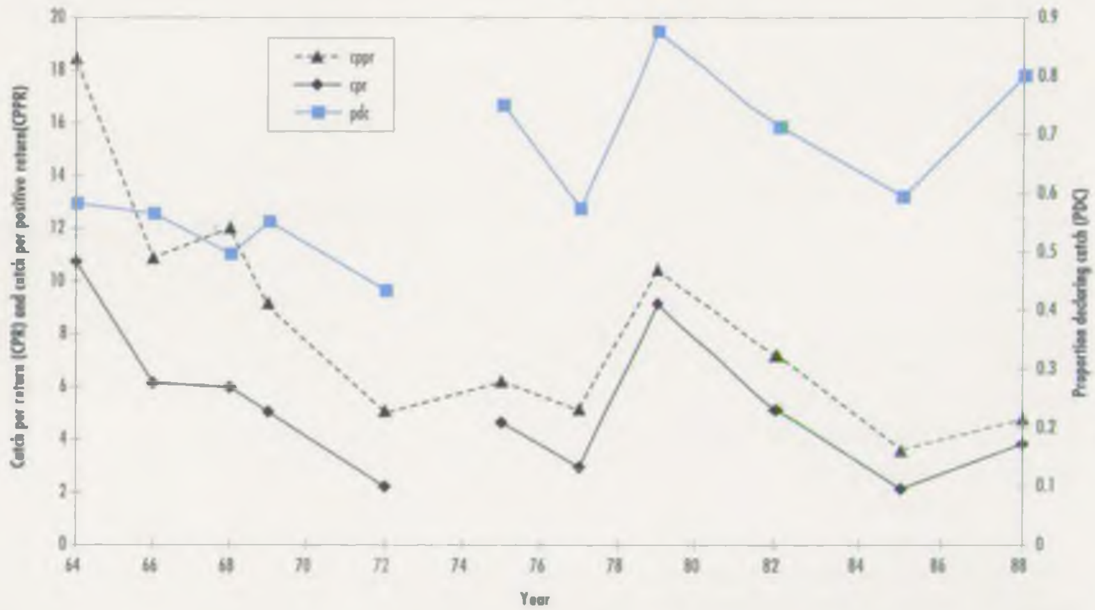
Before the early 1970s, the sea trout rod catch on the Torridge shows a similar pattern to the net catch (Figure 2.7), and to the rod catch in a number of other Devon rivers, with an increase from the early 1950s to the late 1960s, followed by an abrupt decline. From the early 1970s, the declared sea trout rod catch on the

Table 2.9 The average number of day, week and season licences returned per year for the DRA system (1964, 1966, 1968, 1969, 1972) and the SWWA system (1975, 1977, 1979, 1982, 1985, 1988)

Type of licence		Average number of licences per year	
		DRA (1964-1972)	SWWA (1975-1988)
Season	Declaring a catch	130	64
	Declaring no catch	72	7
	Overall PDC	64%	90%
Week	Declaring a catch	84	20
	Declaring no catch	144	18
	Overall PDC	37%	53%
Day	Declaring a catch	41	14
	Declaring no catch	164	37
	Overall PDC	20%	28%

Figure 2.7
Declared sea trout net catch in the combined Taw and Torridge Estuary (1950 to 1990), and declared sea trout rod catch in the River Torridge (1954 to 1990)

Figure 2.8
Proportion of licences declaring a catch (PDC), average declared catch per licence return (CPR) and average declared catch per positive licence return (CPPR) for sea trout season licences in selected years from 1964 to 1988



Torridge continued to decline when other rivers stabilized, or showed a recovery.

Catch of individual anglers on the Torridge
For sea trout, the pattern of change in the PDC, CPR and CPPR for season licences is shown in Figure 2.8. The pattern for PDC and CPR were similar for day and week licences, although the CPPR remains close to unity for day licences.

As with salmon, all three indices show evidence of a decline over the period 1964 to 1972, but this was at a time when sea trout rod catches on some other Devon rivers were declining. The CPR, for example, declines from around 11 sea trout per season licence to around two sea trout. As with salmon, the possible decline in the reporting of zero catches with the change from the DRA to SWWA licences in 1974 may have resulted in an increase in the CPR and PDC for the season; but will not have affected the CPPR. Over the period 1975 to 1988, all three indices were variable, for example the CPR varied around four sea trout per return.

2.4.7 Run size in the River Torridge

The total declared catch, PDC, CPR and CPPR can all potentially be used as the basis for monitoring changes in the run size of fish in a river in that if all else remains constant, a decline in the run size of fish will cause a decline in these statistics. However, they are also influenced by a number of other factors as shown in

Table 2.8, many of which are likely to have undergone changes on the Torridge. In particular, the number of licences returned on the Torridge has fallen between 1964 and 1988, either due to a reduction in the reporting rate, or due to a reduction in the number of anglers. Whatever the reason, this decline will have contributed to the observed decline in the declared catch.

Whilst the decline in declared catch is likely to over-estimate the decline in run size, the PDC, CPR and CPPR may underestimate it. A decline in the number of anglers will tend to increase the values of these statistics (particularly if the exploitation rate was high), and a decline in the reporting rate of zero catches will also cause the PDC and CPR (but not the CPPR) to increase. In contrast to the total declared catch, however, a decline in the overall reporting rate will have no effect on these statistics.

There are other factors which may influence trends in all of the catch statistics, these include the possible decline in the catchability of fish (perhaps as a result of UDN or changes in flow), a decline in the proportion of fish running in season, a change in age composition, the introduction of the bag limit and the possible loss of the less experienced anglers from the Torridge with a reduction in total effort (Table 2.8).

It is clearly very difficult to draw any firm conclusions about what has happened to the number of adult salmonids on the Torridge. All of the available evidence would suggest that there has been a decline in the run size of both species between the mid-1960s and the mid-1970s. This was coincidental with a decline in the fisheries on a number of other Devon rivers, suggesting that the cause was not necessarily specific to the Torridge. The catch statistics on the Torridge throughout the late 1970s and 1980s provide no clear evidence for further systematic changes in the run size of either species. However, this was at a time when other Devon rivers were recovering, and measures were being taken on the Torridge to conserve stocks. This would suggest that there were Torridge-specific factors constraining the migratory populations during this period, the effects of which would have been even more severe had protective measures not been taken.

2.4.8 Spawning escapement

The number of fish that successfully reach their spawning grounds is equal to the number of fish entering the River Torridge (having escaped the net fishery in the combined Taw and Torridge Estuary) minus those caught by the Torridge rod fishery, and those lost to other sources such as natural mortality or illegal fishing. A decline in the run size, in the absence of other factors changing, will reduce the numbers of fish spawning, which, together with a shift towards smaller, later running fish will cause a decline in the number of eggs laid. However, other possible changes on the Torridge such as a decline in the catchability of fish, the proportion running within the fishing season, the number of anglers and the introduction of the bag limit will all tend to increase the numbers of fish spawning (Table 2.8). Estimates of the magnitude of any declines in run size are extremely uncertain on the Torridge due to the changes in other confounding factors, and there is even greater uncertainty over the magnitude of any changes in spawning escapement.

2.5 Changes in Juvenile Salmonid Populations

2.5.1 Methods

In 1964, the first electrofishing survey of juvenile salmonids was undertaken throughout the Torridge Catchment. In that year, sites were netted off and repeatedly fished to obtain an estimate of the numbers of parr present. The second survey in 1975, and all subsequent years, utilized the self-calibrating "removal method" for estimating the numbers of fry and parr present. Sites that were consistently surveyed over the period were used to estimate average densities for the Waldon, upper Torridge, Lew and Okement (Naismith and Wyatt 1996).

In the lower Torridge, fixed effort (20-minute) electro-fishing surveys of up to 28 riffles have been undertaken since 1989, and the data analyzed using a Poisson model.

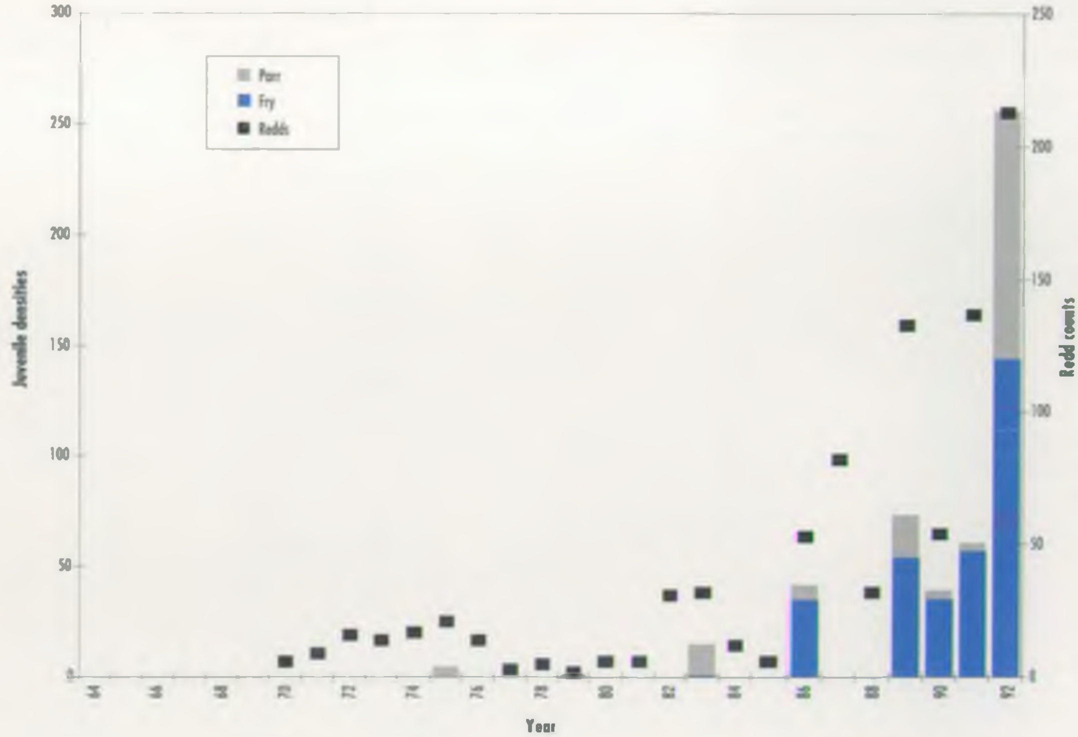
The counting of salmon and sea trout redds on sections of the Torridge began in 1969. Data from the annual redd counts between 1969 and 1991 were plotted on maps and used to identify sections of bank that were regularly patrolled each year. These comprised five main areas: the upper Torridge (six sections), River Waldon (three sections), River Lew (eight sections), River Okement (three sections) and the Lower Torridge (nine sections). The total number of salmon and sea trout redds within each sub-catchment was estimated, allowing for any missing sections.

2.5.2 River Okement

Since the opening of Monkokehampton Weir near the foot of the River Okement in 1978, there has been a rapid increase in annual salmon redd counts and the densities of salmon fry (Figure 2.9), particularly since 1986. However, pH-related pollution events in the Rivers West

Figure 2.9 Juvenile salmon abundance and redd counts in the River Okement in selected years since 1964

Note: Data for fry abundance are not available for 1964



Okement and Okement in late 1989 and early 1991 have reduced the observed salmon parr densities in the 1990 and 1991 surveys.

