

Biological basis of water quality assessment : the Kavango River, Namibia

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ABSTRACT

The Kavango River rises in the central highlands of Angola, flows south to form a 415 km border between Angola and Namibia, and then continues in a southerly direction another 65 km as the primary source of the Okavango Delta, Botswana. The central section of the river along the Namibia/Angola border is a characteristic low-gradient floodplain system; annual floods approach 6 m above normal stage, with the floodplain sometimes extending up to 5 km across. The river is critical to the daily living requirements of the Kavango people, most (85 %) of whom live within 10 km of the river at a subsistence level. Given the prospects of population increase, water development/diversion projects, land reallocation programmes, alteration of land use patterns and chronic drought, the Ministry of Fisheries and Marine Resources is developing baseline procedures to manage the system for the sustainable utilization of its resources, upon which the indigenous people are either directly or indirectly dependent. In this regard, a concerted effort is being made to establish a water quality monitoring protocol for Namibian waters based on biological criteria.

Instream biological criteria are a routine component of water quality monitoring programs in developed countries, but have been seldom utilized in less developed countries. One method which has received favorable use over the past 10 years in North America and Europe is the Index of Biotic Integrity (IBI). The IBI relies on the structural and functional components of the fish community as a reflection of overall aquatic system "health". A fish community assemblage data base obtained in 1992 is utilized to formulate the conceptual basis for an IBI for the Namibian portion of the Kavango catchment. Limitations of the procedure are recognized, and recommendations are given for the establishment of a similar protocol in other sub-Saharan countries.

KEYWORDS : Rivers — Tropical — Quality index — Africa — Angola — Namibia.

RÉSUMÉ

CRITÈRES BIOLOGIQUES DE LA QUALITÉ DE L'EAU : LE FLEUVE KAVANGO EN NAMIBIE

Le fleuve Kavango prend sa source dans les hauts plateaux d'Angola, se dirige vers le sud formant la frontière Angola-Namibie sur 415 km de direction Ouest-Est, et coule ensuite vers le sud pendant 65 km avant de former le delta de l'Okavango au Botswana. La portion moyenne de la rivière le long de la frontière est caractéristique des fleuves de faible pente des plaines d'inondation. Les crues sont d'environ 6 m au-dessus du niveau normal, avec un lit majeur de

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5 km de large. Le fleuve est vital pour les populations locales dont 85 % vivent à moins de 10 km du fleuve. Compte tenu des prévisions d'accroissement de la population, des besoins en eau, des programmes de redistribution des terres, de l'évolution des pratiques agricoles et d'une sécheresse chronique, le ministère des Pêches et des Ressources marines prépare les bases d'une gestion durable des ressources dont les populations locales sont directement dépendantes. C'est dans ce cadre qu'une recherche a été mise en place pour définir un protocole de suivi de la qualité des eaux en Namibie, protocole basé sur des critères biologiques.

L'utilisation de critères biologiques pour suivre la qualité des cours des rivières dans les pays tempérés est commune. C'est moins le cas pour les pays tropicaux. L'indice d'intégrité biologique (IBI) est utilisé depuis plus de 10 ans en Europe et en Amérique du Nord. Il permet une estimation de la santé d'une rivière par l'analyse de son peuplement de poissons. Des données sur le peuplement de la portion namibienne du Kavango, obtenues en 1992, sont utilisées ici pour base d'un indice approprié. Les limites de l'approche sont analysées et des recommandations pour son extension à d'autres pays au sud du Sahara sont présentées.

MOTS CLÉS : Fleuves — Milieu tropical — Indice de qualité — Afrique — Angola — Namibie.

INTRODUCTION

The World Conservation Strategy (IUCN, 1980) recognized that (a) conservation of resources and development are not incompatible, but indeed they are mutually dependent, and (b) unless development is guided by ecological, as well as by social, cultural and ethical considerations, it will continue to fail to meet or sustain its desired economic objectives. It is clear that development within emerging nations must not be at the sake of sustaining natural heritage (Hocutt *et al.*, 1992). Particularly for less developed countries, environmental policies that attempt to anticipate or predict significant economic, social and ecological impacts rather than react to them, are becoming increasingly necessary for the achievement of certain important goals: the satisfaction of basic needs, such as foods, clothing, sanitation and shelter; the development of a high quality environment; the optimum use of available resources; and the control of pollution and other forms of environmental degradation. Such anticipatory environmental policies involve actions to ensure that conservation and other environmental considerations are taken fully into account at the earliest possible stage of any decision that is likely to affect the environment (IUCN, 1980).

The review by Hocutt *et al.* (1992) drew parallels between the development of environmental assessment protocols for emerging nations with the evolution of the process in the USA, whose standards have been adapted worldwide. Notably, the National Environmental Policy Act (NEPA) of 1970 and the Federal Water Pollution Control Act (FWPCA) of 1972 as amended in 1977 and 1987 represents the key federal mandate for the maintenance and protection of water quality in the USA. NEPA established the environmental assessment process, and simultaneously created the U.S. Environmental Pro-

tection Agency (USEPA). The FWPCA provided specific recommendations to protect the integrity of the Nation's waters, primarily through the development of physico-chemical criteria or standards for the discharge of industrial effluents.

Through the mid-1980s, the USEPA relied heavily on physico-chemical guidelines to regulate industrial discharges and minimize impact in aquatic (receiving) systems. However, there was an increasing awareness that such guidelines, although valuable, often did not adequately reflect impact *in situ*. For instance, the USEPA recognized that biological impairment and loss of biotic integrity can result from sub-lethal or synergistic effects of pollutants not measurable by chemical and physical analyses alone (USEPA, 1990). For this latter and very important reason, the Water Quality Act of 1987 amendment to the FWPCA of 1972/1977 specifically authorized the USEPA to require all U.S. states to adopt narrative biological criteria as a part of their water quality standards. This signified a shift in environmental assessment and regulation philosophy, i.e., a move from "discharge pipe criteria" to receiving-system impact.

Hocutt *et al.* (1992) summarized that virtually all water resource development projects on the African continent have either failed to meet their stated objectives, and/or had socio-cultural and ecological impacts that were not predicted beforehand. Many African cultures live at subsistence levels and are highly dependent upon the quality and quantity of adjacent aquatic resources as a means of survival, yet the continent is experiencing accelerated alterations in land use and water quality impacts. Common impacts have included destruction of biodiversity, forests and traditional farms; social disruption, including separation of traditional family or ethnic groups, resettlement into unacceptable areas, land reallocation, and inundation of culturally-

important sites; destruction of traditional fisheries; desertification; salinization; alterations in water quality and quantity, including downstream impacts; accumulation of agro-chemicals; and health and disease (see GOLDSMITH and HILDYARD, 1984; TIMBERLAKE, 1985). Knowledge of pre-developmental aquatic system conditions is crucial if long-term resource utilization is an objective (BREEN *et al.*, 1984).

It is a premise of our presentation that the establishment of biological monitoring protocols is an extension of, and complementary to, biodiversity surveys which are often aimed toward natural heritage programs. We present the conceptual basis for the development of an Index of Biotic Integrity (IBI) for the Kavango River, following the model of KARR (1981). We recommend that African states adapt water quality monitoring strategies to facilitate the management and sustainable utilization of their respective aquatic resources.

Kavango River

The Kavango River rises in the southern highlands of central Angola as the Cubango River, flows in a southeasterly direction along the Namibia/Angola border for ca. 415 km, and continues another 65 km as the primary source of the Okavango Delta, Botswana (fig. 1). The Delta is considered one of the true natural wonders of the world, however this does not preclude various regional plans in Angola, Botswana and Namibia to utilize the river's vast water resources, averaging $10,500 \times 10^6 \text{ m}^3$ per year at the Botswana border (BALDWIN, 1991). Such plans have included Botswana's Southern Okavango Integrated Water Development Project (SOIWDP) and Namibia's Eastern National Water Carrier (ENWC) system (ANONYMOUS, 1992). However, in the case of Botswana, plans for the SOIWDP were canceled once an independent environmental assessment was performed (IUCN, 1992).

