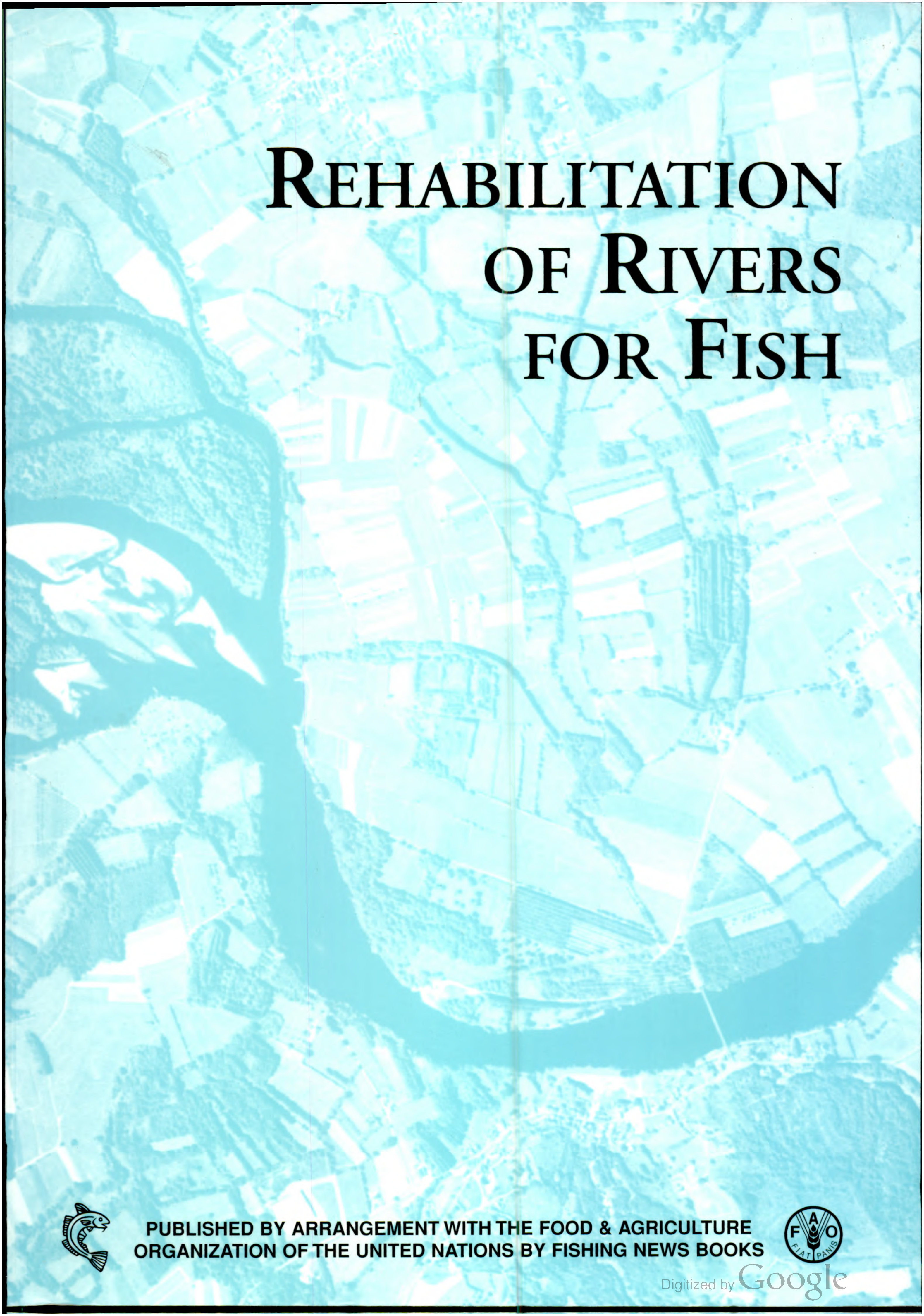
REHABILITATION OF RIVERS FOR FISH



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REHABILITATION
OF RIVERS FOR FISH

A study undertaken by the
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of FAO

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and
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Foreword

For many decades societies have abused rivers using them primarily as mechanisms for disposal of wastes, for transport, for power generation, for agriculture and for industry. In the process of increasing utilization and manipulation the water courses, which previously formed the focus of the landscape providing diversity of habitat for terrestrial, wetland and aquatic plant and animal communities, have lost their original form and function to become simple, often featureless channels. Changes have not been confined to the river itself as there have been large scale changes in land use within the basins including deforestation, damming and accelerated drainage of urban and agricultural lands. Many channelized water courses have proved unable to absorb the increasing run-off resulting from poor watershed management resulting in increased flooding. At the same time there has been a progressive loss of biological diversity in the form of species or sub-species adapted to the former regimes but unable to survive in the modified conditions. There is now a growing realization that the loss of diversity at the species, ecosystem and landscape level impoverishes society and compromises the sustainability of the benefit from aquatic systems. These benefits take many forms depending on the user group but can only be maximized if the ecosystem is maintained in a healthy condition.

Of immediate concern to this Manual are the interests of fisheries, in particular those of Europe. Inland waters in Europe are used both for recreational and commercial fisheries. Present yields from the commercial sector are in the order of 170 000 tons per year and extrapolations from what is known of the recreational fisheries would indicate catches for human consumption at least of the same order of magnitude. While the commercial catch is of limited value compared to other continents, about 680 million ecus per year at 4 ecus a kilo of fish the recreational fishery is immeasurably more important in commercial terms, not only for the direct value of the catch but because of the economic significance of the ancilliary industries. There are also other recreational values inherent in a clean and natural landscape to which society currently awards a high priority.

There is a trend in Europe to reclaim natural habitat wherever possible. The European Unions policy of set-aside of agricultural land is now encouraging land owners and local communities to restore landscape for uses other than agriculture. Recent years have seen an increasing number of projects, some small, some more ambitions to rehabilitate water courses. Many of these projects have been pursued primarily for aesthetic reasons or for the protection of birds and wildlife. With little additional effort and expense the same projects can incorporate features that improve the waterway for fish thereby adding a valuable recreational component. This manual describes the theoretical basis and concrete measures for habitat improvements for fishery purposes and is addressed not only at fishery planners but also at civil engineers undertaking aquatic habitat improvements. It is hoped that the principles and guidelines included in this manual will be of use in incorporating fisheries interests into the methods available for habitat improvement in the planning and execution of future projects for the rehabilitation of water courses.

Preparation

This document was prepared by the European Inland Fisheries Advisory Commission Working Party on the Effects of Physical Modifications of the Aquatic Habitat on Fish Populations under the Convenorship first of Y. Souchon (France) and later J. Coeck (Belgium). The membership of the Working Party was:

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T. Crisp (salmonid habitat requirements), R. Mann, E. Baras and J. Philippart (cyprinid habitat preferences), J. Coeck (main channel rehabilitation structures), R. Welcomme (floodplain rehabilitation), G. Marmulla (fish passes) I. Cowx (stocking), N. Holmes (Vegetation). The manual was assembled from its disparate parts by G. White and finalized for publication by R. Welcomme in collaboration with T. Laughlin. The illustrations were drawn by Emanuela D'Antoni.

For ease of reading the customary academic format of text reference to authorities for concepts and data have not been used although the contribution of all river scientists to the theoretical background to this work is acknowledged. Credits and authorities are cited in reference section where the works concerned complement the text of the manual by further description of techniques and engineering structures.

GUIDELINES FOR THE REHABILITATION OF RIVERS FOR FISH

This manual is a compilation of the methodologies required for assessment of the needs for rehabilitation, the habitat requirements of fish and the various techniques for rehabilitating water courses. To assist the reader in the planning and execution process the following guidelines are suggested. Guidelines take four forms:

Conceptual

Policy formulation and legislation

[redacted]

[redacted]

Sections which support technical guidelines are indicated against the entry in brackets. The manual does not address the steps required for policy formulation.

Concepts

Ecological

River continuum concept describing longitudinal processes along the river channel ***(2.2.1)***

Flood pulse concept describing lateral processes relating the river to the floodplain ***(2.2.2)***

Channel forming discharges **(2.2.4)**

Four dimensional nature of fluvial ecosystems relating longitudinal (river continuum), lateral (flood pulse), vertical (ground water) and temporal dimensions ***(2.2)***

River corridor concept relating river processes, fisheries, wildlife and habitat conservation ***(2.4)***

Importance of habitat and microhabitat diversity to conservation of biodiversity

Resilience of rivers with regard to natural restoration of water quality and habitat structure

Social and Economic

Understanding of the place of human communities and their functions in river basin dynamics

Understanding of the role of fisheries in the local economy

Concepts, continued

Research and Information needs

Acquire understanding of the relationships between habitat and fish communities **(1.1)**

Study fish life cycles, functional units and habitat requirements **(1.2; 1.3)**

Develop understanding of the temporal and spatial separation within and between species; emphasize importance of resource partitioning in fish communities **(1.2; 1.3)**

Develop understanding of relationship of environmental cues to the spawning and feeding movements of fish **(1.2.5)**

Encourage understanding and study of behavioural selection of preferred spawning substrates and location by fish species

Develop understanding of the importance of riparian vegetation as a source of food and cover for fish **(1.4; 2.4.2)**

Principles for improvement

Adopt hierarchical approach to assessment and rehabilitation which will be interactive from localized stretch within river reach, through river tributary inputs and river zones to catchment level

Emphasize spatial and temporal links of habitat modification considering short-term effects first and then long-term ones (4.1)

Emphasize the importance of longitudinal and lateral connectivity (2.5)

Emphasize the importance of diversity in main river channels, residual features and floodplains (1.1.3)

Orient designs not only to prevent or alleviate problems but also to preserve valuable habitats that already exist

The planning process

POLICY

Critically assess current fisheries policies to define objectives of management in terms of use and conservation as well as the type of species and environment required

Critically assess existing laws relating to rivers, fish and fisheries and make recommendations for the appropriate additions and modifications to make them consistent with the defined objectives

Examine land and water use patterns, development plans and industrial activities within the catchment and propose actions to minimize physical and pollution impacts on the river system

Communicate proposals for restoration of rivers to other agencies with similar interests

Consult local communities on allocation and destination of the riverine resources

Establish mechanisms to ensure collective approaches for river habitat improvement

Find political solutions to social and financial costs of rehabilitation and mechanisms for meeting incremental costs of such actions

The planning process, continued

RESOURCE USE

Establish the capacity of the river to support the various human uses without degrading the resource (4)

Establish systems and regulations to limit access and intensity of use to that supported by the system in order to avoid or minimize conflicts

Promote professional qualifications and codes of conduct for fishing and other water uses to minimize impacts of these activities on the resource

Rigorously apply existing legislation to limit the detrimental effects of practices impacting on the river resource

ASSESSMENT OF CURRENT IMPACTS

Establish an historical record of accumulated human impacts on river system

Determine impacts of large-scale catchment land-use activities including mining, power generation, forestry, agriculture, aquaculture, urbanization and industry on fish populations

Identify existing impoundments affecting longitudinal and lateral connectivity, geomorphology and hydrology

Classify impacts of engineering works, fragmentation effects, forecast reversibility and enhancement possibilities

Identify major point-source and diffuse pollutants where water quality is limiting

Analyse current use and cost structure of the aquatic resource including commercial and recreational fisheries

The planning process, continued

ASSESSMENT OF LIMITING FACTORS

Use and develop empirical models for habitat classification, assessment and monitoring **(3.3; 3.4)**

Establish local importance of size variation and composition of gravels and depths for spawning and incubation of salmonid and lithophilous species **(1.2.2; 1.3.2)**

Determine availability of adequate flooded grassland as spawning substrate for phytophilous species **(1.3.2)**

Review availability of sheltered areas for limnophilic species **(1.3.3)**

Establish conformity with minimum flow criteria **(1.2.5)**

Procedures for rehabilitation

PREPARATION

Define objective of rehabilitation project with respect to particular project but with reference to more general plan for the whole river

Carry out a pre-operational surveys to identify improvements which need to be made, taking into consideration current limiting factors

- Assess the position and relationships of fish communities to conservation plans for the whole river basin
- Assess status of fish community under pre-rehabilitated conditions
- Determine possibilities for improving quantity and timing of flow relative to the biological requirements of the fish communities selected (**1.2.5; 4.3.1; 6.2.10**)
- Establish stream flow necessary for in-channel improvement structures to function adequately
- Survey and assess all weirs, dams, levees to determine their impedence to fish migration for all species (**4.3.1**)
- Survey and assess risks of impingement and entrainment of fish at water abstraction points

Use the results of the surveys together with historical data, modelling and informed prediction to prioritize conservation, restoration and enhancement needs

Establish land acquisition needs and purchase or otherwise secure legal title to riparian lands needed for aquatic habitat improvement

Procedures for rehabilitation, continued

PROJECT APPRAISAL

Carry out cost-benefit exercise to assess the direct and recurrent costs for the project and relate it to direct (tangible) and indirect benefits (such as public relations and conservation value and overall well-being of the river) as well as to environmental services (such as improvement in self purification ability and absorption of diffuse nutrient discharges)

Identification of alternative proposals with appropriate costings

Identification of experts in the field to undertake project implementation

Hold consultations to inform resource users of proposed activities and to solicit their feedback into the scheme

IMPLEMENTATION

[redacted]

Improve current speed diversity through installation of rapids by construction of low weirs (5.2.1)

[redacted]

Procedures for rehabilitation, continued

IMPLEMENTATION, continued

- **Reinsert meander structure (5.3.2)**
- **Create multi-stage channels (5.3.3)**

Reconnect floodplains to main channel (6.2)

Plan and construct structures for passage of fish upstream and downstream (7.1)

Plan and construct fish screens and other structures to reduce fish mortalities at water abstraction points (7.2)

Enforce measures to mitigate water quality problems (7.3)

Manage instream and riparian vegetation for the benefit of fish (8)

- **Control excessive vegetation (8.2)**
- **Use aquatic and riparian vegetation to improve habitat quality and cover (8.3)**
- **Use vegetation as a replacement for heavy engineering solutions (8.4)**

Determine need for stocking or introductions in support of existing and projected fish community structure (**9**)

Evaluate risks from any necessary introduction or stocking programmes in the light of genetic interactions, carrying capacity, species interactions and disease control (**9.3**)

Develop and apply protocols for capture, handling and transporting fish to be stocked as well as criteria for stocking densities and release strategies adapted to rehabilitated reach

Monitoring

Implement continuing long-term monitoring of biota and fish communities to evaluate effects of intervention

Assess ability and changes in morphology against predetermined criteria

Evaluate success or failure of control structures

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Part I

CONCEPTS AND INFORMATION REQUIREMENTS

2

Introduction

European rivers have been subjected to modifications from relatively early in the history of the continent. Roman engineers revetted rivers, constructed channels and harnessed water power as early as 100 AD. Water power, with its accompanying dams, again made its appearance in the Middle Ages. There was also a progressive clearance of the forests across Europe during Roman and Medieval times for agriculture to support the growing human population. This increased silt runoff which, in turn, destabilized the floodplains through increased alluvial deposition. This led to the build-up of open meadow type floodplains with a more rapid recycling in channel form and of oxbow lakes as well as increases in the incidence of catastrophic flooding. With the onset of the industrial revolution in the 1700s pressures on the waters intensified to a point where the changes witnessed today were set in motion. Needs for flood control, power, navigation and waste disposal led to the progressive straightening and deepening of channels, their interconnection through canals, their pollution with chemical and domestic discharges as well as to the disconnection and eventual drainage of the floodplain. This process accelerated towards the end of the last century and by the 1950s few unmodified and uncontaminated streams remained in the Western part of the continent. These changes are traced in Table I.1, History of modification of European rivers.

Future priorities for the management of inland waters and their living resources lie with five major strategies which depend on the demands to be placed on the resources and the socio-economic priorities of the societies associated with them. These are:

- do nothing;
- protection;
- rehabilitation;
- mitigation;
- intensification.

Period	Main channel	Floodplain	Changes to fish community
Pre-Roman BC	Basin forested. Lower order streams free flowing with little human influence. Filled with wooden debris. Higher order streams meandering or braided, relatively stable.	Forested, relatively stable with long duration water bodies, ubiquitous.	Pristine fish populations with floodplain and main channel communities.
Roman 1 AD – 1000	Basin locally deforested. Lower order and higher order streams little modified except for very local canalization and use of water power involving weirs and dams.	Some deforestation of plains, particularly in Southern Europe. Deforestation of hill slopes produces increases in siltation.	Some small fisheries, impacted but effects very limited. Stocks remain essentially unaltered.
Medieval – Renaissance 1000 – 1700	Progressive deforestation and land clearance increases silt loads. Lower order streams used for water power with some weirs and dams. Larger channels essentially immune from human interference except for some local bank control in inhabited centres. Increased siltation destabilizes channels increasing meandering and braiding.	Progressive deforestation of floodplain, land reclamation for water meadows. Some floodplain water bodies filled for agriculture. General higher silt loads increase recycling rate of floodplain features, ground water levels begin to fall and flood levels to rise.	Intensification of fishery produces some change to stocks. Changing relationship of main channel to floodplain through increased silt loads probably modifying behaviour.
Industrial revolution 1700 – 1800	Increasing intensification of agriculture in river basins which are now almost completely deforested, although some intensive reforestation in Central Europe from 1750 onwards. Drop in ground water levels, smaller streams becoming modified for better land drainage.	Progression of intensification of floodplain use. Marked fall in ground water, increased flooding provoking beginnings of flood control interventions.	Intensive inland fisheries in continental Europe and local pollution of waters depleting some fish stocks.

Period	Main channel	Floodplain	Changes to fish community
Industrial revolution 1800 – 1900	Larger rivers straightened and deepened in interest of navigation from about 1800 onwards and increasing toward end of century. Water used for waste disposal and pollution becoming locally severe.	By 1880 large sections of channel leveed leading to disconnection of floodplain from system.	Anadromous salmonids disappear from many rivers toward end of this period.
Modern 1900 – 1960	Main channels extensively modified. Channels straightened and deepened, banks revetted. Many rivers reduced to concrete or earthen banked channels only. Pollution severe. Major dams common and minor weirs extensive.	Floodplain completely disconnected in most European systems. Occupied for intensive agricultural and urban use.	Commercial fisheries generally collapsed in western Europe and replaced by recreational uses. Fish population extensively disrupted, further stress on migrating species by dams, many species disappeared and substituted by introduced species. Many rivers fishless.
Modern 1960 – present	Increasing ecological awareness and economic circumstances forcing scaling down of intensive agriculture with a reforestation of some parts of the basin and abandonment of the land in marginal regions. Attempts to reduce pollution and eutrophication locally successful. Attempts to rehabilitate some reaches of smaller streams.	Floodplain still disconnected from river but some rehabilitation of surviving floodplain water bodies. Trend to reforest some portions of the plain.	Fish stocks recovering in areas where concerted attempts have been made at rehabilitation or mitigation.

Table I.1
History of modification of European rivers

Do nothing: This strategy, perhaps the most frequently used over the last two centuries, is adopted where priorities in sectors other than the living aquatic resources are perceived to be so high that any intervention in the aquatic system is felt to be a waste of time. This leads to the highly modified and polluted situation many rivers find themselves in today.

Protection: It is commonly assumed by environmentalists that every effort should be made to preserve inland waters which have not yet been strongly affected by development. Such a management option needs careful evaluation in view of the opportunity cost to local communities. Where it is determined that there is a net benefit in conserving the resource, protection efforts should seek to discourage physical modifications such as the building of dams, levelling of river channels and the revetting of lacustrine shorelines. Access to the water and fisheries should be limited and levels of exploitation of the fishery, extraction of the water and loading with nutrients and pollutants should be strictly controlled. This may require considerable research to generate sufficient understanding of the permissible limits for exploitation. It also requires greater institutional integration of fisheries management into the more general framework of rural development planning and management. It is recognized that where there is a resource that can be exploited, most developing countries will exercise the option to do so, but damage to the integrity of the system can be limited given the political will. By contrast, many developed economies are exercising the option of conserving water bodies as an aesthetic value.

Rehabilitation: The restoration of already modified ecosystems or stocks of fish is advocated where the pressures producing the modification have eased or where new technology can be introduced to reduce stresses. As an example, physical rehabilitation of water courses modified last century for navigation and flood control is currently popular in Europe, North America and Australia. There is a concerted attempt to control effluent quality throughout the temperate zones to reverse trends to eutrophication. Part of this effort has been the reintroduction of vanished species. Rehabilitation usually requires a single major expenditure although the running costs of treatment plants to improve water quality are not negligible. Because the present state of the river or lake to be rehabilitated represents the end point of a series of modifications to the landscape the true objective of restoration is frequently poorly defined. For example, given the history of modification of rivers in Table I.1, it is difficult to decide which stage of the process should form the end point of the rehabilitation process. Current land use patterns may well preempt such decisions, however. It would, for example, be extremely difficult to return to the fully forested condition prevailing in pre-Roman times in any but the smallest of basins. In addition, efforts to rehabilitate are frequently thwarted by lack of knowledge of the preexisting condition or of the requirements of the original fish communities. This implies that research is needed to acquire such data in systems that maintain conditions close to the original state.

Mitigation: Because many of the changes to inland aquatic systems are effectively irreversible and because of the greater value attached to alternative uses of the inland aquatic system, by far the most common tendency today is to attempt to live with modified systems through a series of interventions and management strategies designed to lessen the impact of stress. Actions include the creation of artificial habitat, arranging for flood simulating water releases or systematic stocking to maintain populations of fish which have no alternative source of recruitment. Mitigation usually involves recurring expenditure which should be considered part of the cost of the major modifying use of the system.

Intensification: The final strategy implies the distortion of the aquatic resource for fishery purposes. A range of tools is being deployed to this end including introduction and systematic stocking with desired species, elimination of unwanted species, fertilization of the water body and physical modification of the system to facilitate exploitation. Intensification is becoming a common strategy throughout the tropics and is only in its infancy. Most intensive management has evolved through empirical methods but there is now a demand for sustained research on a number of issues including the cost-effectiveness of stocking and optimal stocking strategies, selection of better strains, needs for intervention into the physics and chemistry of the water body, as well as on the socio-economic and institutional aspects of such fisheries.

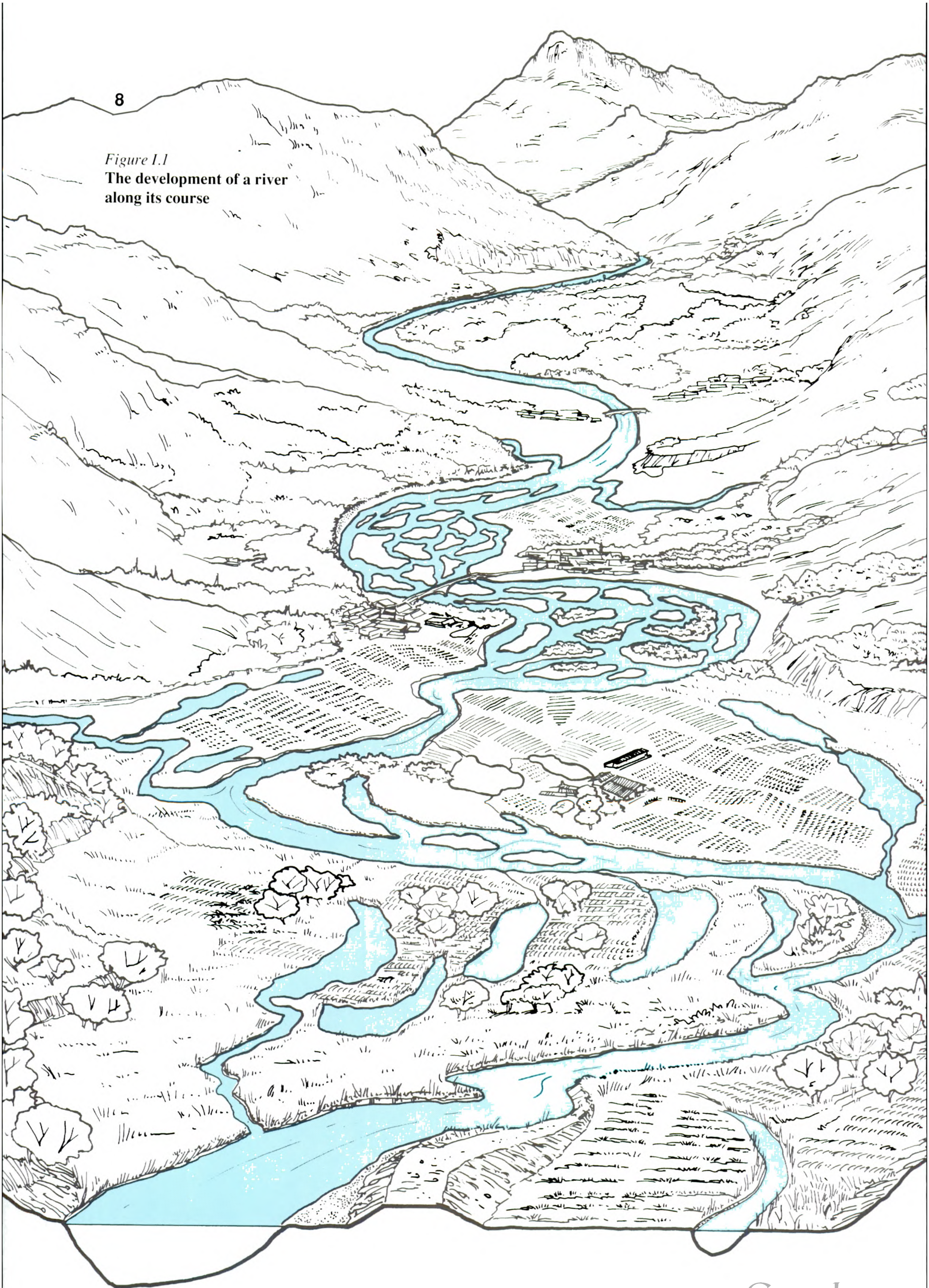


Figure I.1
The development of a river along its course

Chapter 1

Habitat requirements of fish

The physical environment selected by fish depends mainly on geological, morphological and hydrological processes that influence riparian vegetation and form a mosaic of stream channel and floodplain habitats.

▲
Two contrasting views of a river – a rapid reach of a headwater stream and a slow flowing lowland reach
▼

1.1
Relationship between habitat and fish communities

1.1.1 Introduction

River fish provide a major source of food and recreation and are also useful for characterizing environmental conditions in streams and rivers. The biotic diversity and natural characteristics of fish communities are directly related to the variety and extent of natural habitats within a river basin. Consequently a stream ecosystem has to have a complex habitat structure to maintain a healthy and diverse fish community.

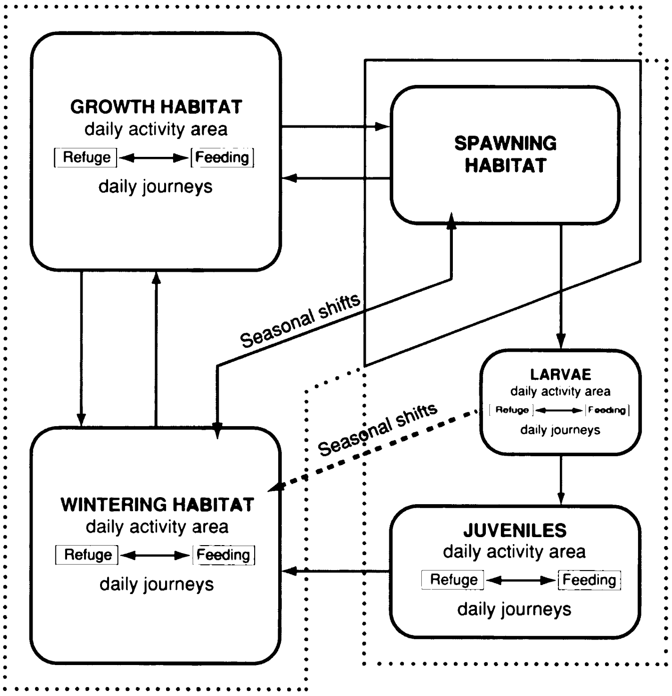
The physical environment selected by fish depends mainly on geological, morphological and hydrological processes that influence riparian vegetation and form a mosaic of stream channel and floodplain habitats. Unlike most other systems that have well-defined boundaries, within which community-ecosystem interactions occur, streams and rivers are highly integrated with the adjacent landscape of which they are part. Rivers and riverine habitats are thus influenced by processes within the riparian corridor and the basin as a whole.

