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The Zambezi Society and The Biodiversity Foundation for Africa are working as partners within the African Wildlife Foundation's Four Corners TBNRM project. The Biodiversity Foundation for Africa is responsible for acquiring technical information on the biodiversity of the project area. The Zambezi Society will be interpreting this information into user-friendly formats for stakeholders in the Four Corners area, and then disseminating it to these stakeholders.

THE BIODIVERSITY FOUNDATION FOR AFRICA (BFA is a non-profit making Trust, formed in Bulawayo in 1992 by a group of concerned scientists and environmentalists. Individual BFA members have expertise in biological groups including plants, vegetation, mammals, birds, reptiles, fish, insects, aquatic invertebrates and ecosystems. The major objective of the BFA is to undertake biological research into the biodiversity of sub-Saharan Africa, and to make the resulting information more accessible. Towards this end it provides technical, ecological and biosystematic expertise.

THE ZAMBEZI SOCIETY was established in 1982. Its goals include the conservation of biological diversity and wilderness in the Zambezi Basin through the application of sustainable, scientifically sound natural resource management strategies. Through its skills and experience in advocacy and information dissemination, it interprets biodiversity information collected by specialists like the Biodiversity Foundation for Africa and uses it to provide a technically sound basis for the implementation of conservation projects within the Zambezi Basin.

THE PARTNERSHIP between these two agencies was formed in 1996 as a result of mutual recognition of their complementarity. They have previously worked together on several major projects, including the biodiversity component of IUCN's Zambezi Basin Wetland project and the evaluation of biodiversity in Tete province described in detail in the first Four Corners TBNRM Biodiversity Information Package.

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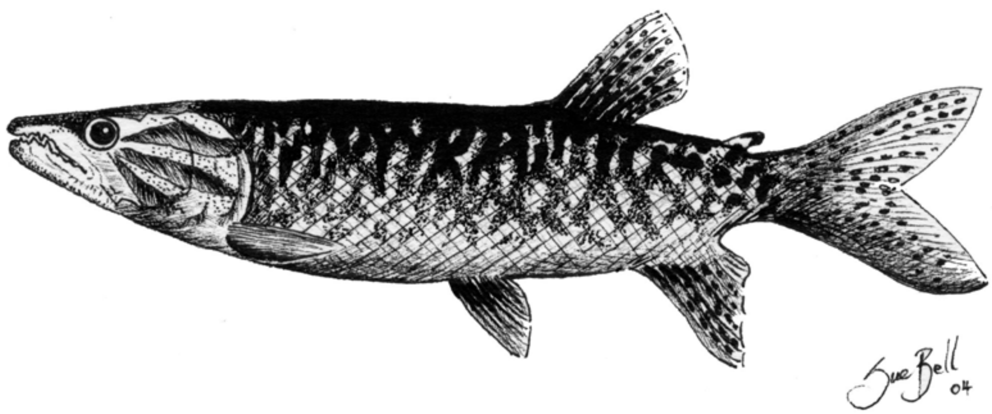

Hepsetus odoe, African Pike

CHAPTER 9. FISHES OF THE FOUR CORNERS AREA

Roger Bills & Brian Marshall

9.1 INTRODUCTION

The Zambezi River basin is part of the 'Zambezian' ichthyofaunal province which comprises the entire Zambezi system, including Lake Malawi, the Cunene River on the west coast and the east coast rivers from the Zambezi's mouth to the Mkuze River in South Africa (Roberts 1975). From an ichthyological perspective, it can be further divided into four discrete regions:

1. The Lower Zambezi – from the Cabora Bassa rapids downstream to its mouth;
2. The Middle Zambezi – from Cabora Bassa rapids upstream to the Victoria Falls and including the Luangwa River (a major northern tributary);
3. The Upper Zambezi – upstream from Victoria Falls and including the Okavango, Cuando and Kafue Rivers;
4. Lake Malawi – Lake Malawi, its affluents and the Shire River down to the Kapachira Falls.

The fish community of the Upper Zambezi River system today reflects its complex geomorphological history of major river course changes and numerous minor river captures with neighbouring systems (Skelton 1994). Geomorphological and ichthyological evidence has resulted in several theories on the evolution of the river systems and their fish faunas, but as far as the Upper Zambezi is concerned these theories essentially concur. An early large river system flowed south-west from the Lake Bangweulu region into the Kafue, Upper Zambezi, Okavango and Cunene rivers. These either flowed into a large central lake centred in the Okavango Delta-Makgadikgadi region, or into the Atlantic Ocean at a point somewhere near the present Orange River mouth. The Middle and Lower Zambezi formed a separate east coast system.

Around the late Tertiary period the Middle Zambezi captured the Upper Zambezi and Kafue rivers. Other river captures led to the Cunene breaking away to drain into the Atlantic Ocean, while Lake Bangweulu drained into the Congo system via the Luapula River. Although the Middle and Lower Zambezi were now linked to the Kafue and Upper Zambezi rivers, the Kafue Gorge and Victoria Falls have prevented the upstream movement and mixing of fishes the middle and upper rivers. Whilst downstream movement over the falls is still possible, it has been argued that the different nature of the environment in the Middle Zambezi has prevented colonization by many upper river species (Balon 1974a, Jubb 1976, Bell-Cross 1982).

For the purposes of this Four Corners review the Upper Zambezi region was defined as: northern Botswana (including the Okavango Delta and Makgadikgadi Pans), the Caprivi Strip of Namibia, the far south-eastern corner of Angola, south western Zambia (up to Senanga including the Kafue National Park but not the Kafue Flats), and northwestern Zimbabwe to the Gwayi River. These boundaries are rather unsatisfactory from an ichthyological perspective since they artificially divide river systems into floodplains and headwaters. Although both ecological regions have characteristic species, there are numerous species that undergo annual breeding migrations between the floodplains and the main streams. There are also a number of fish species that seem to be restricted to the headwaters of the Zambezi and Kafue and do not penetrate to the Four Corners area; many of them are rare and probably in need of protection.

The dominant event in the Upper Zambezi's history has been the series of major river course changes, resulting in considerable mixing of the fish communities. For example, many species across numerous families are shared between the rivers from the Zambian-Congo system south west to the Kunene River. The greatest differences between river faunas are between those systems that split away from each other a long time ago. In this regard the Kunene, with a similarity index of 40 was probably the first to break away from the central complex of rivers, followed by the Kafue (similarity index = 59), while the Okavango and Upper Zambezi are still tenuously connected via the Selinda spillway (Table 9.1). The similarity index for the Upper and Middle Zambezi is relatively low, suggesting that there has been relatively little interchange between the two systems.

Table 9.1. Similarity indices for the fish communities of the Upper Zambezi system.
The index is (no. of shared species/combined total for both rivers) X 100. Data from Skelton (1994).

Upper Zambezi/Cunene	40
Upper Zambezi/Kafue	59
Upper Zambezi/Okavango	87
Upper Zambezi/Middle Zambezi	33

In addition to major river course changes there has been mixing of fishes from neighbouring rivers by river captures and by migrations across shared headwater swamps (Bell-Cross 1965a). Such events have probably been numerous, small in scale and have probably resulted in the transfer of just small numbers of headwater species as only short sections of upper catchments are involved. These events probably account for several instances where species known to be widespread in the Congo system are found as isolated populations in the Upper Zambezi, e.g. *Schilbe yangambianus* and a few headwater cyprinids and kneriids.

The dispersal of fishes upstream from the Middle and Lower Zambezi has been effectively restricted by the Victoria Falls and the Buckenham and Chasunta falls in the Kafue Gorge, which are the downstream limits of the Upper Zambezi and Kafue sub-systems respectively. Waterfalls in the Upper Zambezi’s tributaries also form barriers to certain species and differences in the composition of the fish communities above and below substantial waterfalls frequently occur.

9.2 AQUATIC SYSTEMS IN THE FOUR CORNERS AREA

The fish of the Four Corners area come from four major systems - the Upper Zambezi and the Okavango Delta are the most important. A small part of the Middle Zambezi (Victoria Falls to the Gwayi confluence, but not Lake Kariba) also falls into the Four Corners as does the Kafue River in the Kafue National Park, which includes Lake Itezhi-Tezhi. The fish species that can be expected to occur therefore include most of the species that occur in these four systems giving rise to considerable diversity (Table 9.1).