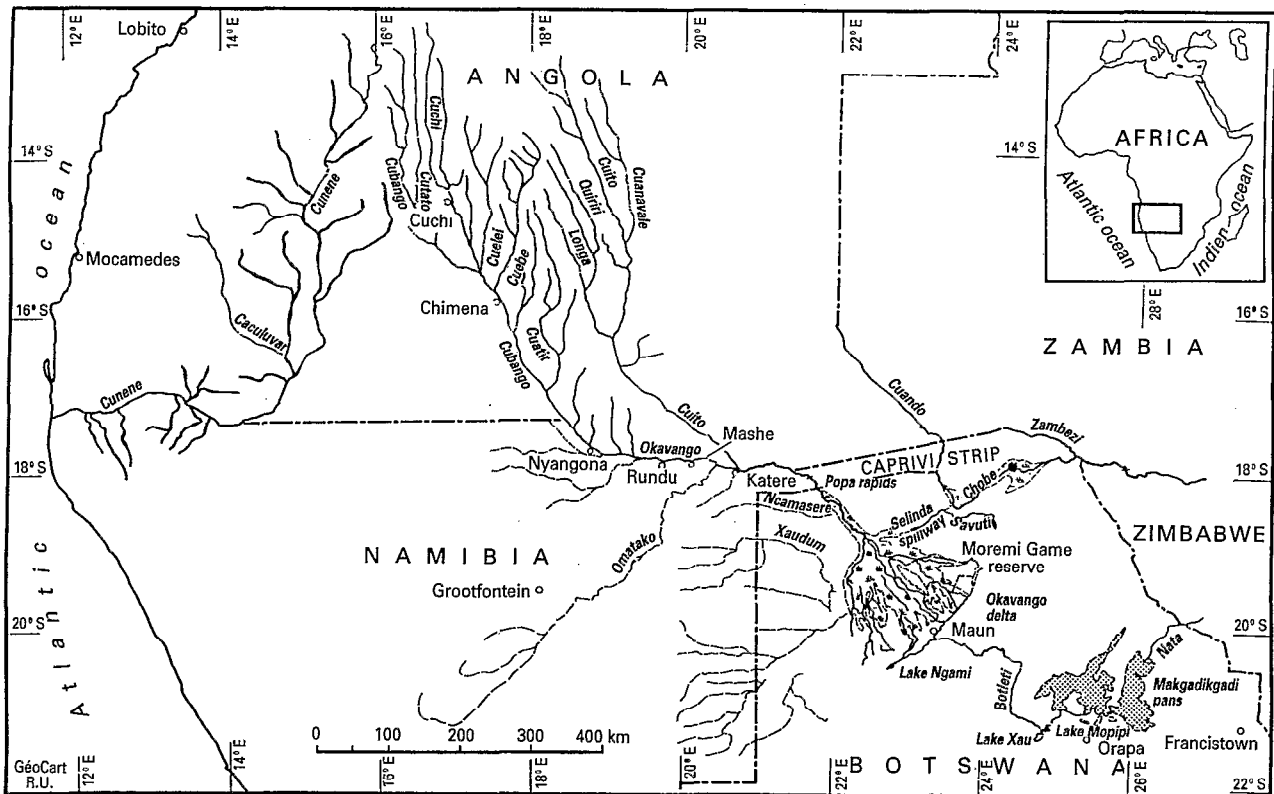


FIG. 1. — Drainage map of the Kavango River basin (from SKELTON *et al.*, 1985).
Le bassin du fleuve Kavango (d'après SKELTON *et al.*, 1985).

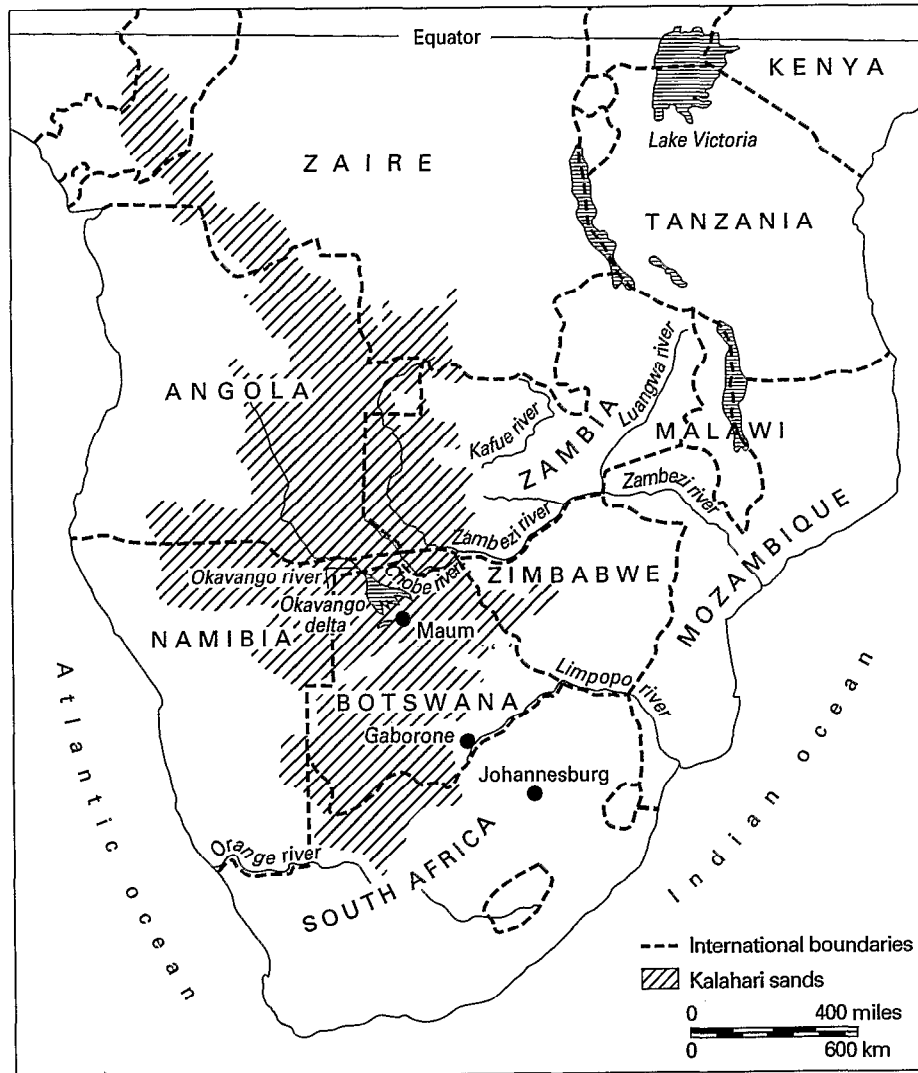


FIG. 2. — The Kalahari Desert biome in southern Africa (from Ross 1987).
Le biome du désert du Kalahari en Afrique australe.

The Kavango River remains a rather unspoiled catchment in a western world context, with minor human impact in Namibia other than through organic enrichment and riparian zone mismanagement. Watershed development has thus far been retarded; however, with political normalization of the region, various water and terrestrial resource utilization schemes are likely to be considered for the catchment. Presumably, the cumulative effect of developmental projects will significantly impact the seasonally fluctuating flood-driven processes of the Kavango River, with subsequent adverse effects on

the quality and quantity of the catchment's water resources.

Put in terms of the indigenous human population, the region is a focus for drought relief aid, being within the Kalahari Desert biome (fig. 2) with an average annual rainfall of <20 cm. Over 85% of the 150,000 Kavango people are considered subsistence wage earners, and live within 10 km of the river (SANDLUND and TVEDTEN, 1992); the population is expected to double over the next decade. The Kavango people are dependent upon the river as a protein source (the fishery), for potable water sup-

plies, bathing and livestock watering. Thus, development activities which are likely to alter the productivity of the system by upsetting the balance between floodplain submergence/exposure will have a profound impact on the local populace. This dependence upon the river is further compounded by the Angolan war to the north, resulting in an increasing number of refugees seeking shelter and relief along the border area and in Namibia.

Knowledge of the seasonal structure and functioning of the floodplain fishery is largely anecdotal. However, given the shifting sand substrate of the river bed, annual productivity is linked to the flooding cycle and its effects on the littoral zone. The river experiences peak flooding February through April, filling extensive floodplains along the Namibian/Angolan border, where the gradient is minimal (fig. 3). Flooding in the lower Okavango Delta lags river flooding by up to 6 months. The floodplain in Namibia is up to 5 km across as annual floods wax and wain. It is the temporary littoral zone which is identified by high macrophyte growth and secondary productivity. The littoral zone vegetation serves as nesting areas, feeding zones and refugia for most fish species. The vegetation itself acts as a mineral and nutrient sink, with Kavango water having minimal levels of conductivity (e.g., <40 umhos) and nutrients during flooding conditions.

As the Namibian Ministry of Fisheries and Marine Resources (NMFMR) seeks solutions to manage the fishery in light of increasing demand, knowledge of the status of the fishery resource and its seasonal variability is an exceptionally important baseline

data requirement. Given (a) the likelihood of implementation of various water diversion/utilization schemes proposed for the future in the drainage, (b) increasing population, (c) the prospects of land reform policy in Namibia (ADAMS *et al.* 1990), which will alter land use patterns and potentially lead to increased overgrazing and desertification; and (d) continued chronic regional drought, it is similarly prudent to commence the conceptual development of a methodology to assess their probable long-term synergistic impact.

Current aquatic resource concerns in southern Africa

GAIGHER *et al.* (1980) listed four major threats to threatened fishes in South Africa's Cape Province: (1) farming and short-sighted land use practices, (2) introduction of exotic fish species, (3) human settlement, mining and industrial development and (4) dam and weir construction. SKELTON (1983) emphasized that the destruction of habitat is clearly the most significant threat to southern African aquatic environments and their respective organisms by stating that... "It is not only realistic but true to say that habitat destruction is becoming more and more evident in southern Africa as the human population grows". Ten years have passed since that statement, and conditions have not improved.

Presently, the Kavango River is relatively free of perturbations related to development projects and modern industrialization. The current state of the Kavango may be deemed fairly pristine (via qualita-

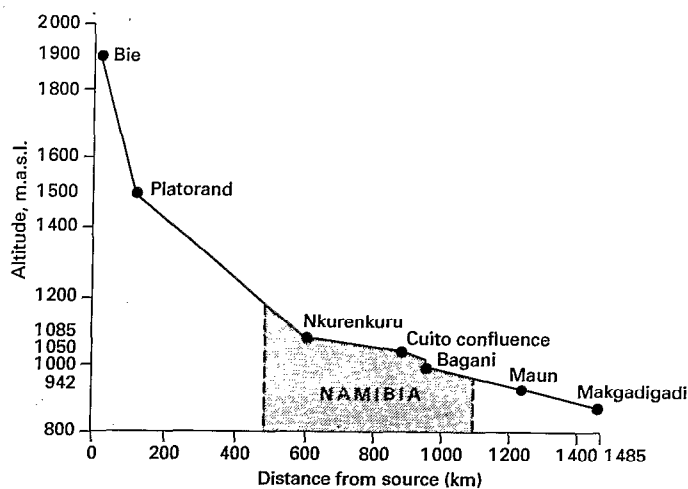


FIG. 3. — Longitudinal gradient profile of the Kavango River basin (from SANDLUND and TVEDTEN, 1992).
Profil longitudinal du bassin du fleuve Kavango (d'après SANDLUND et TVEDTEN, 1992).

tive observations) in areas of sparse human population (e.g. upstream where the river initially forms the Angolan/Namibian border near Katwitwi; downstream near the Botswana border in the region of the Mahongo Game Reserve) and modestly degraded in areas near the river's population centers (e.g. Rundu, Bagani). Factors directly contributing to aquatic habitat degradation in the Kavango River include the effects of livestock grazing (erosion, increased turbidity, demolished aquatic and terrestrial vegetation beds), organic enrichment from human and animal inputs, flow modifications and agro-chemical disturbances.