Water flow is the main agent responsible for shaping the physical habitat and creates complexity through a combination of depositional and erosional processes. The low order streams of the upper course of rivers are usually erosional in nature and the river bed consists of boulders, cobbles and coarse sediments which combine to form the pool-riffle sequences so characteristic of upland water courses. Further structure is provided by debris dropped from riparian vegetation which ranges from tree trunks and branches to the leaf litter on which river food chains are founded. In high order, lowland rivers sediments are usually finer, ranging from sand to fine silt, and are deposited to form point bars, islands and natural levees. At the same time, erosional processes form meanders in the river channels and a variety of lacustrine features on the floodplain.

The term habitat defines where a fish species lives without specifying resource availability or use.

In its broadest sense, the term habitat defines where a fish species lives without specifying resource availability or use. An individual fish seldom spends its entire life in the same habitat and even species which are considered as resident in a particular reach may migrate from upstream or downstream spawning grounds. In its life history an individual commonly requires a different habitat or functional unit with suitable microhabitat conditions for each specific life stage (Figure 1.1). The microhabitat for an

Figure 1.1
Functional units in fish ecology



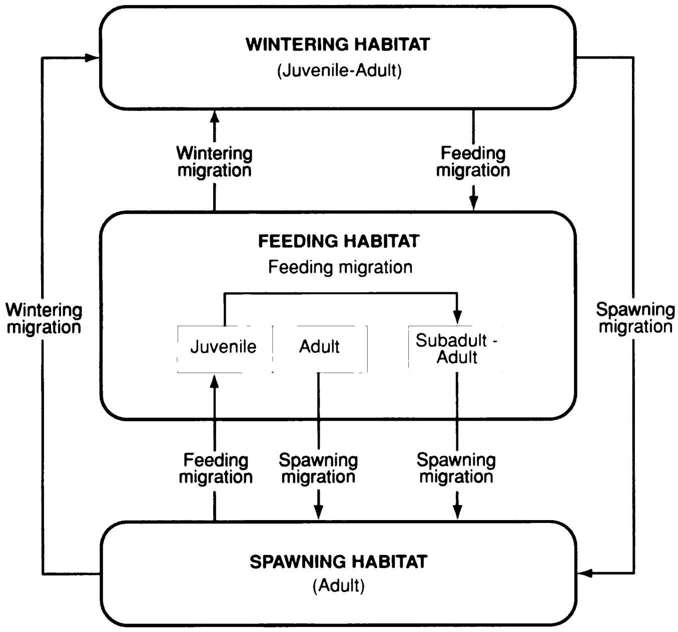
individual fish is the site where the fish is located at any point in time. It is directly influenced by the structural complexity of the reach, light intensity, hydraulic variables, stream substrate and biotic variables such as exposure to predation.

1.1.2 Habitat concepts

Fish in rivers depend on undamaged interactive pathways along four dimensions.

Fish in rivers depend on undamaged interactive pathways along four dimensions, i.e. longitudinal, lateral, vertical and temporal. Fish display migratory patterns that play an important role in their ecology. To complete their life cycle, some fish species need suitable spawning sites that can be quite close to the areas in which they live as adult fish. However, to optimize reproductive success, many fish species return to their natal streams or use upstream spawning grounds or tributaries which in some cases may be considerable distances away from the feeding areas. Other reasons for migration include optimum feeding strategies, avoidance of unfavourable conditions or to enhance colonization (dispersion; Figure 1.1). The scale of the migration can range from tens of metres in the case of resident fish, such as brown trout or sculpins, to tens or hundreds of kilometres in potamodromous species such as lake or river resident brown trout and barbels, or even to thousands of kilometres for diadromous migrants such as sea trout, salmon, eel and sturgeon. Unfortunately, there is no advantage in combining different fish species into migration guilds based on their migration distances because different patterns of migration may occur simultaneously in components from the same age group, within a single species or even within a single population. For example, in the Alpine watershed of the River Rhine in Switzerland brown trout have considerable intra-specific differences in migration whereby some individuals showed resident behaviour and spawned close to where they lived and others carried out spawning migrations of distances up to 50 kilometres.

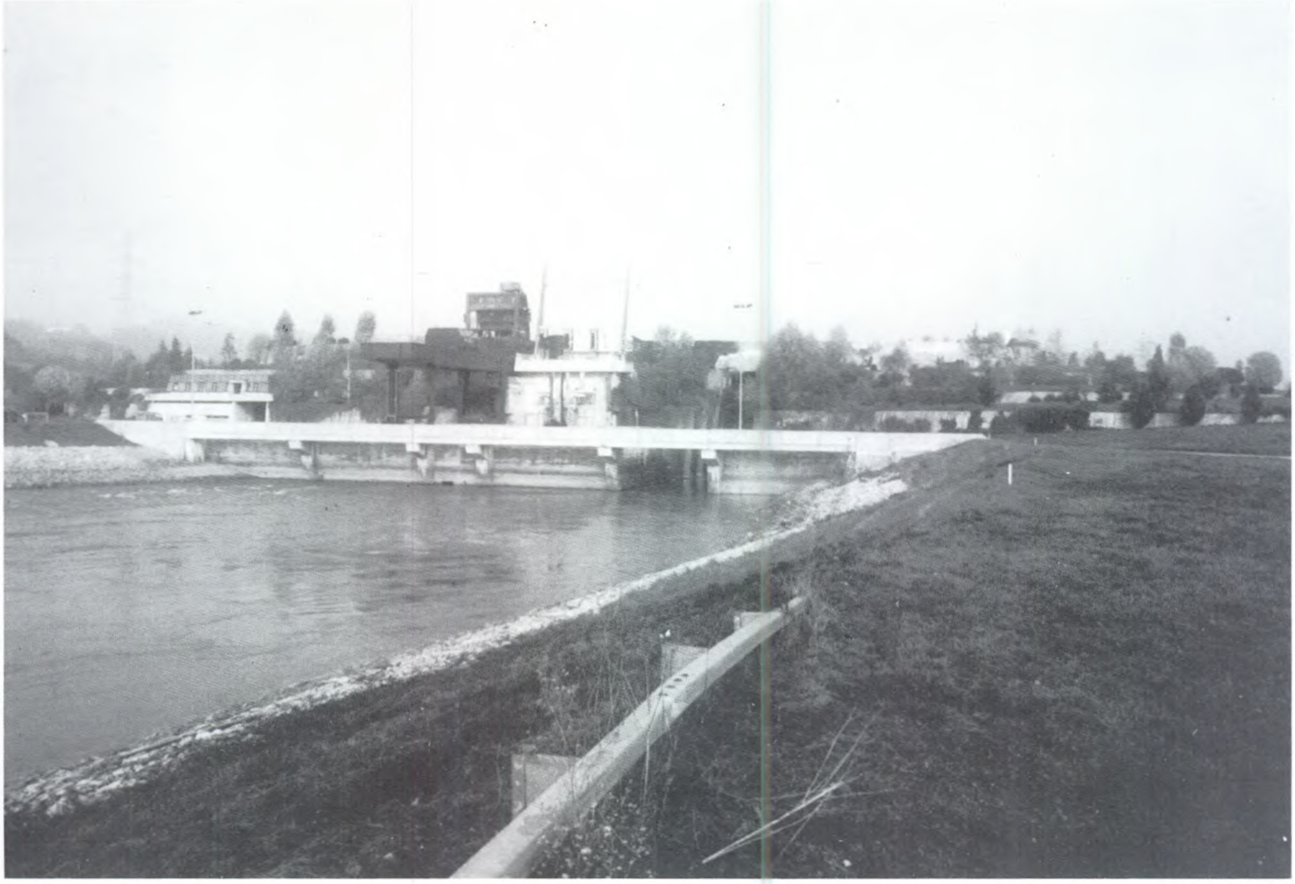
Figure 1.2
Migration patterns of freshwater fish



Survival and life history are directly related to intact longitudinal pathways, including the possibility of migration into tributaries that are often very important for reproduction and also serve as rearing areas for larvae and young fish (Figure 1.2).

Each barrier has an effect on the species composition of fish communities upstream of the barrier, most importantly on the population structure of resident fish populations. This barrier-effect view of the way in which fish communities are distributed in river ecosystems relates to the effect of longitudinal pathways and is connected to the habitat-centred view.

The lateral dimension suggests that the interactions between riparian vegetation and the river channel provide suitable habitats, e.g. inshore zones, connected backwaters and various types of stagnant water bodies. River edge habitats serve not only as preferred feeding and refuge areas but also as spawning areas, depending on the fish species. Fish larvae generally tend to be



▲
Modern rivers are often barred by dams

Riparian and in-channel vegetation provide essential feeding, breeding and shelter habitats
▼

▲
Woody debris contribute to habitat diversity
▼

associated with the river bank. This is the case for young-of-the-year rheophilic species which tend to live at stream edges and lateral habitats (Chapter 3). Unconstrained river channels shift within river corridors and provide the required areas with low flow conditions. Further low flow areas are created by vegetation in the form of accumulations of live vegetation or woody debris. The diversity of aquatic habitats in low order streams depends largely on coarse woody debris (CWD) which plays a major role in stream channel geomorphology and provides a major source of fish cover (Figures 1.3 and 1.4).

The vertical dimension refers to riverine-groundwater interactions and concerns mainly fish species that bury their eggs in gravel depressions called redds, such as lithophilic fish species, e.g. salmon, trout, grayling. Habitat requirements of eggs and embryos during incubation in substrate interstices are different from those of fish living in the open water. To ensure the development of the embryo, sufficient water must flow at sufficient depth through the gravel as to supply the eggs and embryos with oxygen and carry away metabolic wastes. Hydrological processes in the groundwater-river exchange play an important role for successful reproduction of lithophilic fish. Trout seem to avoid zones of undiluted groundwater inflow but prefer zones of intermediate surface-groundwater mix. To maintain high intra-gravel oxygen concentrations in spawning areas, high permeability of the streambed is important. Thus, concentrations of fine sediment greater than 15-30 percent of total substrate volume will be detrimental to the survival of eggs and embryos of salmonid species. Fine sediments can cause serious degradation of spawning habitat. Fine sediment entering streams is delivered mainly by erosion. Agriculture, gravel extraction, mining and road construction are mainly responsible for the increased load.

In addition to the migration needs of fish and the four-dimensional river

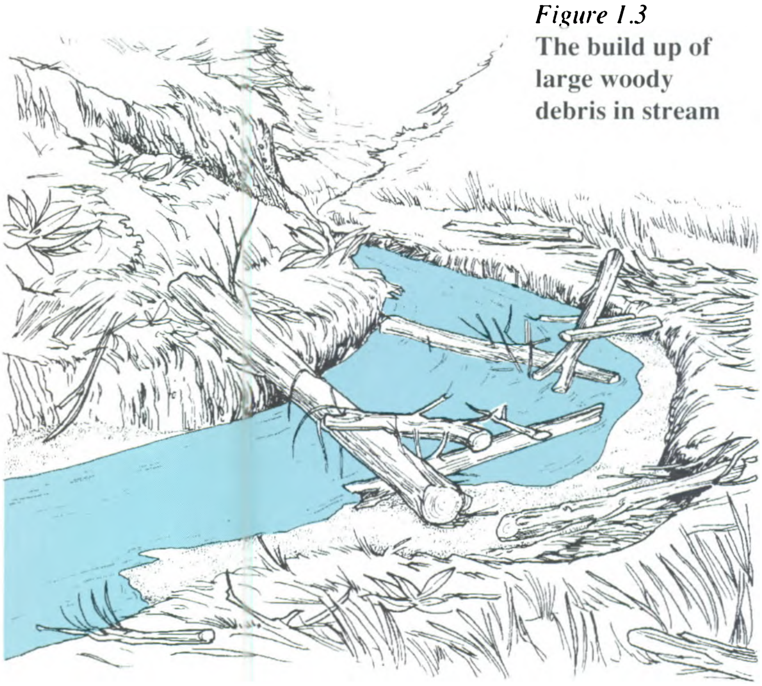


Figure 1.3
The build up of large woody debris in stream

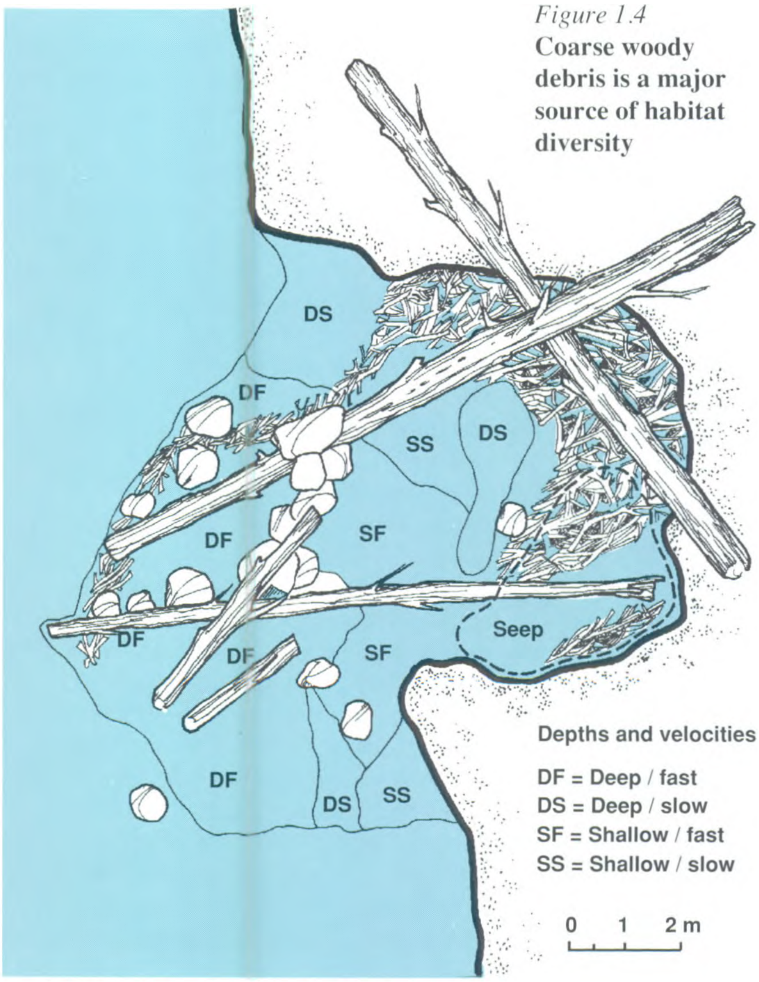


Figure 1.4
Coarse woody debris is a major source of habitat diversity

concept, fish community structure is also influenced by the habitat itself. Fish species composition, abundance and age class structure of a specific population are determined by the organization, diversity and structure of the physical stream habitat (Sections 1.2 and 1.3).

1.1.3 Examples of habitat importance

Longitudinal connectivity

The most spectacular examples of fish migrations in the temperate zone are shown by diadromous species. Anadromous fishes live and feed in the ocean, but as mature fish they leave the sea and start their upstream migration to their natal streams, the final part of homing migration. Catadromous species spend many years of their life in fresh water before they swim downstream to spawn in the sea. All diadromous fish species depend on intact longitudinal connectivity of rivers. The fish fauna of most European countries has undergone many changes over the last 50-100 years. Species richness, for example, has decreased as a consequence of dam constructions in large rivers serving as migration routes for diadromous fishes. Most diadromous species have been lost from Europe's large rivers within the last 100 years. This shows that species richness is not only a function of the available habitat in a specific area but it also depends on the connectivity of the system.

Longitudinal and lateral connectivities are of importance to fish allowing them to move between feeding, breeding and overwintering areas.

Effects of human interventions on fish assemblages have also been shown for species that are confined to smaller longitudinal ranges of a river system (tens of kilometres). Dispersal, colonization and migration of fish is constrained by artificial structures aimed at energy dissipation and streambed stabilization, e.g. boulder and log dams, or by other insurmountable barriers (culverts, weirs). An example of the effect of such obstructions is the fish assemblage in Sagentobelbach, Switzerland, downstream and upstream of a single log dam with a chute height of 40 cm. Below the log dam eight fish species were found, whereas only one species was detected upstream of the log dam. A riverine fish community, therefore, reflects not only the habitat conditions in a particular zone but also the conditions of free fish passage even at the local level.

Lateral connectivity

Lateral connectivity is of importance for fish mainly as seasonal use of backwater, oxbow lake and flooded vegetation habitats associated with river floodplains and other structures. Lateral habitats, which are often characterized by low-velocity areas (flow < 4 cm s^{-1}) at the margins of the stream channel, are important for young-of-the-year fish. Increase in lateral habitat area has resulted in major improvement in the density of age-0 fish. Conversely, reduction in lateral habitat has been correlated with elimination of young-of-the-year fish.

Shoreline diversity in rivers appears to be a simple and indicative parameter of microhabitat quality. In the larval phase, all fish species live in low flow areas in sheltered lentic bays along the shoreline. Even the larvae of rheophilic species do not leave these sheltered areas before summer (when they are about 25 mm long). By late summer, a separation of eurytopic species which remain in sheltered bay habitats and rheophilic species which live on adjacent shallow gravel banks is often observed. Noticeable shifts in fish community structure follow the removal or alteration of the riparian habitat. These responses are intensified when the habitat is made uniform by impoundment or river engineering works. Some fish species disappear whilst others, usually of lesser importance, increase in abundance.

Coarse woody debris (CWD) plays an important role in creating habitat diversity and providing well-structured and suitable microhabitat. The abundance of fish populations in streams and rivers is strongly related to the abundance of CWD and cases exist where the fish density has declined more than eight-fold when this habitat is removed. Simple habitat models, such as those relating habitat area and discharge for different life stages, that do not take the significance of edge habitat into consideration may be inaccurate. In general, a network of logs, roots, branches and small woody debris create a more complex, diverse array of cover and hydrologic features that benefit fish populations.

Macro- and microhabitat

Rehabilitation projects that focus on physical fish habitat and microhabitat structures without first assessing longitudinal and lateral habitat connectivity do not make sense. In the potamon, the potential capacity of a stream reach or stream segment to support a rich fish community depends on the habitat complexity. Depth, substrate and current all appear to be important in the use of microhabitat by stream fish. Natural streams tend to support highly diverse fish communities and remain more stable throughout the seasons than the lower-diversity communities of streams modified by ditch construction, meander removal, dredged bottoms and homogeneous substrates. A further correlation between fish species diversity and habitat diversity, calculated from a combination of substrate, depth and current against fish species diversity, is shown in Figure 1.5. Habitat structure does not only affect the species composition of the fish living in the stream but also has a major effect on the age structure of fish populations.

Distinct relationships have been found between living space impairment and fish fauna. The heterogeneity of the river bed, described by the variability in maximum depth measured in different transects, has been linked to habitat complexity and fish population size (Figure 1.6). Dramatic decreases of fish abundance and biomass, shifts in the species spectrum and complete loss of valuable species occur when the bed structure is made uniform during river engineering works. On average, fish species diversity is 60 percent lower in channelized sections of rivers compared to natural conditions.

Rehabilitation projects that focus on habitat without first assessing longitudinal and lateral habitat connectivity do not make sense.

Macro- and microhabitat availability and use is especially important for salmonid species. This has been specifically linked to the role of substrate heterogeneity in the early life of salmon and trout when the aggressive behaviour of fry in establishing territories is intense. High fry densities are only possible where there are well-structured stream bottoms with complex microhabitats.

At the macrohabitat level, three types of riffle habitats (low gradient riffle, rapids and cascades), six pool types (secondary channel pools, backwater pools, trench pools, plunge pools, lateral scour pools and dammed pools) and a third general habitat category, glides, have been defined. They are useful in

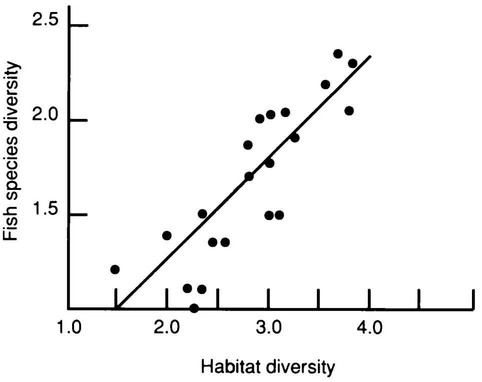


Figure 1.5
Relationship between habitat diversity and fish species diversity

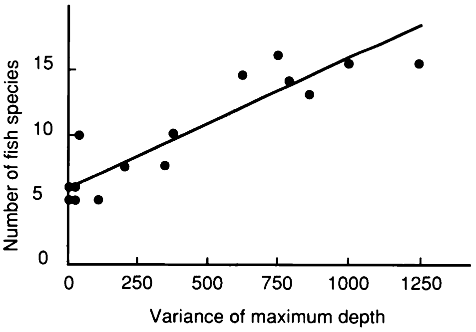


Figure 1.6
Number of fish species related to maximum depth

describing the habitat preferences of fish species: for example, 0+ steelhead trout select riffles with large woody debris, while age-1 fish prefer plunge, trench, and lateral scour pools with woody debris and undercut banks. By contrast the largest individuals of both steelhead age classes are found in swiftly flowing riffle habitats. For practical purposes, such as stream rehabilitation, this macrohabitat-related method provides reliable information about habitat use of fishes.

On the microhabitat level, fish abundance has also been correlated with availability of cover. Sheltered areas in a stream channel where fish can rest and hide, e.g. undercut banks, pools, overhanging vegetation, submerged boulders, woody debris, stumps and roots, can be regarded as cover. These cover requirements depend on the season of the year and for salmonids are generally more important during winter than summer.

Box 1.1
Principal habitat features important to fish

BIOLOGICAL PROCESSES AND GOVERNING HABITAT FEATURES

1. **REPRODUCTION**
   a. Access to spawning areas
      - provision of suitable depths and water velocity
      - absence of barriers to movements

   b. Spawning
      - suitable spawning substrate

   c. Incubation of eggs
      - stability of substrate
      - provision of adequate temperature and oxygen supply and water movement
2. **FEEDING AND GROWTH**
   a. Availability of food organisms
      - bankside and aquatic vegetation
      - substrata suitable for invertebrate production
      - supply of allochthonous organic material

   b. Best use of energy for maintaining position and food gathering
      - cover and shade, e.g. rocks and/or tree trunks
      - diversity of flow type
      - pool-riffle sequences
      - aquatic and bankside vegetation
      - appropriate temperature range
3. **SELF PROTECTION**
   a. From physical displacement by current
      - shelter and visual isolation,
        e.g. varied bed profile through: undercut banks,
        rocks, tree trunks, roots, accumulated debris,
        aquatic vegetation, weedy shallow marginal
        slacks (juvenile), including backwaters and lateral systems

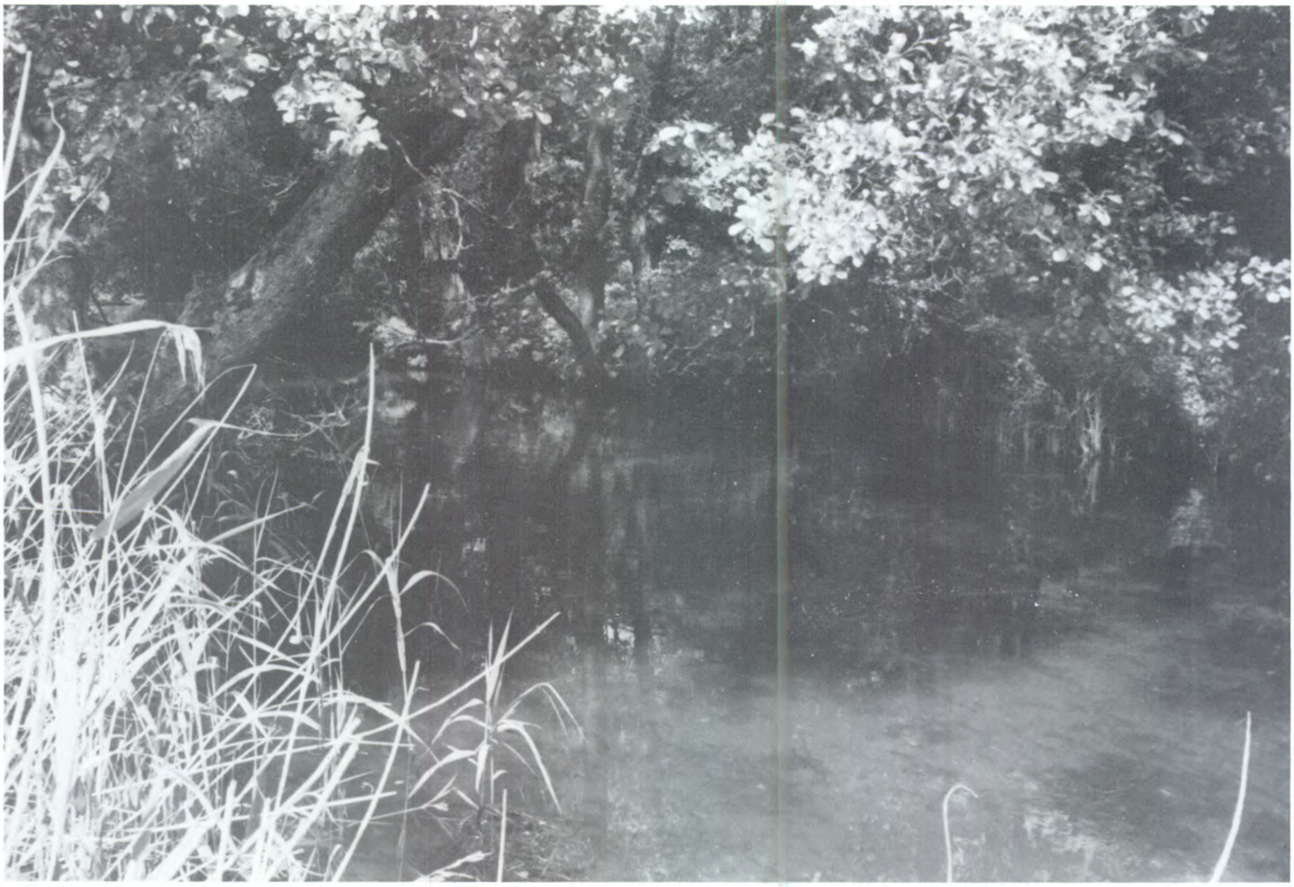
1.1.4 Conclusions

Habitat requirements of fish have to be considered in any effort to maintain or rehabilitate rivers for fish biodiversity. As a general rule, habitat requirements are satisfied by complex habitat structure and biological connectivity. At each specific site, the fish community structure of a river depends on the integrity of the longitudinal connectivity of the system.

The habitat requirements for different fish species, but also for different stages in the life cycle of any one species, are quite divergent. To survive, stream and river dwelling species undergo complex cycles of dispersion and migration. They migrate between three major habitats: wintering habitat; feeding habitat; and spawning habitat (Figure 1.2). A need for understanding the specific requirements and the biological connectivity is important for developing a habitat-centred view of fish communities.

In this context, a functional unit includes spawning, feeding, nursery (growth) and resting (self protection) areas (Figure 1.1), each of which is linked in various ways with environmental features. The principal habitat features important to each of these activities are identified in Box 1.1.

Complex habitat structure is provided by intensive interactions between the river channel and its adjacent environment. Coarse woody debris creates and maintains microhabitat and areas of reduced stream velocity that serve as shelter which is essential to fish during winter and high flow situations. The importance of complex habitat structure is well described for salmonids. In the potamon it has similar or even broader influence on cyprinids and other genera of coarse fish.