Sea trout redd counts have also significantly increased since 1969. In all years except 1990 and 1991, densities of trout fry and parr have been consistently high and typical for this type of river.

2.5.3 River Lew

Since 1964, salmon parr densities in the Lew have remained at levels that would be regarded as typical for this type of river, and higher than observed on the upper Torridge or the Waldon. Redd counts have been significantly increasing since 1969, and fry densities have been significantly higher since 1990.

Trout parr densities, however, have shown a significant decline from what would be regarded as typical densities, with the largest drop occurring between 1964 and 1975 (Figure 2.10). Sea trout redd counts have been significantly increasing since 1969, and trout fry densities have been steady, and higher than the Waldon or the upper Torridge.

2.5.4 River Waldon

In 1964, densities of salmon parr in the Waldon were similar to elsewhere in the Torridge (Figure 2.11). Since then, however, there have been significant declines, with the most notable drop occurring between 1964 and 1975, and densities of salmon parr in the Waldon have become lower than in other major tributaries. Salmon redd counts have also significantly declined between 1969 and 1991. Since 1975 salmon fry have been either absent, or present at very low densities, until 1992 when higher densities were observed.

Trout populations in the Waldon have followed a similar pattern to the salmon. Densities of trout parr have significantly declined, with a large decrease between 1964 and 1975, redd counts have significantly declined since 1969 and fry densities have been lower than elsewhere in the Torridge, with evidence of an improvement in 1992. In 1983 a slurry spill was estimated to have killed 15 000 juvenile salmonids in the River Waldon.

2.5.5 Upper River Torridge

Juvenile salmonid populations in the upper Torridge have shown similar trends to the Waldon. Since 1964, densities of salmon parr in the upper Torridge have declined significantly, particularly between 1964 and 1975, whereas redd counts since 1969 have remained relatively stable. Salmon fry have been present at low densities since first recorded in 1975, but with a high density recorded in 1992.

Trout parr in the upper Torridge have also exhibited a significant decline since 1964, whereas sea trout redd

Figure 2.10
Juvenile trout abundance and redd counts in the River Lew in selected years since 1964

Note: Data for fry abundance are not available for 1964

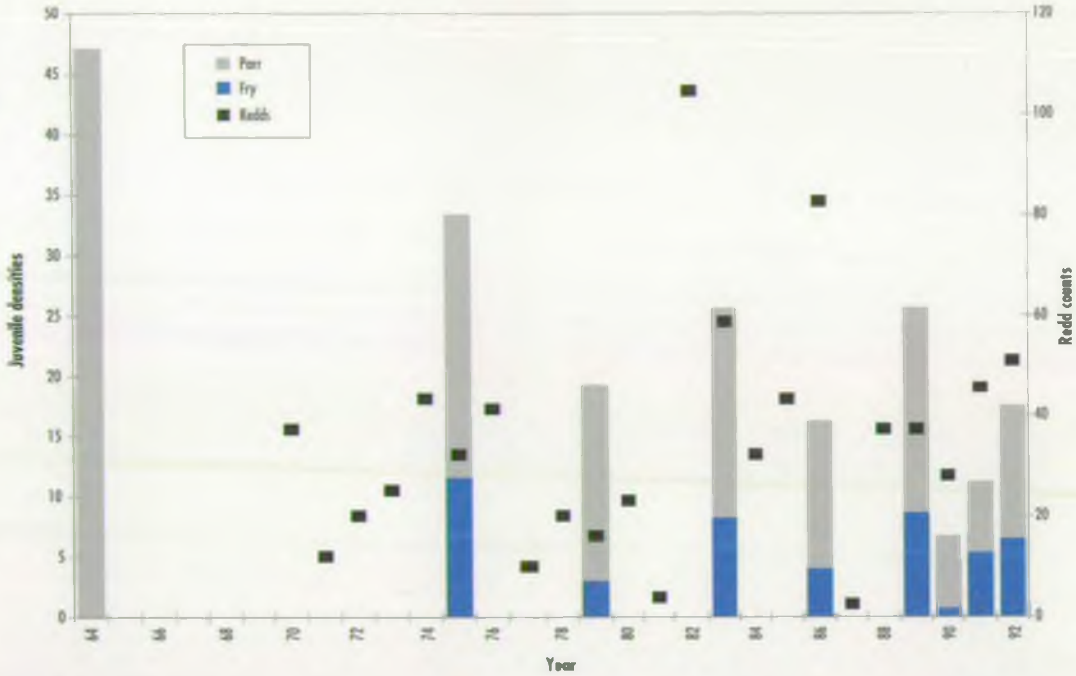
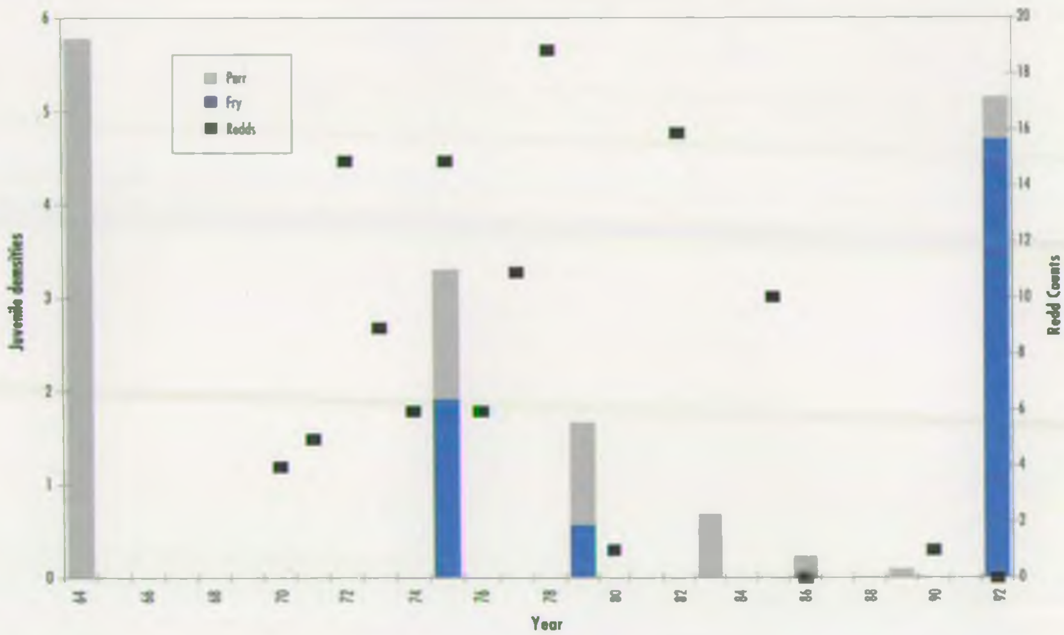


Figure 2.11
Juvenile salmon abundance and redd counts in the River Waldon in selected years since 1964

Note: Data for fry abundance are not available in 1964



counts since 1969 have been increasing and fry densities have been consistently low since 1975. In 1983 another slurry spill was estimated to have killed 35 000 juvenile salmonids in the upper Torridge.

2.5.6 Lower River Torridge

The higher fry densities seen in 1992 in many of the tributaries were also seen in the riffle surveys on the lower Torridge (Table 2.10).

Table 2.10 Estimated number of juvenile salmon caught per 20 minutes sampling on riffles in the River Torridge

		Year			
	Age	1989	1990	1991	1992
Number of juvenile salmon caught	Fry	7.8	5.8	2.4	28.7
per 20 minute sample	Parr	2.0	0.3	3.4	8.7
Number of riffles sampled		28	8	28	20

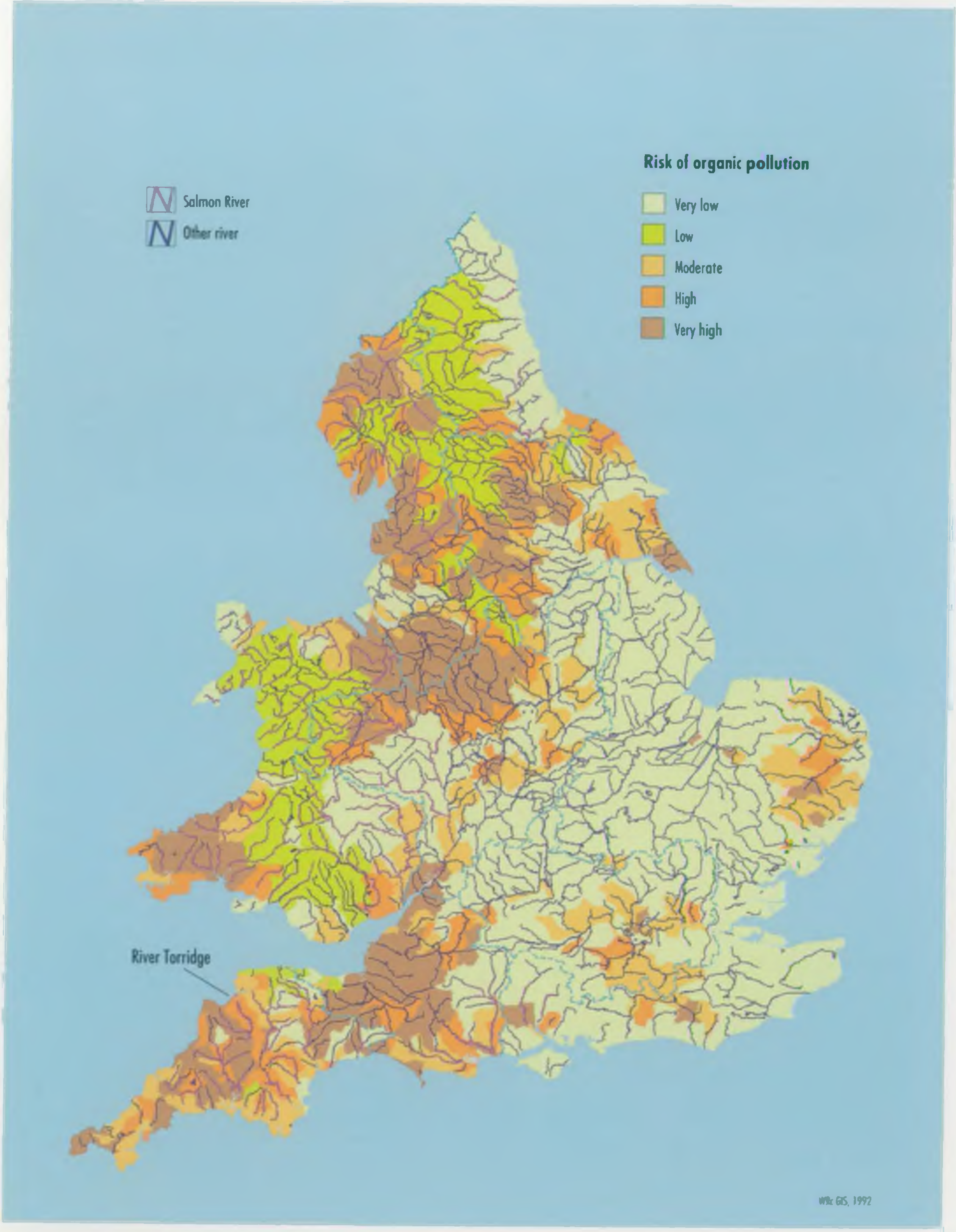


Plate 1 The distribution of salmon rivers and areas at risk from organic pollution from livestock farms