Especially in highly populated areas, herds of livestock along the river's edge can be observed grazing the banks and floodplain habitats, and tromping through backwater pools (VAN DER WAAL, 1991). Increased suspended particulate loads would be expected in these areas of overgrazing, resulting in turbid conditions that may disrupt photosynthesis and destroy benthic habitats. The destruction of riparian vegetation from both cattle grazing and the artisanal method of trampling weed beds for fish harvesting certainly contribute largely to the visibly unstable river banks. Not only do these practices impinge upon the river's primary source of productivity, they also negate the riparian vegetative zones' ability to stabilize river bank structure. VAN DER WAAL (1991) suggested that large-scale soil erosion in densely populated areas may cause deeper oxbows and side channels to fill with sediment, thus minimizing the available refugia for fishes.

Present flow modification schemes such as small-scale irrigation systems and construction of canals for livestock watering pose no real problems currently due to their minimal nature. However, in the event of larger-scale implementation of water diversion projects or impoundment construction such as the Eastern National Water Carrier system in Namibia, the effects of such practices can be considered far-reaching as downstream users are indirectly impacted, the physical stability of the watercourse is altered and the biota is disrupted (APPLETON *et al.*, 1986). The balance between submergence and exposure in floodplain areas is altered both spatially and temporally in instances where the natural hydrologic regime is deviated (BREEN *et al.*, 1984), resulting in loss of habitat when floodplains are deprived of flood waters. Less well known are the secondary, often synergistic effects on the biotic components, water quality and channel morphology, which perhaps operate on relatively long time scales (O'KEEFE, 1986). In the case of the Great Fish River in South Africa, modified flow regimes resulted in the alteration of invertebrate community structure and the translocation of fish species (CAMBRAY and JUBB,

1977; LAURENSEN and HOCUTT, 1986; O'KEEFE and DE MOOR, 1988).

Chemical pollution, although currently not a major threat to the aquatic fauna of the Kavango River, can be considered a prominent factor in the destruction of southern African aquatic habitats and the consequential deleterious effects on fish communities (SKELTON, 1983). The decimation of entire fish populations have been attributed to chemical pollutants, e.g., cattle dip in the Hluhluwe River drainage of South Africa (BROOKS and GARDINER, 1980) and the adverse effects of endosulfan insecticide application has been reported for both fish and birds in the Okavango Delta (DOUTHWAITE, 1982; MATTHIESSEN and ROBERTS, 1982).

The introduction of non-native species is another major threat to the indigenous freshwater fishes of southern Africa. SKELTON (1983) stated that endemic species with restricted distributions are especially vulnerable to predation by recreational species such as trout (*Salmo* spp.) and blackbass (*Micropterus* spp.), which have been introduced throughout South Africa. Presently, there are no known exotic species in the Kavango River proper, but HOCUTT and JOHNSON (*in press*) reported two established species in a spring of the intermittent Omatako sub-drainage.

Biological monitoring

Ecologists have used aquatic biota to monitor water quality since the pioneering efforts of KOLKWITZ and MARSSON (1908, 1909) and FORBES (1928). Since that early work, the concept of biological monitoring has been greatly refined with a general trend away from the indicator species concept towards an integrated, community-based approach (PATRICK, 1949; CAIRNS, 1974; HOCUTT, 1975). One such integrated methodology currently in vogue in North America to quantify the empirical relationships between land use and stream health via fish communities is the Index of Biotic Integrity (IBI), first formulated by KARR (1981).

HERRICKS and SCHAEFFER (1985) defined six criteria that must be met to validate instream biomonitoring programs: (1) the unit of measurement must be biological; (2) the unit must be interpretable at several different trophic levels, either directly or indirectly through the food chain; (3) the unit must be sensitive to environmental alterations; (4) the unit must have a wide degree of sensitivity to changing conditions; (5) the unit of measurement must be well defined and reproducible over space and time; and (6) the variability of the unit of measurement must be low. KARR *et al.* (1986) presented evidence that the IBI meets all these conditions, and with regards

to the last criterion, noted that variation may either be a consequence of sampling bias, a natural phenomenon or anthropogenic affect. As they quote HERRICKS and SCHAEFFER (1985), "The concern is not that a measure be variable, but that the nature of the variability be well understood".

Various taxonomic groups of organisms have proven useful in monitoring water resource quality. For instance, SIEGFRIED (1988) analyzed lake acidification problems in relation to planktonic community structures. Aquatic macrophytes assisted in classifying and determining trophic status in lakes (CANFIELD *et al.*, 1984). An amphibian diversity component aided in assessing coastal streams in northern California (MOYLE *et al.*, 1986). Macroinvertebrate community groups are commonly used as cursory indicators of lotic system quality (HOWMILLER and SCOTT, 1977; SCHAEFFER *et al.*, 1985). PLAFKIN *et al.* (1989) presented the conceptual basis for a rapid bioassessment protocol (RBP) that stresses benthic community composition and function. The RBP approach is championed by many authorities despite the reservations of CUMMINS (1991).

The use of fish communities to biologically assess stream condition and health, i.e., biotic integrity, is now in common practice in North America and Europe (e.g., HOCUTT, 1985, 1988; HOCUTT and STAUFFER, 1980; KARR *et al.*, 1986; ANGERMEIER and SCHLOSSER, 1987; STEEDMAN, 1988; FAUSCH *et al.*, 1984, 1990; OBERDORFF and HUGHES, 1992). A substantial literature base exists for various anthropogenic effects, including aquatic resource degradation through stormwater runoff, stream burial, channelization, thermal pollution, land use practices, mining activities, siltation, organic and inorganic pollution. Guild-based approaches have allowed for insight into structural and functional community-level fluctuations as well as indications of the extent of degradation in aquatic systems (KARR, 1987).

The rationale for use of fish communities in biological monitoring programs is strongly stated, including: (1) The taxonomy, ecological requirements and life history aspects of fishes are generally better known than for other phyletic groups; (2) Through their ontogenetic development, fish occupy a variety of trophic levels and habitats; (3) Different components of the fish community, and their life stages, are sensitive to a number of different sources of environmental degradation, including both the direct and indirect effects of stress; (4) In general, fish are at the top of the aquatic foodchain, and thus are integrators of temporal and spatial alterations in ambient environmental conditions; and (5) Importantly, the fish community has both economic and aesthetic values which can be assigned to it, thus it commands attention from both the public and

government agencies responsible for the sustainable utilization of the aquatic resources of the (particular) catchment. All of these reasons have particular relevance in a developing country context, where other aquatic communities (e.g., macroinvertebrates) are poorly documented and where persons living at the subsistence level are dependent upon the local water resources to meet their daily living needs, including the fishery as a protein resource.

KARR's (1981) original Index of Biotic Integrity (IBI) was constructed for Midwestern USA streams, and integrated 12 attributes of fish assemblages to determine biotic integrity or "health" of the system (tabl. I). Categories of attributes (metrics) included species richness and composition, trophic structure, and fish abundance and health. Each metric reflected the quality of a different portion of the fish community that responds in a different manner to the functioning of an aquatic ecosystem (FAUSCH *et al.*, 1984). The combination of metrics was subsequently refined to reflect insights from individual, population, community, ecosystem, and zoogeographic perspectives (MILLER *et al.*, 1988). The primary underlying assumptions of the IBI concept are presented in Table II.

The conceptual basis of the IBI has been constantly revised since its introduction (e.g., KARR *et al.*, 1986; MILLER *et al.*, 1988; FAUSCH *et al.*, 1990), and now is a standard for the National instream water quality monitoring program of the USA Environmental Protection Agency (USEPA, 1990). The application of the principles of the IBI have also been introduced to Canada (STEEDMAN, 1988) and Europe (OBERDORFF and HUGHES, 1992). The IBI concept is not without its limitations (HOCUTT 1981, 1988; KARR *et al.*, 1986; FAUSCH *et al.*, 1990). However, the beauty of the IBI concept is that it incorporates the principles of community structure and function into an index measurement of stream health. Additionally, the tenets of the IBI can be modified to meet individual catchment or regional needs. An appealing aspect of the IBI is that one does not lose information in its calculation, i.e., the constituent metrics are available for further analysis.

With the expected technological and economic constraints of developing countries, freshwater resource monitoring and assessment strategies in Africa are not highly prioritized and in most cases are nonexistent. In South Africa, however, there have been studies regarding aquatic resource monitoring, dating back to HARRISON (1958, 1961), OLIFF (1960) and ALLANSON (1961). CHUTTER (1972) used benthic macroinvertebrate faunal diversity to formulate a biotic index for assessing the degree of organic pollution in South African rivers; this sys-

TABLE I

The original Index of Biotic Integrity (IBI) metrics proposed by KARR (1981)
Les unités de l'Indice d'Intégrité Biotique proposées initialement par KARR (1981)

Category	Metric
Species richness and composition	1. Total number of fish species
	2. Number and identity of darter species
	3. Number and identity of sunfish species
	4. Number and identity of sucker species
	5. Number and identity of intolerant species
	6. Proportion of individuals as green sunfish
Trophic composition	7. Proportion of individuals as omnivores
	8. Proportion of individuals as insectivorous cyprinids
	9. Proportion of individuals as piscivores (top carnivores)
Fish abundance and condition	10. Number of individuals in a sample
	11. Proportion of individuals as hybrids
	12. Proportion of individuals with disease or other anomalies

tem has been updated recently and is known as the South African Scoring System No. 2 (SASS2) (KLEYNHANS *et al.*). T. D. Harrison and his co-workers (pers. commun) have modified RAMM's (1988, 1990) community degradation index into a multi-disciplinary, environmental-based health index for over 50 South African estuaries. CAMBRAY *et al.* (1988)

listed all the long-term data sets regarding aquatic resources of southern African water-bodies to date, remarking that very few have been synthesized or analyzed for long-term trends related to either natural climatic fluctuations or anthropogenic effects. More recently, DAVIES *et al.* (1993) summarized some notable case histories for South African catchments.