The Upper Zambezi was described by Jackson (1986) as a "reservoir" river with abundant water resources that are retained for much of the year in its tributaries and floodplains. The system is ecologically diverse with headwaters ranging from rocky substrate wooded streams through to shallow sandy rivers draining grasslands, while the main river-floodplain habitats comprise the main river channel, floodplain lagoons, swamps and numerous isolated small lakes. These varied and extensive habitats contribute to its high fish diversity – the highest in the Zambezian Province. Within the Four Corners region the floodplain environment is the most important and includes the Chobe and Linyanti floodplains. There are some rocky stretches such as the Katombora Rapids, but much of the main river channel is sandy and fringed with aquatic vegetation.

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The Okavango River flows into a large inland delta and floodplain system whose morphometry has changed extensively in historical times. At present the upper part of the system is perennial, consisting of permanent lagoons with papyrus along their margins and extensive populations of submerged aquatic plants. The southern part of the delta is seasonally flooded but dries out at the end of the floods. Only about 5% of the water that enters the delta reaches its outlet, the Thamalakane River, which then flows into the Botete River and the Makgadikgadi Pans.

The Kafue River is also a reservoir river, flowing through the Lukanga Swamps and the Busanga floodplain before reaching the Kafue National Park. Itezhi-Tezhi dam is constructed in a narrow gorge at the entrance to the Kafue Flats, a major floodplain located outside the Four Corners area.

The western part of the Middle Zambezi is quite different from the other three systems. Below the Victoria Falls the Zambezi River flows through a series of steep rocky gorges and continues as a fast-flowing rocky stream until it reaches the headwaters of Lake Kariba at the confluence of the Deka and Zambezi Rivers. The largest tributary, the Gwayi River, is highly seasonal and joins the Zambezi after flowing through a series of rocky gorges. A northern tributary, the Kalomo River, drains the Zambian plateau east of Victoria Falls and reaches the Zambezi after dropping over the 37 m high Siengwazi Falls, which are a major barrier to fish movement (Balon 1971).

A series of seasonal pans occur on the Kalahari sands in the Hwange National Park. These are normally fishless but some have been made into permanent water bodies through pumping, and the catfish *Clarias gariepinus* has been introduced into them (Weir 1972).

9.3 FISHES OF THE FOUR CORNERS AREA

Fish are an important natural resource in Central Africa and they have always been exploited by traditional methods. Their importance is now growing with the depletion of terrestrial resources and the introduction of modern fishing gear such as gill nets. Although much of the ichthyological study in the Four Corners area, especially in the Upper Zambezi, has been aimed at fisheries and fish ecology, there has been a considerable amount of taxonomic work. Numerous small taxonomic studies and a few large-scale surveys have contributed greatly to systematic and taxonomic understanding of Upper Zambezi fish. Taxonomic developments are reviewed and checklists are available for the Okavango (Jubb & Gaigher 1961, Skelton *et al*. 1985), the Upper Zambezi (Bell-Cross 1972, 1974, 1982) and the Kafue (Bell-Cross 1965b, 1972, 1982). Most of the work on Middle Zambezi fishes has been done in connection with Lake Kariba, outside the Four Corners area, and has been summarized by Jackson (1961), Balon (1974b), Kenmuir (1983) and Marshall (2000).

The fish that occur in these four systems are listed in Appendix 9.1 The number of families, genera and species likely to occur within the Four Corners area are as follows:

Upper Zambezi: 16 families, 39 genera, 71 species
Okavango (delta): 16 families, 41 genera, 82 species
Kafue: 15 families, 32 genera, 62 species
Middle Zambezi: 16 families, 33 genera, 45 species.

These numbers exclude exotic species, several of which occur in some of the rivers. The total number of species recorded from the Four Corners area to date is 109.

The Upper Zambezi fish fauna is characterised by several small species 'groups' such as the mochokid catfishes or squeakers (7 *Synodontis* spp.); the clariid or air-breathing catfishes (5 *Clarias* spp.), 1 *Clariallabes* sp.; the haplochromine cichlids or river breams (7 *Sargochromis* spp.), 6 *Serranochromis* spp., 2 *Pharyngochromis* spp. and the minnows and barbs (6 genera and 31 species of Cyprinidae). The mormyrids are a more diverse family group (7 genera, 9 species), but one which is growing in size with new taxonomic investigations. Recent studies have compared electrical organ discharges (EODs) and genetics (mtDNA sequencing) to split morphologically cryptic species (Kramer & van der Bank 2000). A summary of information for all these species is given in Skelton (2001).

Taxonomically the characins are widespread and common, few in species and certainly not unique to the Upper Zambezi. However, ecologically the Tigerfish (*Hydrocynus vittatus*) exerts a dominating influence on the Upper Zambezi fish fauna. It is a voracious predator and where it is excluded from rivers by physical barriers (e.g. above the Kafue Falls), low oxygen levels (e.g. the lower Okavango Delta) or shallow water depths (e.g. Upper Zambezi tributary streams) there are significant changes in the composition of the fish communities (Bell-Cross 1974). It is noteworthy that the open-water predatory cichlid *Serranochromis thumbergi* and the African pike (*Hepsetus odoe*) are only common in the lower Okavango Delta and Kafue system where tigerfish are absent.

Notably absent from the Upper Zambezi fish fauna are the anguillid eels, which are widespread in the Zambezi tributaries below Victoria Falls; juvenile eels migrating up rivers are probably too large to scale vertical surfaces when they reach barriers such as the Kafue Gorge and Victoria Falls. The Cabora Bassa and Kariba dams are now additional obstacles to their progress, although there is some evidence that they might be able to overcome them (exactly how is not known). Widespread Congo species, which occur in the Middle and Lower Zambezi, are also absent from the Upper Zambezi and Kafue - they include *Mormyrops anguilloides*, *Malapterurus* spp., *Distichodus* spp., *Protopterus annectens* and *Heterobranchus longifilis.* Their absence from these rivers suggests that a connection between the Congo and the Lower Zambezi, via a route east of Lake Bangweulu, existed prior to the major southern rifting events (Jackson 1986).

9.3.1 Rare and Endangered Species Occurring Within the Four Corners

There are a number of rare species in these river systems but most of them occur in the headwaters of the Upper Zambezi, Okavango or Cunene. They are unlikely to reach the Four Corners area where the ecological conditions are very different. None of the fish in the Four Corners area are on the IUCN Red Data Lists, although there are several species that are rare and warrant protection. They include:

- *Neolebias lozii* - a floodplain specialist which appears to be rare and is known only from the type locality in the Barotse floodplain
- *Nothobranchius kafuensis* – a killifish found in the Kafue River (but possibly only on the Kafue Flats and therefore outside the Four Corners area)
- *Nothobranchius* sp. – a killifish found only in two pans in the Caprivi area of Namibia, said to be critically endangered and threatened by road building (Skelton 2001)
- *Chiloglanis emarginatus* – a globally threatened species (Kleynhans 1997) apparently collected from a tributary of the Gwayi River (Bell-Cross & Minshull 1988).

Little is known about these species. For Red Data assessments to be made more information on their geographic distributions, abundance, breeding, biology and potential threats is needed.

There is also concern about the future of the endemic Middle Zambezi tilapia, *Oreochromis mortimeri*, which is being replaced over much of its range by the introduced species *O. niloticus*.

This species is also a threat to *O. andersonii* in the Kafue River and there is a need to evaluate the impact of this exotic tilapia on the indigenous species. Every effort should be made to exclude it from the Upper Zambezi and the Okavango.

9.4 FISH DISTRIBUTIONS

The detailed distribution of Four Corners fish at a fine scale, their habitat preferences and seasonal changes in patterns are not very well known. Previous surveys have been too few and intermittent in their nature to examine these issues thoroughly and a long-term monitoring programme spread across seasons is needed. There is piece-meal information in numerous scientific papers and survey reports. Much of this has been summarized in Skelton (2001), which provides the most accurate distribution maps.

The majority of fish in the area appear to be widespread and adaptable to varied large river and floodplain habitats. Many species migrate from floodplains into the tributary rivers to breed during the rainy season, while others migrate laterally into floodplain grasslands and lagoons. Some species tend to be restricted to fast-flowing sections of the river and may therefore be restricted to rocky sections where rapids occur. Lists of species groups by habitat for the fishes of the Caprivi (Kwando and Linyanti rivers and associated swamps) are given by van der Waal (1996) and reported on by Marshall (2000). Within the broad 'floodplain' and 'headwater' groups there are also specialists, rarely collected outside of their preferred habitats. Some examples of these are as follows.