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Shady and over-hanging vegetation are preferred habitats for some species of fish

Areas of reduced velocity can serve as shelter during winter
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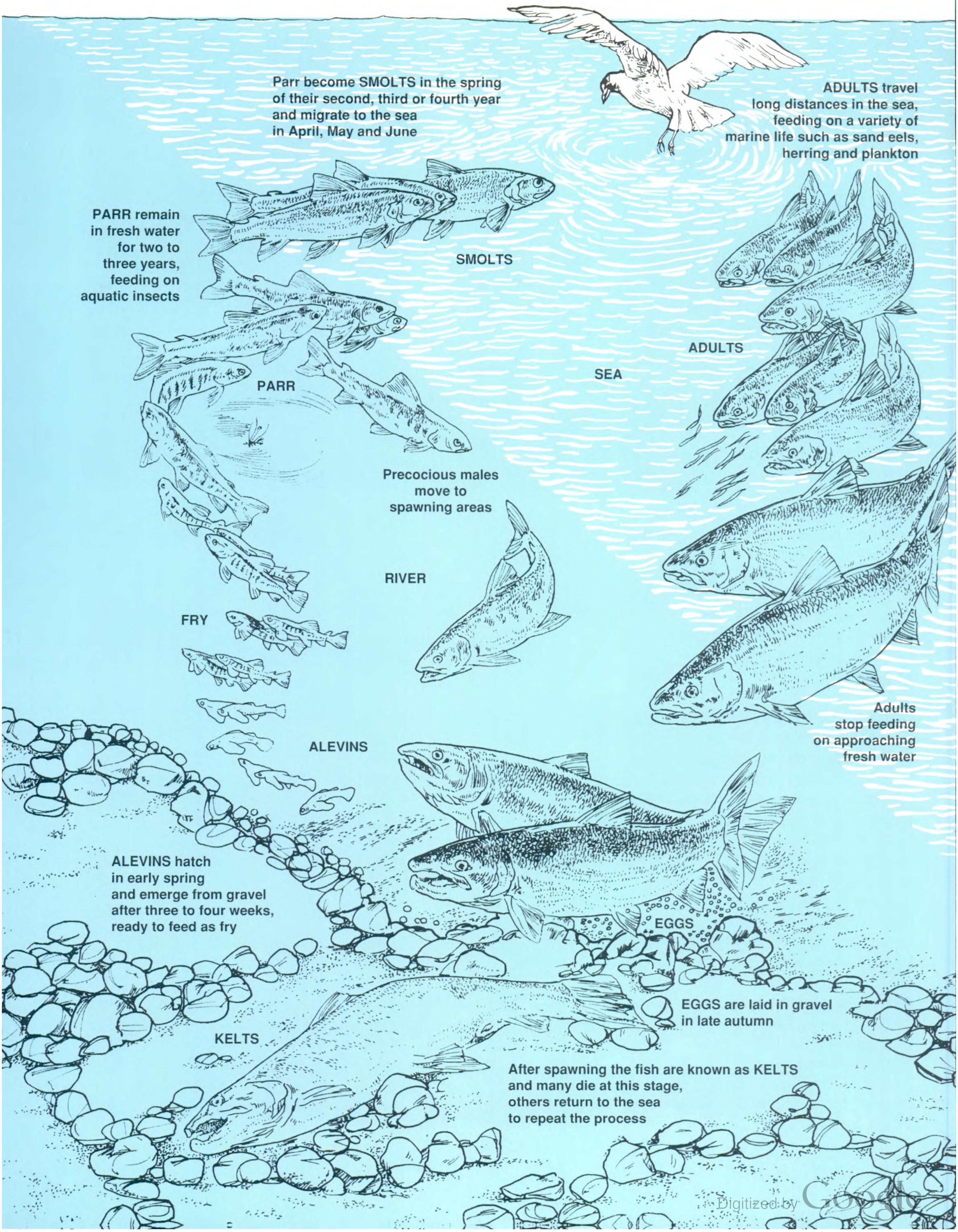
Figure 1.7
Life cycle of the Atlantic salmon



Parr become SMOLTS in the spring of their second, third or fourth year and migrate to the sea in April, May and June

ADULTS travel long distances in the sea, feeding on a variety of marine life such as sand eels, herring and plankton

PARR remain in fresh water for two to three years, feeding on aquatic insects

Precocious males move to spawning areas

Adults stop feeding on approaching fresh water

ALEVINS hatch in early spring and emerge from gravel after three to four weeks, ready to feed as fry

EGGS are laid in gravel in late autumn

After spawning the fish are known as KELTS and many die at this stage, others return to the sea to repeat the process

1.2
Habitat requirements of fish communities: Salmonids

1.2.1 Introduction

The common and widespread river salmonids of Europe are the Atlantic salmon, *Salmo salar* L., the trout, *Salmo trutta* L., which has migratory and non-migratory components in its genetic population, and the grayling, *Thymallus thymallus* (L.). The Arctic charr, *Salvelinus alpinus* L., has a more restricted distribution, mainly in northern and Alpine Europe where populations are centred on cool, clear lakes but movements into rivers for spawning do occur. In a few populations, particularly those flowing into the Arctic seas, the species also exhibits anadromous migratory tendencies. The rainbow trout *Oncorhynchus mykiss* (Walbaum) is now widespread throughout Europe. It was introduced from North America and has been extensively and heavily stocked in put-and-take fisheries, or escaped from fish farms.

Salmonid life cycles have been described in detail in the literature and are illustrated by way of the Atlantic salmon in Figure 1.7. The habitat requirements to support different stages of this life cycle are complex and are discussed in detail below. Similar habitat requirements are also preferred by other salmonid species although some species, e.g. trout, are more flexible in their needs.

1.2.2 Spawning requirements

Salmon and anadromous trout return from the sea to their natal river and seek to spawn in their natal tributary. Some non-anadromous trout also migrate upstream to spawn. The first essential requirement is access to the spawning sites. Spawning site selection by salmon and trout is governed by a complex of environmental cues, including intra-gravel flow, gravel size, depth, stream velocity and cover (Table 1.1). These factors are essential for successful spawning, egg survival and hatching.

Table 1.1
Spawning habitat requirements of salmonids

Water velocity at 0.6 depth (cm s^{-1})	> 15 and $< 2.0\,^{L}$
Water depth	usually deeper than body depth, i.e. $> 0.2\,^{L}$
Redd length	ca $3.5\,^{L}$
Redd width	ca $0.3\text{-}0.6\,^{L}$
Maximum value of medium size of gravel (P mm)	$P = 0.5\,^{L} + 4.6$

L = female fish fork length in cm

Male grayling occupy spawning territories and each territory must contain a bed of fine gravel suitable for spawning, hiding places such as overhung banks and large stones for females before spawning and visual isolation from adjacent territories. The preferred spawning substrate is made up of 40-70 percent pea-sized gravels (< 2 cm diameter), 5-15 percent sand, 20-30 percent small stones (2-10 cm) and a few larger stones. Water depths vary from 20 to 65 cm (mean 36 cm), and water velocities of 33-80 cm s^{-1} (mean 54 cm s^{-1}). Grayling spawning occurs in water temperatures ranging from 3.5-16.2°C, with a preference for the mid-range. Sudden drops in temperature, for example by late snow melts, may inhibit the process.

1.2.3 Eggs, incubation and inter-gravel stages

The mean depth of egg burial by trout and salmon is related to female fish length according to

$$D = aL + b$$

where D is the mean burial depth (cm),

L the female fish length (cm), and $a = 2.40 \pm 7.53$ and $b = 0.262 \pm 0.098$ ($r^2 > 0.60$) for fish of 24 to 74 cm length. It is essential that spawning areas are of non-compacted, stable, permeable gravels. Consequently, in chalk streams, where there is usually a 'cemented layer', no such empirical relationship has been defined. Grayling bury their eggs less deeply. Fish of 20-30 cm length lay eggs at about 4 cm depth, whilst larger fish bury them up to 7 cm deep. Egg burial depth has an influence on the rate of development and the likelihood of loss by washout, asphyxiation and intra-gravel temperature related to free stream water. Embryonic development and median hatch date can be predicted from environmental factors, although temperature is the best single predictor (Table 1.2).

Table 1.2
Models to predict median hatch time

Species	Equation	Relevant temperature range (°C)
Salmo salar	$\log D_2 = [-2.6562 \log(T + 11.0)] + 5.1908$	2.4-12.0
Salmo trutta	$\log D_2 = [-13.930 \log(T + 80.0)] + 28.8392$	1.9-11.2
Salmo trutta	$D_2 = 281T - 0.84$	1.4-15.2
Salmo trutta	$D_2 = 746.0 / (T + 0.5323)1.2233$	*ca* 5.0-13.0
Salvelinus alpinus	$D_2 = 206T - 0.63$	1.4-8.0
Salvelinus alpinus	$D_2 = 476.76 / (T - 0.1314)1.0435$	*ca* 4.0-11.0
Thymallus thymallus	$D_2 = 459T - 1.37$	3.5-16.2
Thymallus thymallus	$D_2 = 6484.6 / (T + 5.103)2.099$	*ca* 3.0-15.0
Hucho hucho	$D_2 = 2647.4 / (T + 3.222)1.7865$	*ca* 4.0-15.0

D_2 = days
T = temperature in centigrades

Water temperature also has a direct effect upon survival of salmonid eggs (Table 1.3). It can influence the relative proportions of the yolk used for tissue elaboration and for metabolism. Low temperature incubation decreases the proportion used for metabolism and gives a large alevin which, in turn, may influence subsequent survival.

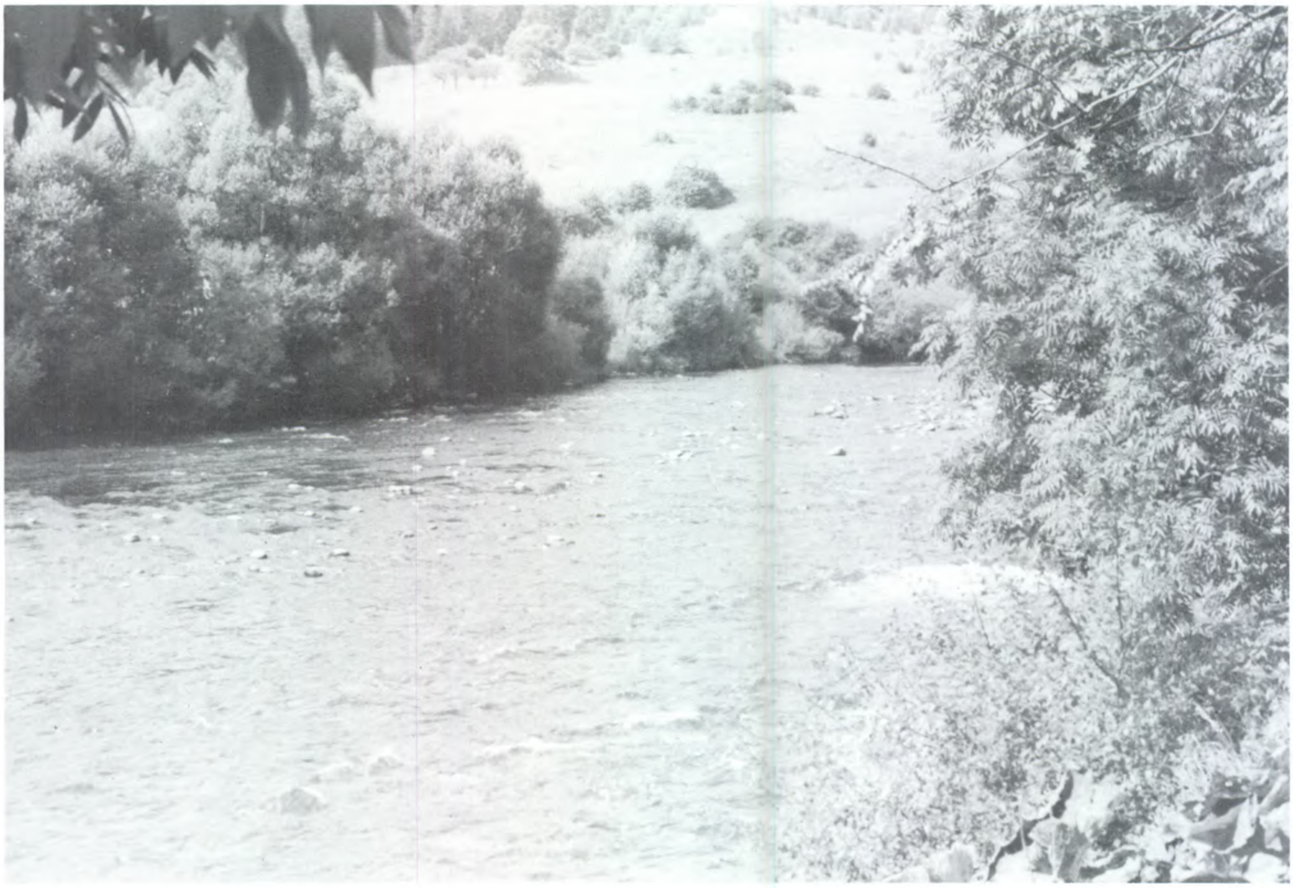
Table 1.3
Effects of water temperature on the survival of eggs

Species	Approximate lower lethal limit (°C)	Approximate upper lethal limit (°C)	Approximate temp range for > 50% survival to hatch
Salmo salar	< 1.4	15.5	0.0-11.0
Salmo trutta	< 0	> 12.0	0-< 12.0
Salvelinus alpinus	< 1.4	12.5	0-7.5
Hucho hucho	1.5	15.5	5.0-13.0
Thymallus thymallus	3.0	18.5	4.1-16.7

The probability of survival of salmonid eggs depends on a complex of interacting factors (Figure 1.8), one of the most important of which is oxygen supply which, in turn, depends upon dissolved oxygen concentration and intra-gravel flow. The removal of toxic metabolites, especially ammonia, also depends on intra-gravel flow. High egg survival can be expected if dissolved oxygen concentration remains at or above *ca* 6 mg l $^{-1}$ (lower values may be tolerated at low temperatures and apparent velocity is at or above 0.03 cm s $^{-1}$).

Gravel composition influences the survival of intra-gravel stages through its effects on intra-gravel flow, hence on the oxygen supply rate, and also its effects on the ease of movement of alevins at the 'swim-up' stage. In general, incubation success decreases as the content of fines (particles less than 1.0 mm in diameter) in the gravel rises above 10-15 percent. Thus concentrations of suspended solids in the river are undesirable as they are likely to result in infilling of the gravel pores with fine material.

The general conformation of the river, especially the natural sequence of riffles and pools, has important hydraulic effects which influence intra-gravel flow. Most redds are made where there is a marked change in hydraulic head over a gravel bed. Such changes occur at the downstream ends of pools where water accelerates before entering a riffle, and also within riffles at gradient changes and in the vicinity of boulders. The main factors involved in intra-gravel flow are gradients in stream surface profiles, gravel bed permeability, gravel bed depth and bed surface configuration. A newly constructed redd is likely to create appropriate hydraulic conditions as fines are displaced downstream



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Gravel bars and riffles provide
spawning sites for salmonids
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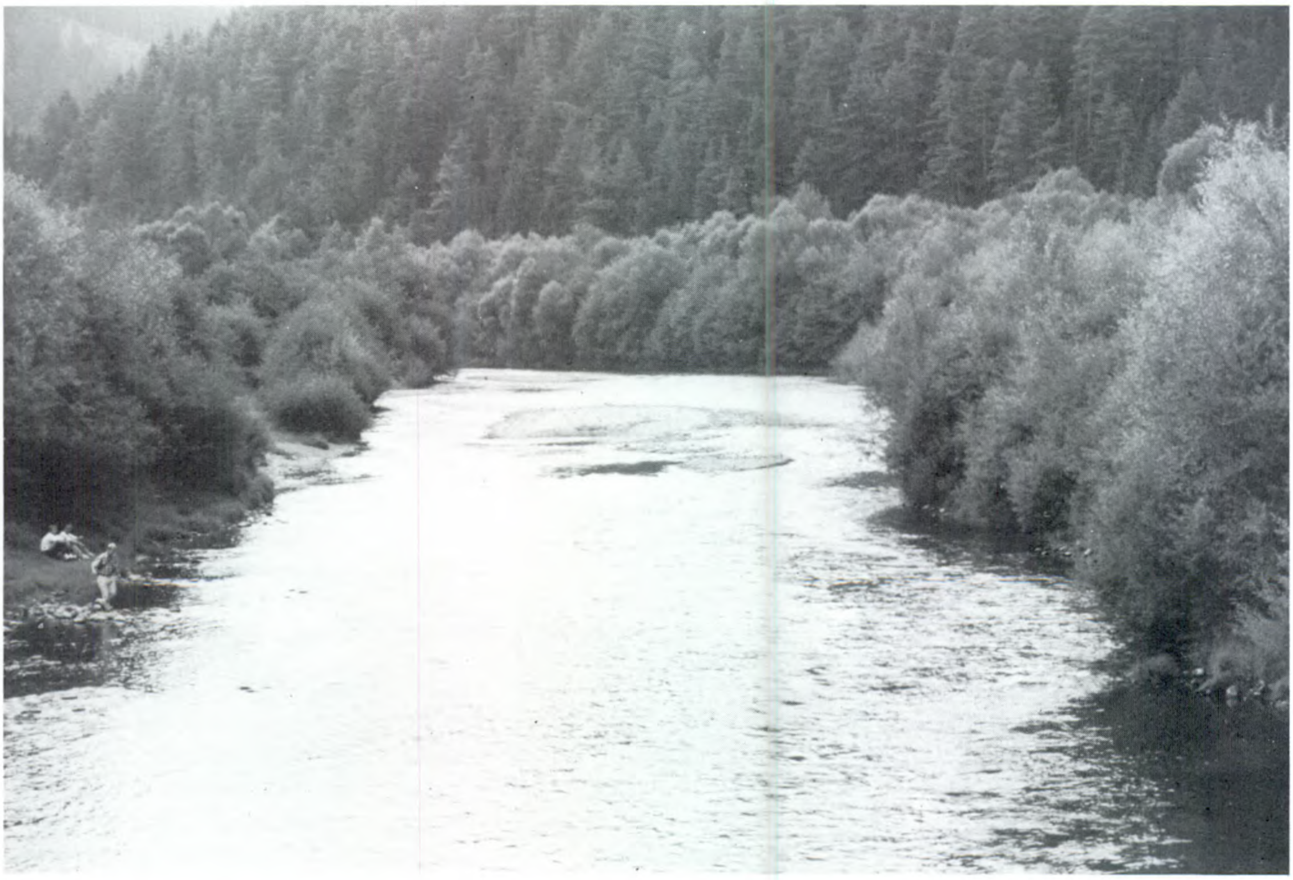
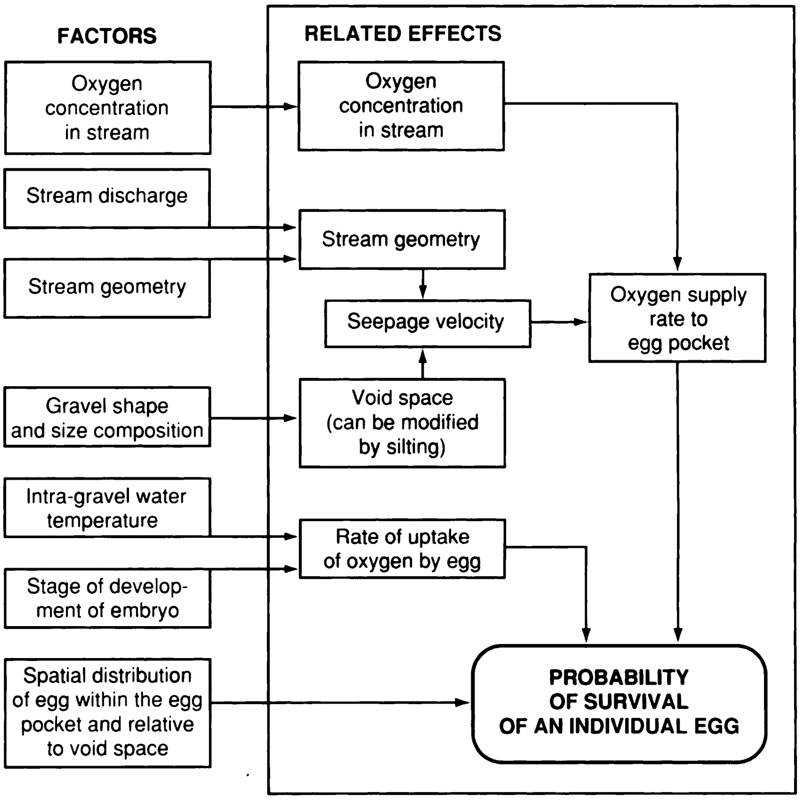


Figure 1.8
Factors influencing survival of salmonid eggs



Low discharge can cause mortality of salmonid eggs.

during the digging process, gravel is re-sorted and there is some evidence that there is a selection of larger size stones by female salmonids to cover the redd after egg-laying. However, in many upland streams redds are rapidly levelled by spates.

Patterns of discharge affect the hydraulics of intra-gravel flow, transport, and deposits of fines; gravel beds are moved and salmonid eggs and alevins are washed out. This is considered a major cause of egg mortality in salmon and trout. Brief exposure due to extremely low flows is rarely likely to be harmful, but high mortalities of sea trout eggs have been recorded during reduced flows arising from impoundment of rivers. Sensitivity to mechanical shock soon after fertilization and over cutting by late spawning fish can also cause mortality.

Acidification of streams can also exert a negative effect as at pH less than 4.5 the action of the hatching enzyme (chorionase) is blocked and there may be death at hatching. There may also be poor survival at higher pH values if aluminium or other toxic metals are present.

Less is known about the incubation process in grayling. As the eggs are, on average, smaller and buried less deeply than those of salmon and trout, they are probably more prone to washout and less prone to asphyxiation or entrapment by fines.

1.2.4 Juveniles and smolts

Water temperature

As fish are cold blooded many of their vital activities are triggered by temperature or have rates which are dependent on temperature. However, the 'trigger temperatures' for feeding and smolt migration and the upper and lower lethal temperatures can be modified by acclimation. Table 1.4 summarizes the optimum, upper and lower critical temperatures for the three common European salmonids. The 'optimum range' is the extent over which feeding occurs and there is no sign of abnormal behaviour. Optimum temperatures for growth are 16-17°C for salmon, 13-14°C for trout and 17°C for grayling.

Dissolved oxygen concentration

Oxygen consumption per unit body weight of fish decreases with fish size and increases with temperature. The overall dissolved oxygen concentration required for salmonid waters is at least 9 mg l $^{-1}$, although concentrations as low as 5 mg l $^{-1}$ can be tolerated for short periods.

Suspended solids

An EC Directive sets a mean value of 25 mg l $^{-1}$ or less for inert suspended solids in salmonid rivers. Good to moderate salmonid fisheries are possible in water with 25 mg l $^{-1}$ to 80 mg l $^{-1}$, with the latter level being exceeded for short periods in natural spates. It has been indicated that as well as low light intensities, turbidity can be a cue which assists in stimulating and extending the period of positive rheotaxis in spawning fish.

Water depth and velocity

Experimental evidence, from work on smooth and semi-natural channels, indicates that salmon parr can maintain station in higher water velocities than trout. Young salmon tend to stay close to bottom except at low flows (less than 10 cm s $^{-1}$), when they move into positions higher in the water column. The downstream dispersal rate of trout is minimal at about 25 cm s $^{-1}$, but increases at higher and lower velocities. By contrast, salmon fry have a high dispersal rate at water velocities of about 7.5 cm s $^{-1}$ and much lower rates at 25-70 cm s $^{-1}$. Similar juvenile population densities are found at all velocities, except for salmon which tend to be less abundant at velocities below 7.5 cm s $^{-1}$. Changes in habitat preference also occur with increase in size, at different seasons of the year, and within and between populations.

Grayling fry emerge from the gravel at a length of about 2.2 cm. They occupy near-surface positions in velocities between 3 and 9 body lengths s $^{-1}$, until they reach 2.5 to 2.8 cm when they adopt a benthic distribution.

Table 1.4
Optimum, lower, upper and critical temperatures for common European salmonids

Species	Optimum range (°C)	Lower critical (°C)	Upper critical range (°C)	Optimum temp for growth (°C)
Salmo salar	6-20	0-6	20-34	16-17
Salmo trutta	4-19	0-4	19-30	13-14
Thymallus thymallus	4-18	0-4	> 18	17

Interactions and habitat structures

Salmon and trout fry emerge from the gravel by night and rapidly disperse downstream from the redd site. They then take up territories. Grayling emergence is mainly diurnal.
The lifetime pattern for trout can be broken down into five phases:

1. downstream movements from the area of hatching to nursery areas (0 to 6 months);
2. further downstream movements from the nursery areas to areas of 'adult growth' (6 to 15 months);
3. limited movements of adults (15 months to spawning);
4. upstream spawning movements;
5. downstream movements after spawning.

The 'optimum range' is the extent over which feeding occurs and there is no sign of abnormal behaviour.

Two distinct components contribute to the population – a large static component and a smaller group of mobile fish.

Dispersal of salmon parr occurs up to mid-August. The majority (70 percent) of fish move less than 100 m although downstream distribution of up to 1 km has been observed. Newly-emerged salmon occupy territories of 0.02 to 0.03 m^2 and larger parr and smolts have territories of >1 m^2. Territory size increases with size of fish to 0.2 to 0.5 m^2 at 5 cm length and 5 to 50 m^2 at 10 cm length. Territory size, hence carrying capacity, also depends upon the proportion of river area suitable for occupation by fish of different species and sizes, and on the availability of shelter and food. There is a general movement of salmon and trout to deeper water as they grow.

Factors which influence the readiness of fish to move upstream include: the physiological readiness of the fish to spawn, river flow, water discolouration, water temperature.

Territory size is reduced by visual isolation which is influenced by the effects of water velocity in causing fish to hold station high or low in the water column and also by the degree of irregularity of the stream bed.

Intra- and inter-specific interactions are known to occur. No social interactions are found between 0 - group and older salmon until the former reach a length of about 6.5 cm when they move into the deeper riffles occupied by the older fish. The survival and distribution of 0 - group salmon can be modified by the presence of trout and of older salmon.

It is clear that a uniform channel will have a relatively small carrying capacity for juvenile salmonids. Provision of a natural sequence of riffles and pools, natural sinuosity of the channel, and cover in the form of boulders, undercut banks and logs will enhance carrying capacity.

1.2.5 Adults and spawning movements

The habitat requirements of older trout resident in fresh water are similar to those of younger trout, although allowance must be made for the effects of age or size in modifying the quantitative aspects of the requirements. The needs of these fish during upstream migration to spawn are similar to those of sea trout and salmon of similar size.

There is considerable variation in the temporal patterns of upstream movement of potential spawners. It is difficult to quantify the stimuli for upstream migration. Factors which are believed to influence the readiness to move upstream include:

- the physiological readiness of the fish to spawn;
- river flow;
- water discolouration;
- water temperature.

Sea trout seem willing to move upstream under a wider range of flow conditions than salmon.

Cover

Upstream movement is usually accomplished in a series of stages. Between stages the fish require cover in the form of large boulders, overhanging banks and deep pools to give hiding places from predators and protection from bright sunlight. In addition to this physical cover, movement occurs most readily during darkness or water discolouration.

Temperature and dissolved oxygen

Temperature extremes can reduce or inhibit upstream movement. Salmon movement is inhibited at temperatures above 22°C and probably ceases entirely between 22 and 25°C. There is also an additive effect of high temperature and low dissolved oxygen content. The lower lethal oxygen concentration for salmon at any temperature between 15 and 27.5°C is given by the equation: $\ln C = -0.513 + 0.046T$, where C is oxygen concentration as mg l^{-1}. Atlantic salmon show reduced sustainable swimming speed when dissolved oxygen concentration falls to between 4 and 5 mg l^{-1} and upstream movement appears to be inhibited at temperatures below 5°C. Similar mechanisms are likely in trout but probably with lower upper and lower temperature limits.