TABLE II

Underlying assumptions of the Index of Biotic Integrity (IBI) concerning how stream fish communities change with environmental degradation (after FAUSCH *et al.*, 1990)

L'évolution attendue de l'Indice d'Intégrité Biotique lors d'une dégradation de l'environnement (d'après FAUSCH et al., 1990)

- (1) The number of all native species and those in specific taxa or habitat guilds declines
- (2) The number of intolerant species declines
- (3) The proportion of individuals that are members of tolerant species increases
- (4) The proportion of trophic specialists such as insectivores and top carnivores declines
- (5) The proportion of trophic generalists, especially omnivores, increases
- (6) Fish abundance generally declines
- (7) The proportion of individuals in reproductive guilds requiring silt-free coarse spawning substrate declines
- (8) The incidence of externally-evident disease, parasites and morphological anomalies increases
- (9) The proportion of individuals that are members of introduced species increases
- (10) The incidence of hybrids may increase

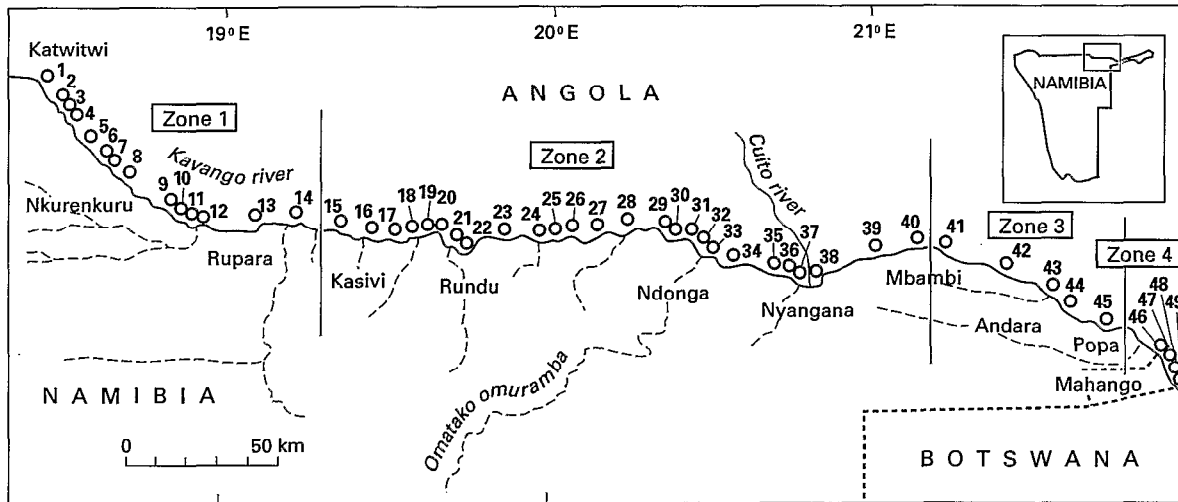


FIG. 4. — The Kavango River area of study, with zonal divisions and sampling locations in 1992.
La division zonale du fleuve Kavango, avec les stations échantillonnées en 1992.

MATERIAL AND METHODS

Study area

From the northern border within Namibia, the Kavango River can be divided into four zones based on the occurrence of extended floodplain and associated habitats (VAN DER WAAL, 1991; VAN ZYL, 1992), substrate and characteristic riparian vegetation (SMITH, 1976; BETHUNE, 1990) (fig. 4). Zone 1, from Katwitwi to Kasivi, is characterized by very little floodplain development and mostly shallow-water environments with sand and/or rock substrates. Small rapids are scattered throughout, with prevalent submergent vegetation and aquatic weed beds in a rather well defined river bed. In Zone 2, from Kasivi to Mbambi, the floodplain becomes well developed, extending at times to over 5 km in breadth (SANDLUND and TVEDTEN, 1992). The main river is wider here, seasonally broadening into innumerable inferior channels, back bays and oxbow ponds (fig. 5). The substrate in the main river is predominantly sand with the occasional occurrence of rock outcroppings. The back bays and oxbow ponds occur as a rule over submerged pasture-land. Zone 3, from Mbambi to Popa Falls, finds the floodplain diminished, with wooded islands encircled by narrower channels. Bedrock, large boulder and gravel substrates associated with rapids are common in this area. Zone 4 below Popa Falls, including the Mahango Game Reserve, is characterized by well

established reed and papyrus beds that are permanently inundated and considered as the uppermost "panhandle" portion of the Okavango Delta proper (VAN DER WAAL, 1987). For the purposes of comparing spatial and seasonal fish assemblage variability as it is reflected with the proposed biological criteria, the focus is concerned with Zones 1, 2 and 3.

Methodology

Fish community samples were taken from 80 localities during five collecting periods along the Kavango River in 1992. A high but increasing flood stage was observed in February which peaked before May and receded until December, 1992 when the river began rising again. Sampling localities were initially chosen based on accessibility, with emphasis given to re-sampling the sites within each collecting period (see figure 4 for a distribution map of sampling localities). However, this proved at times to be impossible given that the character of the river and its floodplain varied throughout the year, thus for the purpose of screening river sections to create a monitoring protocol, locations that were in close proximity (± 1.5 km) to one another in each zone were sometimes lumped as a single location. Exact locations of longitude and latitude were triangulated with a Magellan 1000-Plus Global Positioning Satellite (GPS) hand-held unit.

Sampling was conducted on a seasonal basis with 5 sampling periods throughout 1992. A total of

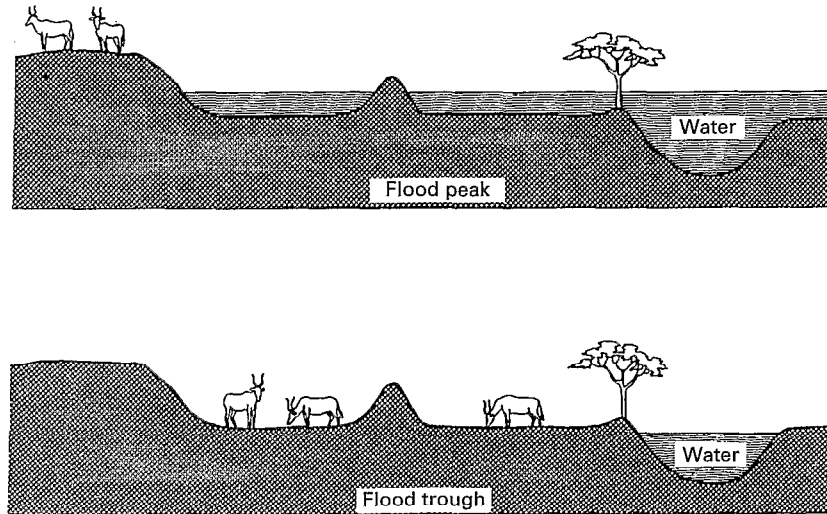


FIG. 5. — Schematic diagram of floodplain river (from FORRESTER *et al.*, 1989).
 Diagramme schématique d'une plaine d'inondation (d'après FORESTER *et al.*, 1989).

TABLE III

Percent (%) occurrence and percent (%) of total catch for each species collected from the Kavango River, 1992. *See below for occurrence ranking

Pourcentage d'occurrence et pourcentage de la prise totale de chaque espèce capturée dans le fleuve Kavango en 1992

Species	% Occurrence	% Total Catch	Species	% Occurrence	% Total Catch
<i>Hippopotomys ansorgii</i>	10.00%	0.14%	<i>Clarias gariepinus</i>	18.75%	0.18%
<i>Hippopotomys discorhynchus</i>	11.25%	0.18%	<i>Clarias ngamensis</i>	25.00%	0.25%
<i>Marcusenius macrolepidotus</i>	27.50%	0.63%	<i>Clarias theodorae</i>	12.50%	0.13%
<i>Mormyrus lacerda</i>	11.25%	0.12%	<i>Chiloglanis fasciatus</i>	12.50%	0.20%
<i>Petrocephalus catostoma</i>	33.75%	1.41%	<i>Synodontis spp.</i>	53.75%	2.12%
<i>Pollimyrus castelnaui</i>	38.75%	0.92%	<i>Schilbe intermedius</i>	41.25%	2.03%
<i>Brycinus lateralis</i>	35.00%	1.45%	<i>Aplocheilichthys hutereaui</i>	25.00%	0.65%
<i>Hydrocynus vittatus</i>	18.75%	0.63%	<i>Aplocheilichthys johnstoni</i>	82.50%	6.21%
<i>Micrallestes acutidens</i>	43.75%	6.29%	<i>Aplocheilichthys katangae</i>	7.50%	0.18%
<i>Rhabdalestes maunensis</i>	3.75%	0.06%	<i>Hemichromis elongatus</i>	11.25%	0.15%
<i>Hepsetus odoe</i>	5.00%	0.05%	<i>Oreochromis andersonii</i>	43.75%	2.90%
<i>Hemigrammocharax machadoi</i>	10.00%	0.18%	<i>Oreochromis macrochir</i>	5.00%	0.04%
<i>Hemigrammocharax multifasciatus</i>	33.75%	1.37%	<i>Pharyngochromis acuticeps</i>	75.00%	5.04%
<i>Nannocharax macropterus</i>	1.25%	0.01%	<i>Pseudocrenilabrus philander</i>	86.25%	13.44%
<i>Barbus afrovenayi</i>	17.50%	0.52%	<i>Serranochromis angusticeps</i>	15.00%	0.20%
<i>Barbus annectens</i>	3.75%	0.03%	<i>Serranochromis carlottae</i>	1.25%	0.01%
<i>Barbus bamardi</i>	16.25%	0.91%	<i>Serranochromis codringtonii</i>	12.50%	0.21%
<i>Barbus barotseensis</i>	8.75%	0.25%	<i>Serranochromis giardi</i>	3.75%	0.03%
<i>Barbus bifrenatus</i>	37.50%	2.38%	<i>Serranochromis macrocephalus</i>	51.25%	1.72%
<i>Barbus eutaenia</i>	30.00%	1.74%	<i>Serranochromis robustus jallae</i>	60.00%	1.05%
<i>Barbus fasciolatus</i>	15.00%	0.83%	<i>Tilapia rendalli</i>	80.00%	10.82%
<i>Barbus haasianus</i>	3.75%	0.16%	<i>Tilapia ruweti</i>	18.75%	2.49%
<i>Barbus lineomaculatus</i>	8.75%	0.35%	<i>Tilapia sparrmanii</i>	80.00%	8.11%
<i>Barbus multilineatus</i>	3.75%	0.08%	<i>Ctenopoma multispinis</i>	7.50%	0.24%
<i>Barbus paludinosus</i>	27.50%	3.76%	<i>Aethiomastacembelus frenatus</i>	5.00%	0.03%
<i>Barbus poechii</i>	62.50%	6.11%	<i>Aethiomastacembelus vanderwaali</i>	10.00%	0.11%
<i>Barbus radiatus</i>	28.75%	3.10%			
<i>Barbus thamalakanensis</i>	43.75%	2.78%			
<i>Barbus unitaeniatatus</i>	8.75%	0.53%			
<i>Coptostomabarus wittei</i>	1.25%	0.01%			
<i>Labeo cylindricus</i>	27.50%	1.98%			
<i>Labeo lunatus</i>	3.75%	0.03%			
<i>Opsaridium zambezense</i>	27.50%	2.21%			
<i>Amphilius uranoscopus</i>	6.25%	0.11%			
<i>Leptoglanis dorae</i>	3.75%	0.03%			
<i>Leptoglanis rotundiceps</i>	1.25%	0.01%			
<i>Parauchenoglanis ngamensis</i>	8.75%	0.13%			