- Species that inhabit rocky stretches of large rivers include the catfish *Clariallabes platyprosopos* and the spiny eel *Aethiomastacembelus vanderwaali*. An adaptation to living in rapid environments, where oxygen levels are constantly high, is seen in *C. platyprosopos*, which has a vestigial suprabranchial organ. This organ, when functional, enables clariid catfishes to breath air when the oxygen concentration in water is low.

- Several species are exclusively found in dense vegetation in swamps. Some are widespread, occurring where suitable habitats are present, e.g. the mormyrids *P. castelnaui*, the small cyprinids *B. brevidorsalis*, *B. haasianus*, *C. wittei*, the citharine *H. machadoi*, the anabantids *M. intermedium* and *C. multispine*, and the dwarf cichlid *T. ruweti*. The distichodontid *Neolebias lozii*, however, is only known from its type locality, in dense vegetation in swamps on the eastern side of the central Barotse floodplain.

- Rocky substrates in headwater streams harbour several specialized fishes. The kneriids and *Amphilius* catfishes are the first species encountered when moving downstream from the source of a river. Kneriids have the ability to climb rock surfaces by sticking on with their pectoral and pelvic fins and are also airbreathers. *Amphilius* catfishes have numerous backward pointing spines positioned on the leading edges of their paired fins which act as adhesion pads and enable them to sit in fast open waters. Further downstream in rapid habitats suckermouth catfishes (*Chiloglanis* sp., Mochokidae) occur. They have a modified mouth which forms a sucking disc which allows them to hold onto rocks in fast-flowing water and to scale vertical water falls. Several small cyprinids are also characteristic of the upper catchments, e.g. *B. neefi*, *B. bellcrossi* and *B. breviceps*.

9.4.1 Regional Variation

Taxonomic, systematic and biogeographic research into the fish of the broader Four Corners region has received little attention over the last 20-30 years. During this period there have been considerable advances in taxonomic methods such as genetics (DNA sequencing and karyology), electric-organ discharge analysis, and more complex morphometric analyses (e.g. truss measurements) and associated statistical programs. These advances in techniques, plus greatly improved comparative museum collections, are enabling scientists to begin teasing apart some of the complex biological groups. It is likely that a number of new forms will be described as a result and the presently available lists of species can be expected to change significantly.

Although there have been revisions of certain groups (Greenwood 1979, 1984, 1992, 1993) and several new species described (Winemiller & Kelso-Winemiller 1990, 1993, Skelton & White 1990), regional variation of what are considered to be widely distributed species has largely been ignored. This is especially true of fishes in the Upper Zambezi system. Some of the more obvious candidates for further study include:

- Amphiliid catfishes of the genera *Amphilius* and *Leptoglanis* which show considerable geographical variation in colour patterns and morphology. There are only three species of *Amphilius* and one *Leptoglanis* described from southern Africa and only one of each are recorded from the Upper Zambezi. Museum collections alone indicate that there are clearly more forms of both species in the system and the family needs a thorough revision.

- The mormyrid *Petrocephalus catostoma* was originally described from Tanzania and is found from Lake Victoria south to Natal in South Africa and west to the Kunene, Namibia. Recently Kramer & van der Bank (2000) split *P. catostoma* into northern populations of *P. catostoma* (northern Churchill) and southern populations (Limpopo River south) of *P. wesselsi* (southern Churchill) on the basis of electric organ discharges, genetics and morphology. It is likely that the remaining *P. catostoma* will be further split.

- The haplochromine cichlids or river breams are distributed broadly in the Upper Zambezi region with species also occurring in Lake Malawi and the Congo system. Several individual species occur throughout this range, e.g. *Serranochromis macrocephalus*, *Serranochromis robustus*, *Sargochromis giardi* and *Pharyngochromis acuticeps*, and there is some colour pattern and morphological variation across these populations. A revision of the group, aimed at understanding the status of geographical populations and the relationships between species and genera is clearly needed.

- The cyprinid *Barbus mattozi* (papermouth) is presently recognised from the Limpopo and the Kunene rivers, where it is common, with isolated records from the Nata and Upper Zambezi rivers. The populations from the Limpopo and Kunene are, however, significantly different in their colour patterns and there may also be significant genetic variation. Two species were originally described, *B. rapax* from the Limpopo and *B. mattozi* from the Kunene, and it seems possible that *B. rapax* will be formally resurrected. It is not known which forms are present in the Zambezi and Nata rivers.

Regional variation or biodiversity is highly relevant to fish conservation as certain species have been and continue to be moved throughout the region for angling and aquaculture purposes (Thys van den Audenaerde 1994, Marshall 2000, Skelton 2001). Water transfer schemes also threaten genetically diverse species by moving them across systems. Such movements can result in the homogenization of this natural variation, a problem noted in populations of trout from Europe and North America (Utter 1981, Ryman & Stahl 1981), but which has not been documented in southern Africa. So far, there is little evidence that the Four Corners area has been much affected by these activities although there is a risk that it will be in the future.

9.4.2 Future Taxonomic Research - Towards Understanding Biodiversity

The detailed, fine-scale distributions of fish, and seasonal variations in species distribution and habitat preferences in the Four Corners area are not well known. However, this is essential information for fisheries managers and for a full appreciation of the area's biodiversity. A programme of taxonomic investigation that will conduct surveys and train local staff, who would then be able to undertake local monitoring over the long-term, is needed. With seasonal and annual variation in numerous key ecological factors, long-term assessments are critical to developing sound management plans. The present AWF–SAIAB biodiversity surveys are aimed at addressing this issue to some extent, but such a programme needs to continue past its present one year time-span.

Rare species and species with restricted geographical distribution should be assessed for their conservation status according to standard IUCN guidelines (Hilton-Taylor 2000). Certain groups are not well studied taxonomically and are extremely difficult to identify in the field, e.g. *Synodontis* catfishes and juvenile haplochromine cichlids. There is also a growing number of undescibed species, e.g. in the genera *Nothobranchius*, *Leptoglanis*, *Aplocheilichthys*, *Sargochromis* and *Pharyngochromis*. These groups need to be examined using both morphological and molecular techniques, species then need to be better described and identification keys altered so that ecologists and fisheries biologists can accurately record fish catches.

The higher systematic relationships of many Upper Zambezi fish 'groups' are poorly understood, e.g. haplochromine cichlids, despite a considerable effort by Greenwood (Greenwood 1979, 1984, 1992, 1993). Studies employing combined molecular, physiological and morphological methods are needed, as are studies of population genetics. Investigations into the degree of genetic differentiation within and between the different sections of the Four Corners area and the Zambezi system as a whole will answer questions about the extent of movement within and between them.

This sort of information is critical for both fisheries and conservation managers. Obvious candidates for study would be commercial species and species from different families that exhibit differing abilities to move or cope with varying environmental conditions, e.g. *M. macrolepidotus, L. lunatus*, *H. vittatus*, *C. gariepinus*, *S. intermedius* and *S. robustus*.

9.5 FISH ECOLOGY AND ECOLOGICAL PROCESSES

The dominant process affecting fish generally in these river systems is the seasonal change in water levels and flows associated with the distinct summer rainy and winter dry seasons. The onset of summer rains in late October results in increased water flows which peak around February-March in the rivers. During these seasonal flooding events most fish undergo breeding migrations either upstream, to smaller tributary streams, or laterally into the floodplains and marginal lagoons (summarized in Table 9.2.)

The pattern is rather different in the Okavango Delta where, because of the long distance from its source in Angola and its extended and convoluted nature, water only reaches the lower delta by June-July (Merron 1991). This is the cool dry season and water temperatures are at their lowest (June average 16ºC). It has been suggested that this might affect the breeding cycles of the fish, but McKinlay (1996) found no significant differences between the breeding of *Brycinus lateralis* in the upper and lower delta. He concluded that breeding cues were obtained from increases in water temperatures and lengthening photoperiods during the spring and not to increasing water levels. This needs to be verified for species in different fish families.