Plate 2 Aerial view of Torridge catchment

Plate 3 Adult salmon

Plate 4
Riparian land use –
a livestock access point

Plate 5
Soil erosion around an
unstable bank

Plate 6 Livestock yard in rain

Plate 7
Agricultural runoff –
muckspreading alongside stream

Plate 8 Water quality monitoring

Plate 9 Salmon bioassay cages – inspecting a basket of salmon eggs buried in riverbed gravel to monitor survival

Plate 10 Recently hatched salmon

Plate 11 Juvenile salmon bioassay cages

Plate 12
Surveying wild juvenile salmonids by electrofishing

Plate 13
River East Okement

3. COMPARISON BETWEEN STUDY CATCHMENTS

3.1 Land Use

Current land use within the study catchments was examined using aerial photography, field visits and the records of the Torridge Farm Campaign. Dairy farms are the most common type of farm in the Hookmoor and Medland Catchments (50%), but are not so common on the Cookbury Stream (38%) or East Okement (20%), and most also support sheep and beef cattle (Table 3.1). Farms supporting sheep and beef cattle, but without a dairy herd, dominate the Cookbury and East Okement study catchments and there are no wholly arable farms. Sheep are the dominant livestock (in terms of numbers) in each study catchment, followed by cattle.

Farm buildings, where animals are housed and waste is collected, represent potential point sources for waste material entering watercourses. The highest density of farms (1.6 km^{-2}) is found in the Medland Catchment, with the lowest (0.3 km^{-2}) in the East Okement. Farms are confined to the lower reaches of the East Okement, but are evenly spread throughout the other study catchments, from their headwaters to their confluences (Figure 3.1).

Substantial differences in grassland type are apparent between the East Okement Catchment and the other study catchments. Unimproved pasture dominates the East Okement in all but the lower third of the catchment (Table 3.1), whilst surviving unimproved pasture in the others is fragmented and widely spread. Improved pasture, maintained by fertilizer and herbicides, is mainly confined to the lower reaches of the East Okement, but dominates the full length of the other study catchments.

Woodland, whilst accounting for up to 10.5% of catchment area, is widely distributed in ribbons of deciduous trees lining river banks, and in some conifer plantations. A survey of riparian management in the study catchments found little effort to prevent bank erosion, as animals are generally allowed to graze right to the edge. The management of animal access points for drinking, which damages river banks, is also minimal.

3.2 Waste Management

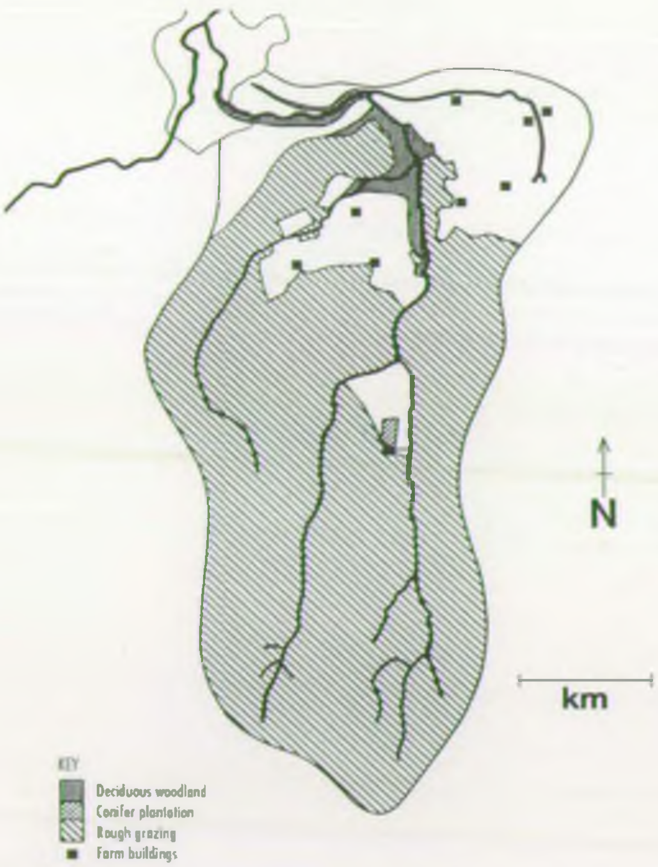
The records of the SWWA/NRA Farm Campaign (1984 to 1989) were used to identify farm waste management practices within the study catchments. The Farm Campaign (1984 to 1987) found that 27% of farms in the Hookmoor and Medland Brooks were polluting and a further 19% were considered to be at risk of doing so (Table 3.2). However, in March 1993, an inspection of these catchments by the NRA River Warden found no evidence of farms polluting watercourses, but 33% were considered at risk during rainfall events.

The Cookbury Stream is notable among the intensively farmed study catchments as the Farm Campaign found an absence of polluting farms and a lower proportion of farms at risk of polluting. This may reflect the smaller number of dairy farms and the higher proportion recorded as producing manure rather than slurry waste (Table 3.2).

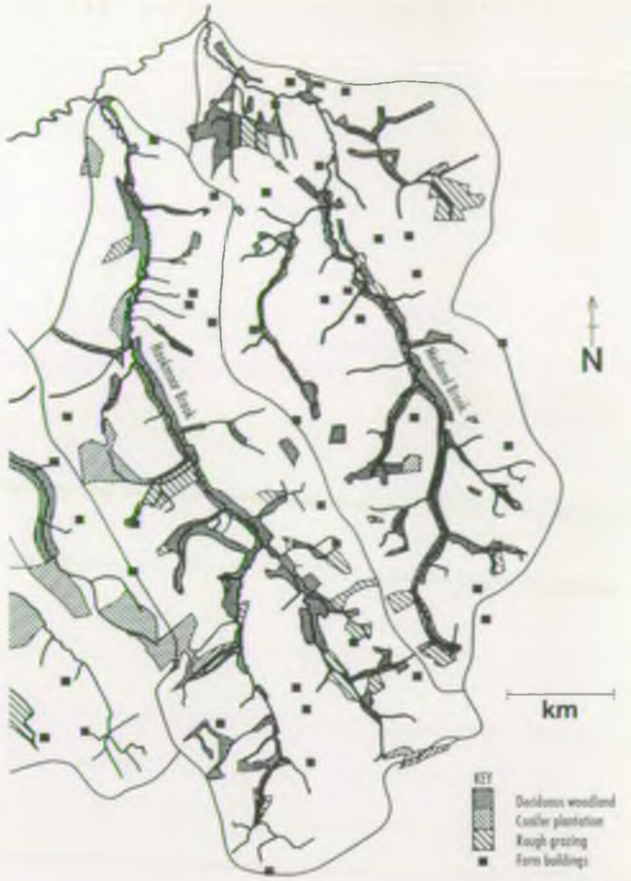
The majority of farms produce silage, including some on the River East Okement, and at the time of the Farm

Table 3.1 Agricultural land use characteristics of the study catchments

	Hookmoor Brook	Medland Brook	Cookbury Stream	East Okement
Area (km^2)	16.2	13.6	21.5	20.1
Number of farms (km^{-2})	1.5	1.6	1.0	0.3
Area of rough grazing (%)	2.9	5.3	5.7	73.9
Number of dairy farms (& %)	10 (50%)	11 (50%)	8 (38%)	1 (20%)
Number of sheep/beef cattle farms (& %)	10 (50%)	11 (50%)	13 (62%)	4 (80%)
Number of dairy cows (km^{-2})	32.9	41.4	14.7	0.4
Number of sheep (km^{-2})	148.4	206.1	105.1	102.2
Number of other cattle (km^{-2})	94.9	103.9	61.9	11.2



Map of the East Okement Catchment



Map of the Hookmoor and Medland Catchments

Map of the Cookbury Catchment

Figure 3.1
Maps of the study catchments showing the distribution of farm buildings, woodland, unimproved pasture and improved pasture/fodder crops (white areas)

Table 3.2 Data from the Torridge Farm Campaign, 1984 to 1987

	Study catchment			
	Cookbury	Hookmoor	Medland	E.Okement
Total number of farms*	21	20	22	7
Polluting (%)	0	30	23	0
At risk (%)	24	20	18	14
Non-polluting (%)	76	50	59	86
Producing cattle slurry (%)	21	56	63	57
Producing manure only (%)	68	44	37	0
No livestock waste (%)	11	0	0	43
Clean water separation (%)	21	28	37	29
Outfall to watercourse (%)	94	94	74	100
Sheep dipping (%)	53	34	26	42

Note: *Records were not always available for each of the parameters.

Campaign only two used a sealed unit to contain the liquor. In addition, 63-79% of farms did not have clean water separation systems dividing rainfall runoff from farm waste, thus increasing the volume of waste requiring storage and disposal. Slurry was produced at some 60% of farms in the Hookmoor and Medland Catchments and 30% of farms in the Cookbury Catchment. Its production appears mainly confined to dairy farms, with those specializing in beef using a traditional straw-based waste management. The majority of those producing slurry have storage facilities, allowing its accumulation on site.

The location of the outfall from a farm drainage system has a direct bearing on its potential effects on watercourses, since they can provide a route for waste discharge. The majority of farm drainage systems in each study catchment are connected either directly to a watercourse or via a ditch. The wide distribution of farms and permanent pasture throughout the intensively farmed study catchments (Figure 3.1) means that the risk of inputs of organic waste, nutrients and pesticides extends from headwater areas downstream; in contrast, pollution risk is mainly confined to the lower reaches in the East Okement.

3.3 Field Drainage

Field drains connected to ditches or emptying directly into adjacent watercourses were found in most fields containing improved grassland (Table 3.3). Consequently, wetland areas, which may provide some natural attenuation of field runoff, were rarely encountered in fields alongside streams in the intensively farmed study catchments. In contrast, the East Okement retains extensive wetland areas, particularly in the upper two-thirds of the catchment.

Table 3.3 Stream order and incidence of field drains, ditches and animal access points in the four study catchments

	Stream Order (Shreve)	Drain discharges (km^{-1})	Ditch discharges (km^{-1})	Animal access points (km^{-1})
Cookbury	17	3.7	9.4	7.1
Hookmoor	7	3.6	13.1	11.1
Medland	5	1.5	4.5	5.2
E Okement	6	0.0	0.0	*

* Shallow banks afford unlimited animal access.

