INLAND FISHERIES

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Summary

Fishing in inland waters is an ancient human occupation, which is increasingly under threat from overexploitation and the impacts of other users of water on the resource. Inland waters are distributed over the world as rivers, lakes, and coastal lagoons. More recently, man-made reservoirs and dams have added to the stock of waterbodies available for fisheries. The fisheries ecology of these various types of water vary considerably according to their physical, chemical, and morphological characteristics. They fish faunas whose complexity is related to the size of the waterbody and its geographical location. These faunas form distinct communities. In lakes, the pelagic community occupies the surface, open waters and the demersal community occupies the inshore and bottom waters. In rivers, the community structure is related to the strategies fish adopt to deal with the differing flow and hydro-chemical conditions throughout the year. Inland fish stocks are exploited for food, ornamental, and recreational fisheries although, increasingly, conservationist attitudes are orienting fishery management towards aesthetic goals.

There are several kinds of fisherfolk according to their degree of dependence on the fishery for food and income. They range from professionals who are totally committed to the fishery as a way of life to recreational fishermen whose material dependence is minimal. Different fisheries are directed at the various types of water body. In lakes, specific fisheries are directed at pelagic and demersal communities and in rivers the pattern of fishing changes according to flood phase. The potential yield of inland fisheries has been related to various factors including measures of richness of the water and morphology. Currently morphological measures have been elaborated for most types of waterbody. Inland fisheries are particularly sensitive to environmental impacts from other users of the water. Management strategies now have to be closely integrated into the general usage of the basin and also should include fisher communities in decision-making and enforcement.

1. Introduction

Fishing in the inland waters of the world is among the most ancient practices of mankind and has continued to provide a major source of animal protein to the present day. Fishing has often been the exclusive right of specific groups but in many areas of the world it attracts the poorer and often landless elements of the community. It is used as a major source of income to many but also serves to supplement diets and incomes through seasonal activities, which are an alternative to other occupations. For this reason inland fisheries have come to be viewed by policy makers as an occupation of last resort and a sort of poor cousin to agriculture. Inland waters are distributed widely over the continents and thus represent a source of animal protein from fish in areas far

removed from the sea. As there is a high demand for fish, most inland fisheries are now exploited at a high level and heavy fishing impacts their stocks. In addition, fresh water is becoming scarce in many areas of the world, and its use for a range of purposes other than fishing is degrading the natural resource base supporting the fishery. This section explores these issues in more detail and is supplemented by a series of more detailed articles on particular problems and groups of species.

2. Types of Inland Water

Inland waters are distributed throughout the continents and are represented everywhere except in the main desert areas. A number of schemes have been devised to classify inland waters but the most basic is into standing waters (lakes, and swamps) and running waters (rivers). Some systems (reservoirs and coastal lagoons) are intermediate between the two. The complexity and richness of the fish stock depends on the type of water body. The fishery in its turn depends on the nature of the fish stock and its response to fishing as well as to the accessibility of the waterbody and the ease with which it can be fished.

2.1 Lakes

Lakes are bodies of water enclosed by land. They can be regarded as relatively closed systems as most of their hydrology is internal. Their connectivity with other systems is limited, although they may have substantial inflowing and outflowing rivers. They range in size from the very large, the Caspian Sea for instance covers 371,795 square kilometers, to small ponds of a few hectares. Their depth varies from 1742 meters (Lake Baikal) to less than a meter.

Lakes may be classified according to their origin and include categories such as glacial lakes, rift valley lakes, depression lakes, river lakes etc. They may also be classified by their richness into oligotrophic (nutrient poor), mesotrophic (balance nutrient status), or eutrophic (nutrient enriched). Very often there are connections between origin and the richness of the water body.

Glacial lakes, which are found throughout the cold temperate zones where ice sheets during the last glaciation scoured depressions out of the underlying rock. The most extensive series of lakes of this type are the Great Lakes of North America. Others cover much of the Northern United States, Canada, Scandinavia and Northern Russia. Glaciation also produced long lakes at the lower end of valleys in all the major temperate mountain ranges. Such lakes frequently appear in sets or districts such as the alpine lakes of Central Europe, and the lakes of New Zealand, Southern Chile and Argentina. Lakes from glacial origins are usually oligotrophic because the rocks underlying the basin tend to be granitic.