Table 9.2. The seasonal cycle of fish abundance and fishing activity on the Barotse floodplains (from Van Gils 1988, cited in Marshall 2000).

Jan-Apr Late rainy season	Apr-Jul Early dry season	Jul-Oct Late dry season	Oct-Dec Early rainy season
Fish move up channels	Fish dispersed on floodplain	Fish move back to channel and lagoons	Fish restricted to dry season refuges
Production of young by most species	Rapid fish growth	Heavy losses to man and predators	Reduction in fish population
Almost no fishing	Maalelo fishery	Intensive fishery	Fishing in pools, swamps and landlocked lagoons

The productivity of fish is intimately linked with the flood cycle (Welcomme 1985, Merron 1991, Merron & Bruton 1985). The flood-waters bring with them nutrients and sediment, some of which are absorbed by the floodplains. The timing, magnitude and duration of the floods affect the onset of migrations and breeding, the frequency of breeding in one season and the growth and survival of young. Successive years of poor rains can also increase the period of time that fish have to stay in the main river channels and can cause a considerable reduction in the numbers of small fish through predation by tigerfish, catfishes and predaceous cichlids. This might be expected to have a knock-on effect to following years as depleted cohorts move through the age classes and reach maturity, although little is known about this aspect in the Zambezi systems.

9.5.1 Fish Movements

Fish are known to migrate upstream and laterally out onto floodplains with incoming floodwaters. Bell-Cross (1974) hypothesised that they responded to increasing water velocity in the early spring, and to decreasing water depth to return to the main channel. During such movements fish also change habitats for breeding and feeding but the finer details of what stimulates them to move, the distances they travel and the location of spawning sites are very poorly known. A few workers have tried tagging fishes with markers and then attempted to recapture them but little success because of low recapture rates (Bell-Cross 1966, G.S. Merron pers. comm.). The other problem with such methods is that nothing is known about where the fish have been between the time of tagging and their recapture and so the information gained is limited.

Today there is a NINA/Namibian Fisheries Department project using radio telemetry technology to track several commercial species in the Namibian sector of the Upper Zambezi (Økland *et al*. 2000, 2002, Thorstad *et al*. 2001, 2002). Such techniques are criticised because the methods are invasive and the post-tagging behaviour of the fish is unnatural. However, techniques are developing rapidly in this field and they promise to provide significant insights into patterns of fish behaviour that will be directly relevant to managing the commercial resources. The advantage of the technique is that fish can be continuously tracked for several months giving more information on foraging patterns, territoriality and responses to changing environmental conditions. Specific questions that might be answered include:

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i. what factors cause fish to move upstream or onto floodplains in the spring, and return to the main channels in the autumn
ii. what are the characteristics of breeding sites for different species and how long do fish spend in these areas
iii. how do fish behave during the dry season (Bell-Cross suggested that many species are territorial at this time and move little)
iv. how do they respond to flood waters, such as those that enter the upper Okavango Delta and cause deoxygenation and fish kills.

The movement of fish between the Upper Zambezi and the Kafue is not possible as the latter enters the Middle Zambezi below Kariba Dam. Movements between the Okavango and the Upper Zambezi are probably limited as the two are only rarely connected via the Selinda Spillway, although this connection may have been more frequent in the recent past. It is not clear how much downstream movement is possible from the Upper to the Middle Zambezi by passing over the Victoria Falls. Balon (1974a) argued that it was possible for fish to survive the 94 m drop over the falls, but this view was challenged by Jubb (1976) who argued that fish could only pass over the falls through human intervention, primarily by passing through the hydroelectric power station. The best way to examine the extent of migration between these areas might be to investigate the population genetics of certain key species that are thought to move long distances and species from different taxonomic groups.

9.5.2 Deoxygenation Events and Fish Kills

In the Okavango Delta, deoxygenation events killing large numbers of fish occur annually (Bills 1996, Conservation International 2000). They are caused by new floodwaters entering the swamps, lifting up mats of vegetation (mainly *Cyperus papyrus*) and flushing out partially rotted leaf litter. The extent of the fish kills appears to be linked to several factors, such as the water levels during the previous year and the consequent buildup of leaf fall material, the magnitude of the present flood, the speed of the influx of new water, and how much access it has to local open streams.

In Botswana, fish kills have been reported from near Nxamaceri in the lower panhandle to Chief's Island in the lower delta. A considerable area is affected and certainly millions of fish die every year. Fish kills occur in other large freshwater swamps but it is not known if they occcur in the Upper Zambezi or the Lukanga swamps on the Kafue. Such kills affect fish productivity and the size of the stocks and they need to be considered in fisheries management plans. It has been argued that: (a) intensive fishing should be allowed in areas affected by deoxygenation to catch fish that will die anyway, and (b) fishing pressure should be reduced in order to preserve the survivors. Such arguments can only be settled once the scale and impact of these fish kills is fully understood.

Fish kills have not so far been properly studied and there are several key questions that would further our understanding. The areas affected need to be delimited more accurately over several years (in low and high flood years) both within the Okavango delta and, if necessary, elsewhere in the Four Corners area. The species and size range of the affected fish, and the sequence of events while they are being killed (usually over only a few days) need to be determined. The behaviour of fish should be monitored from before the floodwaters enter the system until after the fish kills have occurred - radio-tagging and telemetric methods may be the best way. Fish that survive deoxygenation events are reported to leave these areas, but this has not been verified nor is it known where they go. It is essential that water quality data are collected at the same time so that fish behaviour can be correlated with changing environmental conditions.

9.5.3 Drying-Out of Seasonal Swamps

Many fish species move out of the floodplain and headwaters and return to the main channels at the end of the rainy season as the floodwaters start to recede. Here they encounter heavy predation from tigerfish, serranochromine cichlids and clariid catfishes. There must be a trade-off between the risks of predation in the main channel and of being stranded in the drying floodplains.

At the end of the dry season large floodplain areas dry out although the degree to which they do so varies from year to year depending on the extent and persistence of the flood. As the waters dry out predators (humans and birds) move in to harvest the concentrated fishes until, finally, the fish that are left die when the pools dry up completely. Drying lagoons in the Okavango Delta's seasonal swamps often support hundreds of Marabou Storks, pelicans, herons and Fish Eagles for a week or two. The birds then move to other lagoons, triggered perhaps by some combination of critical fish concentration and water depth. Local people have also traditionally taken advantage of these short periods of fish abundance and today use more efficient methods such as gill and seine nets.

Many other lagoons and isolated backwaters do not dry out each year and form important refuges for fish until the next flood season. More thorough studies on the extent of backwaters (perennial and seasonal) and the composition and biomass of fish stocks in them, at all stages of desiccation, would help in understanding the functioning of the floodplains and their fish production. Such information would be of value in fisheries management.

9.6 ADDITIONAL BIOLOGICAL STUDIES ON FISH OF THE FOUR CORNERS

Although the region as a whole has been neglected, some valuable biological studies have been conducted on the fish of the Four Corners area (Table 9.3) and several are continuing today. Understandably, more effort has gone into assessing the fisheries than into purely biological studies. But interpreting fisheries data and using predictive models requires considerable amounts of ecological data; there is an urgent need for further ecological studies. Areas where future research could be directed are discussed below.

Biological studies on the feeding biology, breeding biology, and stock assessment (growth, mortality and biomass) of all commercial and key ecological species are urgently needed for the formulation of fisheries management plans. These should be conducted on a regional basis, as it is likely there will be regional variation between the same species in different sub-catchments.

Movements of fish need to be thoroughly studied in relation to flooding, draw-down and around deoxygenation events using radio telemetry methods. Movements between sub-systems needs to be determined for certain key species by using population genetics.

Fisheries yields in all areas need to be quantified including, as far as possible, all traditional forms of fishing.

The development of Indices of Biological Integrity (IBI) is hampered by the lack of biological data. It is recommended that a programme to develop an IBI for all the systems in the Four Corners should be established in order to provide the all the necessary information that is needed.

Table 9.3. Summary of some of the investigations made into fish biology from the Four Corners area.