Table 3.4 Determinand concentrations in water samples taken during wet weather 1990 to 1992, and estimated total time (days) that concentrations exceeded specified concentrations

	BOD ($mg\ l^{-1}\ O_2$)		Total ammonia ($mg\ l^{-1}\ N$)			Suspended solids ($mg\ l^{-1}$)	
	95%ile	days >5 1991	95%ile	days >0.31 1991	days >0.7 1991	mean	max.
Cookbury	7.7	11.7	0.6	11.7	0.2	93	600
Hookmoor	7.5	15.3	0.5	13.9	0.8	94	1700
Medland	8.4	19.7	0.5	13.7	0.7	81	1800
E. Okement	3.1	0.0	0.1	0.0	0.0	10	80

3.4 Water Quality

3.4.1 Introduction

Water sampling was undertaken at monitoring stations near the foot of each of the four study catchments (Figure 1.1). Three methods were employed: rainfall-induced flow events were spot sampled using automatic samplers triggered by rising water level; dry weather flows were monitored by spot sampling; and a small number of parameters were continuously monitored (Naismith 1996a). Spot samples from flow events and dry weather flows (approximately 340 per study catchment) were used to characterize and compare water quality between study catchments, and the continuous monitoring was used to identify unusual events that might be indicative of the passage of polluting discharges. Pesticide contamination was investigated using discrete sampling and analysis of body burdens in tissue from 19 eels collected from the study catchments.

3.4.2 General water quality determinands

Overview

The study found that water quality in the non-intensively farmed River East Okement was consistently higher than that observed in the intensively farmed study catchments, particularly with respect to BOD, total ammonia, DO and suspended solids. Concentrations of nutrients (phosphate and nitrate) were also higher in the intensively farmed study catchments, probably reflecting the use of fertilizer to maintain permanent pasture. However, no specific evidence of eutrophication was observed within the study catchments.

Water quality during high flows

Rainfall events in all four study catchments reflected the "flashy" nature of the rivers (NRA 1990), this being characterized by a rapid response in river level, rising sharply to a peak with a subsequent steep recession curve. In 1991, some 60 such events occurred with an average duration of 16 hours (total 950 hours, 10.8% of the year).

Some 20 major rainfall events were automatically sampled between October 1990 and September 1992. Three to 12 samples per event were selected for analysis, covering the period of rising water, the peak and subsequent decline in each case. Water quality in all four study catchments was found routinely to deteriorate in association with rainfall-induced flow events, characterized by peaks in ammonia, suspended solids, BOD and nitrite concentrations (Table 3.4). These cause frequent declines in water quality which are of relatively short duration and therefore can be missed by routine water quality sampling programmes (where samples are usually taken once a month).

DO remained above 80% saturation in winter in all study catchments, and did not appear to be adversely affected by rainfall events and the associated high BOD concentrations. This suggests a high reoxygenation capacity within these streams running off upland gathering grounds.

Mean suspended solid concentrations just exceeding the EC Freshwater Fish Directive (Council of European Communities (CEC) 1978) limit of an annual mean of 25 $mg\ l^{-1}$ were observed in the Hookmoor Brook and Medland Brook, largely due to rainfall events.

Rainfall-induced runoff from fields and farm buildings therefore appears to be an important mechanism by which material enters these watercourses. Rainfall events tend to be less frequent in summer but it appears that concentrations, particularly of BOD and ammonia, can be exceptionally high during major flow events marking the end of summer low flows. This is possibly a consequence of the accumulation of material over a relatively prolonged period.

Table 3.5 Determinand concentrations in water samples taken during dry weather 1990 to 1992

	Temp max (°C) days/month	BOD 95%ile days/month ($mg\ l^{-1}\ O_2$)	Ammonia 95%ile ($mg\ l^{-1}$ N)	SS mean ($mg\ l^{-1}$)	DO	
					<80% in summer*	<60% in summer**
Cookbury	18	2.8	0.14	11.4	7.6	0.00
Hookmoor	18	2.5	0.08	5.6	10.9	0.06
Medland	17	2.3	0.08	4.0	9.3	0.06
E. Okement	18	2.0	0.03	2.2	0.0	0.00

Note: * Estimated time (number of days) per month when DO <80% (and <60%**) during the periods June-September 1991 and 1992.

Water quality during dry weather

Levels of BOD and concentrations of total ammonia were low during dry weather (Table 3.5), indicating that none of the study catchments suffered from gross continuous organic discharges. In summer, during periods of low flow, DO concentrations of between 60 and 80% (NWC Class 1B) were recorded in the intensively farmed study catchments, but concentrations remained above 80% (1A) in the River East Okement.

On six occasions during 1991/1992 continuous monitoring in the three intensively farmed study catchments indicated the passage of a transient discharge of waste material during dry weather. The incidents were detected as rises and falls in the concentrations of turbidity and ammonia lasting between two and 14 hours duration, and reaching a maximum concentration of 3.2 $mg\ l^{-1}$ total ammonia on one occasion in the Hookmoor Brook. Dead fish were not observed following any event and none gave rise to any reports of an incident to the NRA by the public. Consequently, retrospective investigation of the source of the incidents once identified was not possible. However, whilst this monitoring exercise demonstrates that such incidents occur, it does not provide a reliable estimate of the frequency of such incidents as the rigours of equipment deployment and the remoteness of site location led to equipment down-time as high as 50%.

Maximum summer water temperatures did not exceed 18°C in any study catchment, which is within the EC Freshwater Fish Directive (CEC 1978) limit. In general summer temperatures appear lower, winter temperatures higher and diurnal variation smaller than has been found in other Devon sub-catchments containing improved farmland (personal communication, Dr B.W. Webb). This may be attributable to some extent to the continued presence of tree cover bordering the majority of the study streams (Figure 3.1).

3.4.3 Metals

Relatively high concentrations of zinc and copper were found in the River East Okement and the Hookmoor Brook, but these may reflect the underlying geology rather than any anthropogenic impact. Both watercourses drain parts of the Dartmoor granite extrusion, within and around which a highly mineralized area is located.

Aluminium toxicity has been linked with low embryo survival in acid waters (O'Donnell *et al.* 1984). However, it is most toxic over the pH range 4.4 to 5.4, which is well below the range observed from spot sampling in the study catchments (Table 2.4).

3.4.4 Pesticides

Herbicides were identified in water samples from each study catchment and the "sheep dip" insecticide, Propetamphos, in the Medland Brook. A history of environmental contamination was also identified by the presence of the persistent organo-chlorine pesticides, which were banned during the 1980s, in the tissue of eels from each study catchment. The concentrations were similar to those previously observed in other rivers in the South West (NRA 1989) and were low by national standards (MAFF 1988). No pollution incidents attributable to pesticides are recorded for the Torridge Catchment, but the results indicate a need for continued vigilance by the NRA and care on the part of farmers.

3.4.5 Biological monitoring of organic inputs to the study catchments

The spatial distribution of organic inputs to the study catchments was examined using the winter Rapid Biological Assessment Keys (RBAKs; Rutt and Mainstone 1995b, NRA 1995) and a summer survey of sewage fungus. A site close to the monitoring stations in each study catchment was also biologically sampled on three occasions in 1990/1991 by the NRA, in the course of the quinquennial River Quality Survey.

Widespread but mild organic impacts were detected in winter in the intensively farmed study catchments, with one localized impact in the East Okement Catchment. However, invertebrate populations appeared unaffected and it was the presence/absence of sewage fungus (generally trace amounts with less than 5% cover) that mainly determined site classifications. In summer, similar small quantities of sewage fungus were found in the intensively farmed study catchments indicating a continuing low organic input. Relatively high concentrations of sewage fungus were found in some farm ditches (maximum 50% cover), highlighting these as a continuing source of organic input to the watercourses. However, these discharges appeared relatively small and were well diluted on reaching the watercourses, both in winter and summer.

Biological sampling by the NRA in 1990/1991 found each study catchment to be "Class A", indicating that observed invertebrate communities were close to those predicted by the River Invertebrate Prediction and Classification System (RIVPACS II) and that they were not subject to chronic organic pollution.

The techniques employed essentially provide a picture of the recent history of conditions in the watercourses at the time of sampling. Therefore, whilst there was no evidence of gross contamination, the occurrence of acute pollution incidents at other times of the year cannot be ruled out.

3.4.6 Pollution incidents and fish kills

Between 1987 and 1991, eleven pollution incidents were reported in the study catchments (Table 3.6). The only fish kill reported (11 salmonids) was due to silage pollution on the Medland Brook. However, this probably represents only a minimum estimate as very few people, even farmers, live adjacent to watercourses to witness such events.

Throughout the study (1990 to 1992) no fish kills were observed within the study Catchments, although kills caused by farm waste discharges did occur in several other intensively farmed sub-catchments of the Torridge.

The summer months are a particularly vulnerable period when flows and hence dilution capacities are low, temperatures are relatively high, and DO concentrations (whilst not critical at 60-80% saturation) are lower than in winter (Section 3.4.2). It requires only one transient pollution event to eliminate or reduce smolt and adult brown trout production in a watercourse for several years (Pickering *et al.* 1992). Consequently, events with a return frequency of several years can cause long-term degradation of stocks despite routinely sampled water quality appearing high.

3.5 River-bed Sediments

3.5.1 Introduction

The concentration of sediment fines within spawning bed gravels can critically affect the permeability of water through interstitial spaces, effectively reducing the delivery of DO to salmonid embryos and therefore limiting the production of salmonids in streams. A number of studies have suggested that the survival of salmon eggs would be low where the proportion of fines of less than 2.0 mm diameter exceeds 20% (Petersen 1978, Wightman 1987). MAFF (1991) suggest a permeability in excess of 1 m hr^{-1}, corresponding to a maximum fines (<2 mm diameter) content of 12 to 15%, in spawning gravels for the successful emergence of alevins.

3.5.2 Sediment particle size analysis

Undisturbed substrate

Sediment sampling was undertaken in each study catchment on a typical riffle area, where salmonids could spawn, close to the water quality monitoring stations (Figure 1.1). Sediments were sampled to a depth of 30 cm using an established freeze coring method (Petts *et al.* 1989) in November 1990, November 1991 and March 1992, and particle size analysis was undertaken on the upper (0 to 15 cm) and lower (15 to 30 cm) profiles.