Rift valley lakes are found along the great fault lines. Lakes such as Baikal and Balkhash in Russia or the East African Great Lakes are usually deep and mesotrophic. They also stratify thermally for much of the year producing seasonal fluctuations in the abundance of nutrients, phytoplankton, and zooplankton.

Depression lakes are often small and shallow, but may also reach great sizes such as Lakes Chad and Victoria in Africa. They tend to be eutrophic, as they are often associated with fertile plains.

River lakes may either be floodplain lakes, in which case they are integral parts of the river system (see under 2.2), or endorheic lakes associate with depressions. Endorheic lakes have an internal drainage and do not discharge to the sea. As a result, they become highly saline over time and often do not support fish.

2.2 Rivers

Rivers are linear features of the landscape that transfer the water falling on the land to the sea. As such they are open systems with considerable connectivity. They have a hierarchical structure ranging from small headwater streams to large rivers. This hierarchy is closely linked to gradient, as headwater streams tend to be located in high gradient uplands, whereas larger rivers are found on low gradient plains. River structure varies with gradient and flow. High gradient streams tend to be segmented into pool and rapids reaches with very coarse sediments.

They are generally erosional features whose beds are being actively excavated transferring sediments downstream. Intermediate gradients support braided reaches in which the river breaks up into numerous anastomosing channels. Sediments here are usually fine gravel or sand deposited on the numerous islands, although a highly erosional component remains whereby the finer sediments are transported further downstream. Low gradient, plains rivers usually consist of two components: The main channel or channels which retain water throughout the year and; the floodplain which is a complex of seasonally flooded land interspersed with permanent lakes. There is usually a single channel although this may break up into anabranches in the form of internal deltas. The main channel meanders over the floodplain and is often unstable. Sediments at this level are usually fine mud and silt deposited on the plain to form features such as levees, scrolls and point bars.

Two main nutrient flows are found in rivers:

- Firstly there is a longitudinal transfer of coarse organic material and dissolved nutrients washed into the river channel from the surrounding basin. This material forms the basis for all upstream productivity and degrades as it proceeds downstream through the activities of a characteristic succession of invertebrates that feed on the material. The River Continuum Concept describes this process.
- Secondly there is a lateral transfer of water onto the plains that brings some nutrient laden silt. At the same time there is a release of locally generated material originating from decaying vegetation, dung, and other deposits on the floodplain. This seasonal enrichment of the floodwaters favors the growth of vegetation on the plain and forms the basis for the explosion of fish production during the floods. During the dry season the same resource is used as the basis for agriculture. The Flood Pulse Concept describes this process.

2.3 Swamps, Marshes and Rice Fields

Swamps, marshes, and flooded agriculture are often associated with rivers as extensions of their flooded area. Many of the world's greatest wetlands are riverine features either as internal or terminal deltas. In some cases large swamp areas may also be associated with depression lakes or exist as independent features of the landscape. Irrigated agriculture, particularly for rice, increases the area of seasonally flooded land and provides potential areas for colonization by fish.

2.4 Reservoirs

Impoundment of streams and rivers has created vast numbers of artificial water bodies worldwide. These are mostly small, taking the form of dams for agriculture, flood control, small-scale power generation, and drinking water supply. Larger, sometimes very large, reservoirs are also a feature of many large river systems. Reservoirs combine many of the features of lakes and rivers. Water transit times are generally short so the nutrient cycle is very much associated with river inputs. Marked seasonality and year-to-year variations in production have been observed in reservoirs as large as Kariba (5364 km^2). At the same time the lower end of the reservoir may be sufficiently deep for stratification to occur. In general reservoirs are regarded as having a lucustrine part near the dam and a riverine portion at the upstream end.

2.5 Coastal Lagoons

Coastal lagoons take the form of lakes separated from the sea by sandbars and often associated with river estuaries or coastal deltas. They are usually shallow and may be permanently or episodically connected to the sea through a channel. They generally show great seasonal variation in salinity being fed from associated freshwater rivers for part of the year and from the sea for the remainder.

3. Fisheries Ecology

The fisheries ecology of inland waters is very different for lakes and reservoirs, rivers and coastal lagoons and each of these environments will be described separately.

3.1 Lakes

The number of species forming the populations of lakes is linked to lake area. For example, a sample of over 160 tropical lakes and reservoirs gave a log-log relationship Number of species = 5.9 Lake area$^{0.2684}$ which had an r^2 of 3.7. The high degree of variability arises because the number of species in lakes of any given area also depends on latitude, altitude, and the trophic and morphological nature of the lake.