River flow

River flow influences the willingness of migratory salmonids to enter a river and move upstream. Three conceptual models describe the influence of flow on upstream movement:

1. adult salmonids require certain minimum (threshold) flows to be exceeded before they will move upstream and these flows were defined as percentages of the average daily flow (ADF). For salmon, 30 to 50 percent of ADF is considered necessary in the lower and middle reaches of rivers (50 to 70 percent for large spring salmon) and > 70 percent ADF in the headstreams. Trout require 20 to 25 percent ADF in the lower and middle reaches and 25 to 30 percent ADF further upstream;
2. *Salmo salar* and *Salmo trutta* are only thought to move during certain parts of the hydrograph, usually the rising and falling limbs or the falling limb only, rather than the spate peak. The requirements are defined as discharge per m of river width. Upstream movement begins when flows reached 0.08 $m^3 s^{-1} m^{-1}$, peaks at 0.2 $m^3 s^{-1} m^{-1}$, and reduces at higher flows;
3. two annual phases of movement occur with peaks in June to August and in October to December.

Obstructions

Chemical obstruction may be caused by plugs of deoxygenated or polluted water, particularly in estuaries or the lower reaches of rivers. Physical obstruction can be caused by dams, weirs, rapids and waterfalls and may be natural or man-made features. The ease with which some of these can be passed varies with river flow.

Some falls are surmounted by leaping. Salmon can leap up to 3.7 m, although the conditions required are complex. The fish generally leap from near to the crest of a standing wave at the foot of the fall. The pool at the foot of the fall should have a depth of at least 1.25 times the height of the fall. It is likely that leaping ability, as swimming speed, will vary with temperature.

Rapids, flows over inclined surfaces and some weirs are negotiated by high speed swimming. The ability of salmonids to pass such obstacles will depend upon water velocity over the obstacle and upon the swimming capabilities of the fish. Fish swimming speeds are mainly influenced by fish size and water temperature. Two different velocities can be defined. The 'sustainable velocity' (V_{sust}) is that velocity which can be maintained over long periods without an oxygen debt being incurred. The 'maximum burst velocity' (V_{max}) is the speed which can be attained in short bursts but which can only be maintained briefly. $V_{sust} = (8L + 0.32T)$ for salmonids, where T is temperature in °C, L is fish length in cm and V_{sust} is in mg l^{-1}. $V_{max} = V_{sust}\ (1.664T^{0.2531})$. Burst speeds can only be maintained for limited periods and endurance at V_{max} decreases with fish size and with temperature. A simpler approach is to assume that V_{sust} = 2 body lengths s^{-1} and V_{max} = 10 body lengths s^{-1}.

Three conceptual models describe the influence of flow on upstream movement – minimum (threshold) flows, critical parts of the hydrograph, and season.

In the present state of knowledge, it is probably reasonable to use predictions from these various equations as an approximate guide to values of V_{sust} and V_{max} for salmonids. The predictions can be used to assess the likelihood that fish of different sizes will be able to pass given barriers under given flow conditions. It is important to note, however, that such predictions will be an approximate guide only, and that they refer to healthy fish in good condition.

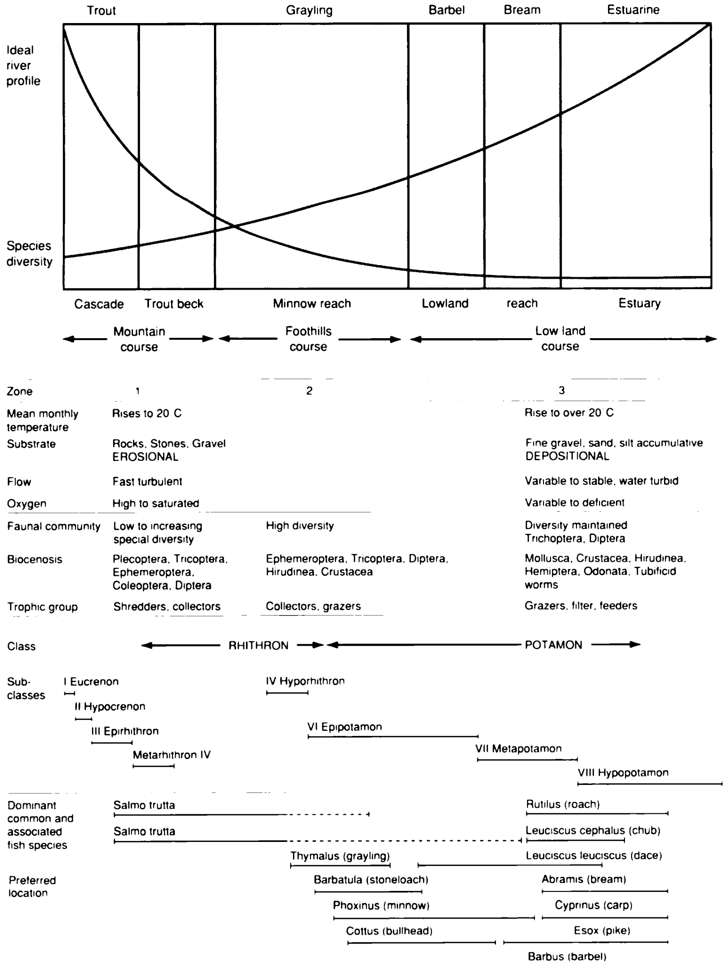
1.3
Habitat requirements of fish: Cyprinids

1.3.1 Introduction

There are more than 80 species of cyprinids in European continental waters and many represent valuable resources for commercial fisheries and angling. In comparison with knowledge of salmonid habitat requirements, there is a dearth of precise information about cyprinids although there are many descriptive and anecdotal accounts.

The preferences and requirements of cyprinid fishes are best described using the functional unit concept. The species functional unit is a spatial entity leading to successful completion of the life cycle (Figure 1.1). It encompasses the notions of home range, daily activity area, seasonal and/or spawning migrations, as well as activity, seasonal and size-related differences in habitat utilization.

Figure 1.9
River zones, biotopes and biocoenoses



Zone	1	2	3
Mean monthly temperature	Rises to 20 C		Rise to over 20 C
Substrate	Rocks, Stones, Gravel EROSIONAL		Fine gravel, sand, silt accumulative DEPOSITIONAL
Flow	Fast turbulent		Variable to stable, water turbid
Oxygen	High to saturated		Variable to deficient
Faunal community	Low to increasing special diversity	High diversity	Diversity maintained Trichoptera, Diptera
Biocenosis	Plecoptera, Tricoptera, Ephemeroptera, Coleoptera, Diptera	Ephemeroptera, Tricoptera, Diptera, Hirudinea, Crustacea	Mollusca, Crustacea, Hirudinea, Hemiptera, Odonata, Tubificid worms
Trophic group	Shredders, collectors	Collectors, grazers	Grazers, filter, feeders

In general, evidence suggests that the 'bottlenecks' to the development of cyprinid populations, as with salmonids, relate principally to the presence of, and access to, appropriate spawning sites, to spawning success, and to the growth and survival of newly-hatched larvae. This is largely because adult cyprinids tolerate a wider range of river conditions than their 0-group progeny. Consequently, an inventory of catchment spawning locations and habitats for each species at different life stages, particularly the 0-group, is imperative for sound fisheries management, and should be given appropriate attention in any rehabilitation programme.

It should be noted that coarse fish species usually occupy the warmer potamonic stretch of rivers (Figure 1.9) and larger rivers which has two important practical implications for habitat restoration. First, habitat restoration measures are on a larger and more costly scale because of high human densities and attendant infrastructural development, which increase practical difficulties. Second, coarse fish habitats are more often exploited for a variety of water sport usages, navigation, casual recreation, abstraction for industry and potable water supply, and effluent disposal from point, e.g. water treatment works, and non-point sources, e.g. urban, agricultural run-off and seepage. These demands complicate the issue but

▲
Cyprinids prefer wide,
slow flowing, lowland reaches
▼

▲
Psammophils lay their eggs on sand in running water although some species prefer quieter backwaters

Phytophils deposit their eggs on submerged macrophytes
▼

must be incorporated in rehabilitation schemes.

1.3.2 Spawning requirements

European freshwater fish utilize a range of spawning substrata (Figure 1.10), which can be used to classify fish into a series of reproductive guilds. These guilds form a useful basis on which to add more detailed, species-specific, information. European cyprinids can be grouped into five categories. They are all open-substrate spawners that do not guard their eggs.

Pelagophils: Eggs are non-adhesive, naturally buoyant and develop whilst being carried by the water current. Larvae are strongly phototropic and swim actively, e.g. checkon, *Pelecus cultratus* (L.) found in catchments of the Baltic, Black and Caspian seas.

Lithophils: Eggs stick to stones and gravel. The larvae are initially photophobic. Optimum gravel sizes and river current velocities vary between lithophil species. For example, *Phoxinus phoxinus* (L.) requires 2-3 cm gravel with velocities of 20-30 cm s^{-1} but have been observed to spawn on finer gravel associated with *Ranunculus* spp. Larger lithophil species are able to spawn on substratum with larger particle sizes, e.g. *Chondrostoma nasus* (L.) use stones up to 10 cm diameter in flow velocities up to 100 cm s^{-1}. *Aspius aspius* (L.) spawn among gravel and large boulders downstream of riffles and *Vimba vimba* (L.) spawn on stony substrata, although the latter have also been observed on

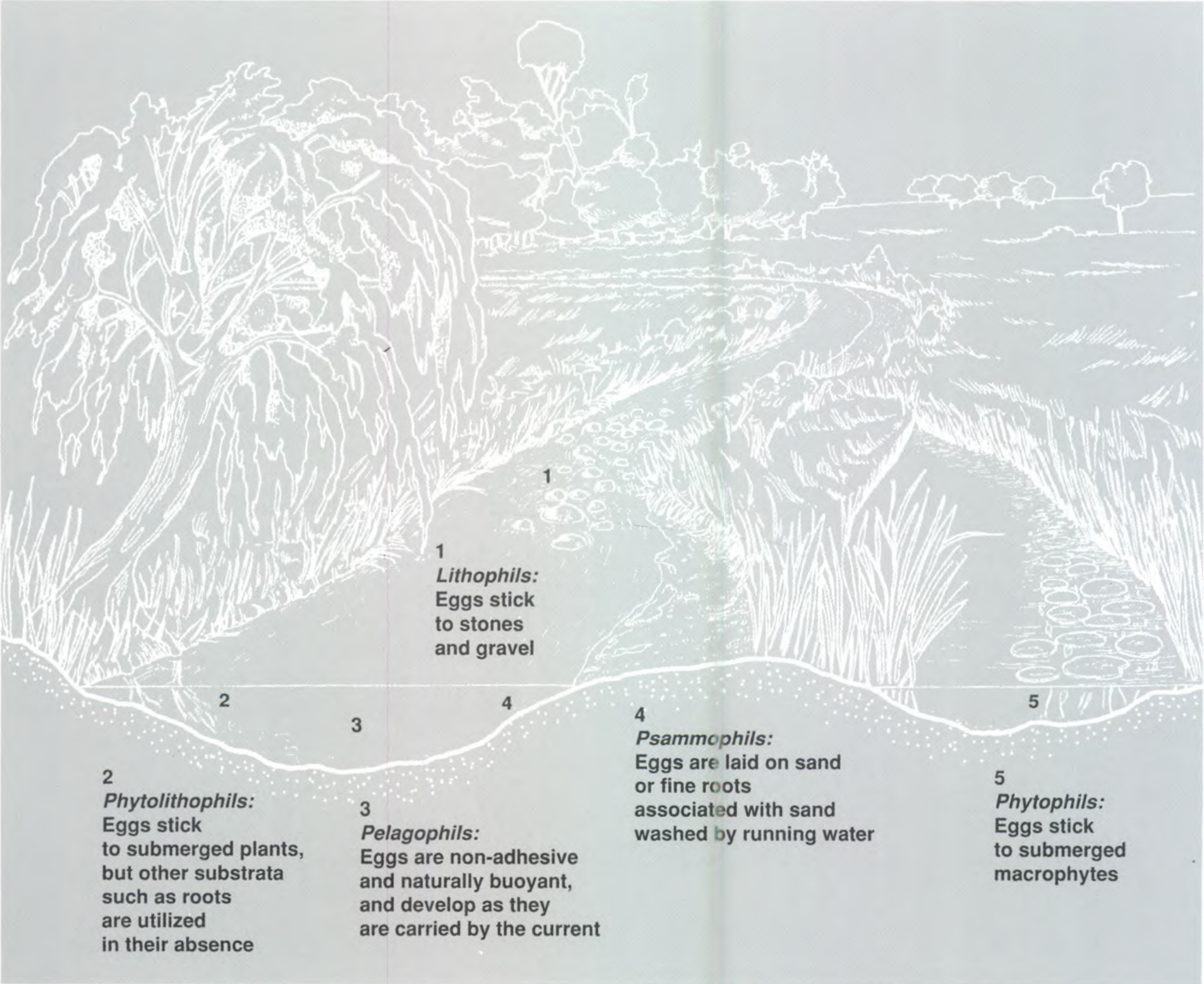


Figure 1.10
Spawning substrata of the five groups of European cyprinids

flooded areas over vegetation and sand. Other species include: *Abramis ballerus* (L.), *Alburnoides bipunctatus* (Bloch), *Chalcalburnus chalcoides* (Güldenstadt), *Leuciscus cephalus* (L.), *Barbus* spp. and *Leuciscus svallize* (Heckel & Kner).

Table 1.5 **Habitat preferences and requirements for reproduction of 17 European cyprinids**

Species	Depth (cm)	Water velocity (cm s^{-1})	Substratum diameter (Ø mm)	Vegetation	Optimum temp (°C)
Abramis brama	variable	< 20	> 5	*Glyceria,* *Sagittaria,* *Nuphar*	12 - 20
Alburnoides bipunctatus	R_{50} = 14 - 20	20 - 50 R_{50} = 40.5	20 - 100	Absent	> 15
Barbus barbus	R_{50} = 14 - 22	R_{50} = 35 - 49	R_{50} = 20 - 50	Absent	> 14
Blicca bjoerkna	Variable	< 20	Indifferent	Hydrophytes Helophytes	16 - 25
Chondrostoma nasus	10 - 25	< 100 R_{50} = 50 - 110	50 - 15	Absent	
Chondrostoma toxostoma		> 50	30 - 100	Absent	
Cyprinus carpio	Variable	< 5	Indifferent	Submerged riparian or floodplain veg.,*Carex,* *Glyceria,* *Phragmites*	> 18
Gobio gobio		10 - 80	3 - 30	Hydrophytes (occasional)	> 17
Leuciscus cephalus	10 - 30	20 - 50 R_{50} = 15 - 75	> 5	Hydrophytes (occasional)	14 - 20
Leuciscus idus			Sand		
Leuciscus leuciscus	25 - 40	20 - 50	30 - 250	Hydrophyes, rootwad (occasional)	6 - 9
Phoxinus phoxinus	10 - 25	> 20 R_{50} = 25 - 45	20 - 100	Absent	
Rhodeus sericeus			Unionids		
Rutilus rutilus	15 - 45	> 20 R_{50} = 35 - 60	50 - 150	*Fontinalis* moss, *Elodea,* *Salix, Scirpus*	14 - 8
Telestes soufia agassizi		20 - 50	30 - 100	Absent	
Tinca tinca	Variable	< 20	Indifferent	*Myriophyllum,* submerged riparian or floodplain veg.	20 - 24
Vimba vimba	< 50	> 20	Stones, sand	(occasional)	

Note: R_{50} refers to 50% central range of variable utilization by species

Phytolithophils: Eggs stick to submerged plants but other substrata are utilized in their absence. Larvae are initially photophobic. These species use a variety of substrata in a range of water velocities. *Rutilus rutilus* (L.) spawns on *Fontinalis* moss on vertical metal pilings, *Elodea* beds, *Salix* roots, *Scirpus*, stones and submerged logs. They prefer spawning in flows > 20 cm s $^{-1}$ and rarely at lower velocities. *Leuciscus idus* (L.) spawns on pebbles covered with algae, plants associated with sand and flooded grass. Although *Abramis brama* (L.) may spawn on stones in lakes, in rivers it utilizes only areas with a weak current and macrophyte substrata, e.g. *Rorippa*, *Botumus*, *Sagittaria*, *Glyceria* and *Nuphar*. *Leuciscus leuciscus* (L.) is usually included in this category but most references suggest it prefers spawning on stony substrata with flow velocities about 30 cm s $^{-1}$. Other species include: *Alburnus alburnus* (L.), *Leuciscus souffia* Risso, *Rutilus frisii* (Nordmann) and *Rutilus lemmingi* (Steindachner).

Phytophils: Eggs adhere to submerged macrophytes. The larvae are not photophobic. *Tinca tinca* (L.) and *Scardinius eryhthrophthalmus* (L.) spawn among *Myriophyllum* beds, and carp *Cyprinus carpio* L. utilize a range of plants, including *Carex*, *Glyceria*, fresh shoots of *Phragmites* and *Salix* roots. Other species include: *Blicca bjoerkna* (L.), *Carassius carassius* (L.), *Carassius auratus gibelio* (Bloch), *Rutilus rubilio* (Bonaparte) and *Rutilus arcasi* (Steindachner).

Psammophils: Eggs are laid on sand or fine roots associated with sand, washed by running water. Benthic larvae are photophobic. *Gobio gobio* (L.) have been found to lay their eggs on *Fontinalis* at velocities between 10 and 80 cm s $^{-1}$ and among plants on coarser substrata. Habitat requirements for reproduction of 17 European cyprinids species are summarized in Table 1.5.

1.3.3 Access to, and availability of, spawning areas

Recruitment success in any population is dependent on availability and quality of suitable spawning habitat (Figure 1.11). Cyprinids are known to migrate considerable distances during the spawning season to such habitats. Thus any major obstacle on the migration route could prevent or delay arrival on the spawning grounds. This can have serious implications on the reproductive success of the species and can lead to a demise in the stocks.

1.3.4 Egg Mortality

One of the key factors causing egg mortality results from siltation of stony spawning substrates. Predation by invertebrates is considered of minor importance. However, there is some evidence that fish, e.g. eels, can affect the levels of recruitment through predation, although losses of 0-group fish from other causes are equally important in these cases.

Many phytophils and phytolithophils lay eggs on substrates just below the water surface where they are vulnerable to sudden falls in water level. Removal of instream vegetation during the spawning period can have a dramatic effect on spawning success. Weeding or cutting to prevent flooding can directly remove the eggs of phytophilous fish species. It can also have a dramatic effect on water levels. For instance, falls in water levels of about 60 cm over three days have been observed in rivers following the removal of *Ranunculus* beds, which in turn affects recruitment success by drying out substantial parts of the egg mass. Similar effects on water level can also result from the operation of sluices and navigation locks.

The risk of egg mortality varies intra-specifically between years according to water temperature, which directly affects incubation time (Table 1.6). Empirical models of the form

$$\log D = a + BT,$$

where D is the incubation time (days) and T mean daily water temperature (°C), have been developed for some species, e.g. for *Rutilus rutilus* $a = 1.88$ and $b = -0.058$; and for *Leuciscus leuciscus* $a = 2.06$ and $b = -0.060$. These are useful tools for assessing the time period over which the eggs should be left undisturbed and need determining for other cyprinid species.

Table 1.6
Aspects of the reproductive ecology of riverine coarse fish

Species	Incubation period	Length at 1st hatch (mm)	Post-hatch behaviour
Rutilus rutilus	30 d at 7 °C 11-12 d at 12.9 °C	4.6-6.5	1st few days – attached to vegetation. Habitat: 1.5 m depth, 0.5 - 1 cms^{-1}, sandy, silt and gravel substrate; vegetation. At 8 - 13 mm: shoaling, sensitivity to current decreases. Habitat of woody debris and vegetation
Leuciscus leuciscus	29 d at 12 °C 14.4 d at 15 °C	5-7	
Leuciscus cephalus	75.5-107.3 h at 18 °C		
Abramis brama	3-12 d (average) 7-8 d at 18 °C	4-6	Gland on head: attach to vegetation. Free swimming when yolk-sac absorbed. Heavy predation by invertebrates and fish up to this stage
Blicca bjoerkna	4 d at 20 °C 5 d at 15 °C	4.8-6	Initially associated with bottom. After 2-3 d attach to aquatic vegetation. At 7-8 mm free swimming. Move to deeper water at end of summer
Barbus barbus	11 d at 14 °C 5-6 d at 19 °C	Depending on egg size and incubation temp	11-19 d to exogenous feeding. Very vulnerable to predation.
Tinca tinca	5-6 d at 18-20 °C	4	Development temperature-dependent (22 °C for good growth). Exogenous feeding commences after 6-10 d
Cyprinus carpio	3-10 days		

One of the key factors causing egg mortality results from siltation of stony spawning substrates

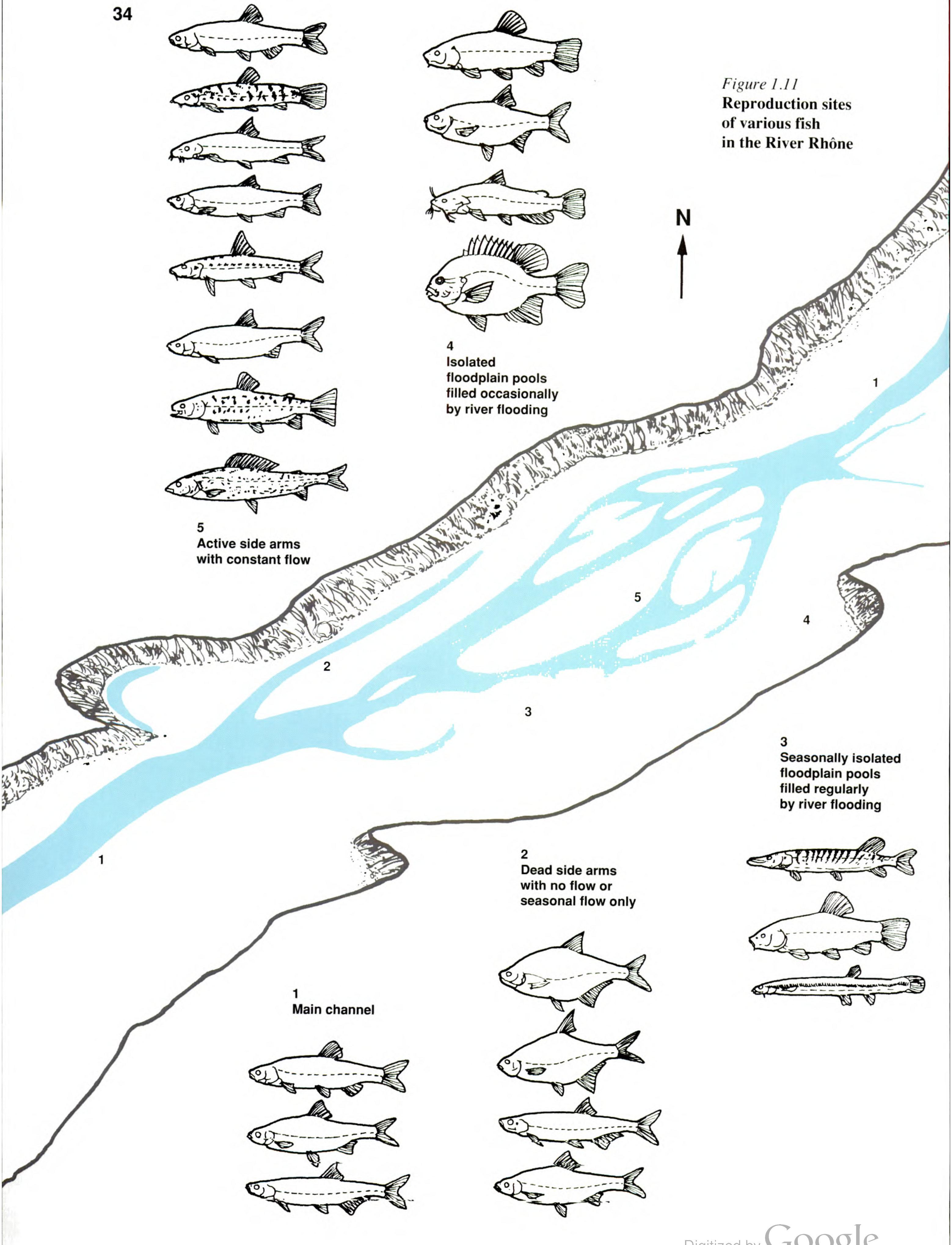


Figure 1.11
Reproduction sites of various fish in the River Rhône

1.3.5 Habitat requirements of larvae and young-of-the-year growth stages

The young stages represent the critical period in the life cycle of cyprinids. The size and behaviour of larvae of seven European cyprinid species in the immediate post-hatching period is outlined in Table 1.7. Larvae can be divided into four groups according to their flow preferences.

Critical and preferred velocities

Critical, sustainable and preferred velocities represent key characteristics in habitat selection and in determining the carrying capacity of the river or stream at various flow regimes. This aspect is particularly relevant to growth and survival of 0 + larvae and juveniles. Critical velocities (CV_{50} [cm s $^{-1}$], values that displaced 50 percent of larvae after 3 min) have been determined for several European cyprinid species at different sizes and in relation to the ambient water temperature (Table 1.8). These models provide a useful guide to the potential tolerance of the larvae of various species to displacement from refugia by episodic spates. However, it should be noted that most larvae select habitats where the flow velocity is well below the critical level. For example, newly-hatched *Rutilus rutilus* and *Leuciscus leuciscus* larvae tend to be confined to riparian habitats where the flow velocity is below 2.0 cm s $^{-1}$, although flow velocities of more than 6 cm s $^{-1}$ are required to displace larvae of 7.5 mm (Table 1.7). For older 0-group fish, the maximum current velocity that can be sustained for at least 15 min increases to about 40 cm s $^{-1}$. Consequently, most 0-group cyprinids will be excluded from habitats with velocities of more than 50-60 cm s $^{-1}$ until late summer when they achieve a length at which they are able to cope with these flows.

An alternative approach to evaluation of critical flow levels is to determine tolerance and preference limits, as P_{95}

Table 1.7
Flow preferences of differents groups of fish larvae

Rheophilic	All stages confined to the main river	*Chondrostoma nasus* *Barbus barbus* *Rutilus pigus* *Rutilius frisi* *Leuciscus leuciscus* *Leuciscus cephalus* *Vimba vimba* *Phoxinus phoxinus* *Gobio kessleri* *Gobio albipinnatus* *Gobio uranoscopus*
Rheophilic	Some stages confined to backwater areas	*Leuciscus idus* *Abramis sapa* *Abramis ballerus* *Aspius aspius*
Eurytopic	Flow indifferent	*Rutilus rutilus* *Alburnus alburnus* *Blicca bjoerkna* *Abramis brama*
Limnophilic	All stages confined to backwater areas	*Eucaspius delineatus* *Scardinius erythrophthalmus* *Rhodeus sericeus* *Carassius carassius* *Tinca tinca*

Table 1.8
Critical tolerance and preferred water velocities for cyprinids

Species	Fish size (cm)	Velocity limits	Temperature °C
Leuciscus leuciscus	0.9 - 2.5	CV_{50} = 10.3 BL s $^{-1}$	15 - 16
	4.5 - 8.0	Tol - 10.08 BL s $^{-1}$	15 - 15
		Pref = 6.33 BL s $^{-1}$	
Rutilus rutilus	0.6 - 1.5	CV_{50} = 13.3 BL s $^{-1}$	19 - 20
	0.75	CV_{50} = 9.20 BL s $^{-1}$	
		Pref = 2.67 BL s $^{-1}$	
Barbus barbus	1.9 - 3.0	Tol = 11.50 BL s $^{-1}$	15 - 16
		Pref = 5.67 BL s $^{-1}$	
	3.0 - 4.5	Tol = 10.81 BL s $^{-1}$	15 - 16
		Pref = 5.67 BL s $^{-1}$	
	4.5 - 6.5	Tol = 10.71 BL s $^{-1}$	15 - 16
		Pref = 5.0 BL s $^{-1}$	
	7.5 - 12.0	Tol = 6.19 BL s $^{-1}$	12 - 18
		Pref = 6.57 BL s $^{-1}$	
Alburnoides bipunctatus	3.3 - 6.0	Tol = 10.10 BL s $^{-1}$	15 - 16
		Pref = 5.67 BL s $^{-1}$	
Gobio gobio	2.8 - 5.0	Tol = 8.85 BL s $^{-1}$	15 - 16
		Pref = 5.29 BL s $^{-1}$	

CV_{50} = Critical velocities displacing 50% of the larvae after 3 min.
Note: Tolerance and preference limits refer respectively to the P_{95} and P_{75} of the probability of use curves for water velocity.

and P_{75} respectively, from habitat probability of use curves derived according to the Instream Flow Incremental Methodology described in Section 3.3 (Figures 1.12 and 1.13).