The spawning riffle sediments in all four sites were typical of upland catchments and comprised a coarse gravel framework beneath an armour layer of coarse and medium gravel. The sediments in the River East Okement were unusually coarse, forming an open framework structure with a low concentration of fines (<2 mm diameter). The substrate was only weakly compacted with no vertical variation in particle size (Table 3.7). In contrast, the intensively farmed study catchments contained high concentrations of fines, of between 18.8% and 35.0% in the lower profiles. These substrates were generally more compact than the East Okement and show an increase in the concentration of fines and a decrease in substrate coarseness with depth. The Cookbury Stream had the highest concentration of fines of all the streams in both upper and lower profiles. The gradient profiles of the main channels in each study

Table 3.6 Pollution incidents reported in the study catchments, 1987 to 1991

Source	Silage	Slurry	Suspended solids	Fish farm	Total
Hookmoor	1	3	1	-	5
Medland	2	3	0	-	5
Cookbury	0	0	0	1	1
East Okement	0	0	0	-	0

Table 3.7 Proportion (%) of sediment finer than 2 mm diameter in upper (0 to 15 cm) and lower (15 to 30 cm) profiles of river-bed sediments

	Upper profile			Lower profile		
Site	Nov 1990	Nov 1991	Mar 1992	Nov 1990	Nov 1991	Mar 1992
E.Okement	10.6	9.4	9.4	9.6	14.7	14.4
Hookmoor	13.6	11.1	14.1	22.2	20.4	23.0
Medland	13.5	10.4	13.6	24.9	18.8	29.5
Cookbury	15.6	17.4	19.0	24.9	35.0	31.5

catchment showed that, whilst the sample sites were at similar altitude, the River East Okement is substantially steeper than the other watercourses, as it descends the northern flank of Dartmoor immediately above the study site. This is likely to result in high current velocities during flow events, creating an unstable sediment structure. The pedology of the East Okement is dominated by peaty soils and gritty loams of the moorland slopes, accounting for the low concentration of fines. In contrast, the soils of the other study catchments are dominated by clays, silts and loams, and the shallower gradients and less disruptive flow events afford more stable structures; factors which allow fines to infiltrate the gravels and concentrate in the lower profiles.

In the Cookbury Stream, the number of first-order feeder streams is larger than the other study catchments by a factor of two, which may increase the sediment supply from source areas. It also exhibits the shallowest gradient among the study catchments and therefore may be more prone to the deposition of fine material.

In the complete absence of historical data it is impossible to determine whether fines loadings are greater than in past decades. Loadings of suspended solids are higher in the intensively farmed study catchments during rainfall events, deriving from a combination of land runoff and erosion of the river bed and banks. The development of arterial field drainage systems has been found to enhance runoff during rainfall (Robinson 1990), implying that the drainage activity throughout the catchment up to the mid-1980s, along with the increased pressure on bankside stability from livestock grazing and drinking access, are possible causative agents.

Artificial Redds

To examine whether the disturbance of fines associated with redd cutting would reduce the concentration of fines, particle size analysis was undertaken on artificial redds. Five redds were constructed at each site in November 1991 using a pickaxe and a water pump. Each measured approximately 1.5 m by 0.5 m, and was excavated to a depth of 30 cm. Sediment sampling of the redd gravels was undertaken within one week of construction, and again in March 1992.

Redd construction resulted in large quantities of fine material being washed out, effectively loosening the gravel and creating void spaces. However, rapid re-infiltration of fine material from the surrounding gravel occurred over a matter of days, as also shown by Wickett (1954) and McNeil and Ahnell (1964), raising fines content to levels that were not significantly different to those present in the surrounding gravels. It would therefore appear that physical measures to artificially improve spawning areas for salmonids may only be effective if the concentration of fines in gravels can be substantially reduced over relatively large areas, so reducing re-infiltration to redds.

3.5.3 Intra-gravel dissolved oxygen

Intra-gravel DO concentration was examined at one site in each study catchment during the winter of 1991/92 using pre-positioned, 10-mm diameter steel stand-pipes and a 1.5-mm diameter oxygen probe (Woolmington 1982, Wightman 1987).

Intra-gravel DO concentrations were highly variable (Table 3.8) both within sites and between samplings, but were consistently lower than river concentrations on each occasion. Results from the River East Okement were limited by vandalism of the sampling stand-pipes.

In March, when measurements were successfully obtained in the River East Okement, the concentrations were significantly higher than those observed in the other three study catchments.

At field temperatures of about 5°C, the lower lethal threshold for embryos for DO lies around 3 to 5 mg l^{-1} (Wickett 1954, Alabaster and Lloyd 1982). DO concentrations that may be lethal to embryos were found in all rivers apart from the East Okement.

3.6 Salmon Embryo Bioassay

In-situ embryo bioassay experiments were undertaken during the winters of 1990/1991 and 1991/1992, using green (just fertilized) salmon eggs, buried in Harris boxes (Harris 1973) within artificially dug redds (Naismith 1996b). These experiments were undertaken to provide a relative measure of survival between study catchments, but this may not accurately reflect survival in redds produced by wild fish. The boxes were buried in December, and sub-samples were either left undisturbed, or lifted once or twice to determine the pattern of mortality, before the experiments were terminated at the time of hatch in March. In 1992, some of the boxes lifted in January were transferred to upwelling egg baskets, designed to prevent the accumulation of fine sediment in the egg boxes, and others were reburied as a control.

The survival data obtained (Table 3.9) were characterized by very high variation in per cent survival between egg boxes within the same river, and this severely reduced the power of the experiment. Overall there was a highly significant difference between rivers, with the highest survival in the East Okement (37.4%), becoming progressively worse in the Hookmoor Brook (23.9%), Medland Brook (15.8%) and Cookbury Stream (2.0%). The relative egg survival was consistent with expectations

Table 3.8 Intra-gravel dissolved oxygen concentrations (mean and range in mg l^{-1} O_2), river dissolved oxygen concentrations and temperature in the study catchments

			Month				
			Dec	Jan	Feb	Mar	Apr
East Okement	Gravel	DO	-	-	-	6.6 (4.9-10.2)	-
	River	DO			11.2		
		Temp				10.3°C	
Hookmoor	Gravel	DO	-	6.4 (1.1-11.1)	4.0 (1.2-7.1)	3.6 (1.5-5.1)	-
	River	DO		12.2	11.1	10.8	
		Temp		4.1°C	2.5°C	6.0°C	
Medland	Gravel	DO	-	9.7 (9.5-9.9)	4.4 (2.8-6.7)	3.2 (0.8-5.7)	-
	River	DO		11.9	10.0	9.9	
		Temp		4.1°C	4.0°C	10.1°C	
Cookbury	Gravel	DO	4.9 (4.3-5.7)	5.6 (4.6-7.3)	-	4.6 (3.0-8.8)	4.8 (3.0-5.5)
	River	DO		13.0		10.9	10.9
		Temp	6.2°C	4.2°C		6.3°C	10.0°C

Table 3.9 Egg survival (%) in the study catchments from December to March, estimated from a binomial model

Year	1991			1992		
Number of lifts	2	1	0	2	1	0
Okement	-	49.5	-	22.7	65.3	29.5
Hookmoor	12.0	12.7	0.5	37.9	50.0	26.4
Medland	0.0	4.0	4.0	15.0	36.5	16.6
Cookbury	0.0	0.8	1.0	2.0	4.5	2.3

Table 3.10 Percentage monthly summer and winter survival rates for newly introduced and acclimatized salmon fry, and the corresponding annual average survival for acclimatized fish

	Summer		Winter		Overall annual
	New	Acclimatized	New	Acclimatized	(Oct. to Oct.)
East Okement	81.5	85.2	86.0	94.3	26.9
Hookmoor	57.8	96.0	71.1	95.4	59.0
Cookbury	71.1	86.4	90.0	95.6	31.8

based on sediment loadings (Section 3.5.2) and intragravel DO concentrations (Section 3.5.3) in the study catchments.

The highest mortality was observed from January onwards, when the eggs become eyed and oxygen requirements increase.

The overall survival in the boxes lifted in January 1992 and placed in upwelling baskets was not significantly different from the survival in the boxes that were lifted at the same time and reburied. However, problems were encountered with maintaining an adequate flow of water through the upwelling baskets, and so the results are felt to be unreliable.

3.7 Juvenile Salmon Bioassay

An *in-situ* bioassay using caged juvenile hatchery-reared salmon was employed in the River East Okement, the Hookmoor Brook and the Cookbury Stream to examine mortality on a continuous basis, and provide a means of rapidly identifying the effects of any observed pollution events (Naismith 1996b).

Cages were constructed from heavy duty PVC and Netlon mesh, with a quick-release, transparent perspex lid to allow in light to the fish. The base of each cage contained substrate from the surrounding river to provide refuge for the fish. Ten cages each containing three fish were deployed in the three study catchments at a site close to the water quality monitoring station (Figure 1.1). Hatchery reared juvenile (6 to 10 cm) salmon of Torridge parentage were deployed for two month periods from October 1991 to October 1992, with a staggered change-over of half the total deployed each month so that at any time there were "acclimatized" fish present against which to check any mortality results from deployment of a new batch of fish. Mortality was recorded on a weekly basis.

3.7.1 Comparison of survival between study catchments

Comparison of survival data was undertaken between: new (first month of deployment) and acclimatized fish (second month of deployment); summer (April to September) and winter (October to March) months; and between the three study catchments.

The analysis of the survival data using a binomial model (Table 3.10) showed that the monthly mortality of newly introduced fish was significantly greater than that of acclimatized fish, and mortality was significantly higher in the summer months. Mortality rates were highest in the Hookmoor Brook, and lowest in the East Okement, but these differences were not significant.

3.7.2 Specific mortality events

Instances where mortalities occurred in both the new and acclimatized fish, indicating the possible passage of a pollution event, were compared with available water quality data. Such events were more frequent in summer than in winter, and their relatively low frequency showed that such mortalities did not routinely occur in association with rainfall-induced flow events. However, relatively high mortalities in the Hookmoor Brook and Cookbury Stream (but not the East Okement) in August and September 1992 appeared to coincide with flow events induced by the first heavy autumn rains, which tend to "scour" watercourses following the prolonged summer low flows. On four occasions, rises in mortality appeared to be associated with rises in turbidity or ammonia that were not associated with rainfall events, suggesting the passage of a discharge downstream.

3.8 Juvenile Salmonid Populations

3.8.1 Introduction

Comparative studies of juvenile salmonids in the intensively farmed Hookmoor Brook and non-intensively farmed River East Okement were undertaken in 1991 and 1992 (Naismith and Wyatt 1996). Survey reaches were selected on the basis of the known distribution of juvenile salmonids, and the number of survey sites determined by the application of appropriate power calculations (Wyatt and Lacey 1994) to data collected in 1990. Twenty-seven electrofishing sites (50 m long) were selected on a 10-km reach of the Hookmoor Brook: nine sites on the "lower reach" (3 km), where the *in-situ* bioassays and water quality monitoring were undertaken; eight sites on the "middle reach" (4 km); and ten sites on the "upper reach" (3 km), where only brown trout populations reside. Nine electrofishing sites were selected on a 2-km reach of the lower East Okement, as migratory salmonids are excluded from its middle and upper reaches by an impassable waterfall.

The abundance of fish at each site was estimated using the removal method, and averaged over all sites to give an estimate of the population within each reach. The annual "survival" in numbers of fish in different year classes in each reach was also estimated and this includes the net effect of survival within the reach, as well as immigration into and emigration out of the reach.

Habitat surveys were undertaken at each electrofishing site, using the HABSCORE methodology (Milner *et al.* 1985, Milner and Wyatt 1991). HABSCORE is a technique for measuring habitat features which utilizes statistical models to give estimates of habitat quality expressed as the density of salmon (fry and parr) and trout (fry and parr) that would be expected under "pristine" water quality conditions. The outputs from the HABSCORE model were used to correct observed densities for differences in the natural habitat quality of the East Okement and Hookmoor Brook.