* Commonness ranking in text based on the following criteria:

Rank	Range
very common	> 75.0%
common	40-74.9%
fairly common	25-39.9%
uncommon	10-24.9%
scarce	5-9.9%
rare	< 5.0%

TABLE IV

Percent (%) of total catch for each family or group of fishes per Kavango River zone
Importance de chaque famille ou groupe d'espèces (en % de la prise totale) dans chaque zone du fleuve Kavango

Fish Family or Group	Zone 1	Zone 2	Zone 3	Zone 4	Total
Cichlids	44.5	53.3	30.0	15.6	46.2
Cyprinids	19.0	28.7	42.3	30.2	27.8
Characins	16.4	4.8	4.8	6.4	8.4
Cyprinidonts	8.1	6.2	3.7	35.9	7.0
Siluriforms	7.0	4.3	8.8	1.7	5.2
Mormyrids	3.5	2.0	8.1	3.5	3.4
Citharines	0.9	1.7	2.1	3.5	1.6
Anabantids	0.0	0.3	0.2	3.5	0.2
Mastacembelids	0.4	0.04	0.1	0	0.1
Hepsetids	0.1	0.03	0.1	0	0.1

14 families, 33 genera and 63 species were collected (the taxonomically difficult catfish of the genus *Synodonis* are treated here as a single species). The relative occurrence (% occurrence) and relative abundance (% total catch) of each species is indicated in Table III. The percent of total catch per zone (upper, floodplain, lower) for each family or group of fishes is indicated in Table IV. The following discussion is structured such that each family of fishes (or group) is addressed in descending order of total relative abundance.

Biological criteria based on fish community assemblages were developed for assessing the Kavango River. Regional ichthyological literature (JUBB, 1967; POLL, 1967; VAN DER WAAL and SKELTON, 1984; BELL-CROSS and MINSHULL, 1988) and personal observation, were the cornerstone for developing the biological criteria for a Kavango River IBI. Diet, habitat preferences and ecological requirements for all species known from the Kavango River were characterized (HOCUTT and JOHNSON, 1992). There was no trophic discrimination between the different life stages of the individual taxa (STAUFFER *et al.*, 1978; KARR *et al.*, 1986).

Fish sample collections were obtained using a variety of gears, dependent upon water levels and habitats encountered. The primary objective was to obtain a representative sample (HOCUTT, 1978) of the fish communities within the localized habitats, with each collection terminating only after no new species were found with continued use of gear(s) employed.

In backwater areas, with slow to stagnant flow conditions and dense aquatic vegetation, the ichthyocide rotenone was the primary collecting tool. The technique normally involved mixing powdered rotenone with water and a small amount of dish soap to enhance the solubility of the powder. The mixture

was then broadcasted into the habitats, and after a few moments the stunned fish would be netted after they began to surface. During minimal flow conditions and if deemed appropriate, a seine net would sometimes be placed at a defined point to collect any fishes drifting with the current.

In shallow-water flowing habitats, especially with gravel and sand substrates, a 3 × 1.5 m seine net with 5-mm mesh was the collecting gear of choice. The seine would be dragged along the substrate, vigorously poked into weed beds, or plunged and swept over fish visible through the clear water. In the case of shallow flowing waters with gravel and submerged aquatic vegetation, the "cast and kick" seining method was used. Dubbed the "Yankee-doodle dance" by an amused spectator, P. H. Skelton, this technique calls for casting the net in a downstream direction, anchoring it in the substrate, and thoroughly disturbing the gravel and plant material by kicking and churning up the bottom. Often times if called for, seining was done to supplement a rotenone collection, and vice versa.

Attempts were made to use a Coffelt 12-v gas-powered backpack, a Smith-Root model VII 24-v battery-charged backpack, and a Coffelt 700-watt boat/shore-mounted electrofishing units to sample fishes. All these units were found to be ineffective due to the low conductivity encountered, with exceptions being in higher flow, rocky habitats. The normal protocol with the backpack unit was to shock in an upstream direction probing the substrate and aquatic vegetation with the meshed end of the anode pole, with the dip netter following close behind collecting stunned fish.

Other fish collecting methods also were used occasionally such as wire-mesh minnow traps employed at camp site collecting localities. In the evening, four

traps would be baited with bread, tethered to shoreline vegetation, casted out and retrieved the following morning. An experimental gill net with four different mesh sizes was used sparingly to collect larger rheophilic fish; it was set either overnight or for several hours before retrieval. A 30 × 1.5 m bag seine with 70-mm mesh was occasionally used in turbid backwaters. Some collections were supplemented by using a large beach seine (5 × 25' with 5 × 5' bag of .25" mesh), while simple dip netting was employed under other occasions. Angling, the remaining sampling method used, was selective for the more predatory species, such as tigerfish (*Hydrocynus vittatus*). Light to medium weight spin-casting rigs or fresh-cut bait were used either from boat or shore.

Fishes were preserved in 10 % formaldehyde immediately after collecting and stored at least ten days for proper hardening. The samples were then rinsed with freshwater for several days before transfer to 70 % ethyl alcohol. All specimens were donated to the State Museum of Windhoek for cataloguing and permanent storage.

Seasonal data interpretations presented below are based exclusively on relative abundance, i.e., numbers of each taxa collected. Data are presented in an annotated fashion, with parallel discussion of relevant literature emphasizing the works of BELL-CROSS and MINSHULL (1988) and VAN DER WAAL and SKELTON (1984). Species are ranked on the basis of their relative abundance; however it is understood that fish collecting is a qualitative and gear-selective procedure that might mask the conclusions presented.

RESULTS

Fish community samples (tabl. 3-4) from the Kavango River were used to formulate the preliminary measurements (or metrics) based on faunal attributes regarding species richness and composition, trophic structure, abundance and condition. The metrics proposed to characterize the status of the Kavango River fish assemblage are listed in Table V, and with the variation of each metric summarized by river zone and season in Tables VI and VII, respectively.

Proposed metrics for IBI

SPECIES RICHNESS AND COMPOSITION

Faunal composition and species richness were assessed using four metrics designed to monitor overall biodiversity and habitat-specific fish assemblages.

TABLE V

List of proposed biological criteria metrics used to characterize and assess tropical floodplain river systems
Liste des variables proposées pour caractériser et analyser les systèmes fleuve-plaine d'inondation tropicaux

Species Richness and Composition

- (1) Total number of native fish species
- (2) Total number of benthic specialist species
- (3) Total number of cichlid species
- (4) Total number of pelagic-rheophilic species

Trophic Composition

- (5) Proportion of individuals as principal herbivores and detritivores
- (6) Proportion of individuals as principal invertivores
- (7) Proportion of individuals as opportunistic scavengers
- (8) Proportion of individuals as piscivores

Fish Abundance and Condition

- (9) Total number of individuals in a sample
- (10) Total number of exotic and introduced species
- (11) Proportion of individuals with visible anomalies

Metric 1 : Total number of native fish species. — This was included as a general indication of relative biodiversity, with the rationale being that species richness will decrease with increased environmental degradation. KARR (1981) proposed this metric for midwestern U.S. stream fish assemblages; others retained it (see MILLER *et al.*, 1988) in various regional North American applications, and OBERDORFF and HUGHES (1992) included it in their characterization of the Seine River basin in France. While this metric has shown wide applicability in temperate waterways, there is no reason why its basic premise would not hold true in tropical systems.