Excessive flow effectively limits the carrying capacity of the river for juvenile fish.

Whichever approach is used, excessive flow effectively limits the carrying capacity of the river for juvenile fish to small areas of the river where suitable flow velocities are found, and may be represented by as little as 2-3 percent of the river's surface area. This limitation of the actual carrying capacity by critical flows is particularly relevant in regulated, channelized and/or dredged rivers where anthropogenic activities reduce habitat diversity. Initially, some newly-hatched

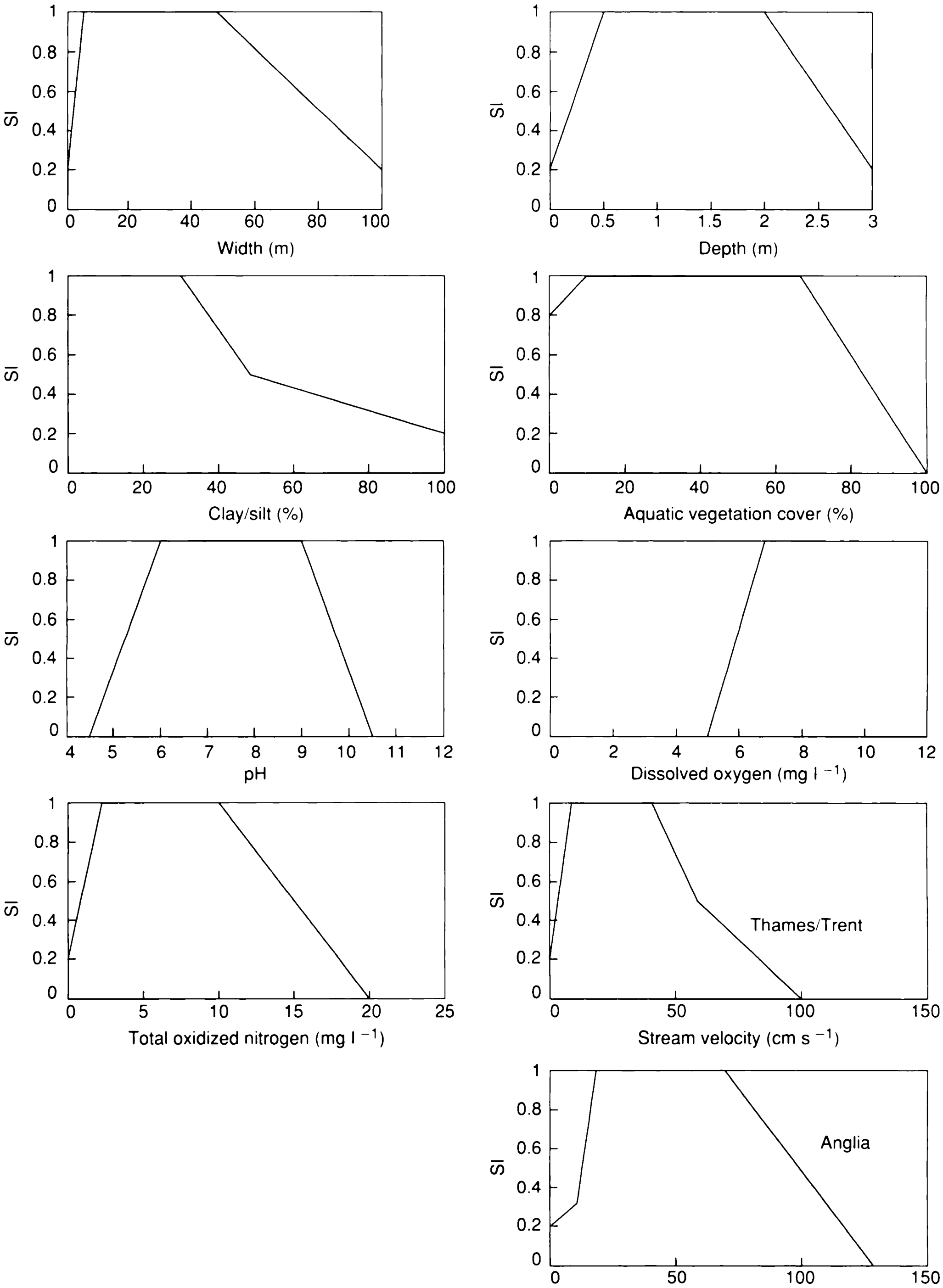


Figure 1.12
Habitat suitability curves for *Leuciscus cephalus*

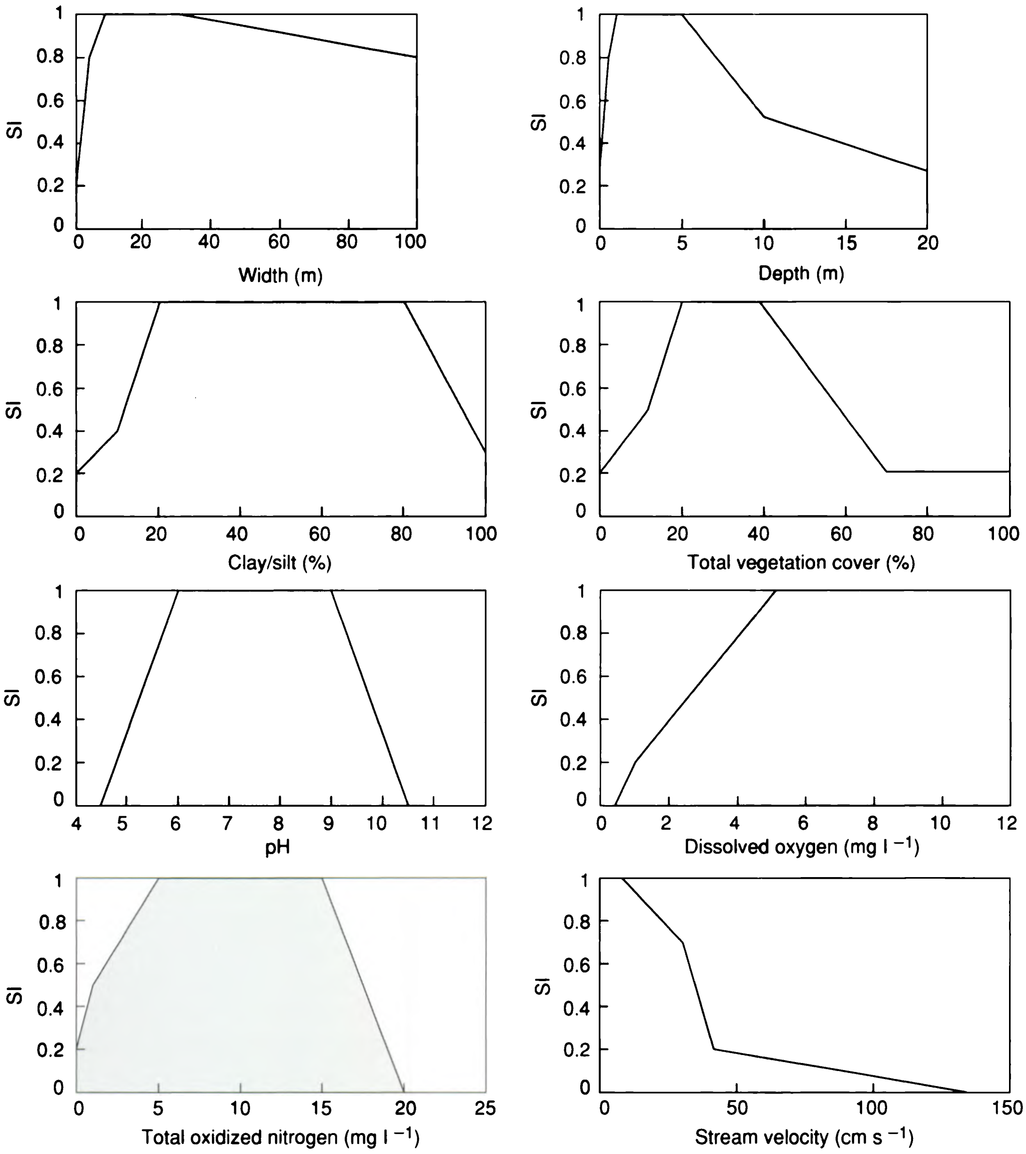


Figure 1.13
Habitat suitability curves for *Rutilus rutilus*

fish which have adhesive glands, such as *Rutilus rutilus*, will resist displacement by attaching themselves to vegetation, stones, etc.

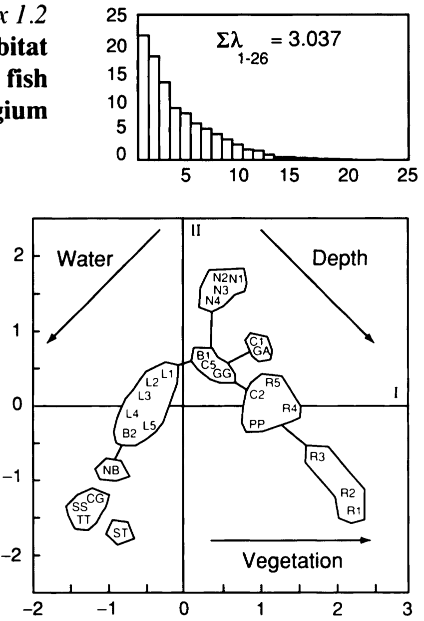
It has been suggested that water velocity plays only a minor role in determining habitat distribution beyond the critical limits of the fish's physiological tolerance. However, it also plays a determining factor in shaping the habitat as it conditions most of the attributes of each microhabitat such as substratum (reduction in particle size with decreasing velocity) and vegetation types, e.g. predominance of *Myriophyllum* sp. in lentic habitats (Section 1.4).

Microhabitat requirements

In addition to river current, other environmental characteristics influence microhabitat distribution and the subsequent survival and recruitment of cyprinid larvae. Cyprinid larvae can be grouped according to their association with various habitat features, especially water depth, channel width and shape, substratum particle size, vegetation cover and type, and water temperature. The habitat preferences curves derived for various species (Figures 1.12 and 1.13) and the results of correspondence analysis for an assemblage of cyprinid species in the River Ourthe, Belgium

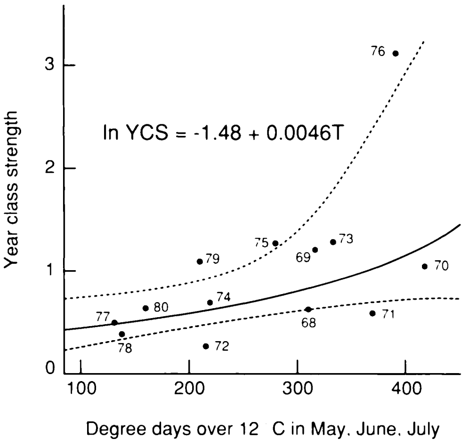
In addition to current, other characteristics influence microhabitat distribution, survival and recruitment of cyprinid larvae.

Box 1.2
Occupation for habitat by young-of-the-year fish – River Ourthe, Belgium



Species, age, size	N	Species, age, size	N
B1. *Barbus barbus* 0+ < 35 mm	13	PP. *Phoxinus phoxnus* 0+	47
B2. *Barbus barbus* 0+ ≥ 35 mm	13	GG. *Bobio gobio* 0+	33
C1. *Leuciscus cephalus* 0+ < 35 mm	39	GA. *Gasterosteus aculeatus* 0+	32
C2. *Leuciscus cephalus* 0+ ≥ 35 mm	28		
N1. *Chondrostoma nasus* 0+ < 25 mm	22	R1. *Rutilus rutilus* 0+ < 25 mm	63
N2. *Chondrostoma nasus* 0+ 25-29 mm	169	R2. *Rutilus rutilus* 0+ 25-29 mm	178
N3. *Chondrostoma nasus* 0+ 30-34 mm	403	R3. *Rutilus rutilus* 0+ 30-34 mm	156
N4. *Chondrostoma nasus* 0+ 35-39 mm	175	R4. *Rutilus rutilus* 0+ 35-39 mm	74
N5. *Chondrostoma nasus* 0+ ≥ 35 mm	27	R5. *Rutilus rutilus* 0+ ≥ 40 mm	31
L1. *Leuciscus leuciscus* 0+ < 40 mm	70	ST. *Salmo trutta fario* 0+	19
L2. *Leuciscus leuciscus* 0+ 40-44 mm	285	SS. *Salmo salar* 0+	39
L3. *Leuciscus leuciscus* 0+ 45-49 mm	342	CG. *Cottus gobio*	32
L4. *Leuciscus leuciscus* 0+ 50-54 mm	145	TT. *Thymallus thymallus* 0+	168
L5. *Leuciscus leuciscus* 0+ ≥ 55 mm	45	NB. *Noemacheilus barbatulus*	706

Figure 1.14
Year class strength of *Leuciscus leuciscus* related to temperature in the previous year – River Frome, UK



(Box 1.2), help to identify these associations. However, simple observations are equally useful. For example, *Leuciscus cephalus* and *Alburnus alburnus* larvae are often found in lentic water, 20 to 50 cm deep, with a silted gravel substrate and associated macrophytes and woody debris. By contrast, *Leuciscus leuciscus* larvae avoid woody debris but prefer macrophyte and attached periphyton cover in a range of water depths. Initially *Rutilus rutilus* larvae prefer water 50 to 100 cm deep with thick macrophyte growth but, later, they move into shallower areas (20-50 cm), often in association with *Leuciscus leuciscus* larvae.

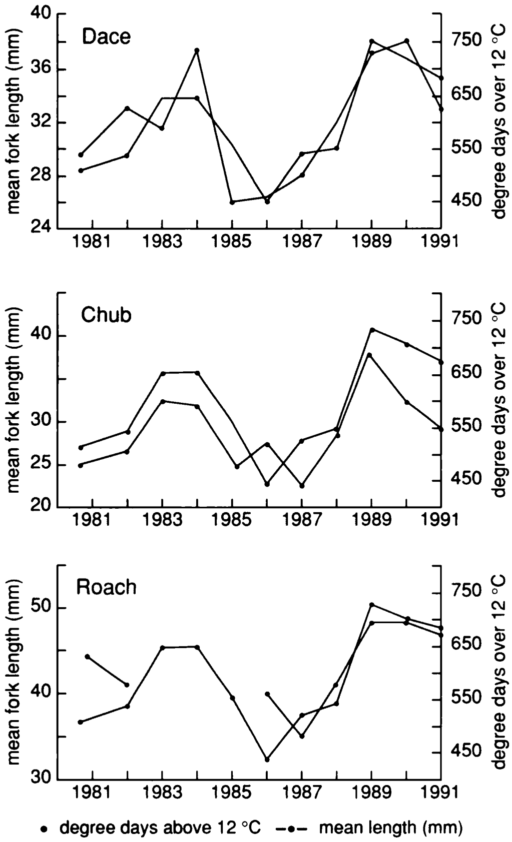
There is also a strong relationship between shoreline habitat diversity and the number of fish species (0-group). However, shoreline slope and diversification are only two factors and other larval microhabitats, including proximity of suitable spawning sites and connected backwaters (feeding areas and refugia during winter floods), are also important.

Water temperature

The overall action of water temperature on recruitment is well known for many European cyprinid species in the form of a correlation between summer temperature and year class strength (Figure 1.14). This relationship probably covers several aspects, including size reached at the beginning of the first winter (Figure 1.15), and their subsequent capabilities to face higher critical velocities.

The influence of temperature is, however, much more profound as physicochemical parameters, especially temperature and oxygen concentration,

Figure 1.15
Length of roach, chub and dace fry in September related to temperature – Yorkshire Ouse, UK



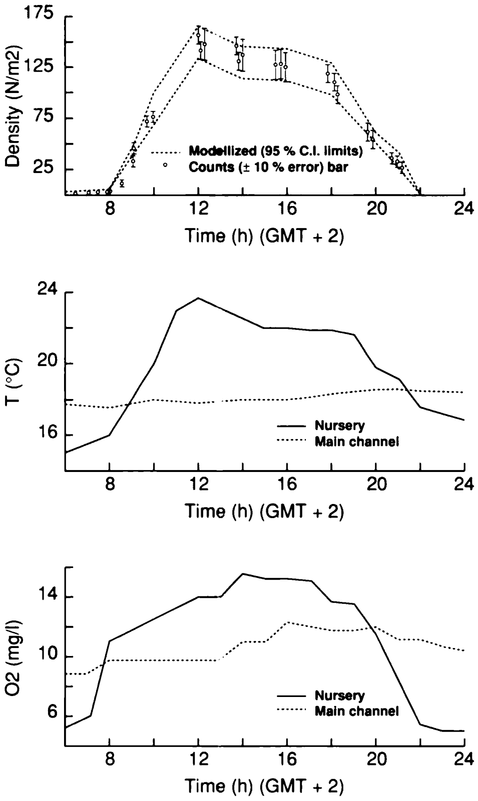


Figure 1.16
Daily variations in use of nursery in habitat in summer – River Ourthe, Belgium

are influenced by microhabitat morphology. For example, there are considerable differences in the diurnal temperature and oxygen levels between shallow nursery areas (depth less than 5 cm and water velocity less than 5 cm s $^{-1}$) and the lotic conditions (depth 40 cm and water velocity 60 cm s $^{-1}$) in the centre of a stream, e.g. Figure 1.16. Temperature and oxygen daily amplitudes in the example of the River Ourthe were respectively 0.9°C and 3.8 mg l $^{-1}$ in the main channel, but they reached 8.7°C and 10.2 mg l $^{-1}$ in the nursery area. The higher temperatures in nursery habitat in the late morning and afternoon were characterized by high densities of 0-group cyprinids (150 fish [3-6 cm]/m^2) which were not found elsewhere or at other times.

This association with temperature is also illustrated by the probability of use of water velocity by 0-group *Leuciscus leuciscus* on two days when water temperature in the main stream was similar (15.7°C and 15.8°C) but solar radiation conditions (air temperatures 13-14°C and 21-23°C), which can locally elevate water temperature in backwater nursery habitats, were different (Figure 1.17). On the sunny day, most dace were clumped in shallow/lentic microhabitats whereas these habitats were mostly avoided on the day when their temperature was below that of the

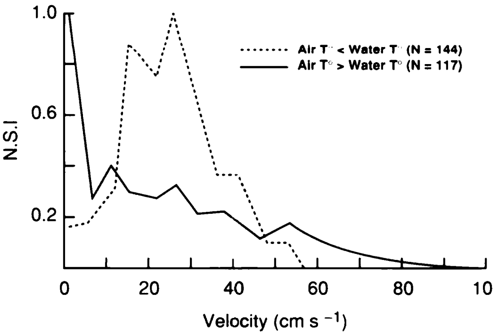


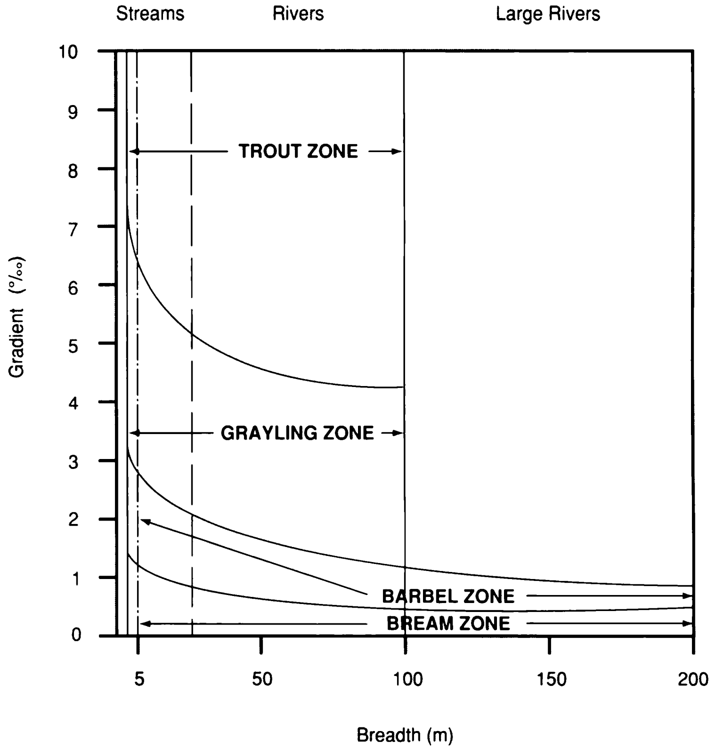
Figure 1.17
Differences in use of nursery by juvenile *Leuciscus leuciscus* on two days with similar water temperature regimes but different conditions of sunshine

stream. Being able to select optimal temperatures is of importance to all fish stages. However, it is particularly important to 0+ smaller stages with a large surface area/volume ratios when foraging, digestion, assimilation, optimal energy budgets and increased swimming speeds to escape predators and ability to hold station are vital for survival.

1.3.6 Habitat requirements of adult cyprinids (> 0 + life stages)

Older cyprinid fishes also have preferred physico-chemical requirements which can be expressed by suitability curves (Figures 1.12 and 1.13). As longitudinal gradients of physico-chemical variables exist in rivers, these preferences are often translated into zonation patterns of fish species assemblages in rivers, where species with similar habitat preferences are grouped. This observation has been used to formulate river classification schemes based on zones ('trout', 'grayling', 'barbel', 'bream') in which a number of discernible and characteristic species assemblages inhabit different types of river reach (Figure 1.18). This longitudinal pattern, based on four zones, still provides a useful summary of the habitat requirements of European freshwater fishes (Figures 1.18 and 1.19). In this classification gradient is the primary feature characterizing the zones, and any given biogeographical area, river or stretch of river of like breadth, depth and slope will have nearly identical biological characteristics and very similar fish populations. Also, the width of the stream is important in influencing fish fauna: *Thymallus thymallus* and *Barbus barbus*, for example, are rarely found in streams less than 5 m wide, even when the gradient is suitable.

Figure 1.18
Faunal zones in Western European rivers



The longitudinal pattern based on four zones provides a summary of the habitats used by European freshwater fishes.

An abiotic-biotic continuum concept, based on functional relationships between abiotic and biotic factors as mechanisms for regulating fish communities, has also been developed (Figure 2.2). In this approach there are no sharp limits between zones but a more gradual change in species composition. The range of the abiotic-biotic continuum varies from a stable predictable environment with a high species diversity, strong interspecific competition and narrow ecological specializations to an unstable environment where fish are on the brink of physiological tolerance with no biotic selection or diversification.

The problem with many of these schemes is that the differences between species occupying the same broad zone ('trout', 'grayling', 'barbel', 'bream') are absent from the classification. This limitation of knowledge is widespread and there is an important need for more precise information on the habitat requirements of cyprinids.

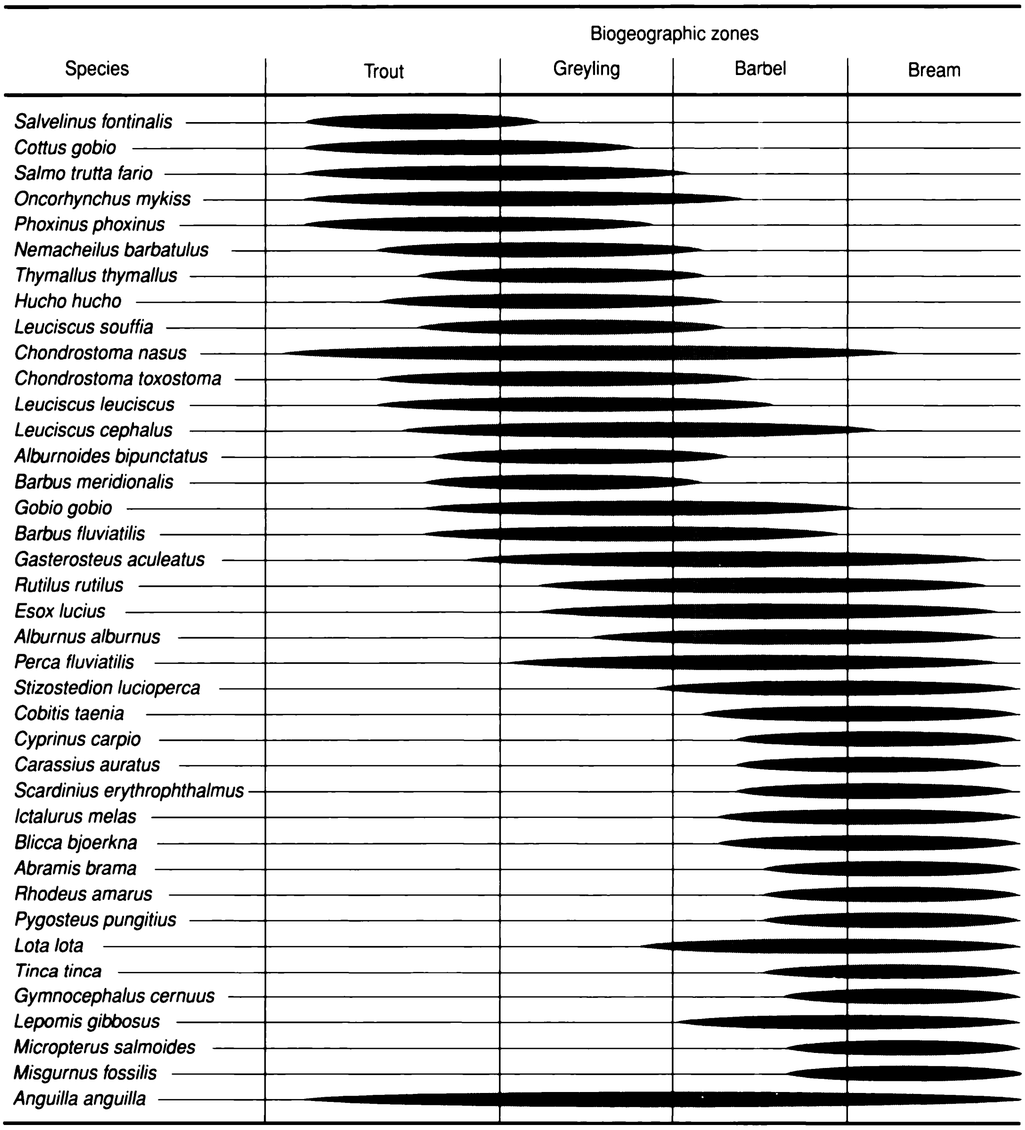


Figure 1.19
Fish populations in Western European rivers by faunal zone

1.4

The importance of in-stream and riparian vegetation

Aquatic and riparian vegetation are vital for a healthy and sustainable watercourse system.

Aquatic and riparian vegetation are vital for a healthy and sustainable watercourse ecosystem. This is as true for man-made drainage channels as it is for pristine, natural rivers. However, vegetation is more likely to be of greatest significance for fisheries when a watercourse has little or no variation in physical structure; it is here that the aquatic vegetation becomes a physical habitat in its own right. Thus aquatic and marginal plants may be a key factor determining whether or not there is any fishery interest in the highly modified urban watercourses which are most accessible to the majority of people.

Aquatic vegetation plays many important roles in maintaining and improving the health of waterways; Box 1.3 lists some key characteristics which are particularly important for healthy fisheries. Such a fishery is likely to require variations in water temperature, depths and velocities, as well as a huge variety of physical structure. Vegetation can often help provide all of these, even in those watercourses which have been heavily engineered in the past. In addition a balanced aquatic plant community is an attractive feature of aesthetic value and amenity which is appreciated by anglers, boaters, walkers, picnickers and anyone utilizing waterways for recreation.