Between the summer and autumn surveys of 1991, the NRA transferred 2 900 salmon fry and 200 trout fry from the River Okement to the River East Okement to mitigate against a predicted acid-runoff fish kill, which was expected in the River Okement under the prevailing climatic conditions. The 1991 year class was excluded from survival calculations because of this stocking.

3.8.2 Salmon

Salmon densities in the lower East Okement did not depart significantly from those expected for the habitat (Table 3.11), with one exception in 1991, when salmon fry were not found in the upper half of the survey reach. Similarly, in the Hookmoor Brook, densities of salmon fry and parr in the accessible middle and lower reaches were close to what would be expected for the habitat.

The difference between the salmon fry densities in the East Okement and Hookmoor Brook (Table 3.11) was not significant, but after correction for the superior habitat quality using HABSCORE in the East Okement, the densities in the Hookmoor Brook were significantly greater. In contrast, the densities of salmon parr were significantly lower in the Hookmoor Brook, and the differences remained (but to a lesser extent) after habitat correction.

Annual survival of salmon in the East Okement was 24.7%, similar to the estimates from the bioassay (26.9%). In the Hookmoor Brook, survival was around 7% in the middle and lower reaches, significantly lower than in the East Okement, and much lower than the estimate from the bioassay (59.0%). The difference in

Table 3.11 Habitat quality, average summer numbers and annual survival rates for juvenile salmon in the East Okement, Hookmoor Brook and Cookbury Stream

		Habitat quality (expected numbers 100 m^{-2})		Numbers (100m^{-2})		Annual survival
		Fry	Parr	Fry	Parr	(%)
Okement		29	28	11	21	25
Hookmoor	Upper	0	0	0	0	-
	Middle	10	5	15	2	6
	Lower	10	4	13	1	7
Cookbury		10	4	0	0	-

Table 3.12 Habitat quality, average summer numbers and annual survival rates for juvenile trout in the East Okement, Hookmoor Brook and Cookbury Stream

		Habitat quality (expected numbers 100 m^{-2})		Numbers (100m^{-2})		Annual survival
		Fry	Parr	Fry	Parr	(%)
Okement		23	20	12	16	52.5
Hookmoor	Upper	69	36	23	3	20.4
	Middle	35	26	26	9	36.0
	Lower	34	17	5	5	57.8
Cookbury		71	28	10	3	–

survival between the two rivers can be explained in part by the poor habitat quality for older salmon parr in the Hookmoor Brook (Table 3.11) which would not have affected the bioassay results.

3.8.3 Trout

The highest densities of trout fry in the Hookmoor Brook were found in the middle reaches, where the greatest spawning activity was observed (Table 3.12). Differences in trout densities between the upper, middle and lower reaches of the Hookmoor Brook were significant for both fry and parr, and the differences could not be explained by habitat. In addition, densities were somewhat less than would be expected for the habitat quality, particularly in the upper and lower reaches, suggesting that other factors are influencing abundance.

Trout densities in the East Okement were generally similar to those predicted for the habitat. Densities of trout fry were relatively low in the lower half of the survey reach in 1991, but this was compensated by immigration, resulting in a significant rise in numbers at these sites the following spring.

When each of the Hookmoor Brook reaches were compared with the East Okement, trout fry densities in the lower reach of the Hookmoor Brook were found to be significantly lower than in the East Okement, which could not be explained by habitat differences. The trout parr densities in all reaches of the Hookmoor Brook were also significantly lower than the East Okement, even after habitat correction.

Annual survival of trout in the East Okement was 52.5%. In the Hookmoor Brook, survival was lowest in the upper reach (20.4%) and highest in the lower reach (57.8%), and these between-reach differences were highly significant. Survival in the lower reaches of the Hookmoor Brook was similar to that in the East Okement; however, both fry and parr densities in this section of the Hookmoor Brook were suppressed. Survival in the upper and middle reaches of the Hookmoor Brook was significantly lower than in the East Okement. These differences cannot be explained by habitat, and therefore could suggest impacts from anthropogenic inputs affecting the upper reaches, which through dilution do not impact further down.

3.8.4 Pathology

No abnormalities in the internal organs, gills or epidermis of wild juvenile salmonids were found in either intensively or non-intensively farmed study catchments, indicating that pathological conditions are unlikely to be responsible for observed differences.

3.9 Stocking Experiment in the Cookbury Stream

A 5 km section of the Cookbury Stream from its confluence with the River Waldon had been walked in autumn 1990 and 1991, and no evidence of redd cutting had been found. Juvenile surveys had found salmon to be absent and trout densities were generally significantly less than would be expected for an unpolluted stream of similar habitat.

In April 1992, 627 adipose fin-clipped salmonid fry of Torridge origin (later found to have been salmon/sea trout hybrids) were stocked at a density of 500 fish 100 m^{-2} into a 50-m site on the Cookbury Stream, 0.5 km above the water quality monitoring station (Figure 1.1), to examine whether the stream was capable of supporting an enhanced juvenile stock. Electrofishing surveys in July 1992 revealed densities of stocked fish at the release site of 17.4 fish 100 m^{-2}, and in October of 8.8 fish 100 m^{-2}. This would suggest that the densities of fry in the Cookbury Stream are constrained by recruitment, rather than habitat or water quality.

4 CONCLUSIONS ON THE FACTORS AFFECTING RIVER QUALITY AND FISHERY STATUS

4.1 Evidence for Environmental Changes in the Torridge Catchment

4.1.1 Land use

Land use in the Torridge Catchment has undergone extensive changes, particularly in the late 1960s and 1970s, resulting in fewer but larger farms, supporting substantially increased livestock densities. This has been supported by the introduction of silage making, with associated implications for the management and safe disposal of liquor, that has encouraged a major shift to permanent improved pasture maintained by fertilizer application. Furthermore, changes in livestock husbandry have caused a shift to indoor overwintering of cattle which, together with silage making, has increasingly concentrated organic waste production in and around farm buildings.

An essential part of grassland improvement has been an increase in land drainage activities from the 1950s to the mid-1980s, particularly in some headwater areas of the Torridge. Such developments are likely to have affected the process of sediment supply and deposition within watercourses.

Over the past decade there has been a stabilization of cattle numbers, and the Torridge Farm Campaign and other initiatives have resulted in a substantial reduction in the number of farms continuously polluting watercourses. Consequently, the impacts from agriculture in the Torridge Catchment may be less severe now than they were in the mid-1980s.

4.1.2 Water quality

Historical water quality data have only been available since 1974 and therefore do not cover the full period of land use change. Since that time the data do not suggest any continuous trends of improvement or decline, but rather discrete periods of poor quality. In particular, widespread failures to comply with RQOs for BOD and ammonia, which indicate organic pollution, occurred in the mid-1980s, associated with particularly dry summers. It is notable that widespread failures did not occur in the preceding droughts of 1975 and 1976, and in the subsequent 1989/1991 droughts, suggesting that organic contamination may not have been as severe at these times.

Pollution incidents, particularly those associated with agricultural activities, have been increasing since the early 1980s; however the extent to which this reflects increased public awareness is unclear.

4.1.3 Salmonid fisheries

Evidence from the catch statistics would suggest that there has been a decline in the run size of salmon and sea trout between the mid-1960s and the mid-1970s. This was coincidental with a decline in the fisheries on a number of other Devon rivers and the arrival of UDN in the region in 1968, suggesting that the cause was not necessarily specific to the Torridge. Catch statistics provide no clear evidence for further systematic changes in the river population of either species throughout the late 1970s and 1980s. However, this was at a time when other Devon rivers were recovering, and measures were being taken on the Torridge to conserve stocks, suggesting that there were Torridge-specific factors constraining the migratory populations during this period.

Populations of salmon and trout parr in the upper River Torridge, River Lew and River Waldon have shown significant declines from what would be regarded as healthy populations in the mid-1960s. Fry populations have also been low since data have been available in the mid-1970s. There is evidence that salmon and trout fry densities have been improving since 1990, and it is possible that the fish populations are recovering, perhaps as a response to fishery protection measures, or to the reduced risk of pollution as a result of the Farm Campaign. It is therefore possible that the conditions prevailing during the comparative investigation in the study catchments may be less severe than the conditions at the time of the SWWA study in the mid-1980s.

4.2 Mechanisms of Impact

4.2.1 Embryo survival

The results of the *in-situ* salmon embryo survival studies showed average survival was as low as 2% (Cookbury Stream) in intensively farmed catchments, compared with 37% in the non-intensively farmed River East Okement. This suggests that there is an impact on embryo survival. The discovery that the river-bed gravels in the intensively farmed catchments contained fine sediment concentrations likely to be damaging to salmonid embryo survival, and that the actual interstitial DO levels in these gravels were low enough to be lethal to embryos, implicates spawning gravel quality as a factor responsible for low embryo survival. The low densities of trout fry and the lack of salmon fry in the Cookbury Stream are consistent with poor egg survival. In the Hookmoor Brook the low densities of trout fry in the lower reaches were also consistent with poor egg survival; however salmon fry densities in the same location were normal.

4.2.2 Juvenile survival

The juvenile salmon bioassays showed that survival in the intensively farmed catchments was not significantly different from survival in the East Okement. The stocking experiment in the Cookbury Stream revealed habitat and water quality capable of supporting fish, in areas where wild populations were severely depleted. The observed survival of the juvenile salmon populations in the Hookmoor Brook could largely be explained by the habitat quality, and the survival of juvenile trout in the lower reach of the Hookmoor Brook was similar to the survival in the East Okement. This demonstrates that the survival of juvenile salmonids does not appear to have been adversely affected by water quality in many parts of the intensively farmed catchments during the study. The survival of trout in the upper and middle reaches of the Hookmoor Brook, however, were low suggesting that localized anthropogenic impacts are a factor that may affect juvenile production.

No pathological abnormalities were found in the juvenile population of any study catchment. Overall, the bioassay experiment on juveniles found annual survival rates across all sites to be lower in summer than in winter.

4.2.3 Pollution incidents and fish kills

The continuing occurrence of polluting discharges in the Torridge Catchment during the study, some of which caused observable fish kills, continues to implicate poor farm waste management as a possible mechanism affecting long-term degradation of stocks. Such transient events are rarely detected through routine water quality sampling and their recording tends to rely on observer reports, especially of fish kills. That these occur predominantly in summer appears to be a reflection of the prevailing lower flows and hence dilution capacity.

4.3 Influence of Agriculture

4.3.1 Sediment quality

Although sediment fines concentrations are higher in the intensively farmed study catchments, than in the non-intensively farmed study catchments it is difficult to infer whether this reflects an historical change in concentration. The observations may partly reflect differences in the soil type and the steeper gradient in the non-intensively farmed River East Okement, which create a less stable substrate for deposition. The Cookbury Stream, which was the experimental site most affected by fines, contains twice the number of first order feeder streams, which may increase sediment supply from source areas, and has the shallowest gradient. The processes by which sediment is supplied to watercourses and by which it is deposited are complex. However, the coincident decline in juvenile populations and the intensification of agriculture implies several possible causes, including riparian management. The increased livestock activity on river banks over the last 30 years, due to grazing and drinking, and drainage of marginal wetlands, may have exacerbated sediment supply by erosion runoff and poorer bank stability, whilst improved field drainage may affect hydrology and hence instream erosion and deposition processes.