Authors	Date	Region	Field
Bell-Cross	1965a	Upper Zambezi	Fish dispersal
Bell-Cross	1966	Upper Zambezi	*H. vittatus* – biology
Carey	1966a,b	Kafue	Feeding and growth rates
Carey & Bell-Cross	1967	Upper Zambezi	Commercial species- breeding biology
Dudley	1972	Kafue	*Tilapia* biology
Benl & Foersch	1978	?	*C. multispine* – biology
Dudley	1979	Kafue	*Oreochromis* – growth & size
Dean	1984	Okavango	*H. vittatus* – feeding biology
Holden & Bruton	1986	Okavango	*H. odoe* – nesting biology
Merron	1991	Okavango	Biology of commercial species
Holden & Bruton	1994	Okavango	*P. philander* –early life history
Schwanck	1994	Kafue	*Oreochromis* – behaviour
Merron & Mann	1995	Okavango	*S. intermedius* – breeding & feeding
Merron *et al.*	1990	Okavango	*H. odoe* - breeding biology
Winemiller	1991	Upper Zambezi	*Serranochromis* – comparative ecology
Merron	1993	Okavango	*Clarias* - pack-hunting
Booth *et al.*	1995	Okavango	*O. andersonii* – feeding & breeding
Booth & Merron	1996	Okavango	*O. macrochir* – feeding & breeding
Winemiller & Kelso-Winemiller	1994	Upper Zambezi	*H. odoe* and *H. vittatus* – ecology
Winemiller & Kelso-Winemiller	1996	Upper Zambezi	Catfish - comparative ecology
Hay *et al.*	1996	Okavango	Developing an Index of Biotic Integrity
McKinlay	1996	Okavango	*B. lateralis* – breeding biology
Kramer	1997	Upper Zambezi	Mormyrids – electrophysiology
Hanika	1998	Upper Zambezi	*C. gariepinus* – electroreception & prey detection
Hanika & Kramer	2000	Upper Zambezi	
Kramer & v.d.Bank	2000	Upper Zambezi	*P. catosotoma* – electrophysiology
Økland *et al.*	2000	Upper Zambezi	
Thorstad *et al*.	2001	Upper Zambezi	Cichlids - tracking of movement

9.7 MONITORING

It is generally agreed that some kind of monitoring is needed in order to determine the the rate and scale of environmental change and it is relatively easy to draw up complex monitoring programmes that are designed to answer complex questions. But it is much more difficult to carry out and sustain such programmes. The success rate of long-term monitoring programmes in tropical Africa is very poor. The reasons for this are that they are often too ambitious and local institutions, which ultimately have to carry them out, lack the capacity to do so; they often have no trained manpower, no material resources, and limited funds.

A monitoring programme should therefore be designed to use simple equipment that can be maintained locally and it should be possible for junior staff to carry it out because of the high turnover of senior staff at most African institutions. A good example of such a programme is the experimental gill netting that has been carried out weekly in one area of Lake Kariba since 1969 (see Karenge & Kolding 1995a, 1995b).

Investigations into the biodiversity of the Okavango Delta and the Zambezi River have been carried out by SAIAB scientists over the last decade using a wide range of semi-quantitative methods (Skelton *et al*. 1985). These include the use of seine nets (3 and 8 mm mesh size), hand nets, gill nets (10 m panels of 22, 28, 35, 45, 57, 73, 93, 118 and 150 mm mesh), throw nets, battery-powered electro-fishing gear, rotenone ichthyocide, angling with rods and line, and baited longlines. All of these methods are selective and so the best results are obtained by using a wide variety of gear and by collecting in varied habitats at each site. Repeat visits to the same sites during different seasons are also recommended.

Gear and methods need to be accurately described so that they can be standardized. The area sampled, or the time spent sampling, should be recorded so that estimates of relative abundance, expressed as catch per unit of effort (CPUE), can be made to allow results from different sites and times to be compared. Geographical coordinates, photographs and sketch maps of sites are essential if future researchers are to return to the exact locations. Other additional variables worth recording include the conductivity of the water, its temperature, clarity and flow, the size and physical structure of the river, the composition of the substrate, aquatic and terrestrial vegetation and aquatic invertebrates. This process of standardization is already in progress in the AWF Four Corners Fisheries programme.

Biodiversity data collected from rivers in the region have rarely been rigorously analysed with statistical models, partly because biodiversity surveys themselves have been rare events. If regular assessment programmes are planned, then the use of some kind of biotic integrity index should be considered. An Index of Biotic Integrity has been developed for fish in the Namibian section of the Okavango River by Hay *et al*. (1996) and other IBIs have been developed for some African rivers (Toham & Teugela 1999). Whilst there are certain problems with this index, and it has not been widely used, it could form the basis of a developing model. One of the major problems is that the ecological information about the fish species is poor, e.g. knowledge of feeding biology and habitat preferences of species. Consequently, the development of a fish IBI requires an improvement in the knowledge of fish ecology.

Major changes in fish distribution and behaviour will occur seasonally with the annual flood cycle, and from year to year with changing flood magnitudes. Repeat sampling at the same sites is likely to produce significantly different results. The only effective way to overcome this problem is to sample extensively, to establish a long-term monitoring programme, and to attempt to correlate the results with the water flow regime.

Long-term biodiversity programmes require the establishing of fixed monitoring sites. These need to account for all major river zones and habitats within those areas. In the Upper Zambezi the zones would be (following Bell-Cross 1974), the southern Barotse floodplain, the central Barotse floodplain, the Upper Zambezi river above the floodplains, the tributary rivers, and forest lakes. Within each area several sites need to be chosen that sample all micro-habitats. In the Botswana sector of the Okavango system the regions would be the upper pan handle, the lower panhandle, upper delta, lower delta, drainage rivers and sump lakes (which could include the Makgadikgadi Pans).

In addition to biological factors, local logistics also need to be considered when choosing monitoring sites. If such long-term programmes are to be sustained members of fisheries departments or museums within the Four Corners region need to be adequately trained, equipped and funded since no monitoring programme can succeed unless local institutions are able to carry them out over the long-term. Adequate funding is likely to be the major constraint. Because of this monitoring sites should be close to fisheries department offices or major roads so that they are easily accessible and can be surveyed at low cost.

9.8 THREATS

9.8.1 Water Abstraction and Dams

The main ecological determinant in the Four Corners area is the river flood cycle, hence the greatest threat to fish communities comes from activities that alter the flow regime. These include the large-scale abstraction of water or dams, and numerous schemes have been proposed over the years. The proposed Eastern National Water Carrier would pump water from the Okavango River into the interior of Namibia and could reduce the Okavango's flow significantly (Skelton & Merron 1984, 1985, 1986). Another proposal, currently in the pre-feasibility study phase, is to place a 10-15 m high weir in the area of the Popa Rapids in Namibia in order to produce electricity.

The Upper Zambezi is threatened by a proposed storage reservoir that could be built at the Katombora Rapids to supply water to an expanded hydropower station at Victoria Falls. This reservoir would reach into the lower Barotse floodplain and drown much of the Linyanti floodplain, with consequent detrimental effects on the fish communities.

The most seriously threatened part of the Four Corners is the western Middle Zambezi, where deep gorges offer tempting opportunities to engineers. Two proposed dams, one at Batoka Gorge below Victoria Falls and the other at Devil's Gorge just below the Gwayi/Zambezi confluence, would drown the last remaining river sections above the Kariba Dam. These gorges presently support populations of rheophilic fish that have declined in or disappeared from Lake Kariba; the dams would have a severe effect on these species and bring about a significant loss of biodiversity.