Metric 2 : Total number of benthic specialist species. — This replaces the number of darter species metric of KARR (1981) while retaining its original intent of assessing benthic habitat conditions. Such substrate habitats are known to be degraded by the effects of siltation (KARR *et al.*, 1986), which is a major concern regarding southern African lotic water resources (GAIGHER *et al.*, 1980; SKELTON, 1983). The fish to be included in this metric are defined as those with specific biological requirements adapted for benthic habitats. When assessing southern African fauna, the following groups should be included in this metric; *Labeo* spp. (small, benthic dwelling species of this cyprinid genus), Amphiliidae (mountain catfish), Bagridae (grunter catfish), *Chiloglanis* spp. (members of this Mochokidae catfish

TABLE VI

Summary values for each proposed metric on a zonal scale
Valeurs proposées des variables pour l'étude zonale

Metric	Minimum			Average			Maximum		
	Zoné 1	2	3	1	2	3	1	2	3
Number of native fish species	8	2	10	17	14	18	30	30	24
Number of benthic specialist species	0	0	0	1	0+	1	5	4	1
Number of pelagic rheophilic species	0	0	0	2	1	1	4	4	4
Number of cichlid species	2	0	2	6	5	6	9	9	8
Proportion (%) of individuals as principal herbivores/detritivores	2.2	0.0	3.7	25.0	30.5	25.1	59.4	90.6	88.8
Proportion (%) of individuals as principal invertivores	27.8	0.0	7.8	67.9	59.5	63.7	95.3	87.2	92.0
Proportion (%) of individuals as opportunistic scavengers	0.0	0.0	0.0	5.2	3.8	9.0	41.1	25.0	36.0
Proportion (%) of individuals as piscivores	0.0	0.0	0.0	2.0	6.1	2.2	5.5	67.0	8.4
Number of individuals in sample	47	8	61	192	214	160	555	769	266
Proportion (%) of individuals as introduced or invasive species	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Proportion (%) of individuals with visible disease or anomalies	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0+	0.0

genus specifically adapted for rocky habitats) and Mastacembelidae (spiny eels). Benthic specialists of the Kavango River included in the calculation of this metric are the following species: *Labeo cylindricus*, *Amphilius uranoscopus*, *Leptoglanis dorae*, *L. rotundiceps*, *Parauchenoglanis ngamensis*, *Chiloglanis fasciatus*, *Aethiomastacembelus frenatus*, and *A. vanderwaali*.

Metric 3: Total number of cichlid species. — This metric replaces the number of sunfish species metric of KARR (1981) keeping its intent of measuring the degree of degradation of submerged vegetation, which members of the cichlid family generally inhabit. There are 17 cichlid species known from the Kavango River in Namibia, all of which should be included when tallying this metric; 14 were collected in this survey (tabl. IV).

Metric 4: Total number of pelagic rheophilic species. — This new metric is designed to assess open-water flowing areas by monitoring the number of species inhabiting such habitats. Degradation of open-water flowing habitats should be reflected by a decrease in pelagic rheophiles. Species to be examined in calculation of this metric include the majority of the characins (*Brycinus lateralis*, *Hydrocynus vittatus*, and *Micralestes acutidens*) and the cyprinid *Opsaridium zambezense*.

TROPHIC STRUCTURE

Alterations in habitat and water quality due to land use practices often result in food resource fluctuations in aquatic systems, which are reflected in the structural changes in trophic composition (KARR

TABLE VII

Summary values for each proposed metric on a seasonal scale
Valeurs proposées des variables pour l'étude saisonnière

Metric	Season	Minimum					Average					Maximum				
		Feb	May	June	Sep	Nov	Feb	May	June	Sep	Nov	Feb	May	June	Sep	Nov
Number of native fish species		5	2	5	11	7	13	15	20	18	15	23	26	30	26	24
Number of benthic specialist species		0	0	0	0	0	0+	0+	1	2	1	1	2	5	4	4
Number of pelagic rheophilic species		0	0	0	0	0	2	1	1	1	2	4	3	3	2	3
Number of cichlid species		2	0		2	2	6	5	6	5	6	7	8	9	7	9
% herbivores/detritivores		3.9	0.0	0.0	12.6	1.1	37.0	24.1	17.0	24.0	32.7	90.6	85.5	59.4	32.7	81.0
% invertivores		0.0	14.5	37.1	24.4	7.8	58.3	70.4	72.0	64.9	51.7	91.4	95.3	91.8	79.5	81.5
% opportunistic scavengers		0.0	0.0	1.2	0.7	0.0	1.3	3.6	8.7	8.6	6.5	5.5	22.3	35.6	34.5	41.1
% piscivores		0.0	0.0	0.0	0.0	0.0	3.4	1.9	2.3	2.5	9.1	9.4	9.4	4.2	8.4	67.0
Total individuals		37	53	8	61	43	174	260	221	149	158	561	758	769	285	299
% introduced/invasive species		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% with disease or anomalies		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

et al., 1986). Four metrics were developed to monitor these fluctuations in tropical floodplain rivers.

Metric 5 : Proportion of individuals as principal herbivores/detritivores. — This new metric is used to assess the quality of the aquatic system food base at the primary level. Fishes to be included in this group are defined as those with diets known to comprise primarily plant material, plankton, detritus and algae. Members of this dietary assemblage found in the Kavango River include : *Labeo cylindricus*, *L. lunatus*, *Oreochromis andersonii*, *O. macrochir*, *Tilapia rendalli*, *T. ruweti*, and *T. sparrmanii*.

Metric 6 : Proportion of individuals as principal invertivores. — Designed to assess the secondary or invertebrate food base, this is similar to those modified from KARR's (1981) original metric proportion of insectivorous cyprinids (see MILLER *et al.*, 1988). Principal invertivores are defined as those fish with diets primarily consisting of aquatic larvae, insects, crustaceans and mollusks. With the absence of stomach analysis data for most of the tropical fish fauna in southern Africa, species with unknown feeding

preferences having mouth and lip morphology suggesting invertebrate diets were included in this group. Invertivorous cyprinids dominate the Kavango River fish biodiversity.

Metric 7 : Proportion of individuals as opportunistic scavengers. — This is similar to KARR's (1981) percent omnivore metric in that the proportion of opportunists is thought to increase as degradation disrupts the food web by limiting or decreasing available food base components. Members of this group are fishes known to show catholic feeding behavior or feeding plasticity. The following Kavango River species are designated as opportunistic scavengers : *Clariallabes platyprosopos*, *Clarias dumerilii*, *C. gariepinus*, *C. ngamensis*, *C. stappersii*, *Parauchenoglanis ngamensis*, *Schilbe intermedius* and *Synodontis* spp.

Metric 8 : Proportion of individuals as piscivores. — This original metric of KARR's (1981) is retained to assess trophic diversity at the top of the food chain. Fishes are deemed piscivores if as adults their diet is comprised primarily of fish, while as

juveniles invertebrates may be their food items of choice. The following list includes all fishes of the Kavango River used in the calculation of this metric: *Hydrocynus vittatus*, *Hepsetus odoe*, *Serranochromis allis*, *S. angusticeps*, *S. macrocephalus*, *S. robustus* and *S. thumbergi*.

ABUNDANCE AND CONDITION

Relative abundance and fish health of populations are evaluated using the following three metrics, all of which are based on those proposed by KARR (1981).

Metric 9: Number of individuals in a sample. — This metric evaluates sample abundance as it relates to catch per unit of sampling effort. The logic behind this is that with similar sampling methods and effort, degraded sites are expected to harbor fewer individuals than sites with higher quality conditions (KARR *et al.*, 1986).

Metric 10: Proportion of individuals as introduced or invasive species. — This is similar to metrics modified to replace KARR's (1981) original percent hybrids (MILLER *et al.*, 1988), but is unique in that it includes native invasive species. The rationale behind this is that since the Kavango River proper is absent of both exotic and regionally invasive species (SKELTON *et al.*, 1985; VAN DER WAAL, 1991), the initial effects of exotics on the native fish assemblage structure can be monitored and documented, e.g., if indeed *Trichogaster trichopterus* and *Astyanax orthodus* are successful in colonizing the river proper from the Omatoko sub-drainage (HOCUTT and JOHNSON, *in press*). The obvious assumption here is that the integrity of native fish communities is compromised when foreign species have invaded or are introduced.

Metric 11: Proportion of individuals with visible anomalies. — This metric is a direct evaluation of fish health, and is retained from KARR (1981). Any individuals observed to have disease, deformities, lesions and tumors are included in the calculation of this metric.

Seasonal and spatial trends

SPECIES RICHNESS AND COMPOSITION

Metric 1: Total number of native fish species. — On a longitudinal basis, this metric yielded higher values in the non-floodplain zones, with the greatest median and average relative species richness in zone 3. Seasonally, species richness was found to be lowest in the February, May and November sampling periods, while on the average the June effort yielded the most species per collecting site. It was during this period when the most diverse collections were obtained, with two samples of 30 species each, from

zones 1 and 2, respectively. The least diverse collection was obtained during May in zone 2, harboring only two species.

Metric 2: Total number of benthic specialist species. — As to be expected, these species occurred most frequently in the non-floodplain zones, with zone 3 showing the highest frequency of appearance (over half of all samples). Benthic specialists were rarely found in zone 2, as over 75 % of all collections within that zone were absent of these species. Almost 50 % of the Zone 1 samples contained members of this group. The September collecting period found the highest incidence of occurrence of these species, with 70 % of all samples having benthic specialists. The most species of this group (5) collected at any one site occurred in Zone 1 during June.

Metric 3: Total number of pelagic rheophilic species. — Zone 1 found the highest relative species occurrence of this group, with 2 species collected per site on the average and over 80 % of all samples containing at least one pelagic rheophile. Zone 2 had the lowest relative frequency of occurrence, with just over 50 % of all collections having a member of this group. The pelagic rheophilic group peaked in relative frequency during the February and November sampling periods, with 2 species obtained per collection on the average. The May sampling effort yielded the lowest relative incidence regarding this group, with over half the collections absent of any pelagic rheophiles. The maximum possible number of pelagic rheophilic species (4) was obtained in all three zones exclusively during the February sampling period.

Metric 4: Total number of cichlid species. — On a longitudinal basis, this metric showed no trends as relative occurrence of cichlid species was quite similar from zone to zone on the average. Basically, the same can be said regarding seasonal comparisons, as averages and medians barely fluctuate from period to period. The May sampling effort, however, indicates a slight decrease in the median value. A single collection was absent of any cichlids, obtained during May in zone 2. The maximum number of cichlids collected in any one sample (9) was taken from zone 1 (twice in June) and zone 2 (once in both June and November).