4.3.2 Water quality

The comparative work on the study catchments demonstrates that water quality in the non-intensively farmed River East Okement was consistently higher than that observed in the intensively farmed study catchments, particularly with respect to BOD, ammonia, DO, suspended solids and nutrients.

On the assumption that this reflects the wider situation in the Torridge Catchment before the period of agricultural intensification, then these changes in "land use" have caused a deterioration in water quality. Biological sampling implicates organic waste production from farms as causing a mild impact throughout the intensively farmed catchments. This is reflected in the higher BOD and ammonia concentrations observed.

The intensively farmed catchments have a higher density of farm buildings, livestock, improved permanent pasture and silage production, which are distributed throughout the catchments, creating a pollution risk from point sources from headwaters to foot. Organic materials (slurry, dirty water, silage liquor) have been concentrated around farm buildings in overwintering storage facilities, and farm drainage systems invariably connect directly to watercourses. This generates a high potential for localized impacts which, through dilution and self-purification, may not be detected downstream.

Deteriorations in water quality are routinely caused by flow events following rainfall, when runoff from farm buildings and fields occurs. This is probably a major source of the variability in water quality observed in routine sampling

5 RECOMMENDATIONS FOR FUTURE MANAGEMENT

5.1 Introduction

In order to protect salmonid populations effectively against any adverse effects from changes in land use, it is important to have a comprehensive national strategy that is geared to impact prevention as far as is possible, supported by a capability to ameliorate impacts when they arise. Within the sphere of impact amelioration, attention needs to be focused on tackling causal mechanisms and providing short- and medium-term relief whilst the fundamental problems are being addressed.

Within the type of strategy described, management activity can be seen to be divided into four main areas:

(i) predicting future land use change and potential impacts;
(ii) detecting environmental and ecological change in the field;
(iii) implementing appropriate remedial measures; and
(iv) introducing instream mitigation measures.

Based on the experience of this project, these areas of management are dealt with separately in the following sub-sections.

5.2 Prediction of Change

Prediction of land use/management changes that are likely to impact upon salmonid populations is crucial to the implementation of a proactive strategy. There are four main components:

(i) forecasting land use changes (primarily based on agricultural economics);
(ii) predicting changes in the water quality of salmonid rivers (in relation to factors such as organic pollution, suspended solids and pesticides);
(iii) predicting effects on the physical structure of salmonid habitats (such as changes in flow regimes, the availability of refugia, and the quality of spawning gravels); and
(iv) predicting likely biological impacts based on likely changes to the physico-chemical environment.

Within agriculture, a great deal of effort is expended in forecasting changes as a result of the supply/demand balance and grant reforms, considering the basic capacity of the land to support different types and intensities of land use. Grant reforms may be driven by supply/demand or environmental issues (or both), and indeed are used to steer land use change in desired directions. In short, much knowledge is gathered by agricultural/land use strategists that is of potential benefit to proactive environmental protection. National-scale land use models exist that can provide likely scenarios for land use change, from which ecological effects can be predicted.

Taking information on likely future scenarios of land use and assessing the consequences for salmonid populations (and riverine ecology in a wider context) is an activity that will always carry a high level of associated uncertainty, combining as it does uncertainty in both land use predictions and the nature of impact mechanisms. In relation to water quality, the process can be made more objective by the use of non-point source pollution models that can predict changes in contaminant loadings to rivers. Ecological models that link environmental factors to effects on biological communities represent an important future means of objectively predicting biological impact.

Inevitably, the land use and physico-chemical components of predicting change are cross-functional issues that should be dealt with accordingly. The co-ordinating role of the NRA Rural Land Use Group is vital in this respect. Information on likely changes can be fed to individual Functions (or cross-functional working groups) in order to evaluate the implications for their specific areas of concern.

5.3 Detecting Environmental and Ecological Change

In addition to being able to predict the impacts of land use changes, it is important to be able to detect and monitor ecological changes when they occur, whether they have been predicted or not. It has often taken considerable time to recognize declines in fish populations and identify the factors responsible - identification of problems at an early stage will reduce the need for major restoration work at a later date.
In terms of providing a national strategy, this activity would sensibly involve the establishment of a network of 'indicator' catchments, with the aim of assessing the likely nature and scale of effects nation-wide. This would include the monitoring of land use activity in the catchment and changes in the ecological status of the river network, in addition to detailed studies of the underlying mechanisms of ecological change.

Such an approach can only hope to monitor general trends in land use change, whilst trying to identify the mechanisms underlying any subsequent ecological effects. Local monitoring is required to determine the nature and scale of problems specific to particular catchments, with decisions on appropriate catchment management being supported by information provided from indicator catchments. Special investigations of priority catchments may be deemed necessary, for which guidance on appropriate monitoring would be valuable. Multidisciplinary monitoring techniques that would be useful in such investigations are discussed separately in Section 5.6, based on the experience of this study.

As with the prediction of land use change, the issue of indicator catchments is cross-functional, since they can be established to detect changes in water quality and quantity, physical habitat structure, fish populations, and both plant and invertebrate communities. Planned R&D projects are likely to involve the establishment of a series of representative catchments for specific investigations; these might be integrated and widened to provide a network for longer-term monitoring. Again, the NRA's Rural Land Use Group has an important co-ordinating role to play.

5.4 Remedial Measures

5.4.1 Targeting management action

The effective application of remedial measures involves appropriate spatial targeting of impacting sources and the subsequent selection of suitable measures in relation to the nature of the source. Both of these activities inevitably require catchment-specific investigations aimed at providing the relevant information. Recommendations concerning the targeting of management activity and the remedial measures available are discussed in subsequent sub-sections. Owing to the nature of the study, the recommendations made relate specifically to catchments under intensive livestock management.

The targeting of remedial action can broadly be divided into three distinct areas on the basis of the source of impact:

(i) pollution sources associated with farmyards and associated waste storage facilities;
(ii) non-point source pollution from land runoff; and
(iii) riparian habitat degradation.

Pollutant loads from farmyard areas can be effectively tackled by a programme of farm visits, with appropriate remedial actions being enforced through the 1991 Control of Pollution (Slurry, Silage and Agricultural Fuel Oil) Regulations. They have been shown to be an effective means of improving water quality, particularly during dry weather and summer conditions when the dilution capacity is low. Biological indicator keys using the benthic macroinvertebrate community have been shown to be a very useful tool in pin-pointing pollution sources associated with farmyard areas (Rutt and Mainstone 1995b), and their use should be considered when planning farm visits.

Targeting pollution control activity at non-point source loads is a far more difficult task, involving consideration of land characteristics and the scale of livestock waste loadings across the catchment. In terms of salmonid populations, the two most important non-point source pollution issues in livestock-dominated catchments are organic pollution from livestock wastes and sediment delivery from eroding soils. Maps and Geographical Information Systems can both help in the identification of high risk areas, and non-point source pollution models can also be employed in order to try and quantify loads (see Section 5.2).

Physical degradation of riparian areas that detrimentally affects salmonid habitat availability can be investigated through the use of habitat assessment techniques. The principal technique available is the HABSCORE model for predicting salmonid abundance from a range of habitat variables. A more extensive method may soon be available from the NRA R&D Programme.

5.4.2 Specific measures for livestock waste

A wide range of remedial measures is available for preventing pollution from farmyard areas, including the provision of adequate farm waste storage capacity, the separation of clean water from yard runoff, the establishment of reception pits for dirty water, and appropriate construction of silage clamps. Specifications exist for such waste containment facilities (e.g. CIRIA 1992) to which the NRA can work when agreeing remedial action with the farmer. In relation to farm visits, it is important that farms considered "at risk" are revisited during wet weather, paying particular attention to the separation of clean runoff from roofs etc. (which can be drained directly to watercourses) from the dirty water running from yards and waste handling facilities (which should drain into reception pits).

The application of livestock wastes to land should be addressed on a farm-by-farm basis through consideration of factors affecting the assimilative capacity of the land. For the prevention of direct runoff to rivers, the key factors are soil permeability, soil moisture deficit, land slope and proximity to watercourse. A no-application zone alongside watercourses (including drainage ditches) should be observed in all circumstances, which may vary in width according to local conditions. The capacity of the soil/sward to assimilate nutrients should also be considered so that both short- and long-term loadings to receiving waters can be minimized (Mainstone *et al.* 1995). The aim of the assessment should be to produce schedules for the application of slurry and other materials, indicating the location (at a field-scale or higher resolution) and the time/rate of application. The timing and rate of application are crucial: application during the growing season, in amounts that can be assimilated by the growing sward, will maximize nutrient uptake and minimize the risk of transport to receiving waters (particularly if soil-injected).

Farm Waste Management Plans are an ideal vehicle for assessing the adequacy of waste storage facilities and producing schedules for the low-risk application of wastes to land. Their development for individual farms should be encouraged through the dissemination to farmers of details on competent contractors.

5.4.3 Specific measures for sediment transport

The study has shown that the accumulation of fine sediment in salmonid spawning gravels is an important mechanism of impact on salmonid fish populations. Although the reasons for high rates of accumulation are unclear, remedial measures that will help to minimize the runoff of fine sediment from the land are likely to improve spawning conditions. Control of animal access points and the maintenance of bank stability, through fencing and the establishment of adequate bankside vegetation, has the potential to reduce greatly sediment delivery from the immediate riparian area (Mainstone *et al.* 1994).

The relative importance of sediment delivery from areas further afield than the immediate riparian area is unclear in pasture-dominated catchments, and requires investigation. Where remedial measures are deemed to be required, pasture management that ensures a healthy and unbroken sward serves to minimize erosion losses. This includes the control of stocking densities at appropriate levels and the use of rest periods where no grazing occurs.

5.4.4 Buffer zones

The imposition of dedicated buffer zones (i.e. zones where the vegetation is managed specifically for the amelioration of runoff quality) in riparian areas and across key runoff pathways can be effective in reducing both particulate loads from soil erosion and organic pollution from livestock wastes (Mainstone *et al.* 1994). A dense sward needs to be maintained for effective physical filtration, but even then break-through flow can occur if runoff energy is too high. Under-drainage systems, which are common in pasture-dominated landscapes, can circumvent buffer zones in situations where fissures or macropores in the soil provide contaminants with rapid access to drains. Research into the efficacy of buffer zones is being undertaken by MAFF, whilst that on optimal buffer zone design is being pursued by the NRA.

5.4.5 Prevention of contamination by sheep-dip and other pesticides

Although no significant pollution from sheep-dipping operations has been observed on the Torridge within the timeframe of the study, sheep-dip presents a clear pollution risk to salmonid populations in livestock-dominated areas. NRA-funded research on the disposal of sheep-dip waste (Blackmore and Clark 1994) recommended that dipper contents should be spread thinly to land at rates no higher than 5 m^3 ha^{-1} (ideally following dilution with slurry) in locations and at times where there is minimal risk of runoff to the river network.

No-application zones alongside watercourses should be established for pesticides in order to avoid spray drift and runoff from the riparian area.