Some of the general concerns about dams and their effects on fish are:

a) They will reduce the flow down rivers through water extraction and losses to evaporation. This is critical for species which breed in flooded habitats (including all floodplain specialists) and reduced flooding could reduce the stocks of many species.

b) The flow regime of the river will be altered. This is critical for fish since an increase in water flow seems to be the cue for them to move upstream on breeding migrations. Without increased flows at the correct time of year breeding and subsequent recruitment will be seriously affected. This might reduce the numbers of species like the cyprinids, many of which lay a single large batch of eggs per year, but increase the numbers of serial spawners such as the cichlids that can produce several small clutches per year.

c) They can reduce the quantity of sediments brought into floodplain areas such as the Okavango Delta where reduced sediment inflows are likely to cause erosion of the main channels and consequently reduce flooding of the floodplain and delta. This could transform huge areas of seasonally flooded grasslands in the lower delta into permanent grasslands and result in a massive loss in fish productivity.

d) Dams are typically constructed in rocky areas and the inundated region above the dam changes in nature from a rocky rapid to a sedimented rocky lake. There is a considerable loss of habitat for species that inhabit rocky areas with running water and they will decline or disappear completely. In Lake Kariba rheophilic species disappeared and cichlids became the dominant family in place of cyprinids and distichodontids (Begg 1974, Kenmuir 1984).

e) In seasonal rivers, or rivers which occasionally dry up, recolonisation has to come from fish surviving in permanent water in the lower reaches. Where seasonal rivers flow into dams the faunal changes that occur in those dams will be reflected by extinctions in both the dams and the seasonal rivers (Marshall 2000). For example, the barred minnow *Opsraidium zambezense* and the catlets *Leptoglanis rotundiceps* and *Chiloglanis naumanni* have disappeared from Lake Kariba and many of the inflowing streams.

f) Dams prevent breeding migrations of fish and suitable fishways are rarely incorporated into dams to allow their passage. Fishways or ladders should be considered wherever possible, but they must be designed specifically for certain species and they need to be maintained effectively.

g) Small dams are generally not common in the Four Corners area. Marshall (2000) estimates that approximately 14,000 dams greater than one hectare in size have been constructed (often in headwater areas) in Zimbabwe. With increasing agricultural development it is likely the number of small dams will increase, with two major impacts on fish:

   i. Small streams may dry up below the dam causing local extinctions, which could be a serious loss of biodiversity if the species concerned shows significant geographic variation.
   ii. These dams are frequently stocked with exotic fishes; many of them thrive whereas they often do very poorly in river environments. Thus small dams can act refuges for exotics and innocula from them are continually invading the streams in their vicinities. This is a significant threat to indigenous fish species.

Inter-basin transfer schemes (IBTs) are designed to supply water to areas where the demand for water is greater than the supply. The biological costs of such schemes are high and irreversible because they are, effectively, man-made river captures and result in the transfer of a variety of aquatic animals to the recipient system. This can have a variety of adverse consequences such as genetic pollution through hybridization and the loss of biodiversity as new species compete with or prey upon those in the river system receiving the water. Various proposals have been made to pump water from the Zambezi River across the relatively flat terrain of Botswana to the Witwatersrand area of South Africa. Such a project would have adverse effects at both ends; the flow of the Zambezi would be considerably reduced while the Orange-Vaal system would receive an infusion of Upper Zambezi fishes with potentially disastrous consequences for its native species.

9.8.2 Alien or Exotic Fish

The introduction of exotic fish species and the translocation of indigenous ones outside their native range has been carried out all over southern Africa and created many problems. So far, the Okavango and Upper Zambezi seem to have no alien species although there is a risk that Nile tilapia *Oreochromis niloticus* will reach them since this fish is being aggressively promoted by aquaculturists. The advent of peace in Angola is likely to see the appearance of donor-funded aquaculture projects in the headwaters of these rivers and invasion by exotic species is quite likely.

The Middle Zambezi has a large number of exotic and translocated species, but the only ones likely to occur in the Four Corners are kapenta (*Limnothrissa miodon*) and Nile tilapia (*O. niloticus*), which are likely to occur in the sections of Lake Kariba above the Gwayi-Zambezi confluence. It is not known if they occur in the riverine sections upstream. The Kafue system has 19 exotic and translocated species (Table 9.4), which may in some cases have hybridized with indigenous populations; pure stocks and hybrids can be impossible to distinguish (Thys van den Audenaerde 1994). The impacts of most of these introductions are not known at present and it is likely that many of these species are still undergoing active expansions of their ranges and numbers.

Table 9.4. Introductions of alien fish species and translocations of indigenous ones in Zambia. Most fish taken to the Kafue system were introduced at Chilanga, at the eastern end of the Kafue Flats and may not be in the Four Corners area. From Thys van den Audenaerde (1994).

Family	species	river system and status
Clupeidae	Limnothrissa miodon	Successful in L.Kariba and Itezhi-Tezhi
Cyprinidae	Labeo altivelis	Kafue: no further information
	Ctenopharyngodon idellus	Kafue: no further information
	Cyprinus carpio	Kafue: no further information
	Tinca tinca	Kafue: unsuccessful
Bagridae	Bagrus meridionalis	no information; may not have been introduced
Salmonidae	*Oncorhynchus mykiss*	Luangwa: unsuccessful
Poeciliidae	*Gambusia affinis*	Kafue: unsuccessful
	Poecilia reticulata	Kafue (Kitwe)
	Xiphophorus helleri	Kafue (ponds)
Centrarchidae	Lepomis cyanellus	unconfirmed
	Lepomis macrochirus	L. Tanganyika catchment: apparently failed
	Micropterus dolomieu	Kafue: apparently failed
	Micropterus punctulatus	Kafue: apparently failed
Cichlidae	Astatoreochromis alluaudi	Kafue: apparently failed
	Boulengerochromis microlepis	Kafue: apparently failed
	Oreochromis andersonii	L. Tanganyika and L. Rukwa drainages
	Oreochromis aureus	Kafue: restricted to ponds
	Oreochromis macrochir	Middle Zambezi, Chambeshi
	Oreochromis mweruensis	Kafue: no further information
	Oreochromis mortimeri	Kafue: may have hybridised
	Oreochromis niloticus	Kafue and mid-Zambezi; now widespread and expanding its range
	Serranochromis robustus	L. Tanganyika drainage
	Tilapia sparrmanii	L. Tanganyika drainage
	Tilapia rendalli	Luapula strain to Kafue

The only purposeful introduction of fish into the Kafue river system has been that of kapenta into Lake Itezhi-Tezhi (Mubamba 1993) in order to develop a fishery in this man-made lake. Despite very low numbers of fish being introduced (less than 4000 15-20 mm juveniles, pers. obs.), they have multiplied dramatically and are now the basis of an active fishery. As in lakes Kariba and Cabora Bassa the exercise is considered a fisheries success as it is providing protein and incomes for local peoples, and to date no significant and negative impacts have been identified (Mbewe 2000). All other introductions are escapes from aquaculture facilities within the Kafue River catchment or unofficial releases by aquarists.

The exotic species include *Cyprinus carpio* and *Ctenopharyngodon idella*, both of which are capable of transforming aquatic environments by increasing turbidity and reducing aquatic weeds respectively, having a dramatic effect on indigenous fish comunities. The guppy (*Poecilia reticulata*) and the sunfish (*Lepomis macrochirus*) can infest small water bodies by out-competing and/or preying upon indigenous species. Species from other continents, because of their distant relationships to indigenous species, are unlikely to interbreed with them.

Translocated African species include *Oreochromis* and *Tilapia* species, which are widely used throughout the world in aquaculture. Being native to Africa they present problems of hybridization and genetic contamination. They threaten populations of indigenous species by being more aggressive competitors or through hybridization. *Oreochromis niloticus* is now well established in the Kafue River and in the Middle Zambezi, where it appears to be displacing the native *O. mortimeri*. Local translocations of *T. rendalli* and *O. mweruensis* from the Northern Province of Zambia and *O. mortimeri* from Kariba have occurred and will cause similar genetic contamination resulting in the genetic homogenisation of fish stocks.

One other notable translocation in the Four Corners region was that of *Clarias gariepinus* into pans in the Hwange National Park. These pans had been converted from seasonal water bodies to permanent ones by pumping water into them, and some crocodiles were put into them. *Clarias* were introduced to provide food for the crocodiles, but the effect was to drastically reduce the populations of invertebrates in the pans (Weir 1972). These catfish have apparently spread to other pans in the park (J. Salnicki, pers. comm.), presumably with similar effects on the invertebrates. It has probably had a similar effect on amphibians since this catfish reduced tadpole populations in seasonal pools near Harare (T. Muteveri, unpublished thesis, Univ. Zimbabwe).

The use of exotics, especially *Oreochromis* and *Tilapia*, should be restricted in southern Africa and certainly prohibited in the remaining pristine areas of the Upper Zambezi and Okavango. No aquaculture facility should be regarded as "escape-proof" and introductions to ponds should be considered in the same way as direct introductions into rivers. Where good aquaculture species are present, e.g. *O. andersonii* and *O. macrochir*, local stocks should be used and enhanced production should be achieved by standard methods of stock improvement (e.g. selective breeding) and better farming systems. Fisheries departments in the region need to assess their policies towards the continued use of exotic species and strains and the movement of fishes within their countries. A common regional (SADC) policy should be developed and enforced. There are a host of other issues around exotic aquatic animals and readers are referred to de Moor & Bruton (1988, 1996) for a thorough review.