TROPHIC COMPOSITION

Metric 5: Proportion of individuals as principal herbivores and detritivores. — The medians and averages for this trophic group are roughly constrained within the 20 to 30 % range for the three zones, with zone 3 showing slightly higher relative values than the other two. Temporally, herbivore and detritivore proportions show two distinct modal

groupings : (1) February, September and November, and (2) May and June. The former sampling periods portray a consistency in their medians, which are confined to the 25 to 30 % range, while the latter are markedly lower, approximating the 15 percentile. Furthermore, these latter sampling periods each contain a single sample completely lacking any members of this dietary assemblage, both of which occurred within zone 2. The maximum relative proportion of herbivore/detritivore feeders was found in zone 2 during the February effort, comprising over 90 % of the entire sample.

Metric 6 : Proportion of individuals as principal invertivores. — The median and average range over all three zones for this trophic group is roughly between 60 and 75 %, with Zones 1 and 3 slightly higher relative to Zone 2. A seasonal trend is revealed when comparing the proportion of invertivores to the proportion of herbivores/detritivores (fig. 6). The May and June efforts, which harbored the lowest proportion of the latter, yield the highest proportion of the former relative to the other sampling periods. The invertivore assemblage during May and June ranged between 70 and 78 % based on medians and averages, while the remaining periods ranged from roughly 50 to 67 %, with the November effort yielding the lowest relative proportion for this group. February of zone 2 harbored the only collection absent of principal invertivores, while the maximum proportion obtained was during May within zone 1

where this dietary assemblage comprised over 95 % of a single collection.

Metric 7 : Proportion of individuals as opportunistic scavengers. — Based on both medians and averages, the proportion of this group peaked in zone 3, while zones 1 and 2 were fairly similar and slightly lower. Throughout the year, on average the proportion of this group per sample ranged from a low in February (1.3 %) to highs in June and September (over 8 %). Collections lacking opportunistic scavengers were obtained most frequently in February, while all samples in June and September contained some members of this group. The highest proportion of this feeding group from a single collection was found in a November sample from zone 1, where this opportunist assemblage comprised over 40 % of all individuals.

Metric 8 : Proportion of individuals as piscivores. — Zone 2 was found to harbor the highest relative proportions of piscivorous fishes based on both median (3.0 %) and average (6.1 %), while the other zones ranged between 1.5 to 2 % for these parameters. Seasonally, fish eaters were most prevalent during the November sampling period where two collections yielded piscivore proportions over 20 %, and one sample was comprised of 67 %; these three samples were all obtained within zone 2. Each zone and each sampling period found collections absent of this group, with zone 2 and May sampling efforts having higher relative incidence of this result.

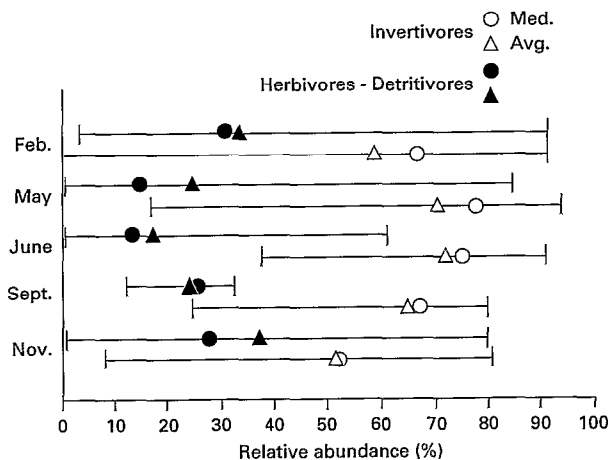


FIG. 6. — Seasonal trophic composition in relative abundance for principal invertivore and herbivore-detritivore feeding groups.

Variations saisonnière de la composition trophique pour les principaux herbivores-détritivores et insectivores.

ABUNDANCE AND CONDITION

Metric 9 : Number of individuals in sample. — The range of average values along the Kavango River for this metric spanned from 160 in zone 3 to 214 in zone 2. On a seasonal basis, the average number of individuals peaked during the May effort and bottomed out during the September sampling period. The smallest and largest number of individuals collected from any single site (8 and 769 specimens, respectively) were both obtained from zone 2 in June. The results of this metric are simply general indications of relative abundance and nothing more, as they are not calculated as a function of catch per unit of sampling effort.

Metric 10 : Proportion of individuals as introduced or invasive species. — No introduced species are known from the Kavango River proper at the present time.

Metric 11 : Proportion of individuals with visible anomalies. — After examining over 14,000 individuals, only a single specimen (juvenile *Oreochromis andersonii*) collected in November within zone 2 was found with a visible anomaly (ectoparasite).

DISCUSSION

Inherent within fluctuating systems such as seasonal rain driven, tropical floodplain rivers, there are difficulties regarding assessment and characterization. As opposed to lotic systems in temperate climates with characteristic steadfast processes, relatively speaking (see VANNOTE *et al.*, 1980), tropical floodplain rivers are much less stable and unpredictable (LOWE-McCONNELL, 1987; DAVIES *et al.*, 1993), perhaps tending towards community states without structure (O'KEEFE, 1986).

CAMBRAY *et al.*, (1988) perceived that aquatic organisms adapted to very constant and predictable conditions may become recognizably different within a year or two of a minor change, while those of a highly fluctuating system might not react perceptibly over many generations. As data sets regarding fluctuations in natural tropical systems (i.e. water quality) are either nonexistent or un-synthesized (CAMBRAY *et al.*, 1988), monitoring the impacts of natural variability and catastrophic events is impossible since knowledge of baseline conditions has not been achieved. CAMBRAY *et al.* (1988) theorized that the effects of anthropogenic interference on the long-term cycles of inland aquatic biota on the continent are often obscured by non-foreseen natural processes (e.g., unpredictable and inequitable distribution of rainfall). This emphasizes the point that natural disturbances and those of anthropogenic origin must be discernible to properly understand cause and effect relationships relating to degradation and biotic response (DAVIES *et al.*, 1993). It has been generalized that in the case of southern African systems, changes due to anthropogenic disturbances exceed those due to normal annual events, while natural abnormal catastrophic events can alter the aquatic environment to a similar degree (CAMBRAY *et al.*, 1988).

The proposed IBI metrics derived to characterize the Kavango River fish fauna (tabl. V) were highly variable, both spatially and temporally (tabl. VI and VII). To summarize : (a) *of the four species richness metrics*, (1) the average number of species was highest in Zone 3, and highest in June. (2) The number of benthic species peaked in September, 70 % of all samples, with highest numbers generally occurring in Zone 3. These species were absent in 75 % of the Zone 2 collections. (3) The pelagic species numbered highest in Zone 1, lowest in Zone 2, and seasonally were found in greatest numbers in February and lowest in May. (4) The number of cichlid species showed the same basic trends seasonally and longitudinally ; (b) *amongst the trophic metrics*, (5) the percentage of herbivores and detritivores was generally the highest in February, September and November samples (20-

30 % of the total), and lowest in May and June (± 15 %). (6) The number of invertivores varied inversely with the herbivores and detritivores (fig. 6), with the highest relative numbers (70-78 %) in May and June. They were reasonably well distributed across all three zones (60-75 %). (7) The opportunistic scavengers peaked in Zone 3. They were present in lowest numbers in February, and highest in June and September (8 %). (8) Piscivores, especially tigerfish, were probably under-sampled, but seemingly occurred in highest percentages in Zone 2, and in November ; and (c) *of the abundance and condition metrics*, (9) numbers of specimens, peaked in May, but were distributed evenly longitudinally. Metrics (10) numbers of introduced and invasive individuals and (11) those fish with anomalies, each were considered representative of a near-perfect state with only one specimen of fish observed with an anomaly.

The variability in the metrics noted for the Kavango above contrasts considerably to STEEDMAN'S (1988) excellent study of Ontario streams ; the low variation he observed for sampling stations within and between years is a desirable asset of IBI scoring, while high variability can imply low resolution of the index. We interpret the variability as natural, which, ideally, will influence the sampling protocol in future studies, e.g., standardizing sampling gear, stations and time of year.

These data indicate a pronounced structural response of the fish community in relation to the alternating flood and drought conditions in the river (e.g., fig. 3), with lowest diversity and fewest numbers of specimens occurring during the low flow months, October to December. It also appears that the reproductive strategies of some Kavango fishes are in advance of flooding (e.g., cichlids) while other species (e.g., many cyprinids) are in sync with flooding and the stimulation of littoral zone plant growth. These observations concur with the synthesis of LOWE-McCONNELL (1987) that could be used to predict that many Kavango floodplain fishes will exhibit (a) greatly fluctuating populations, (b) short life cycles with early maturation and rapid growth, and (c) seasonal reproductive cycles, with predominate r-type selection.

Given the shifting sand substrate of the river bed, it can be assumed that productivity is driven by the annual flooding of the littoral/riparian zone and the consequent promotion of growth of higher vegetation (WELCOMME, 1979). Phytoplankton productivity is considered negligible in the Kavango, but the true significance requires assessment. The high macrophyte growth in the littoral zone serves as nesting areas, feeding zones and refugia for most fish species with few having a true affinity for the more

open structureless mid-channel. The Co-PIs have defined the floodplain zone of the Kavango as longitudinally encompassing approximately 375 km of the river.

The River Continuum Concept of VANNOTE *et al.* (1980) serves as the current general model of longitudinal structure and functioning of lotic systems. However, JUNK *et al.* (1989) provided insight to the functioning of floodplain rivers through their manuscript outlining the Flood Pulse Concept, which recognized that flooding is the major "driver" of lowland or floodplain rivers. The concept implies that the frequency, magnitude, and rates of rise and fall of flooding will be reflected in the ecological character of the associated biota (DAVIES *et al.*, 1993). JUNK *et al.* (1989) defined the floodplain as an Aquatic-Terrestrial Transition Zone (ATTZ), that excludes permanent lotic and lentic habitats within the zone of inundation, thus emphasizing the floodplain as an area of alternation of wetting and drying phases (DAVIES *et al.*, 1993).