5.5 Mitigation

5.5.1 Introduction

The range of management techniques available to salmonid fishery managers to mitigate against anthropogenic impacts is well-documented and they are already in use, to a varying extent, in most salmonid-dominated river catchments. It is important that mitigation measures should not be seen as an alternative to tackling the problems of pollution at source (Section 5.4). However, since remedial measures may be difficult to identify and implement, mitigation can provide a short-term means of stock conservation, and may also be required in the longer-term if the root causes of decline prove intractable.

5.5.2 Gravel rehabilitation

Instream methods of reducing the "fines" content of salmonid spawning gravels are likely to increase embryo survival through enhanced oxygen availability at this critical life stage. In the Torridge Catchment, spawning riffles have been artificially recreated by the physical redistribution of gravels from well-scoured areas on the outside bends of meanders. Existing gravel beds have also been artificially cleaned of fine material. However, unless the causative factors are addressed, any benefit will be temporary and on-going rehabilitation efforts will be required.

The effectiveness of gravel cleaning by hand, water pump or tractor/horse ploughing will depend on local conditions, and will require coverage of relatively large areas to prevent the rapid re-infiltration of fines from surrounding undisturbed gravel, as observed in the study. Whilst some evaluation has been undertaken of gravel cleaning techniques (such as the work on southern chalk streams by MAFF, the NRA and the Game Conservancy Trust), they have not been systematically evaluated. It is recommended that further research is carried out to investigate the efficacy of measures to improve impacted spawning gravels.

5.5.3 Control of exploitation

When a population of salmonids is placed under significant stress, recruitment into the adult stock can be affected and the availability of adult fish (migratory and non-migratory) can decline. This affects the ability of the population to cope with exploitation, which may therefore need to be reduced. In catchments where salmonid populations are found to be in decline or under stress due to unknown factors, reasonable measures should be considered to reduce exploitation until those factors have been identified and remedied. Measures that should be considered include a tightening of controls on both net fisheries (e.g. through modification of Net Limitation Orders) and rod fisheries (such as reductions in bag limits, a requirement to return fish, or extensions to the close season).

5.5.4 Stocking

The project has identified poor ova survival to be a likely mechanism of impact on salmonid populations in catchments with intensive agriculture. In such situations, where water quality and in-stream habitat is only capable of sustaining juvenile salmonids (as in the Cookbury Stream), it is recommended that the stocking of juveniles and the use of stream-side incubators are considered as short-term means of mitigation whilst causative factors are addressed. However, it is important that any such action should not interfere with studies aimed at identifying the underlying mechanisms of impact.

The adaptive importance of observed genetic differences between different salmonid stocks is currently unclear; however, such differences may well reflect physiological adaptation to local conditions that may be impaired by contamination of the gene pool. Steps should therefore be taken to ensure that genetic contamination of resident populations does not occur during stocking exercises. Juveniles used for the re-stocking of affected sub-catchments or river reaches should be derived from wild broodstock from the river to be stocked. If this precaution cannot be observed due to practical constraints imposed by available rearing facilities, existing arrangements need to be reviewed. Optimum stocking strategies are currently being pursued through the NRA's R&D programme

5.5.5 Provision of access to new spawning areas

Access to new spawning gravels can provide a boost to recruitment that mitigates against the effects of stressors acting upon salmonid populations; however, such initiatives should be undertaken with due consideration to resident fish populations in inaccessible streams. The salmonid populations of such habitats may represent distinct genotypes due to prolonged isolation from the main river network, whilst other fish species may be impacted by competition and predation. As with all other mitigation measures, it is important that the opening up of new spawning areas should not detract from efforts to resolve the underlying reasons for decline.

5.6 Monitoring

5.6.1 Environmental monitoring

Routine water sampling

Routine water quality monitoring is based on only a small number of spot samples each year and, whilst being capable of identifying gross changes in environmental quality, can fail to detect episodic events of importance to salmonid populations or longer-term changes. It is recommended that more frequent spot sampling, automatic sampling or continuous monitoring should be considered as a means of identifying the nature of any water quality impact on fisheries. Such measures are resource-intensive and it is recommended that their use is carefully targeted both spatially and temporally following assessment of likely impacts using all available survey data and field observations.

To assist investigations in agricultural areas it is recommended that a practical field technique for identifying and classifying the scale of diffuse runoff, as opposed to the RBAK method for point sources from farm buildings, is developed to target areas where farm waste plans and possible interception in riparian areas should be considered.

Fish kills

Reported fish kills provide evidence for the occurrence of, and the cause-effect relationship in, episodic pollution events that have an impact on fish populations. Where they occur, they consequently provide a means for rapidly identifying and implementing remedial measures within a catchment. It is recommended that the logging of location, cause and source of fish kills and pollution incidents within a catchment is used as a routine environmental monitoring technique, and that results are reviewed annually to identify remedial measures (e.g. farm campaigns) that can be implemented on a catchment/sub-catchment basis. It must be recognized, however, that major impacts acting on embryos and juveniles at the sub-lethal level will not be detected by this method.

Sediment fines

Where poor survival of embryos is suspected, the loadings of sediment fines should be examined. Such measurements provide a rapid quantitative method of assessing probable impacts on embryo survival; however, specialist skills and equipment are required. It is recommended that research is required to provide a better understanding of the sources of fines and the mechanisms by which they are deposited within river gravels, specifically in salmonid spawning areas. This should address how land use practices, including field drainage and increased livestock densities, influence their transport and deposition.

Biological sampling

Biological and chemical river quality sampling provide complementary information on general environmental quality. RBAKs have been specifically developed to provide a convenient, on-the-bank, method for classifying the severity of organic impacts from farming and for identifying point sources (Rutt and Mainstone 1995b). Their use in detecting pollution sources, as a means of targeting pollution control effort, is recommended in catchments with organic pollution problems. However, as with water quality sampling, it must be recognized that sampling frequency is a crucial factor; if a stress on the invertebrate fauna is transient rather than chronic, recolonization of an impacted area can be relatively fast (of the order of four to eight weeks).

5.6.2 Fisheries monitoring

Introduction

The regulation mechanisms operating in salmonid populations will cause different life-stages to respond differently to a particular stress. For example, a stress affecting marine survival may first be detected in the rod or net catch but, depending on the dynamics and regulation of the juvenile population, this may not be picked up in juvenile surveys. Conversely, a severe problem with egg survival may be detected immediately in the juvenile populations, but it will be several years before the rod or net fishery would be affected. In addition, the methods available to monitor the different life-stages have very different costs, assumptions and uncertainties associated with them.

Juvenile surveys

It is recommended that juvenile salmonid surveys are used as the principal means for detecting and assessing environmental impact on fisheries where impacts are likely to be acting on the freshwater phase of the lifecycle. As in the Torridge Catchment, they allow the detection of long-term trends and can be used to obtain information at any geographic scale.

It is recommended that juvenile surveys for impact assessment are adequately scoped at the design stage to allow genuine impacts to be identified against the background of high spatial and temporal variability. Basic techniques for designing river fishery surveys are given in Wyatt and Lacey (1994).

Habitat quality has been shown to have a profound effect on the distribution and survival of juvenile salmonids. It is recommended that salmonid habitat assessment techniques such as HABSCORE are used to assist the interpretation of juvenile surveys.

Catch statistics

Data from the Torridge have illustrated the problems with assessing long-term trends in migratory salmonid populations from catch statistics. In particular, the influence of long-term changes in factors such as the number of licences returned, reporting rates and changes in licensing administration on the interpretation of catch statistics, has been highlighted.

It is therefore strongly recommended that information on licence numbers and fishing effort should be routinely collected, compiled and reported to avoid the misinterpretation of catch data. It is important that a consistent method of recording effort is adopted to afford local, regional and national comparisons of catch data. In addition, any proposed changes in rod-licence administration, data collection or reporting should be assessed in terms of continuity and compatibility with historical data.

The relationship between data on declared catch and effort, and the actual catch, run size, and spawning escapement is complex, and simple measures such as total declared catch or catch per returned licence are unlikely to be adequate indices for monitoring adult salmonids. It is recommended that procedures are developed for the consistent interpretation of catch statistics; this could be achieved by utilizing long-term catch statistics on rivers with counters or trapping facilities. The resulting procedures are likely to: include the comparative assessment of catch statistics in different rivers; utilize data on catch, effort, environmental variables; and integrate information from rod and net fisheries on appropriate rivers. Ongoing NRA R&D on the use of catch statistics to determine fish stock size, the development of a salmon lifecycle model and the development of salmon spawning targets are all likely to contribute to such procedures.

Spawning activity
Redd count data show extreme variability due to their subjective nature and confounding factors such as water clarity and flow. Redd counts are therefore unlikely to be sensitive measures of quantitative changes in spawning activity over time, and must be interpreted with extreme caution. It is recommended that, where redd counting is used to assess changes in spawning activity, that data collection is stratified and targeted into river reaches that can be revisited annually using the available resources. Analysis of the counts can then allow for any missing data or changes in practice from year to year.

Redd counting does provide the only direct measurement of qualitative patterns in spawning within a catchment. Where problems with egg survival are suspected or anticipated, it is recommended that redd counts are used to assess the presence and distribution of spawning adults, and assist interpretation of juvenile data.

Embryo bioassays
Deployment on the River Torridge has demonstrated embryo bioassays to be an effective technique for identifying differences in embryo survival in different tributaries. It is recommended that, due to the resource implications, embryo bioassays are used as an investigative tool for determining pre-emergence survival only in rivers where sediment fines loadings are high and/or mortality at the embryo stage is suspected, rather than as a routine monitoring technique. The use of embryo bioassays/studies should also be considered to examine the effectiveness of spawning gravel rehabilitation measures.

Embryo bioassays can give particularly variable results, even within a riffle, due to variability in the micro-environment. For studies to be of value, adequate replication is essential and, where possible, the number of replicates required should be statistically determined in advance.

In-situ juvenile bioassays
The use of *in-situ* juvenile salmonid bioassays can be an effective way of assessing mortality from water quality problems, since the effects of habitat, inter- and intra-species interactions and migration are eliminated.

To have sufficient power, *in-situ* bioassays should be replicated sufficiently and deployed over a sufficient time period to detect significant differences in survival. The technique will therefore tend to be resource-intensive, and is not recommended as a routine means of identifying impacts on salmonid populations. However, it should be considered as an investigative procedure where spatial or temporal water quality effects are important. The deployment of *in-situ* bioassays in the project has detected significant differences between new and acclimatized fish, and strong seasonal effects. It is recommended that the design of bioassay investigations makes adequate allowance for these factors.

The design of the cage used in this study, with a quick release perspex lid, robust construction and adequate substrate proved successful, and the design is recommended for similar investigations.

Adult traps and counters
On many rivers in the UK, catch statistics are the only means of assessing changes in the adult runs of migratory fish, and the absolute levels of spawning escapement for comparison with spawning targets. The catch statistics on the Torridge illustrate the problems with reliance on catch statistics. The installation of adult trapping facilities or electronic fish counters on a river provide more reliable information on run size, but entail considerable capital expenditure.

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