9.8.3 Alien Aquatic Plants

Three species of introduced aquatic weeds present in the Four Corners are well known as problem plants. They water hyacinth (*Eichhornia crassipes*), the water fern *Azolla filiculoides* and Kariba weed (*Salvinia molesta*). Under suitable conditions they can cover still waters almost completely, reducing light penetration and the flow of water, and reduce oxygen concentrations by depositing large quantities of organic matter from root and leaf fall. This can be a particularly serious problem in swamps and backwater lagoons where oxygen is already low. There is some evidence that fish diversity and biomass in weed-covered areas is lower than in uncovered waters (Marshall 2000, Gratwicke & Marshall 2001), which is important because much of the diversity and biomass of floodplain fishes is to be found in such areas.

Fortunately, all three plants can be effectively controlled with biological control agents (Henderson & Cilliers 2002), which should be employed wherever these weeds occur. *Eichhornia* has been controlled by a number of organisms, the most effective are the weevils *Neochetina bruchei* and *N. eichhorniae.* The weevils *Stenopelmus rufinasus* and *Cyrtobagus salviniae* have been used to control *Azolla* and *Salvinia*, respectively. Another floating plant, *Pistia stratioites*, can also become a pest species under certain circumstances but can also be controlled with a weevil, *Neohydronomus affinis*. Biological control should be integrated with other activities if it is to work effectively. For example, it has been suggested that a perceived increase in *S. molesta* in the Okavango Delta could be due to the eradication or reduction of biological control agents by the aerial spraying programme aimed at eradicating tsetse flies. The validity of this suggestion is unknown but some coordination could ensure that weevils were introduced annually after the effects of insecticide aimed at killing tsetse has dissipated.

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9.8.4 Pollution

Pollution is always a potential threat to most aquatic systems and can be difficult to deal with because it might originate a long way upstream from the affected area, possibly even in another country. Most of the Four Corners area is rural, with a relatively low population density and no major cities or industrial areas. Hence the incidence of water pollution is still low, although there are some areas of concern. These include:

- Sewage and general urban pollution from larger settlements is greater around the larger cities such as those of the Zambian copperbelt which may contaminate the Kafue River. Raw sewage discharged into the Zambezi River (from the towns of Victoria Falls and Livingstone) below Victoria Falls has caused severe contamination by faecal coli, even though it was originally thought that the volume of sewage effluent was small in relation to the flow of the river (Feresu & van Sickle 1990). This situation emphasizes the need to control urban effluents at an early stage of a town's development.

- The Kafue River has been severely contaminated by heavy metals from the mines on the Zambian copperbelt (Norrgren *et al*. 2000, Mwase 1994, Mwase *et al*.1998). These metals are highly toxic to fishes, particularly top predators, and as they accumulate up the food chain they pose a threat to humans as well. Other areas of concern include the coal mines in the Hwange District of Zimbabwe and the Southern Province of Zambia.

- Insecticides have been used extensively to eradicate tsetse flies (*Glossina* spp.) in the Okavango Delta (Fox undated, Fox & Matthiesson 1982, Morely & Taylor 1980). A variety of chemicals have been used, ranging from persistent ones like DDT to the less persistent deltamethrin and endosulphan, but their impact on non-target organisms has not been fully evaluated, apart from some work by Russell-Smith & Ruckert (1981). DDT, which is of particular concern because of its persistence and bio-accumulation, is still being used for mosquito control in the region but it is administered from backpacks and in very specific ways within villages. Thus quantities are substantially reduced compared to aerial spraying programmes and the movement to water bodies is more difficult.

Despite several short term and very specific studies the overall long-term impacts of pollution in the region has not been studied. As impacts from pollution are likely to increase with increasing human populations, and be only noticed decades from now, it is recommended that a long-term monitoring programme be established. The ultimate aim of this should be to reduce pollution levels and their impacts.

9.8.5 Sedimentation

Sedimentation is an essential natural process in rivers, but alterations to the rate of sedimentation can change the environment significantly and thus change the fish communities. Reduced sedimentation frequently occurs below dams and can lead to increased erosion of river channels and increase desiccation of downstream wetlands. This is believed to have happened below the Kariba and Cabora Bassa dams, for example. An increase in sedimentation is usually accompanied by a change in its composition, notably an increase in the inorganic components. This blankets the substrate and fills in crevices, as well as increasing the turbidity of the water. As a result, there is a reduction in surfaces for animals and plants to colonise, photosynthetic activity, the oxygen content of the water, and refugia for crevice-dwelling species and juveniles. All of these impacts reduce the diversity and biomass of all biota. Among the first fish species to disappear would be rocky habitat specialists such as *Amphilius* and *Chiloglanis* catfishes, mastacembelid eels and certain small minnows.

The extent to which sedimentation is a problem in the Four Corners area has not been assessed. Most of the terrain is flat and sandy and soil erosion may not be a serious problem, except in the Middle Zambezi where gradients are steeper and there is evidence that many rivers have been extensively silted up. It should also be noted that a decrease in sediment transport (for example by a dam) can have equally serious consequences, especially in the Okavango Delta where sedimentation is important in maintaining channels.

9.8.6 Climate Change

It is widely accepted that climates are changing, and that global warming has begun, but there is less agreement on what its consequences will be or how to deal with them. The impacts of climate change on the Four Corners area have not been determined and there is no consensus on whether the area will become wetter or drier. Predictions on the effects of climate change on fish populations can only be made with the use of sophisticated models such as the Vortex extinction-predicting model (Miller & Lacy 1999). It requires a considerable amount of biological data for each species being modelled, eg. reproductive system, age at first and last reproduction, maximum progeny produced per year, variance in recruitment between good and bad years, mortality rates, carrying capacity of habitats, harvesting levels, sanctuary areas. This level of information is simply not available for any fish species in the area and the meaningful use of such models seems unlikely in the near future. If an information base to do this kind of work was to be developed then species targeted for study should include habitat specialists, species with restricted geographical distributions and economically important species.

9.9 THE FOUR CORNERS AREA AND FISH CONSERVATION

A large trans-frontier conservation area (TFCA) has greater political status compared to smaller National Parks and, most importantly, large international conservation organizations may not be as influenced by local politics as national bodies might be. They also have greater access to international leaders, funders and scientists. There are consequently several important ways in which a TFCA can help the conservation of fish biodiversity:

a) Dams, water extraction and the introduction of exotic species are a major threat to fish biodiversity. Because of the linear nature of rivers, activities in one country can have a major impact on others (e.g. the introduction of *O. niloticus* into the Middle Zambezi) and there is usually insufficient consultation between countries about these matters. A TFCA could serve as a conduit for information and as a means of alerting government officials to these problems.

b) There appears to be a general lack of appreciation of such problems within fisheries departments, which are mostly orientated towards fisheries and aquaculture issues and not to conservation and biodiversity. A programme of environmental education, aimed at all fisheries officers, selected wildlife officers and other key decision makers from governments and NGOs, is therefore recommended. It should explain what biodiversity is present, what its value is and describe the threats it faces; periodic workshops to establish local programmes to monitor and evaluate the impact of these threats could be held from time to time. This in turn could spawn lower level progrmmes to reach local leaders, fishermen and other relevant resource users. AWF is ideally suited to arranging such education projects as part of the Four Corners programme.

c) The region supports active fisheries used by traditional, commercial and tourist fishermen, and aquaculture is also growing in importance. The five countries that share the region have different regulations and management policies, which has already been recognized as a problem by the shared waters working group (workshop proceedings, Kasane). Two obvious issues that should be considered are restrictions on fishermen's activities and on the introduction of exotic fish. Such issues become problematic when one country enforces a regulation and a neighbour does not; ideally all countries should agree on a common policy. A large protected area spanning the national boundaries could provide the higher political impetus for harmonising fisheries regulations. The TFCA should actively seek ways to provide the necessary political support to assist the individual fisheries authorities in each of the five countries to achieve these objectives.

d) Development schemes require experts to determine their impacts but local fisheries officers rarely possess these specialized skills. Such agencies as AWF could arrange for consultants to assess Envionmental Impact Assessment reports and give independent advice to governments. Two examples of how this could be done are:

i. The prefeasibility study examining a hydroelectric power scheme near the Popa Raids in Namibia is being conducted by Namibian authorities and consultants paid by Namibia. Independent experts could be contracted by the TFCA to assist the Botswana Government in assessing the highly technical study which will be produced by the prefeasibility team to ensure that the impacts on the Okavango Delta have been fully considered.

ii. Certain aid and development organizations in Africa have programmes that are not compatible with biodiversity conservation. This particularly applies to organizations that promote aquaculture and actively propagate *O. niloticus* (described as the "aquatic chicken"). High-level consultations with these organizations by a larger international organization are needed to explain the problems and concerns, and perhaps could change their activities. Of course the governments concerned should have a clear and consistent policy on these matters and organizations like AWF should assist them in formulating such policies.