Fish in lakes are generally divided into two main communities:

Demersal communities have numerous species adapted to the large range of habitats found along the shores and near the bottom. Many different communities may be

associated with different substrates such as rock reefs, sandy shore, muddy bays etc. Species in these areas feed on a wide range of foods ranging from benthic muds, benthic organisms, plants, and other organisms attached to rocks and other substrates as well as other fish (see chapter *Warm Water Fish: the Carp Family* for a discussion of the carps and chapter *The Tilapia Family: Environmental and Social Aspects of Reproduction and Growth* for tilapias). Demersal species show a range of breeding habit often with advanced systems of parental care such as nest building or mouth brooding.

Pelagic communities, found at the surface in the open water, usually consist of far fewer species but are greater in total biomass. Trophic habits are much more restricted being confined to zoo- and phyto-plankton and other fish (see chapter *Coldwater Fish: Whitefish and Smelt* for discussion of the lacustrine whitefishes for example). Breeding tends to be confined to egg-scattering although some species migrate inshore to spawn. In smaller lakes, the differences in the use of the water column between demersal and pelagic fishes is less but stratification among species still exists.

Lakes are generally chemically and physically stable environments on a year-to-year basis but may undergo considerable seasonal change within any one year. In shallow lakes the water is thoroughly mixed by wind and wave action but deep lakes usually stratify in response to temperature differences between the surface and the deeper waters in the summer. In this case, the bottom water (Hypolimnion) may become deoxygenated to a degree that it cannot support fish. In any eventuality, nutrients accrue in this layer during the period of stratification. The stratified condition breaks down as temperatures cool in the autumn and an overturn occurs, mixing the water and producing a pulse of nutrients. Lakes in the cool Temperate Zone and Arctic usually freeze over in winter with a risk of reduced oxygen below the ice. Smaller lakes in the tropics may dry out in the dry season. Some degree of seasonality is therefore a feature of lakes at nearly all latitudes.

3.2 Rivers

The number of species in rivers is highly correlated with the size of the river system as indicated by main channel length or basin area. When 47 rivers from the major continents were compared a relationship: Number of species = 0.297 basin area$^{0.477}$ was obtained. This had a high correlation $r^2 = 0.91$. Little effect of latitude has been detected on species richness in rivers.

Gradient is one of the major conditioners of fish faunas in rivers and they may be divided into segments or zones depending on the type of fish fauna present. High gradient streams tend to be segmented into pool and riffle reaches which generally have specifically adapted, flow-loving species. Such species often have hooks, spines or suckers that enable them to fasten themselves to rocks and vegetation. Alternatively, they live under the rocks or in still water areas of the pools. Such areas also attract fish from downstream that favor such well-aerated areas for spawning.

Fish assemblages from the downstream regions are much more complex as a function of the increased complexity and extent of the environment. They fall into three principal

behavioral guilds, which are often categorized according to the nomenclature originally developed by traditional peoples in the Mekong River.

White fish. This guild groups large, strongly migratory fishes from several families that move large distances within the river channels between feeding and breeding habitats. The fish may pass their whole life history in the main channel or may move onto the floodplains to feed. They are generally intolerant of low dissolved oxygen concentrations preferring migration as a means to escape the adverse condition downstream during the dry season. Whitefish are generally one shot spawners, scattering numerous eggs, which may remain to hatch in situ or may be pelagic or semi-pelagic being swept downstream with the current.

Black fish. This guild consists of fish that move only locally from floodplain water bodies to the surrounding plain when flooded and return to the pools during the dry season. They have are adapted to remain on the floodplain at all times often having auxiliary respiratory organs that enable them to breathe atmospheric air or behaviors that give them access to the well oxygenated surface film. They have a wide range of elaborate breeding behaviors that allow them to maintain the eggs and newly hatched fry in relatively well-oxygenated localities.

Grey fish. These are species that are intermediate between the floodplain resident and the long distance migrant's guilds. Grey fish generally execute short migrations between the floodplain, where they reside at high water for breeding and feeding, to the main river channel where they shelter in marginal vegetation or in the deeper pools of the channel over the dry season. These species are less capable in surviving extremely low oxygen levels but do have elaborate reproductive behaviors, which enable them to use the floodplain for breeding.