Healthy fisheries may also depend upon, or be considerably enhanced by, the vegetation of the riparian zone and the land-use of the abutting floodplain. In the context of this section the riparian

Box 1.3
Importance of aquatic plants to fish

- Water purification – a. direct: for example, by oxygenation and conversion of toxic ammonia to usable nitrates; b. indirect: provision of huge surface area for microbes to do the same tasks
- Nutrient re-cycling – removal during growth season, return during senescence
- Physical link between water and air for many invertebrates, e.g. caddis, which are food for fish and have aquatic larval stages and aerial adults
- Refugia for zooplankton which graze phytoplankton and keep water clear
- Cover for huge range of invertebrates, many of which are food for fish, e.g. shrimps
- Cover for fish – value and type varies with age/species of fish as well as type of vegetation
- Spawning areas and sites of oviposition for many cyprinid and percid fish, e.g. tench, roach, rudd, perch, plus pike
- Food source (living and dying) – direct source for vegetarian fish, e.g. carp; indirect source via other animals
- Affects flow patterns – accretes sediments and deflects flows so provides quieter waters and faster shallows
- Creation of discrete habitat structure which is as functional as physical structure.

▲
Varied types of riparian vegetation are essential to maintain a diverse community of fish
▼

zone is defined as that area of the bank stretching from the water's edge to the top of the bank where there is the potential for cultivation or building development. Box 1.4 summarizes some attributes of riparian vegetation that can enhance fishery interests.

Backwaters, ditches and other open water habitats are also important for the well-being of a river fishery.

Backwaters, ditches and other open water habitats, including those of floodplains connected to rivers, may be also important for the well-being of a river fishery. If these are used as recruitment areas, the type of aquatic and riparian vegetation in them, and the manner in which the plants are managed, may be as important as that in the main channel.

From this it can be concluded that aquatic and riparian vegetation is a prime factor in determining the value of a riverine fishery. However, the key to success is having the right balance. Too much or too little is rarely of value. It is not just having the right amount of plants that is important, it is having a balanced proportion of the natural variety in physical form of different species. Hence a patch of river crowfoot will provide a totally different environment for fish compared with a bed of water lilies. The important role that aquatic plants can play in creating lateral diversity in a watercourse and in thus benefitting fish in a variety of ways through their life cycle can be illustrated by the dace. Young dace can only tolerate slack water, so in rivers with no backwaters they can only thrive in dense, reedy margins protected from the current; adults, on the other hand, prefer deeper, faster-flowing water so occur more in mid-channel where there is less vegetation.

The same principle is true for the riparian zone. If both banks have a dense layer of mature trees and shrubs which totally occlude the channel, the in-stream environment for fish will be very different from one in which the banks are open and covered with mown grass. Potentially the channel of the former will be devoid of submersed aquatic vegetation and provide little cover or food for fish whereas the latter may be choked by its vegetation which smothers out other life. A combination is usually ideal for fish and for other wildlife interests too.

Box 1.4

Key attributes of riparian vegetation in relation to fisheries

1. Trees and shrubs provide:
    - shade to cool waters; most fish are intolerant of, or avoid, full sun; variations in water temperature are also important;
    - control excessive 'weed' growth by shading;
    - overhangs, both trunks and branches, provide favoured cover for many fish, e.g. chub and dace;
    - underwater fine root systems are important habitat for invertebrates (potential food);
    - fine roots may be used as spawning habitat by species which utilize vegetations, e.g. pike;
    - invertebrates and leaves dropping into the water are an important source of fish food, e.g. for dace and chub, especially in low productivity rivers;
    - improved landscape setting to enjoy angling.

2. Herbs, rushes and reeds growing up the banks also fulfil many of the roles described above

3. Vegetation, especially if tall and arching over the water, combine many of the above roles in addition to fulfilling many attributes of the aquatic vegetation listed in Box 1.3.

Chapter 2

River form and function

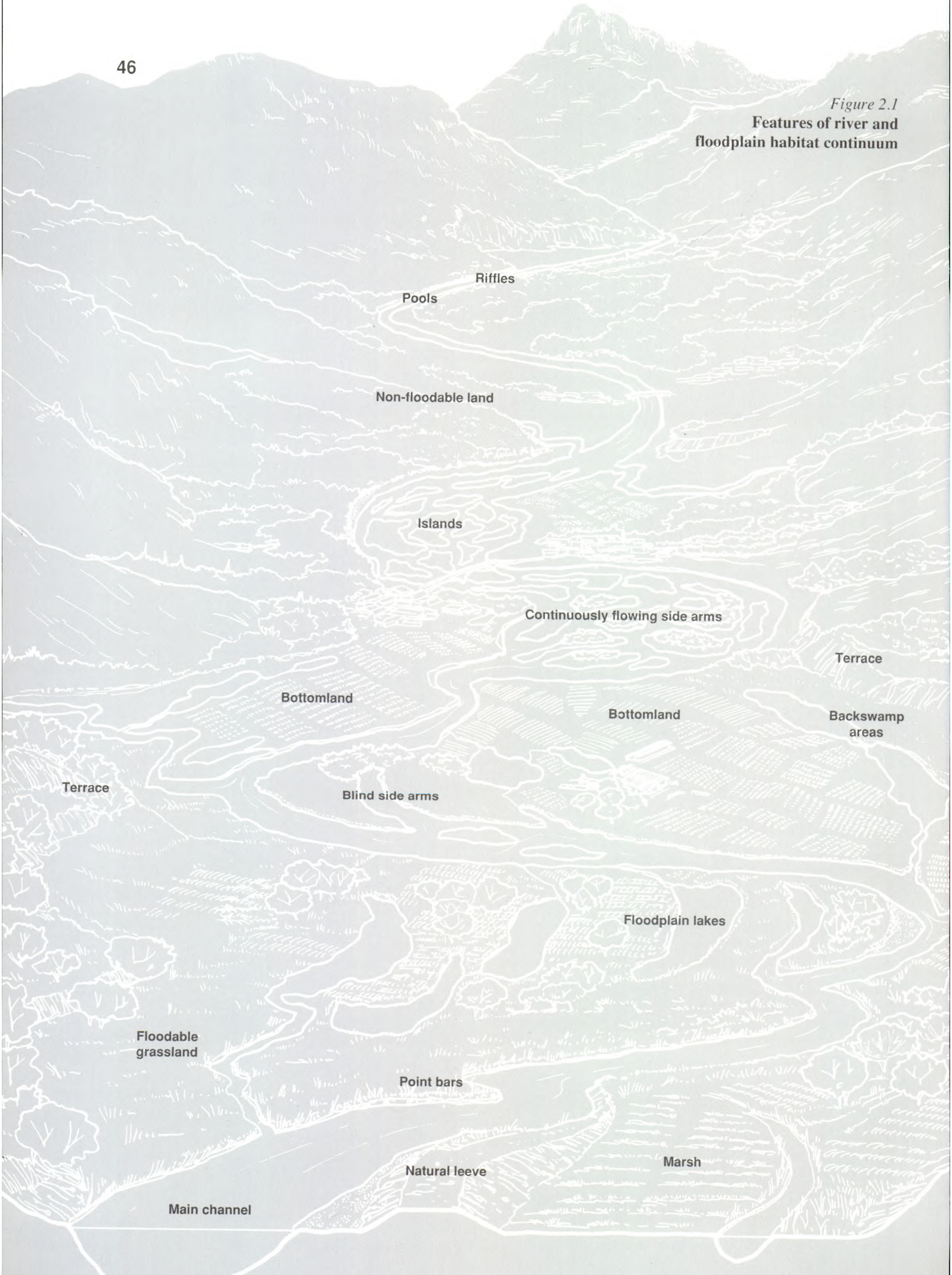


Figure 2.1
Features of river and floodplain habitat continuum

2.1

Introduction

A fluvial hydrosystem comprises the whole river corridor – the river channel, riparian zone, floodplain and alluvial aquifer. It can be considered as a four-dimensional system being influenced not only by longitudinal processes, but also by lateral and vertical fluxes, and strong temporal changes. Fluvial hydrosystems provide corridors through the landscape, and the marginal zones (ecotones) provide buffers between the watercourse and the variety of land uses within the catchment (Figure 2.1 and Box 2.1).

Any attempt to rehabilitate a river should be based on a thorough understanding of how that river functions. Clearly as rivers have become modified the functioning of the system has changed to adapt to the new conditions. The regulation and simplification of aquatic systems that have formed part of river management practice over the past century have produced a corresponding simplification in the diversity of the fauna and flora. This is not to say that a modified ecosystem is necessarily unhealthy, many regulated rivers contain well regulated communities living in harmony with the conditions surrounding them. The problem is that such communities are usually limited in diversity and are perceived as not corresponding to the 'natural' situation. There is now a tendency to try and restore modified systems for fish, recreation and aesthetic appeal.

Much of freshwater aquatic science has aimed at assessing waterways and their communities to provide some index of their health and functionality. Initially the main problems were to improve degraded water quality to a point where aquatic life could be restored to systems. Later it was realised that degradation had not only occurred in the quality of water but in the structure of the environment itself, and more recent models have been aimed at defining the role of the form of river systems on the processes that make them work as viable ecosystems. This section sets out models of how rivers are now perceived to function as a support system for life. These models provide the basic guide as to what types of intervention are needed to rehabilitate systems.

Box 2.1
Features of river and floodplain habitat continuum

	HABITAT
Aquatic	
I	Main channel: Pools Riffles Point bars Islands Bank features
II	Continuously flowing side arms and anabranches
III	Side arms connected to river at downstream end only
IV	Seasonally flooded floodplain lakes
V	Floodplain lakes rarely influenced by floods
VI	Backswamp areas maintained wet through groundwater seepage
VII	Areas of grassland / marsh / bottomland hardwood subject to seasonal inundation to an extent dependant on flood intensity
VIII	Non-floodable land on floodplain or at floodplain margin. usually plateau, terrace or levee which directly influence floodplain function
Terrestrial	

A fluvial hydrosystem can be considered as a four-dimensional system influenced not only by longitudinal processes, but also by lateral and vertical fluxes.

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The same river reach can present very different conditions at low water and during a flood
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secondary production within the fluvial hydrosystem;

4. the river and groundwater regimes determine the nature of vertical interactions within the zone.

2.2.2 The flood pulse concept

Large floodplain rivers derive most of their animal biomass from within the floodplain; they are dominated by lateral exchanges between floodplain and river channel and nutrient recycling within the floodplain. Biota are adapted to the pronounced aquatic and terrestrial phases: aquatic organisms colonize the floodplain at rising and high-water levels because of feeding and spawning opportunities; terrestrial organisms occupying non-flooded habitats along the borders are adapted to exploit the floodplain at low-water levels. Floodplains and floods are now regarded as essential components of fluvial systems. The improved production arising from the alteration of terrestrial and aquatic states is termed 'the flood-pulse advantage', which can be defined as the amount by which annual multi-species fish yield exceeds that from a system lacking annual floodplain inundation. Without the flood pulse, production within the fluvial hydrosystem is drastically reduced, and community composition and energy pathways are radically changed.

Large floodplain rivers derive most of their animal biomass from within the floodplain.

2.2.3 Hydraulic stream ecology

The concept of hydraulic stream ecology is founded on the basic ecological principle that the relative difference in speed between an organism and the medium in which it lives affects the energy budget of the organism. Current

The relative difference in speed between an organism and the medium in which it lives affects the energy budget of the organism.

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The different groups of organisms in different reaches of the river

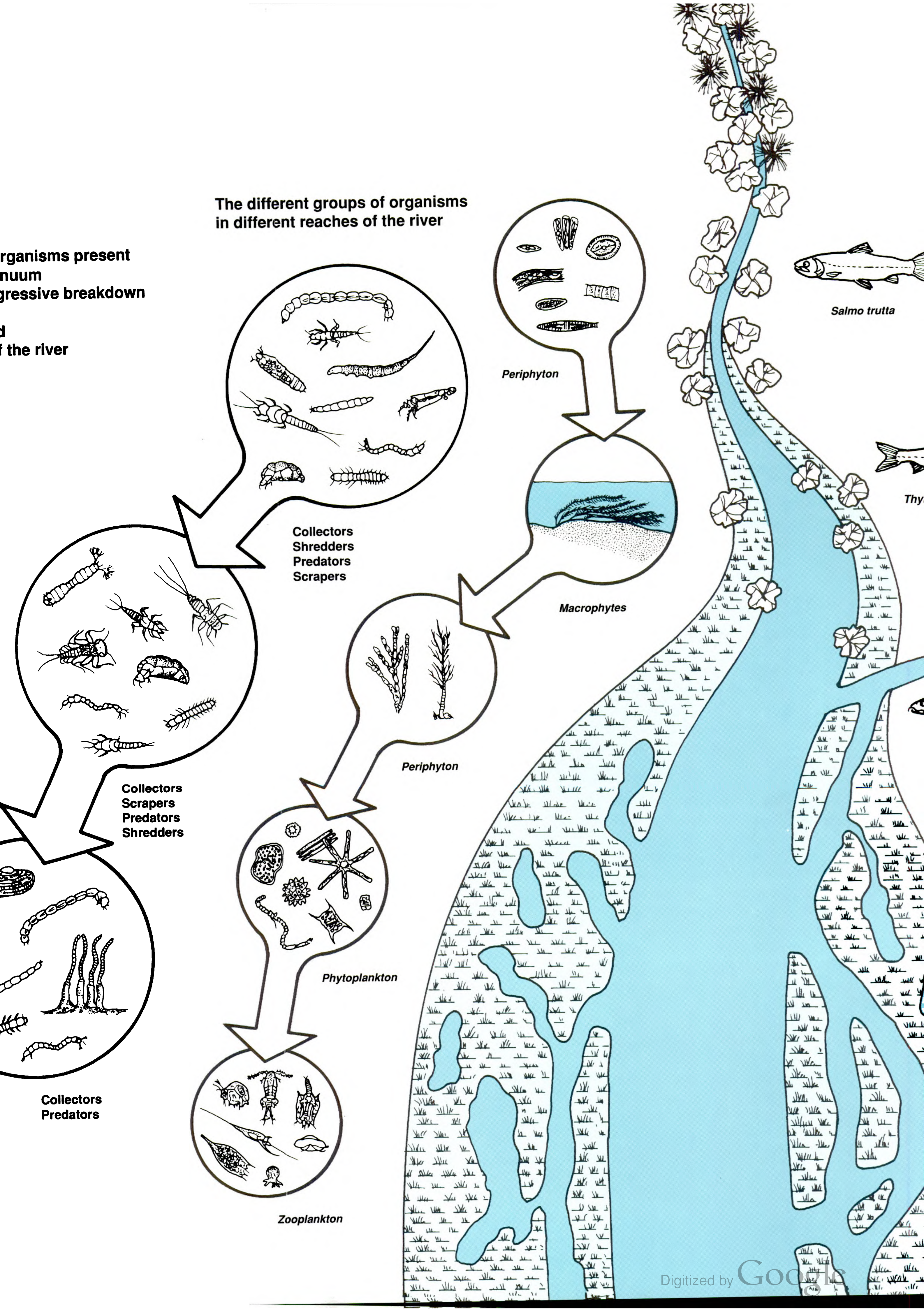
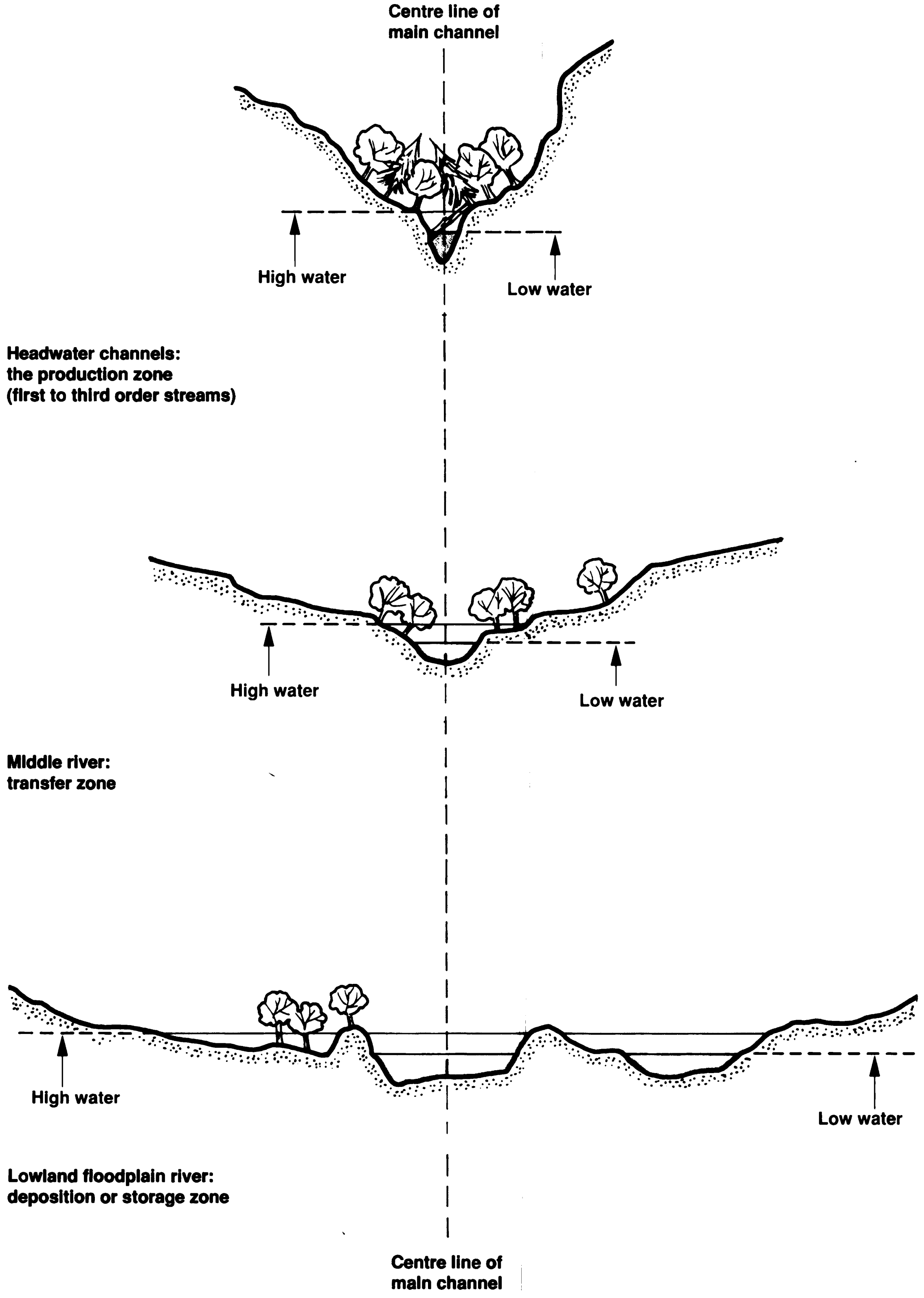


Figure 2.3
Typical stream cross-sections along the river continuum



velocity influences respiration and other measures of metabolism in all major groups of organisms found in running waters. Velocity also affects the feeding biology and behavioural characteristics of lotic animals, including: rheotaxis, locomotory activity, schooling and territoriality.

Consideration of channel-forming flows is important if the diversity of instream, riparian and floodplain habitats is to be protected or restored.

The hydraulic conditions where organisms live arise from the interaction of flow and channel form: the shape of the channel in cross-section, especially its asymmetry; bedform, such as pool-riffle development; the heterogeneity of the channel margins; and its platform. In natural channels, the heterogeneous flow environment supports a large variety and abundance of biota and hydraulic refugia play a major role in determining the impact of hydrological changes.

2.2.4 Channel-forming discharges

Consideration of channel-forming flows is important if the diversity of instream, riparian and floodplain habitats is to be protected or restored. Channel and floodplain processes are intimately linked, although models to quantify these links remain in their infancy. For management purposes, channel-forming flows may be viewed as following.

First, it is important to consider **floodplain-maintenance flows**. Floods disrupt the floodplain system by lateral erosion, meander cut-off and channel avulsion, bar deposition, cut-off channel siltation, and overbank sedimentation.

The channel substrate provides important habitat for a wide range of invertebrates and fish.

Such disturbance sustains habitats for pioneer species and lower successional stages and the mosaic of landform-sediment-vegetation units reflects the channel stability. Some channels maintain a stable course for long periods (>100 years) whereas, at the other extreme, channel migration by more than 1000 m y $^{-1}$ has been reported.

Secondly, it is necessary to consider the **bankfull flow**. Channel form is a function of the full range of discharges and sediment loads experienced, but the bankfull flow has been viewed as a hydrological benchmark, representing the range of intermediate flows that determine the size and shape of many alluvial channels. For a range of rivers, the discharge has been shown to have a return period of between one and three years, with a modal value of about 1.5 years, using the annual series.

Thirdly, **flushing flows** must be assessed. Flushing flows are moderately high discharges required to maintain the quality of the substrate, preventing vegetation encroachment into the channel and removing superficial and interstitial accumulations of fine organic and inorganic sediments.

2.2.5 The hyporheic zone

The channel substrate provides important habitat for a wide range of invertebrates and fish, especially salmonid-spawning habitat. Once perceived as a stable environment, the sub-surface zone along the river corridor is now recognized as an important and dynamic system that is largely determined by the hydrological conditions. In many cases, the hyporheic zone is of limited extent bordering the channel but in some geomorphological settings, notably glacial troughs infilled with highly permeable gravels, the zone may be extensive. The dimensions of the ecotone vary strongly in space and time in relation to surface flow and groundwater levels.

Two of the most important ecological factors, thermal gradients and oxygen profiles, are closely linked to the strength and direction of flow lines in the hyporheic zone. Thus, the influence of flow on processes and biological communities within the hyporheic zone should be of concern to all those involved in fisheries research, benthic invertebrate studies and environmental impact assessments.

2.3
Perspectives for river restoration

2.3.1 Rivers as storage systems

Throughout the world, the morphology of river systems has been dramatically altered by human action. The changes have been induced directly by dams and reservoirs and channelization, and indirectly by land-use developments throughout the drainage basins. The link between hydrological change, morphological change and ecological change may be better understood if rivers are considered as storage systems rather than as transport systems.

Model rivers may be viewed as a series of storages with different transport velocities, retention times and turnover rates. The yield of sediment and organic matter to the oceans is but a small fraction of that generated on hillslopes.

That part of the gross erosion or sediment mobilization within a catchment represented by the sediment yield at the catchment outlet is defined by the sediment delivery ratio. Values of the delivery ratio below 10 percent are common. Some of the material will be stored on hillslopes, but there are many storages along a river: bars, fans, floodplains, backswamps, channel fills and deltas. These represent different sedimentary environments, some, such as cut-off channels and backswamps, retaining large amounts of organic material. Some floodplain sediments, together with their organic deposits, can remain stable for thousands and tens of thousands of years. Throughout the temperate zone, valley aggradation during the period of Holocene sea-level rise has resulted in the long-term storage of thickness of sands, gravels, alluvium and organic deposits.

On a shorter time-scale, woody debris jams, macrophyte beds, the roots and overhanging branches of riparian vegetation are important retention features for leaf litter and sediment. To varying degrees, instream deposits are periodically flushed from the system following decomposition of debris jams and/or by high floods. Debris jams can retain a substantial proportion of the organic matter in channels and typical residence times vary from a few years to a few hundred years.

Throughout the world, the morphology of river systems has been dramatically altered by human action.

2.3.2 Channel dynamics

At any point along a river, the channel morphology is adjusted to the supply of sediment from upstream and the flow regime, modified by local conditions. The relationship of sediment and discharge for a stable channel balance can be described by:

$$Q_s D \infty SQ$$

where Q_s is the sediment load, Q the stream discharge, D is the sediment size and S the stream slope.

At any point along a river, the channel morphology is adjusted to the supply of sediment from upstream and the flow regime.

An increase in the size or quality of sediment input to a river, perhaps consequent upon catchment for construction, may cause channel aggradation with dramatic effects upon channel slope. On the other hand, an increase in the fluid discharge, say due to urban development or deforestation, or an increase in slope following channelization, will have repercussions for sediment transport, potentially causing channel degradation. Thus, any change in the supply of sediment to the river or a change in the fluid discharge, either in magnitude or distribution

Traditional river management has been based on the assumption that rivers are in equilibrium with their external environment but such an assumption is probably invalid.

through time, will lead to adjustments of channel morphology. This balance between forcing function, process and channel form, however, does not imply static conditions. The morphology of a channel represents a quasi-equilibrium form maintained by inter-adjustments of the different channel dimensions including: width, depth, slope, wetted perimeter, hydraulic radius, bed form, boundary roughness, and sinuosity. The quasi-equilibrium channel represents the most probable state given the recent history of flows and sediment loads, and reflects local constraints such as bank-material characteristics, bed sediment, valley width, etc. Constraints include bedrock outcrops or boulder rapids that inhibit channel slope adjustment, and valley narrowing, terraces or even riparian woods that limit lateral movement.

Along most sectors the channel dimensions will show a degree of seasonal and annual variability, particularly in terms of substrate, bedform and cross-sectional shape. Variability also occurs at the magnitude of individual flood events which can cause erosion and deposition of both channel bed and banks. Nevertheless, channel forms present predictable geometrical characteristics (Box 2.2) and these can provide scale frameworks for ecological analyses.

In rivers and streams, disturbance plays a critical role in organizing communities.

2.3.3 Systems characterized by change

Traditional river management has been based on the assumption that rivers are in equilibrium with their external environment but the dynamic interactions of the large number of variables involved over a range of different timescales means that such an assumption is probably invalid.

Over a period of 1-10 years rivers are characterized by changing flows, variable rates of particulate matter transport and changing channel forms. Biota respond to these changing forces, and this in turn generates dynamic biological interactions. Over short timescales most river systems may be viewed as in a transient state. Within such systems, an 'equilibrium' should not be defined as a constant environment. Space must be provided to allow the river to sustain its natural dynamics: 1) to allow lateral channel movement; and 2) to allow inundation of the river margins.

In rivers and streams, disturbance plays a critical role in organizing communities and ecosystems and this has important management implications, especially with regard to the long-term effects of human impacts. For example, the diversity of vegetation patches on floodplains is related to the rejuvenation of successions associated with channel erosion and deposition so that the patch mosaic reflects age structure and patch type. Thus, for example, along the River Rhone the floodplain mosaic reflects the varying morphological stability of the different channel sectors. In the rapidly shifting braided sectors, frequent disturbance inhibits long plant successions and pioneer populations dominate. Less active sectors, in contrast, are characterized by hardwood forests. River regulation increases the recurrence interval between disturbing events and this leads to marked changes in floodplain patch characteristics; pioneer communities and early successional stages being most severely affected. This example illustrates the sensitivity of fluvial ecosystems to changes in the disturbance regime. In the Rhône, Rhine and Danube rivers it has been shown that human impacts change the types and effectiveness of the recovery processes so that system response may involve new successional directions. In some cases, transient states may persist for 100 years or more after an impact.

Box 2.2
Morphological relationships and responses in discharge and sediment loads

1. Morphological relationships

(from Chorley, Schumm & Sugden, 1984)

		Equation reference numbers
	Pool-riffle spacing = 2 $w = 5\text{-}7\ w$	
	$1 = 2 \times 2w = 12.34\ w$	**1.1**
	$P = 3.5\ F^{-0.27}$	**1.2**

2. Morphological responses

a. (after Schumm, 1969)

	$Q = (w\ d\ l)\ /\ S$	**1.3**
e.g.	$Q^{+} = w^{+}\ d^{+}\ l^{+}\ S^{-}$	
	$L = (w\ l\ S\ F)\ /\ (d\ P)$	**1.4**
e.g.	$L^{+} = w^{+}\ l^{+}\ S^{+}\ F^{+}\ d^{-}\ P^{-}$	
	$Q^{+}L^{-} = w^{\pm}\ L^{\pm}\ S^{-}\ F^{-}\ d^{+}\ P^{+}$	**1.5.1**
	$Q^{-}L^{+} = w\ \ S^{-}\ F^{+}\ d^{-}\ P^{-}$	**1.5.2**
	$Q^{-}L^{-} = w^{-}\ L^{-}\ S^{\pm}\ F^{-}\ d^{\pm}\ P^{+}$	**1.5.3**

b. (after Starkel, 1983) with reference to 1.5.3

$d^{+}\text{-------}Q^{-} < L^{-}$	**1.6.1**
$d^{+}\text{-------}Q^{-} > L^{-}$	**1.6.2**

Q = channel-forming discharge
L = bed-material load
W = channel width
D = channel depth
F = width/depth ratio
l = meander wavelength
P = sinuosity
S = slope
+/− = direction of change (+ = increase; − = decrease)

Note: Several authors have defined simple relationships between morphological variables, e.g. 1.1, 1.2. Such observations were used by Schumm (1969) to propose simple (1.3, 1.4) and complex (1.5) process-response equations which describe the predominant direction in which the dependent morphological variables change for different charges of discharge and bed-material load. Uncertainty in the direction of the response, e.g. $d\pm$ in 1.5.3, has been interpreted by Starkel (1983) as an indication of the dominant influence of one of the independent variables, e.g. 1.6.1, 1.6.2. Such relationships have been confirmed by studies of both paleohydrological changes and human impacts.