One area of concern is that the TFCA, as it is presently defined, does not include the upper reaches of the Upper Zambezi systems where there are unique habitats with numerous endemic species of fish and other animals. They are also spawning areas for many other species which live most of their lives in the floodplains. Ideally, some means of incorporating the headwaters into the TFCA, or establishing protected areas within the headwater zone specifically to conserve aquatic biodiversity, should be sought.

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Appendix 9.1. Fish species from the Okavango, Upper Zambezi and Kafue river systems (from Skelton (2001) and unpublished museum records from SAIAB, AMG & NMZB). ● = indigenous species (present in the Four Corners area), ○ = indigenous species (absent from Four Corners area), ⦿ = indigenous species (absent from Okavango Delta, but present upstream), ▲ = exotic species (present in Four Corners area), △= exotic species (absent from Four Corners area), **?** = reported but doubtful.

	Okavango	Upper Zambezi	Kafue	Middle Zambezi
Protopteridae				
Protopterus annectens				○
Clupeidae				
Limnothrissa miodon			▲	△
Mormyridae				
Cyphomyrus discorhynchus	●	●		●
Hippopotamyrus ansorgii	○	○		
Hippopotamyrus sp.			●	
Marcusenius macrolepidotus	●	●	●	●
Mormyrops anguilloides				●
Mormyrus lacerda	●	●	●	
Mormyrus longirostris				●
Petrocephalus catostoma	●	●	●	
Pollimyrus castelnaui	●	●	●	
Pollimyrus sp.		●		
Paramormyrops jacksoni		○		
Anguillidae				
Anguilla bengalensis				●
Anguilla marmorata				○
Anguilla mossambicus				○
Kneriidae				
Kneria angolensis		○		
Kneria polli	●	●	●	
Parakneria fortuita	○			
Cyprinidae				
Barbus sp. (cf. *afrohamiltoni*)	○		○	
Barbus afrovernayi	●	●	●	●
Barbus annectens				○
Barbus barnardi	●	●	●	
Barbus barotseensis	●	●	●	
Barbus bellcrossi		○		
Barbus bifrenatus	●	●	●	
Barbus breviceps	○			
Barbus brevidorsalis	○	○	○	
Barbus eutaenia	⦿	●	●	
Barbus fasciolatus	●	●	●	●
Barbus haasianus	●	●	●	
Barbus kerstenii	⦿	●	●	
Barbus lineomaculatus	⦿	●	●	
Barbus kessleri		●		
Barbus mattozi	○	●		○
Barbus miolepis	○	○	○	
Barbus multilineatus	●	●	●	
Barbus neefi		○	○	
Barbus paludinosus	●	●	●	●
Barbus poechii	●	●	●	●
Barbus radiatus	●	●	●	●
Barbus thamalakanensis	●	●		
B. trimaculatus				○

	Okavango	Upper Zambezi	Kafue	Middle Zambezi
Barbus unitaeniatus	●	●	●	●
Barbus sp. (cf. *eutaenia*)	●	●	●	
Barbus sp. (cf. *viviparus*)		●		
Coptostomobarbus wittei	●	●	●	
Ctenopharyngodon idella			△	
Cyprinus carpio			△	△
Labeo altivelis				●
Labeo congoro				●
Labeo cylindricus	●	●	●	●
Labeo lunatus	●	●		
Labeo molybdinus				●
Labeobarbus codringtonii	●	●		
Labeobarbus marequensis				●
Mesobola brevianalis	◉	●		
Opsaridium zambezense	◉	●		●
Characidae				
Brycinus imberi				●
Brycinus lateralis	●	●	●	●
Hydrocynus vittatus	●	●		●
Micralestes acutidens	●	●	●	●
Rhabdalestes maunensis	●	●	●	
Distichodontidae				
Distichodus mossambicus				●
Distichodus schenga				●
Citharinidae				
Hemigrammocharax machadoi	●	●	●	
Hemigrammocharax multifasciatus	●	●	●	
Nannochrax macropterus	◉	●	●	
Neolebias lozii		●		
Hepsetidae				
Hepsetus odoe	●	●	●	●
Claroteidae				
Parauchenoglanis ngamensis	●	●		
Schilbeidae				
Schilbe intermedius	●	●	●	●
Schilbe yangambianus		○		
Amphiliidae				
Amphilius uranoscopus	◉	●		○
Leptoglanis rotundiceps	●	●	●	●
Leptoglanis sp.	●	●		
Leptoglanis sp.		●		
Malapteruridae				
Malapterurus shirensis				●
Clariidae				
Clarias gariepinus	●	●	●	●
Clarias liocephalus	○	○	○	
Clarias ngamensis	●	●	●	
Clarias stappersii	●	●	●	
Clarias theodorae	●	●	●	
Clariallabes platyprosopus	●	●	●	
Heterobranchus longifilis				●
Mochokidae				
Chiloglanis emarginatus				●
Chiloglanis fasciatus	○			
Chiloglanis neumanni		●	●	●
Synodontis leopardinus	●	●		

	Okavango	Upper Zambezi	Kafue	Middle Zambezi
Synodontis macrostigma	●	●	●	
Synodontis macrostoma	⊙	●	●	
Synodontis nigromaculatus	●	●	●	
Synodontis nebulosus				●
Synodontis. thamalakanensis	●	●		
Synodontis vanderwaali	●	●		
Synodontis woosnami	●	●		
Synodontis zambezensis				●
Aplocheilidae				
Nothobranchius kafuensis			●	
Nothobranchius sp.		●		
Cyprinodontidae				
Aplocheilichthys huteraui	●	●	●	
Aplocheilichthys johnstoni	●	●	●	●
Aplocheilichthys katangae	●	●	●	
Aplochelichthys sp.	●	●		●
Hypsopanchax jubbi		○		
Poeciliidae				
Poecilia reticulata			△	
Gambusia affinis				△
Mastacembelidae				
Aethiomastacembelus frenatus	●	●	●	
Aethiomastacembelus vanderwaali	●	●		●
Cichlidae				
Hemichromis elongatus	●	●		●
Oreochromis andersonii	●	●	●	
Oreochromis aureus			△	
Oreochromis mortimeri				●
Oreochromis macrochir	●	●	●	△
Oreochromis niloticus			▲	▲
Pharyngochromis acuticeps	●	●		●
Pharyngochromis sp.	?	●		
Pseudocrenilabrus philander	●	●	●	●
Sargochromis carlottae	●	●	●	●
Sargochromis codringtonii	●	●	●	●
Sargochromis giardi	●	●	●	●
Sargochromis greenwoodi	○			
Sargochromis mortimeri	●	●	●	
Sargochromis sp.		○	○	
Sargochromis sp.		●		
Serranochromis altus	●	●	●	
Serranochromis angusticeps	●	●	●	
Serranochromis longimanus	●	●		
Serranochromis macrocephalus	●	●	●	●
Serranochromis robustus	●	●	●	△
Serranochromis thumbergi	●	●	●	
Tilapia rendalli	●	●	●	●
Tilapia sparrmanii	●	●	●	●
Tilapia ruweti	●	●		
Anabantidae				
Ctenopoma multispine	●	●	●	
Microctenopoma intermedium	●	●	●	
Total	89	102	74	53
Total (Four Corners Area)	71	82	62	45

THE AWF FOUR CORNERS TBNRM PROJECT IS FUNDED BY USAID THROUGH THE REGIONAL CENTER FOR SOUTHERN AFRICA