In addition to the permanent residents of rivers diadromous fish occupy the inland water system for only part of their life cycle. Anadromous species such as the salmonids (see chapter *Salmonid Fish: Biology, Conservation Status, and Economic Importance of Wild and Cultured Stocks*) and sturgeons (see chapter *Sturgeons and Caviar*) spawn and pass their early life stages in freshwaters. Catadromous species such as the eels (see chapter *Eels: Commercially Important Catadromous Fish*) pass their adult stages in rivers and lakes and return to specific areas in the sea to breed. Both these behaviors require long migrations and highly specific physiological adaptations to enable the fish to return to their natal waters for breeding. In general, anadromy is commoner in the Arctic and Temperate zones where the seas are richer than rivers and catadromy predominates in the tropics where the rivers are richer than the marine environments.

3.3 Swamps, Marshes and Rice Fields

These generally poorly oxygenated habitats tend to attract fish of the black and grey fish guilds with a predominance of airbreathing species. Some such habitats are strongly seasonal holding water during and after the rains but eventually drying out completely. In such cases, new fish may migrate in from adjacent watercourse. In completely isolated systems, however, some species have developed the capacity to survive the dry

phase either buried in mud, in cocoons or as dormant eggs. These “annual” species appear spontaneously shortly after the temporary waterbody is filled.

3.4 Reservoirs

Fish occupying reservoirs are drawn from the fauna of the impounded river. However, many riverine species are unable to adapt to the new regime and disappear from the main body of the reservoir. Some migratory species may persist in the shallow upper end of the reservoir, as that remains accessible to the river. Other species may adapt well to the new ecosystem often by changing their breeding and feeding habits radically. Reservoir faunas often consist of the minority elements of the river fauna, which take on a new prominence by occupying the new habitats. After impoundment there is a regular succession of dominant species that may last for more than a decade before a more or less stable fauna is established. There is also a pulse of productivity during which levels of harvest are considerably increased as nutrients freed by the flooding are used up. Where native species have proved unable to adapt to the new conditions it has proved necessary to introduce exotic lacustrine species such as the tilapias (see chapter *The Tilapia Family: Environmental and Social Aspects of Reproduction and Growth*) and carps (see chapter *Warm Water Fish: the Carp Family*) into the basin to compensate.

3.5 Coastal Lagoons

Coastal lagoons are transitional systems that are occupied by three main blocks of species. Freshwater species move into the lagoon from the inflowing rivers during rainy and flood seasons to feed when the water is mainly fresh to slightly brackish. During periods of low flow these species withdraw into the rivers and are replaced by marine species that migrate in from the sea, often to reproduce during dry seasons when the water is primarily saline (see chapter *Shad of the Northeastern Atlantic and the Western Mediterranean: Biology, Ecology and Harvesting* for a discussion of shads and bass which show this behavior). A few species are permanently resident in the lagoon being adapted to the fluctuating salt concentrations.

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Biographical Sketch

Dr. Robin Leon Welcomme was born in London. England in 1938. He was educated at Birkbeck College, University of London and later obtained a PhD at Makerere College, University of East Africa for a thesis on the effects of climatic change on the biology and ecology of certain fishes of the Lake Victoria basin.. He began his scientific career in 1963 as a Scientific Officer at the East African Freshwater Fisheries Research Organization, Jinja (Uganda) and was later employed as Fisheries Biologist in Benin, West Africa until 1971 He then took up employment as a Fishery Resources Officer in FAO, Rome (Italy). He was promoted steadily to achieve the rank of Chief, Inland Fishery Resources and Aquaculture Service, and became Secretary of the European Inland Fisheries Advisory Commission as well as Technical Secretary to other regional fishery bodies until his retirement from the Organization in 1997. Dr. Welcomme is now a Senior Research Fellow, Renewable Resources Assessment Group, T.H. Huxley School of Environment, Earth Sciences and Engineering, Imperial College, London where he continues his work on inland fisheries management, on river fisheries and inland water biodiversity. In his career Dr. Welcomme has published Approximately 110 scientific works including 4 books. He has travelled to and worked in over 70 different countries both advising member governments and local institutions on conservation and sustainable development of fisheries resources in rivers, lakes and associated wetlands. He has also organized numerous meetings of commissions, working parties and technical networks particularly in Europe, Africa and Latin America.