2.4
Rivers as corridors through landscapes

The case for considering river corridors in a catchment context is based on four key functions:

1. water-quality control;
2. instream habitat enhancement;
3. nature conservation;
4. recreation and amenity.

Functions 1 and 2 are most effective within the headwaters (Zone 1) whereas functions 3 and 4 offer opportunities for environmental enhancements throughout river networks.

2.4.1 River margins for water-quality control

In temperate rivers, it has been clearly demonstrated that riparian buffer zones, particularly those with organic-rich soils, provide an ecological service in that they significantly improve the quality of water passing from agricultural systems into the aquatic system. Buffer zones can reduce sediment-bound phosphorous and nitrogen to streams by 80-87 percent and groundwater nitrate inputs by more than 90 percent. Three primary processes are active in controlling water-quality in areas of semi-natural vegetation along river margins:

1. retention through interception of sediment-bound nutrients, pesticides and other contaminants transported by surface run-off, which is particularly important in the case of phosphorus;
2. uptake by vegetation or microbes of soluble nutrients – the primary process for nitrate removal;
3. absorption by organic and inorganic soil particles.

The effectiveness of buffer zones for water quality improvement is a function of flow path and buffer zone width.

2.4.2 Riparian zones to protect instream habitats

Riparian vegetation is especially important in determining instream habitats in the low-order (1-3) streams, providing shade, cover and organic debris (Figures 2.4 and 2.5). The input of particulate organic matter (mainly twigs and leaves) has been established as being particularly important for aquatic ecosystems: organic carbon being the most important fuel for running-water food webs. The provision of shade, regarding instream temperatures and limiting growth of macrophytes and

Figure 2.4
Effects of degradation of ecotones on fish diversity and productivity

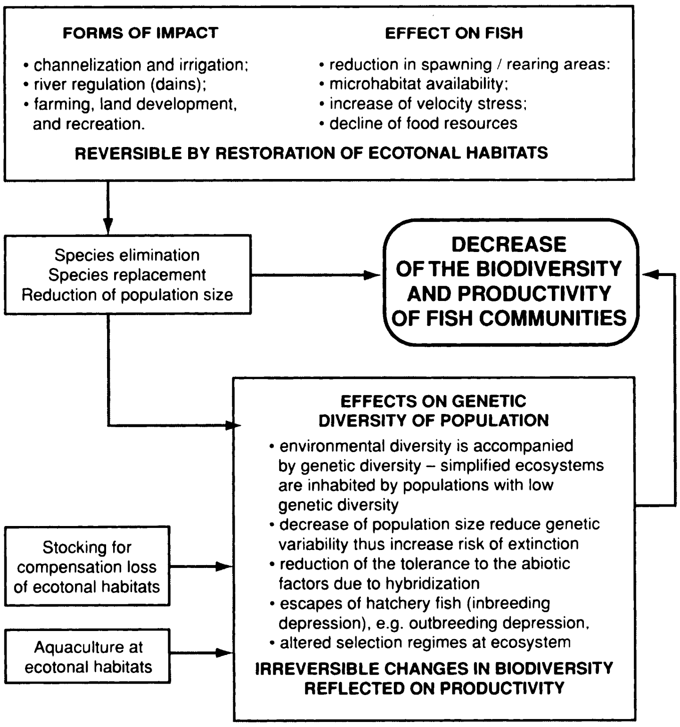
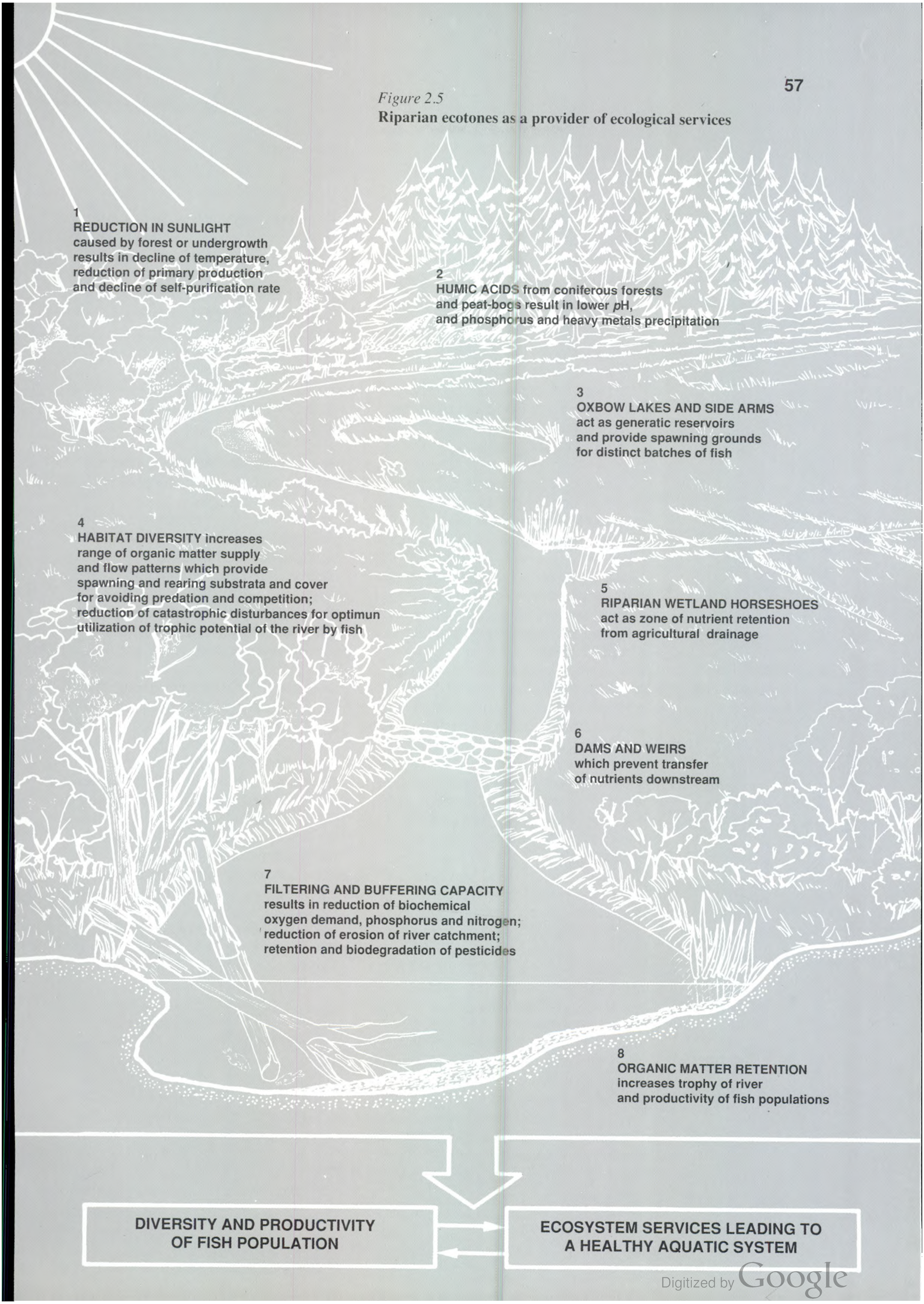


Figure 2.5

Riparian ecotones as a provider of ecological services



1
REDUCTION IN SUNLIGHT
caused by forest or undergrowth results in decline of temperature, reduction of primary production and decline of self-purification rate

2
HUMIC ACIDS from coniferous forests and peat-bogs result in lower *p*H, and phosphorus and heavy metals precipitation

3
OXBOW LAKES AND SIDE ARMS
act as generatic reservoirs and provide spawning grounds for distinct batches of fish

4
HABITAT DIVERSITY increases range of organic matter supply and flow patterns which provide spawning and rearing substrata and cover for avoiding predation and competition; reduction of catastrophic disturbances for optimun utilization of trophic potential of the river by fish

5
RIPARIAN WETLAND HORSESHOES
act as zone of nutrient retention from agricultural drainage

6
DAMS AND WEIRS
which prevent transfer of nutrients downstream

7
FILTERING AND BUFFERING CAPACITY
results in reduction of biochemical oxygen demand, phosphorus and nitrogen; reduction of erosion of river catchment; retention and biodegradation of pesticides

8
ORGANIC MATTER RETENTION
increases trophy of river and productivity of fish populations

DIVERSITY AND PRODUCTIVITY OF FISH POPULATION

ECOSYSTEM SERVICES LEADING TO A HEALTHY AQUATIC SYSTEM

algae, is also an important function of riparian vegetation.

The benefits and services provided by buffer zones in catchment management include provision of marginal cover, provision of food in the form of invertebrates, reduction of fine solid materials, reduction of the risk of chemical pollution, and reduction of the input of fertilizers.

The benefits and services provided by buffer zones in catchment management include:

- provision of marginal cover;
- provision of food in the form of invertebrates;
- reduction of fine solid materials;
- reduction of the risk of chemical pollution;
- reduction of the input of fertilizers.

In middle-order streams (4-6/Zone 2) where autotrophy prevails and the most diverse fish communities are found, the riparian zone is crucial to fish production.

There is accumulating evidence that, in addition to providing supplementary, primary and secondary production for fish populations, a diverse buffer zone of emergent macrophytes, herbs, shrubs and trees, creates shelter zones on the downwind side of the vegetation which hold local concentrations of aerial plankton from terrestrial sources across the floodplain. In some cases, fish eat more invertebrates than occur in a given stream. Directly, terrestrial insects provide up to 50 percent of the food of drift-feeding salmonids in some low trophy streams, but the amount varies seasonally.

River margins provide both important habitats and linear corridors of connectivity through the landscape.

Half of the riverine invertebrate community occurs on snags and, while species living in logs account for only 15 percent of the invertebrate production, they provide 80 percent of the drift and are important for most fish species in rivers. Thus, careful mapping of such features is essential because of their influence on the distribution of river channel erosion and deposition. These organic dam systems are prone to change on a short and long term basis, maintaining diversity within the system. Incautious removal of such dams on a large scale changes their effect on the routing of discharge, especially peak discharges, along the channel. This causes average velocities to be increased up to two or three times in lower reaches resulting in bank erosion and channel widening. An increase in channel width-depth ratio and the mobilization of considerable amounts of fine sediment occurs, reducing the diversity of instream habitats.

2.4.3 River margins for wildlife conservation

River margins provide both important habitats and linear corridors of connectivity through the landscape. The importance of the interaction between geomorphology and vegetation in floodplain environments for maintaining biotic diversity is well established. River margins are especially important for mammals, reptiles, amphibians and fish. They support some of the richest terrestrial vertebrate faunas and have high breeding bird densities. For example, the removal of riparian vegetation along the Sacramento River resulted in 95 percent fewer birds and 32 percent fewer species. Along large (Zone 3) rivers, especially those in the tropics with a predictable flood season, river margins are important for sustaining fish productivity. The ratio of bank length to surface area decreases exponentially downstream as the river widens but in non-channelized rivers with braided channels and in floodplain rivers it may increase again. Isolation of the floodplain considerably reduces the diversity of the essential component of large river systems.

2.5
Lateral connectivity

Lateral connectivity consists of three functional elements within the river and the floodplain (Figure 2.6) which play different but inter-linked roles in the ecology of the river system and are of importance to fisheries. These are:

1. a network of **channels** and lagoons connected to the river channel so that flood waters regularly enter and leave them – this represents an intermediate area between the main channel (**eupotamon**) and the floodplain, called **parapotamon**;
2. **water bodies** that connected with the main channel during floods (**pseudopotamon**) – flood waters frequently drain into such water bodies at drawdown and are of two types: a) shallow water bodies formed from river braids called **plesiopotamon;** and b) deeper water bodies from main channel cut-offs called **palaeopotamon**;
3. grass/herb rich **water meadows** or **wetland forest** that do not retain water during drawdown.

The temporarily flooded areas provide spawning and feeding refuges for many species and substantially improve yields following on good floods. Indeed there are extensive reports indicating strong positive correlations between catch, year class strength in fish populations and flood strength for most flood rivers. These arise principally from improved spawning success, survival and growth due to greater areas being inundated. The network of channels and backwaters serve as refuges for many species during flood conditions but also as a major habitat for a range of species.

2.6
Recreation and amenity

In river corridors two features particularly influence landscape quality: the existence of the land-water interface and its degree of naturalness. Diversity (patchiness) and nature conservation interests are also important. There are positive public attitudes towards preservation of multiple-use river corridor amenities, including wildlife habitat, riparian vegetation and open space. Thus, multi-purpose management functions have been advocated for riparian areas in lowland, urban and upland situations, stressing the aesthetic and recreational potential of such areas, as well as their role in water quality and erosion control.

Three functional elements within the river and floodplain are connected laterally.

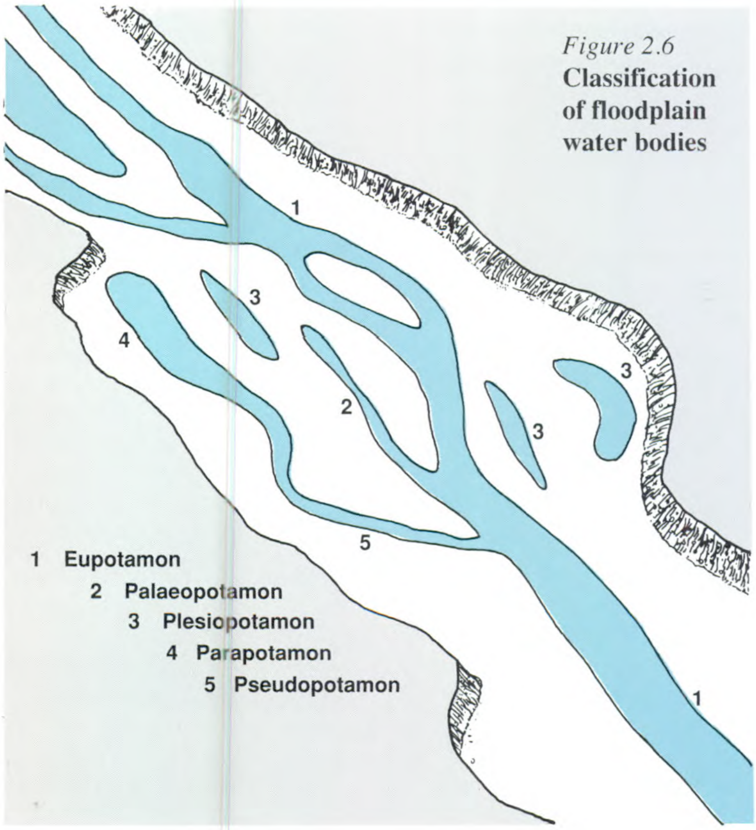


Figure 2.6
Classification of floodplain water bodies

▲
Flooded hardwood forests
are valuable spawning sites
▼

Chapter 3

Methods of habitat assessment

▲
Sampling large rivers
is often a difficult task
▼

3.1
Introduction

The four fundamental components which determine the productivity of any riverine habitat are:

1. the flow regime;
2. water quality;
3. the physical nature of the floodplain;
4. the energy budget, e.g. temperature, sediments, organic matter and nutrients, of the total diversity of plants and animals within the system.

The ways in which the magnitude of these factors are altered by human interference are discussed in Chapter 4. Habitat evaluation methods must attempt to quantify the interaction and relative importance of these four components. Until recently, assessment systems concentrated on defining instream flow needs by geomorphological and hydrological techniques. Systems involving fish populations were used in so far as they provide a basis for human use of the riverine habitat.

Subsequently, a more diverse assessment protocol has developed to take into account the total complexity of the system and includes invertebrates, plants and birds, as well as noting the importance of archaeological and landscape value.

Assessment techniques are varied and function at different levels of complexity. They can be put into two basic groups.

1. ***Rapid assessment techniques*** are based on an inventory of physical characteristics of the selected stream reach. These include a large number of factors that field workers have agreed are important in distinguishing between rivers, and which determine biological quality. This category can be further subdivided into checklist components, scoring systems and empirical model methods.
2. ***Biolological response techniques*** require a more detailed approach to develop relationships between habitat variables and biota. These use habitat suitability criteria for target species (indicator species and assemblages).

The following is an attempt to outline chief characteristics, aims and objectives, data requirements and potential uses for the different techniques. It is not intended to provide a definitive description of the techniques but act as guide to the most appropriate methods that can be used to provide the information for planning an appropriate rehabilitation proposal.

Rapid assessment techniques are based on an inventory of physical characteristics of the selected stream reach.

Biological response techniques require a more detailed approach to develop relationships between habitat variables and biota.

3.2

Rapid assessment techniques

Rapid assessment techniques are founded on the premise that the biological potential of a site is dependent on the quality of the habitat at that site.

Rapid assessment techniques are founded on the premise that the biological potential of a site is dependent on the quality of the habitat at that site. Inventory work is based on cross-sections located along a selected reach and takes account of instream habitat, channel morphology and structural features of the bank, riparian vegetation and near floodplain. Spacing of cross sections can be placed randomly (if resources allow a large sample), at regular intervals, above and below inputs, to describe the character of specific habitats such as riffles and pools or to define critical or limiting conditions. A minimum of five cross-sections is recommended for this approach. The problems with these assessment methods are: which attributes to measure, how to measure them and, in the case of scoring systems, how to transform scores into an index or rating system indicating habitat quality.

It is important to remember that there is an historical and developing vocabulary in the field and that a vast archive of data exists by which to establish time scales. For example, traditional methods for recording hydrological parameters such as "discharge as a fixed percentage of the Average Daily Flow (ADF)" or as a flow duration statistic, such as "the 95th percentile in setting minimum acceptable flows", are important for comparison with values obtained using newer techniques.

A 'fluvial auditing' approach can be used to classify and record the features of the channel and bordering slopes.

A 'fluvial auditing' approach can be used to classify and record the features of the channel and bordering slopes in any basin to emphasize the inputs and outputs of sediment and the trend of morphological change over the 'medium term' (10-100 years). The technique notes the location and dimensions of selected fluvial features, e.g. riffles and pools, and uses their type, density and distribution as part of the evidence for balance in the sediment system of the basin being assessed. As well as qualitative information, the assessment criteria require the collection of quantitative information, for example, width and depth ratios, in the same way as a plant or bird census may do. This technique was designed to classify and record the features of the channel and riparian zone during River Corridor Surveys. There is also a need for more geomorphological baseline data in parallel with standard engineering and River Corridor Surveys, with the detail of the survey tailored to meet the needs and nature of the management problem. Due recognition should be given to:

- establishing the morphology of the reach (cross-section, profile, plan), identifying natural control features, rock ledges/bars, as well as artificial structures such as weirs;
- establishing the nature, composition and stratification of the bed and bank sediment;
- establishing the nature of both bed- and bank-rooted vegetation;
- identifying flow conditions, location of zones of flow convergence (scour) and divergence (fill);
- relating flow processes to channel morphology;
- assessing the stability of the river using historical maps, aerial photograph sequences and previous surveys identifying areas of erosion and deposition;
- establishing the nature of floodplain morphology and sedimentary characteristics.

Such approaches need evaluation by a fluvial geomorphologist as there are no guidelines for a simple analysis of the data and their synthesis into a score or index.

3.3
Scoring and index systems

Data collection for this type of approach is similar to those for rapid assessment techniques but, by assigning a rating or score to the physical, chemical and biological characteristics present, a relative index of habitat quality is achieved. The habitat parameters which are evaluated to determine their increasing biological significance are weighted accordingly. The ratings are then totalled and compared to a reference to provide a final habitat ranking. Scores increase as habitat diversity and quality increases. To ensure consistency in the evaluation procedure, descriptions of physical parameters and their relative criteria are included in the rating form.

Rapid Bioassessment Protocols (RBPs) for use in streams and rivers are based on the evaluation of habitat parameters to provide an assessment of habitat quality.

Rapid Bioassessment Protocols (RBPs) for use in streams and rivers are based on the evaluation of various habitat parameters to provide an assessment of habitat quality. In this approach habitat parameters are separated into three principle categories: primary, secondary and tertiary. Primary parameters characterize the stream microhabitat such as bottom substrate, available cover, flow-velocity and depth regime. Because these are considered to be most important to the instream biota, they are given the widest score range. For example, in the case of fish, these would be resting, spawning, food producing and cover microhabitats. Hydraulic models coupled with these criteria have led to the development of the Instream Flow Incremental Methodology (IFIM), most widely used by the US Fish and Wildlife Service.

Secondary parameters measure the mesohabitat such as channel morphology, turbulence, channel alteration and sinuosity and are accorded a narrower score range. Tertiary parameters evaluate the reach with channel gradient, width/depth ratio, dominant particle size and landform, features which are given the least score range. These data are used in the Physical HABitat SIMulation Model (PHABSIM) to generate flow/habitat relationships (Section 3.5).

The Index of Biotic Integrity (IBI) uses a series of fish community attributes related to species composition and ecological structure to evaluate the quality of the aquatic community.

Another useful index is the Index of Biotic Integrity (IBI) which uses a series of fish community attributes related to species composition and ecological structure to evaluate the quality of the aquatic community. Twelve biological parameters are defined related to species composition and richness, trophic composition and fish abundance and condition. The value of each parameter for a degraded stream is compared with the value at a site located in a similar geographical region on a stream of similar size where human influences have been minimal. The total IBI score is calculated by summing the 12 values, giving a scale of scores from 12 (very poor) to 60 (excellent). The IBI attempts to incorporate professional judgement in a schematic and sound manner, and to set quantitative criteria that enable the determination of ecological quality of a fishery.

3.4
Empirical model methods

Linear and multiple regression models such as the Habitat Quality Index (HQI) have been developed to evaluate habitat.

Linear and multiple regression models have also been developed in habitat evaluation studies. These include many attributes which are strongly inter-related, thus careful selection of habitat attributes is necessary to minimize the problem of autocorrelation between variables. A second problem is the non-linearity between physical and biotic variables. This can be overcome by using a rating system, such as the Habitat Quality Index (HQI) based on two regression models that related eleven trout habitat variables representing food, shelter, streamflow variation and maximum summer stream temperature to trout biomass and density in streams. Each variable in the model is rated with respect to trout from zero (worst) to four (best) according to a rating schedule (Table 3.1). Unfortunately the HQI, and probably most empirical models that are created to predict biotic indices, such as trout density, may be useful only on a regional basis. Nevertheless, at the regional level, biomass and habitat measurements tend to be highly correlated when using scoring systems.

Quantification of habitat factors related to fish biomass is not well advanced in Europe, partly because other limiting factors in the stream environment mean that the index of habitat quality is considered to be not necessarily an index of fish abundance. In addition, 'probability-of-use relationships' are not well developed or do not correspond well to US data, which further supports the regional importance of developing scoring systems. Habitat evaluation methods (HABSCORE) have been developed for salmonid streams in Wales. Habitat information is recorded on a standard form and can be used to explain up to 90 percent of the variance in numbers of 10-20 cm trout in hard water streams, but is less effective for soft water streams. There is also a need to consider habitat features at both the site (mesohabitat/microhabitat) and catchment (macrohabitat/reach) level. The technique provides a useful starting point for stock assessment, particularly in terms of precision and cost. This approach is similar to the RBPs and HQI systems.

Probability-of-use curves have been described for riverine trout populations similar to those originally outlined in a discussion of Instream Flow Incremental Methodology. Water velocity, depth and substratum types are the key environmental variables for which separate curves are given for trout fry, juveniles and adults ('ecological species').

Empirical models to date have largely focused on salmonid habitat assessment. Although there is considerable literature on habitat requirements of coarse fish in rivers (Section 1.3), these refer largely to the macrohabitat (reach) and mesohabitat (channel morphology) level. This extensive information is mainly at the inventory stage (Figures 1.12 and 1.13) and scoring/indexing systems to support modelling approaches for coarse fish habitat assessment, and therefore provide better bases for coarse fisheries rehabilitation and management, will probably be available in the near future.

Empirical models for habitat classification and assessment of riverine habitat other than for fish do exist and are referred to in some measure in Section 3.6. The Trent Biotic Index (TBI) and the Biological Monitoring Working (BMWP)

Table 3.1
Trout habitat variables used in Habitat Quality Index

	Definition of variable and associated score				
Variable	0	1	2	3	4
Late summer flow index[1]	< 0.1	0.1-0.15	0.16-0.25	0.26-0.55	> 0.55
Annual flow variation	Intermittent flow	Seldom dry, extreme fluctuation, base flow very limited	Never dry, moderate fluctuation base flow 2/3 of channel	Small fluctuation, stable base flow in most of channel	Little or no fluctuation
Maximun summer temp. (°C)	< 6; > 26.4	6-8; 24.2-26.3	8.1-10.3; 21.5-24.5	10.4-12.5; 18.7-21.4	12.6-18.6
Nitrate (mg/l)	< 0.01; > 2.0	0.01-0.04 0.91-2.0	0.05-0.09; 0.51-0.9	0.1-0.14; 0.26-0.5	0.15-0.25
Benthic invertebrate density (no/m_2)	< 2,550	2,551-9,950	9,951-24,950	24,951 - 500,000	> 500,000
Benthic invertebrate diversity	< 0.80	0.80-1.19	1.20-1.89	1.90-3.99	> 3.99
Shelter (%)	< 10	10-25	26-40	41-55	> 55
Eroding banks (%)	75-100	50-74	25-49	10-24	0-9
Submerged aquatic vegetation	Lacking	Little	Occasional patches	Frequent patches	Well developed and abundant
Water velocity (cm/s)	< 8; > 122	8-15.4; 106.6-122	15.5-30.3; 91.4-106.5	30.4-45.5; 76.1-91.3	45.6-76
Stream width (m)	< 0.6; > 46	0.6-2; 23-46	2.1-3.5; 15.1-22.9	3.6-5.3; 6.7-15	5.4-6.6

[1] Late summer flow index is defined as the following ratio: mean yearly flow/mean flow during August and first half of September

scoring systems are examples, and although they are scoring for water quality, they do take account of physical habitat conditions as the samples must be taken from, and be representative of, a riffle/pool habitat.

A classification of sites based on assessment of invertebrate assemblages has also been developed in the UK as part of its computer software package called RIVPACS (River Invertebrate Prediction and Classification System). RIVPACS is used to assess water quality in rivers. These techniques have value in assessing habitat diversity, for example, pool-riffle sequences, and have merit in habitat assessment in fisheries improvement work.

Another approach to riverine habitat assessment is by River Corridor Surveys. This system, defined for nature conservation, is of major importance to fisheries as it records channel features, substrates, channel vegetation, channel cross section data, bank vegetation and structural features, vegetation and floodplain features, adjacent land and land-use features usually up to 50 m from the river bank on both sides. Usually 500-m sections are described. Riparian ecotone and buffer zone vegetation are recorded carefully down to individual trees with precise locations. Quantification of data and scoring/index data from selected sites is relatively easy and a desirable next step within overall assessment related to rehabilitation, conservation and enhancement schemes.

River corridor surveys record channel and riparian features to assess diversity.

3.5

Biological response techniques

The Instream Flow Incremental Methodology (IFIM) uses habitat suitability criteria to develop relationships between habitat variables and fish.