The variability in the Kavango is compounded by three distinct zones of different physiographic features of the stream bed, the channel, substrate and littoral zone formation, all influencing fish structure and function as well as sampling bias. Thus, it is premature to finalize criteria for the Kavango based on a single year's effort; however, this data base is extremely useful for serving as a baseline and refining a monitoring protocol after continued sampling.

HOCUTT (1981) first drew attention to the limitations of the IBI concept, and recommended that the inherent difficulties of obtaining a representative sample should not be minimized, especially in a developing country context. Factors which influence this concern are (a) the qualitative nature of sampling, (b) gear selectivity, and (c) experience, training and motivation of the personnel involved. Additionally, it should be recognized that biota are seasonally abundant or scarce dependent upon ecological and life history requirements, including (a) migratory habits, (b) reproductive strategies, (c) habitat preferences, (d) behavior, e.g., some species might be nocturnal, (e) longitudinal zonation, and (f) zoogeographic considerations. Importantly, most species pass through different trophic levels during their ontogeny (WINEMILLER, 1991), and this must be a long-term consideration in refining an IBI model (STAUFFER *et al.*, 1978; KARR *et al.*, 1986).

Added to these general limitations are others which apply to most African countries: (1) a limited or modest data base on the life history of regional fishes not targeted for commercial enterprise (the latter always receive priority); (2) a void of information on fish community structure and function, and

(3) how these parameters are affected by natural variability (longitudinally and seasonally) within the system; and (4) the often expansive catchments, encompassing two or more countries with different management priorities and agenda. Another limitation is (5) the sheer number of indigenous species in many African catchments, numbering >700 species in the Zaire River system (SKELTON, 1993).

From the perspective of systematics and biogeography, the taxonomy of many species in sub-Saharan Africa is under review, and often difficult (GREENWOOD, 1983). Additionally, many species have discontinuous or disjunct distributions resulting from either physical (CRASS, 1962), ecological (JACKSON, 1962) or behavioral (BELL-CROSS, 1965) barriers. GAIGHER and POTT (1973) listed other possible causes of discontinuity such as range constriction due to competition, extermination by predation and catastrophic destruction of fish-life in intermediate areas. Historic climate change yielding adverse conditions (low temperatures, and aridity) has resulted in distribution gaps and isolation of African fishes species (SKELTON, 1980). These factors in addition to those above will hinder the construction of an IBI.

It is highly desirable to establish routine monitoring and assessment procedures for Africa's inland waters (e.g., see KLEYNHANS *et al.*, 1993). However, techniques such as the calculation and use of the rather sophisticated IBI may be restricted, as noted by our data base and the other limitations listed above. For this reason, certain African countries lacking taxonomically trained personnel or adequate resources, may want to devise a simplistic approach for use in their regional waters. J. Cairns and his co-workers (CAIRNS *et al.*, 1968; CAIRNS and DICKSON, 1971) demonstrated several years ago in the construction of a Sequential Comparison Index (SCI) that the consistency of taxonomic identification is more important than systematic preciseness when constructing community-based indices of stream health. The SCI was developed as a simple rapid procedure for analyzing aquatic community data based on the visual similarity of a specimen being compared to another. It was found that even persons without training in biology could recognize different taxonomic groupings of organisms based on gross anatomical features, and this information could be adapted to calculate a "diversity" index for the sample being examined.

It is apparent for floodplain rivers such as the Kavango that sampling efforts need to be coupled with certain flow characteristics or flood stage over a period of many years to ascertain the status and condition of faunal assemblages, and whether a somewhat fixed community structure exists

(O'KEEFE, 1986). Emphasis should also be given to sampling in coincidence with biotic processes such as growth stage and reproductive intervals (CAMBRAY *et al.*, 1988), so as to track environmental conditions as related to fish community life histories. Furthermore, the development of standardized sampling methodology will give more meaning to faunal comparisons on both intra- and inter-drainage scales.

As KLEYNHANS *et al.* (1993) noted for the Transvaal, RSA, many sub-Saharan catchments have been sufficiently impacted that it is difficult to reconstruct what represents a pristine condition, or to establish control stations. Additionally, it is difficult to judge which species are sensitive or tolerant to various categories of ecosystem disturbance. KLEYNHANS *et al.* (1993) attempted to overcome these problems by evaluating parameters such as known distribution patterns, habitat and flow requirements, and relative commonness, in relation to the historical data bases. Their philosophy is based largely on the recommendations by the USEPA (PLAFKIN *et al.*, 1989) for implementing rapid bioassessment protocols to screen for "troubled waters".

CAIRNS (1981) observed that biological assessment and monitoring of inland waters can be expected to pass through four developmental phases: (1) awareness, (2) observational, (3) predictive and (4) managerial. He noted that developed countries are at the predictive stage, but conceded that present practices had proven inadequate for the prediction of effects or the validation of the predictions. KARR (1987, 1991, 1994), however, considered that aquatic ecologists were at the threshold of predictive capability, and defended the science by drawing analogies to the U.S. Bureau of Economics 80% failure rate to predict even the sign of change of the nation's gross national product, despite having a massive data base and powerful economic models. WELCOMME (1979a) implied that a $\pm 25\%$ precision should be an objective of predicting the effects of environmental change on fisheries.

The biological criteria for aquatic resource assessment proposed in this investigation for the Kavango River is regarded by no means as definitive, and by all means preliminary. As the first attempt to characterize a floodplain river system by the structure, function and condition of its resident fish community assemblages, this work is considered as a base line model to build on in the face of continuing environmental degradation and resource disparagement. As biologists become more familiar with ecological requirements and tolerance responses, those species which prove to be indicative of particular disturbances will be revealed, and the IBI biocriteria model can be shaped and evolved into a more effective monitoring tool.

This does not preclude the fact, however, that other procedures which were historically used in the Northern Hemisphere, but recently discarded in favor of the IBI approach, should be re-evaluated for their utility in African states and other developing countries, e.g., the Jaccard coefficient (HOCUTT *et al.*, 1974), species richness indices (PIELOU, 1975) or Sequential Comparison Index (CAIRNS and DICKSON, 1971). This is especially so given the various limitations of the IBI procedure noted above, which are compounded in Africa due to limited skilled manpower, variable environmental conditions influencing monitoring procedures, and general anecdotal state of knowledge on aquatic community structure and functioning. The objective should be to evaluate established models, and to adapt them to the national or regional need to establish a relatively simple rapid procedure for screening and monitoring water quality.

SUMMARY

The establishment of aquatic resource monitoring protocols in African states should not be viewed as an academic exercise. All continental rivers either have modified flow regimes or land use-associated impacts. Given the likelihood of increased water resource utilization, stream alterations, development activities, population expansion, riparian zone modifications, global warming and so forth, it is prudent to consider long-term water quality surveillance programs for all catchments. As stated in the introductory remarks, such programs should be considered complementary to, and an expansion of, biodiversity surveys aimed toward the documentation of natural heritage. As summarized by the World Conservation Strategy (IUCN, 1980), sustainable development and the maintenance of natural systems are mutually dependent processes.

Some of the first steps to establish a biomonitoring protocol are as follows: (1) Reference stations are mandatory, thus the initial screening of prospective "control" sites is required; (2) Effort, gear, methodologies and personnel should be standardized; (3) Basic research on life history strategies of fishes, and their structural and functional attributes in relation to the ambient environment is a critical need. If possible, seasonal sampling efforts should be conducted during flooding, peak flooding, post flooding and low flow conditions to establish natural variability; (4) Various biotic indices need to be evaluated on a case-by-case basis, and refined to meet specific needs. No single index is universally free from bias (USEPA, 1990); (5) Biotic information should be

supplemented by physico-chemical data where possible; and (6) Importantly, inter-basin management plans should be established by respective countries for all catchments since most bisect international boundaries, and there is a genuine need to avoid a "tragedy of the commons" (HARDIN, 1968).

ADDENDUM

This manuscript was presented as part of the Proceedings of the International Symposium on Biological Diversity in African Fresh and Brackish water Fishes (PARADI), Dakar, Senegal, 15-20 November 1993.

The senior author noted during his presentation that the symposium was significant in that it would serve as a benchmark of aquatic resource monitoring activities in Africa. For instance, three additional presentations considered the modification of the Index of Biotic Integrity (IBI) for regional application: G. P. Ganda (Sierra Leone), A. Kamdem Toham *et al.* (Cameroon), and T. Oberdorff (general overview). Several other presentations also considered fish community impacts from anthropogenic sources: W. O. Alegbeleye and P. E. Anyanwu (Nigeria), F. W. B. Bugenyi (Uganda), A. Cohen *et al.* (Lake Tanganyika), P. de Rham (Madagascar), I. Doadrio and A. Machordom (North Africa), T. D. Harrison *et al.* (South Africa), E. F. B. Katunzi (Tanzania), J. W. Lewis *et al.* (*ex situ* monitoring), G. S. Merron (Okavango Delta), and M. L. J. Stiassny (Madagascar), among others. Added to this were various reviews which highlighted the impacts of exotics and fish transfers: S. A. O. Dache (Lake Victoria), P. de Rham and M. L. J. Stiassny (Madagascar), M. Gophen *et al.* (Lake Victoria), R. Lowe-McConnell *et al.* (the Great Lakes), R. Ogutu-Ohwayo and M. Bruton (general overview), J. P. Olowo and R. Ogutu-Ohwayo (Uganda), and B. C. W. van der Waal (Namibia). It is apparent that the door has been opened for the

continued development of water resource assessment and bio-monitoring protocols amongst African states!

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