The Instream Flow Service Group (US Fish and Wildlife Service) recognized the need to incorporate demands of particular instream uses and developed the Instream Flow Incremental Methodology (IFIM) using habitat suitability criteria for target species to develop relationships between habitat variables and fish. It is one of the most widely used methods in North America for estimating the changes in flow on trout habitat and is gaining acceptance in Europe.

Field measurements of water depth, velocity, substrate composition and cover at calibration flows are taken to enable the suitability for a particular species to be described. Incremental changes in flow are then examined to predict the corresponding effect on availability of suitable microhabitat over the full range of flows using PHABSIM. The PHABSIM system is a set of computer models that are the cornerstone of the IFIM. The underlying principles of PHABSIM are:

- the chosen species exhibits preferences within a range of habitat conditions that it can tolerate;
- these ranges can be defined for each species;
- the area of stream providing these conditions can be quantified as a function of discharge and channel structure.

PHABSIM uses mechanistic suitability index curves from Habitat Suitability Index models which are closely related to stream hydraulics and channel structure, such as velocity, depth, substrate and cover, for each life stage of each fish species. These give the frequency with which values of habitat variables are used by individual species. The instream flow SI graphs are based on the literature, professional judgment, laboratory studies or field observations.

The outputs from PHABSIM are a measure of physical microhabitat availability as a function of discharge and channel structure for each set of habitat suitability criteria (SI) curves entered into the model.

The PHABSIM procedure contains the following primary components:

- physical measurements of depth, velocity, substrate and cover within the stream reach;
- computer simulation of the stream hydraulics at different discharges;
- determination of a composite probability of use from the suitability value for each combination of depth, velocity and substrate found within the stream reach, for each species and life stage;
- the calculation of 'weighted usable area' (WUA) for each stream flow, species and life stage for each season.

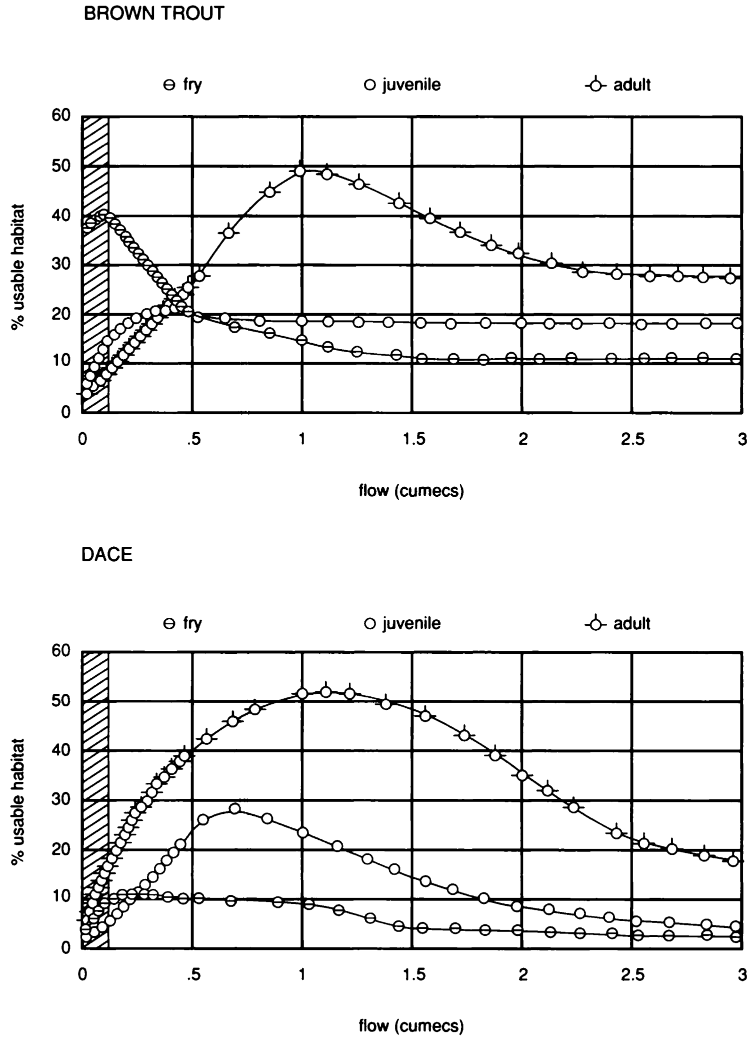
PHABSIM can be used to:

- help formulate instream flow recommendations;
- assess the effects of altered stream flow regimes;
- evaluate habitat improvement projects, mitigation proposals and fish stocking programmes; and
- assist in regulating releases from existing water storage projects.

Evaluation of PHABSIM has also shown that several assumptions are violated in its application and that fish populations do not always respond to changes in the WUA; much debate on the ability of PHABSIM to assess changes in standing crop of fishes due to changes in flow regime has resulted. However, it must be emphasized that predictions of PHABSIM are explicitly made in terms of changes to ***the physical properties*** of the aquatic habitat (velocity, depth, substrate) and ***do not predict biomass of organisms***, for example, of changes in fish. Failure to recognize this has led to criticism when PHABSIM results were applied and interpreted without reference to other factors such as water quality, temperature, food availability and fish mortality.

This approach has been successfully adopted to assess the impact of low flows and for appraisal of an interbasin transfer scheme on habitat availability within the River Glen catchment, Lincolnshire, UK. Figure 3.1 gives an example of discharge versus habitat availability relationships for two target species, brown trout (*Salmo trutta*) and dace (*Leuciscus leuciscus*). Analysis of the results highlighted the geomorphological limitations of selected reaches and enabled recommendations to be suggested for improving habitat quality.

Figure 3.1
Curves developed using PHABSIM for brown trout and dace – West Glen, UK



3.6
Classification of aquatic habitats

Fluvial systems are now recognized as ecological systems in their own right, but their classification is still in a formative stage.

There is a long history of organizing information and classification of biological and ecological systems so that understanding can be advanced and management principles and practice can be developed. Fluvial systems are now recognized as ecological systems in their own right, but their classification is still in a formative stage because of the dynamic changes that occur over broad spatial and temporal scales, and classification systems only reflect the current state of knowledge on river function. Most attention remains focused on conceptual and regional approaches to stream classification rather than on general approaches across contrasting ecoregions, indicating a vexation in some workers at the lack of a globally effective stream classification system when attempting to develop and apply conservation management over broad geographic areas. It could be argued that such a quest is of academic merit only and that, because of the inherent complex characteristics within each stream type (system structure, biogeochemistry, resistance and resilience to change and productivity) which are related to local climate, geology, disturbance due to cultural, demographic, economic and political regimes, the conceptual and regional approach is the realistic one by which assessment of conservation and fisheries potential can be translated into management prescriptions and application.

Fish have formed the basis for stream classification systems for biological, economic and political reasons.

Classifications coupling biological and physico-chemical features at the catchment level within the eco-region have practical value in assessing the conservation potential of rivers, and implicit in this the needs and potential of fisheries are included.

Individual organisms and assemblages act as biological indicators of habitat quality by actively selecting and market testing the available resources, macro- and microhabitats, for which they are peculiarly adapted. Most traditional classification systems were based on fish or invertebrate assemblages. More recently, systems have been based on patterns of riparian vegetation and aquatic plants. All biotic classification schemes assume a predictable relationship between the stream biota and geomorphological and hydrological controlling factors acting on the system.

3.6.1 Fish community classification

Fish have formed the basis for stream classification systems for biological, economic and political reasons. Because fish are presumed to be at the top of the food chain, and because of their commercial, recreational and conservation value, it can be argued that they best represent the general ecological and resource conditions of rivers. Fisheries managers, scientists and national resource agencies have the growing responsibility of identifying fish communities and their ecological requirements, and designing ways of maintaining their integrity in the face of continued habitat deterioration. Despite the merits of this type of classification, there are limitations that may impede widespread application (Box 3.1). Individual species can show high yearly variability in production apparently independent of physical habitat conditions.

Ultimately, zoogeographic factors restrict the geographic scope of classification schemes based on fish assemblages. However, many other factors affect

Box 3.1
Advantages and disadvantages of using fish populations and communities for stream classification

Advantages
- relationships between community function and habitat quality
- predictable response to habitat change
- community attributes are integrators of local and upstream habitat quality
- species are indicators of stream function, e.g. trophic guilds
- coupling of biotic resources to physical habitat

Disadvantages
- variability in species composition across zoogeographic regions
- structure can vary between drainages due to differences in biotic, e.g. competition – recruitment, and abiotic, e.g. flow, controls
- intensive sampling effort often required; difficulty in quantitatively sampling large rivers

community dynamics and limit geographical scope. Environmental regimes vary with climate and geology, regional variations from predictable to highly variable flow patterns, producing persistent, resilient communities, to those which show sharp temporal fluctuations in structure. In streams where competition and predation are important, shifts in physico-chemical conditions can alter intensity and direction of competitive and predator-prey interactions.

3.6.2 Invertebrate community classification

Classification schemes based on benthic invertebrate communities coupled with physico-chemical stream features are important tools in assessing river quality and disturbance. Sites with greatest habitat diversity have greatest conservation value with parameters, of altitude, width, pH, and water hardness, interacting vigorously, and with strong correlation shown to a fisheries resource value. These approaches in organizing species into meaningful trophic guilds also relate to changes in assemblages along the river continuum from the headwaters to the mouth (Figure 2.1) and of the relative contribution of externally and internally derived energy sources and longitudinal gradients in channel form.

Classification schemes based on benthic invertebrate communities are important tools in assessing river quality and disturbance.

3.6.3 Plant classification

Riparian vegetation patterns have been developed in the USA because of their considerable importance as active boundaries at the interface (ecotone) of land and aquatic systems and their potential as sensitive indicators of environmental vitality and change. They play an important role in the ecology of stream fish and invertebrates as food sources and shelter (Section 1.4).

Riparian vegetation patterns play an important role in the ecology of stream fish and invertebrates as food sources and shelter.

3.7

Fisheries potential based on stream classification

Although the number and diversity of classification systems for streams is large, there is a developing consensus on the attributes of a classification system.

Although the number and diversity of classification systems for streams is large, there is a developing consensus on the fundamental attributes of an enduring classification system. These relate to broad temporal and spatial scales; the integration of structural and functional characteristics under various disturbance regimes; and the conveyance of information on underlying mechanisms affecting instream features. It is important to accomplish this at relatively low cost and communicate findings at a high level of understanding among planners, water resource managers, fisheries and angling organizations, conservation agencies, recreational water users, and catchment users such as agriculture, forestry, industrial and urban complexes.

Other approaches to the estimation of fisheries potential are based on simple regressions of fish yield against geographical and physical parameters. These have been developed mainly in tropical systems in Africa, Asia and Latin America but all indications suggest that temperate rivers behave in a similar manner.

3.7.1 Correlations with floodplain area

Catches from rivers with large active floodplains generally lie between 50 and 80 kg/ha. Very large floodplains may produce less than this due to the incomplete penetration of river floodwaters to the edges of the plain. Indications from European river retaining floodplains such as the Danube suggest that yields from such systems were about 40 kg/ha.

3.7.2 Correlations with river length

Catches from all rivers rise with the distance from the source. Ideally this should be some function of the square of the distance and in Africa has been calculated at:

$$C = 0.03L^{1.98}$$

This equation can be used to generate the expected yield per kilometre of river at different distances from the source as follows:

$$Catch_{kmy} = 0.064y^{0.95}$$

3.7.3 Correlations with basin area

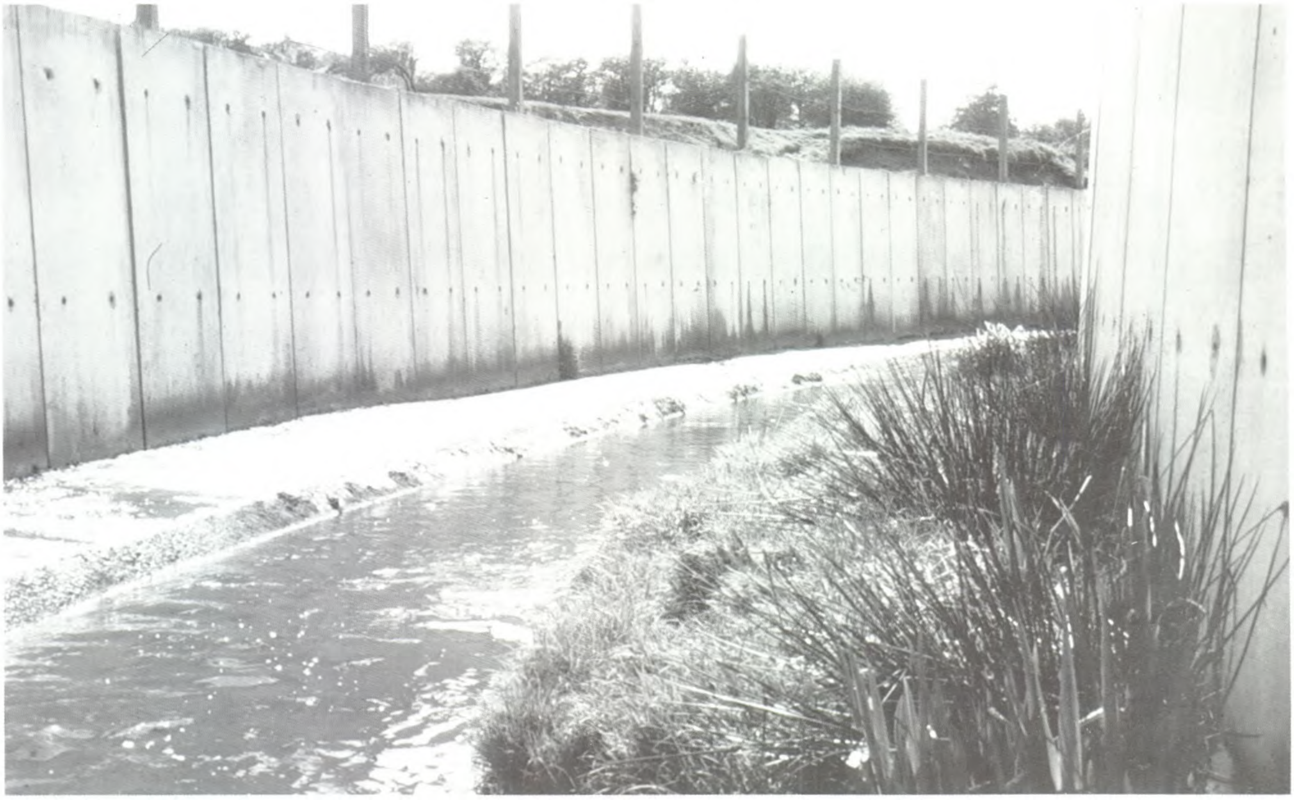
The length of the longest channel of a river is strongly correlated with the basin area and there is, therefore a strong correlation between basin area and catch:

$$C = 0.03A^{0.97}$$

Clearly regressions of this type represent the mean of many rivers and variance is high. Estimations made using them are of little use for direct management of individual rivers but do provide a level of information sufficient for planning at a more general level.

Chapter 4

Impact of man's activities on aquatic habitats



▲
Rivers can be reduced
to encased concrete channels

An example of the featureless bank
structure of a fully channelized river
▼

About 77 percent of rivers in North America, Europe and the former Soviet Union are considered as severely modified.

4.1
Introduction

In the consideration of the basic processes that control the natural production of fish and fisheries potential of water bodies, the direct effect of man's activities have been largely ignored. In the long history of man's intervention on aquatic resources there are now few areas in the world untouched by man-made environmental changes.
About 77 percent of rivers in North America, Europe and the former Soviet Union are considered as severely modified. Even the 'virgin' wilderness areas of the polar regions, the Americas or tropical Africa are subject to such phenomena as acid rain, rising carbon dioxide concentrations, suppression of the high altitude ozone layer and deposition of persistent pesticides – all of these deriving directly from man's activities. In practice, it must be accepted that these man-made environmental changes are a part of the 'natural' ecosystem, as they tend to be generalized in their effects and outside local control.

There are, however, many effects of man's activities within river catchments which can be controlled. It is convenient to consider two types of impact under the general idea of water 'use'.

Indirect impacts are those where the waters are not used directly but, due to the accumulative nature of drainage basins, will have an effect on associated water bodies and an important impact on any fisheries interests. It is necessary to emphasize these impacts because they are likely to be overlooked, or downgraded in importance when water masses are considered from the standpoint of the engineer or administrator responsible for defining priorities for use.

Direct impacts are those resulting from interventions in the river channel or on its floodplain.

Indirect impacts are those where the waters are not used directly. Direct impacts are those resulting from interventions in the river channel or on its floodplain.

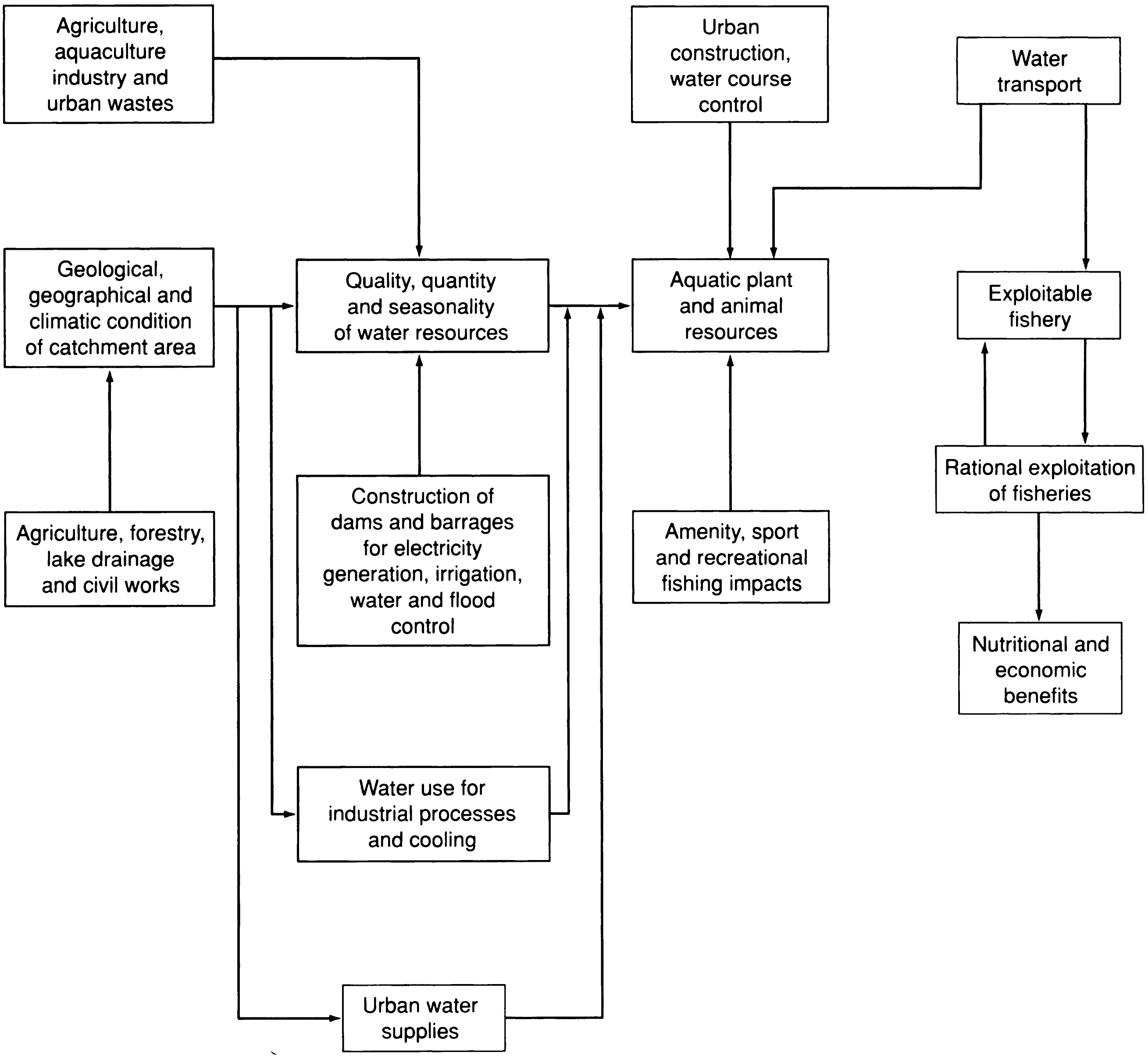
Box 4.1 and Figure 4.1 summarize the effects of users on different parts of the riverine habitat. It can be seen that both the stream and wetland environment are the most vulnerable to changes brought about by user impacts. This vulnerability is a direct reflection of the relatively small volume of water that makes up these systems.

Box 4.1
Relative vulnerability of ecosystems to user impact

	Impact	Streams	Rivers	Lakes	Wetlands
A. Indirect	1. Agriculture and forestry	++	++	++	++++
	2. Civil works	++++	++	+	++++
	3. Extraction industries	++++	++	+	++
	4. Manufacturing industry	++++	++++	++	+++
	5. Urbanization	++++	+++	++	+
B. Direct	1. Dams and barrages	+	++++	++	++
	2. Land drainage	+++	+	+	++++
	3. Industrial and urban use	+	+	+	+
	4. Recreation and transport	+	+	+	++

Note: + = intensity of effect

Figure 4.1
Multi-user impacts on water resources



4.2
Indirec

al
vities

pact of agricultural activities rn so-called ‘non-point source’ pollution. This is the diffuse discharge of dissolved and suspended materials in run-off or seepage drainage waters. Such discharges occur with drainage from unmodified catchments but may be greatly increased where the land is cultivated or is used for animal husbandry and forestry (Table 4.1). Typically this input is intermittent in its intensity and will depend particularly upon the rainfall pattern and the seasonal cycle of agricultural inputs. The effects may be reduced by efficient land management and conservation measures.

Other agriculture-generated wastes, such as wastes from intensive animal husbandry operations, silage liquor and vegetable washings, may also enter the drainage system as direct discharges of the pollutant.

Apart from the actual discharge of materials which alters the composition of the receiving waters, bad soil conservation practices, in particular deforestation and the drainage of wetland areas that may act as a buffer water reservoir, can lead to changes in the flow regime and physical pattern of drainage within a catchment.

Under particular patterns of rainfall and drainage, the soils of some forest areas (particularly conifer plantations) produce a highly acidic run-off with detrimental effects on the fish populations of the receiving waters.

The major effects of these agricultural activities are:

Nutrients: The fishery may benefit when increased concentrations of nutrients lead to increased levels of production, although shifts in species composition may follow sustained eutrophication. When the nutrient load is too high, excessive primary production and plant growth may lead to reduced production and loss of fish throughout periods of lethally low dissolved oxygen concentrations.

The major impact of agricultural activities comes from ‘non-point source’ pollution.

Suspended solids: Turbidity due to the carriage of silt in the water mass may physically block out light from the water column. This will reduce the ability of the plants to photosynthesize and thus lower the levels of primary production. Silt in the water may also create conditions that will cause stress and perhaps death of fish. The settlement of suspended solids in areas where water flow decreases will affect the physical conditions of the stream bed configuration. This may change the pattern of water courses, and bury spawning and feeding areas to the detriment of the fish production.

Toxic materials: Pesticides can be leached from the soils or washed off vegetation and thus pass into the drainage waters and directly kill or severely reduce plant and animal life. Badly applied pesticides can enter the waters directly as spray drift or from the washing of spraying gear and storage tanks.

Deforestation in the basin and poor forestry practice have been shown to lead to river habitat destruction.

Deforestation in the basin and poor forestry practice have been shown to lead to river habitat destruction and

Table 4.1
Effects of human interventions in river basins on the aquatic environment, flora and fauna

e	Effect on aquatic fauna	ent
	Depletion of populations of riverine fish.	fi rec. be a
ervoir	Depletion of populations of riverine fish.	Introductic species, bio. better adaptec growth and reproduction in the reservoir environment.
	The effects of drawdown and refilling destroy aquatic vegetation and fish breeding areas.	Stocking with young fish where recruitment is seen to be a limiting factor.
ects	Loss of thermal cues, and reduction in growth potential and reproductive potential of aquatic organisms.	Mixing of surface water with hypolimnial water to minimize shifts in temperature regime.
al	Interferes with lateral nutrient interchanges reduces overall productivity of aquatic and terrestrial systems.	
eral ation es	Denies fish access to floodplains and side arms of river.	Install in-stream structures to create artificial breeding environments.
	Selective disappearance of obligate floodplain spawners.	
	General loss of habitat diversity.	Install artificial in-stream habitat structures.
el	Removes habitats such as secondary channels, dead arms etc. changing nutrient dynamics and removes habitat for breeding, feeding and refuge; reduces numbers and biomass of food organisms.	Reinstate river habitats.

Intervention	Nature of change	Effect aquati
Channelization, continued	Increases flow rate in channel.	Young suitab colon conse rheop speci
Revetment of banks and channel bottoms	Blocks vertical connectivity.	Block wate betw bott
Dredging and gravel extraction	Excavates channel bed and isolates channel from floodplain. Install artificial in-stream habitat structures. Reinstate river habitats.	Pre floo Inc se int nu m in m a D p f
Deforestation in basin	Increases in silt loading leading to changes in channel and floodplain morphology. Increases amplitude between high and low water discharges, may lead to desiccation of portions of river channel. Point source pollution.	I

modifications in discharge regimes and seston flows. This causes increases in silt loading to the river from elevated erosion due to felling, timber extraction, logging-road construction, particularly where 'clear-cut' techniques are employed, and cause changes in channel and floodplain morphology. Habitat and community diversity decreases, log and debris dams proliferate altering flow regimes in some instances with loss of food organisms and choking of spawning substrates for psammophil and lithophil fish species.

> *The construction of dams, bridges, roads and their associated earthworks and quarries can have devastating effects on natural aquatic ecosystems.*

On catchment slopes, deforestation affects water, topsoil and nutrient conservation; run-off is decanted straight into stream channels and flood peaks become higher and shorter. Water conservation and slower release of water to streams is lost and lower dry season flows combine to produce adverse conditions for some fish species which require a smoother transition from one phase to another. Anadromous species are particularly badly affected.

4.2.2 Civil construction works

The construction of dams, bridges, roads and their associated earthworks and quarries can have devastating effects on the natural aquatic ecosystems of the area. The final result of the construction work may be an element in the shared use of a water resource - typically a dam - but here the concern is mainly with the violent and relatively short period of the construction phase and the long-term effects that result from it.

> *Mining for ores and coal, and extraction of sands and gravel contribute to aquatic habitat degradation.*

The primary problem is the disturbance due to the movement of large amounts of solid materials and the exposure of soils to erosion and dispersal by wind, water and mechanical machinery. This will be particularly important at times of intense rainfall and can lead to drastic changes in the topography of the rising waters and the condition of the substrate. The debris (e.g. from pieces of rock to fine silt) may block waterways and drainage channels. Near to the construction site these may be devoid of life. Excavation and earth movement may also uncover areas of toxic materials (e.g. lead and copper compounds) which may then be flushed into the water courses.

4.2.3 Extraction industries

Mining for metal ores and coal, and the extraction of sands and gravel for the construction industry use available water resources directly in the industrial process itself, for cooling, prevention of dust, hydraulic jet extraction and in the treatment of the ores. In addition to this direct use, there is the indirect interference in the drainage patterns and the discharge of water pumped out of the mine workings.

The major effects of these conditions (Table 4.1) are:

Acid discharges: The change in the *p*H of natural waters towards *p*H values 4 or below tends to create an aquatic environment with reduced numbers of species and a lowered level of production. In part this low production is brought about by the acid environment creating conditions where the nutrients present are not so readily available to the plants. The natural reduction in levels of acidity by mixing with waters of higher pH levels, or by exposure to the daily cycle of pH changes in a highly productive environment, causes the deposition of the hydroxide flocs and the smothering of substrate to the disadvantage of the plants and animals.

Toxic salts: These tend to be the salts of the heavy metals which are particularly prevalent in the mine water discharge and mine waste drainage. Where concentrations are high enough they may be directly toxic to the fish or the fish food organisms. This toxicity may be acute and lead to rapid fish death, or sub-lethal causing stunted growth and a low level of production. Heavy metals may persist in the environment and build up to high concentrations in some animals and