



Ecological research on South African rivers – a preliminary synthesis

J H O'Keeffe

A report of the Committee for Nature Conservation Research
National Programme for Ecosystem Research

SOUTH AFRICAN NATIONAL SCIENTIFIC PROGRAMMES REPORT NO

121

1986

Issued by
Foundation for Research Development*
Council for Scientific and Industrial Research
P O Box 395
PRETORIA
0001
South Africa
from whom copies of reports in this series are available on request.

Printed in 1986 in the Republic of South Africa

ISBN 0 7988 3802 7

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PREFACE

Rivers in southern Africa have undergone radical man-derived changes through the last century. These have been clearly measurable changes in aspects such as water volume, water quality and flow regulation. In functions such as materials transport and hydrological recharge, the changes have been apparent but seldom quantified. In other aspects such as species diversity and community dynamics, change has usually been so subtle as to be more often assumed than measured.

These changes have been paralleled by similar or even greater perceptual changes as to the value of rivers to man. It is only recently during the "dry cycle" of below average rainfall years that the general public has been made to realize the truly limiting nature of our rivers-dominated water supply system. These changes have been mirrored directly by recent scientific research into rivers. The current overwhelming concern is for water and the economic problems of its supply to urban areas. This has given rise to the neglect of investigations into the ecological functioning of rivers. The value of rivers as dynamic habitats for important biotic communities and species; their ability to reflect the environmental health of catchments; their role as sites for important ecological processes such as migration of plants and animals, nutrient transport and detoxification, are all topics deserving of serious research attention.

Rivers, as habitats with unique ecological characteristics, present a special challenge to conservation managers. They do not fit any of the conventional management models developed for the conservation of protected areas or species. They are subject to the environmental impacts of every major event that might take place anywhere within an entire catchment, including the vagaries of our highly variable climate. In addition all major catchments are subject to the indisputable primary requirement of water for people. Accommodating all these factors is not possible without compromise. It is also not possible without the skilful application of long-sighted land use planning. This research synthesis has been compiled in order to provide an initial background of scientific information on which to base these planning decisions. In the long term, this document and its subsequent or related publications within a nation-wide river research programme, must provide the basis for a totally new and adaptive philosophy of river conservation.

The publication of this preliminary synthesis is a first step in the process of focusing attention on these aspects of river research. It is intended to provide in a single condensed overview, a summary of what is known, and as a consequence, a guide to what it is necessary to know. It will be of value to those who use and manage rivers for specific purposes. It will be of use more specifically to those wishing to undertake research to meet future management and conservation needs.

This synthesis is produced as the first substantial contribution to the River Research Programme of the Committee for Nature Conservation

Research. It has been developed together with two companion reference works, "A bibliography of South African river ecology" and "A directory of South African river research" (both, Ecosystem Programmes Occasional Report Series, 1986). All of these texts are products of a research project undertaken by Dr J H O'Keeffe of the Institute for Freshwater Studies, Rhodes University, Grahamstown. The project is part of the National Programme for Ecosystem Research, funded and managed through the Foundation for Research Development of the CSIR.

A A Ferrar
COORDINATOR: NATURE CONSERVATION RESEARCH

ABSTRACT

Ecological research on South African rivers has progressed in a number of phases. Until 1950 work was mainly taxonomic and descriptive, an essential prerequisite for more detailed studies. The realisation that South African rivers, a vital national resource, were deteriorating in the face of overexploitation, led to a coordinated research programme by the NIWR in the 1950's and 1960's, which included in-depth studies on representative rivers such as the Great Berg, the Tugela, the Jukskei/Crocodile and the Vaal. Major advances resulted from this programme, including the description of physical zonation along rivers, and the associated changes in the biotic community; the identification of the main factors limiting species distributions in rivers, such as temperature, silt, food availability and flow rate. Comparisons with conditions in temperate Northern Hemisphere rivers indicated that South African rivers are prone to more violent events such as flooding and drying out, that most are geologically young, and therefore steeper, faster flowing, and with poorly developed floodplains. Considerable effort was devoted to understanding the consequences and effects of pollution in rivers, particularly through changes in the invertebrate fauna.

In the last thirty years a large number of South African rivers have been impounded to improve their water storage and supply capacity, and since the river research programme of the 1950's and 1960's there has been a corresponding switch to research on the lentic water bodies created by these dams. As a result, research on flowing water ecology has largely been confined to the enthusiasm and efforts of a few individual workers. A number of new conceptual ideas have been developed in other parts of the world, notably in the USA, and South African researchers have yet to have the opportunity of testing and using these ideas for the understanding and maintenance of river systems here.

This report reviews the literature on South African river ecology, summarizes the level of knowledge available at present, and suggests research directions and specific projects which will contribute most to our ability to maintain the essential functions of our rivers in the future.

SAMEVATTING

Ekologiese navorsing oor Suid-Afrikaanse riviere het in 'n aantal fases vordering gemaak. Tot 1950 was die werk hoofsaaklik van 'n taksonomiese en beskrywende aard, 'n noodsaaklike voorvereiste vir meer gedetailleerde studies. Die besef dat Suid-Afrikaanse riviere, 'n lewensbelangrike nasionale hulpbron, deur oorbenutting agteruitgegaan het, het tot 'n gekoördineerde navorsingsprogram deur die NIWN in die vyftiger en sestiger jare gelei. Hierdie navorsingsprogram het in-diepte studies oor verteenwoordigende riviere soos die Groot Berg-, die Tugela-, die Jukskei/Krokodil- en die Vaalrivier ingesluit. Groot vooruitgang is as gevolg van hierdie program gemaak, onder meer met die beskrywing van fisiese streke langs riviere, en die samehangende veranderinge in die biotiese gemeenskap; die identifikasie van die vernaamste faktore wat spesiesverspreiding in riviere beperk, soos temperatuur, slik, beskikbaarheid van voedsel en vloeitempo. Vergelykings met toestande in riviere in die matige Noordelike Halfronde het aangedui dat Suid-Afrikaanse riviere sterker onderhewig is aan gebeurtenisse soos oorstromings en uitdroging; die meeste is geologies jonk en daarom steiler; die vloei is vinniger met swak ontwikkelde vloedvlaktes. Aansienlike moeite is gedoen om die gevolge en effekte van besoedeling in riviere te verstaan, veral betreffende veranderinge in die ongewerwelde fauna.

Gedurende die laaste dertig jaar is 'n groot aantal Suid-Afrikaanse riviere opgedam om die waterberging en voorsieningskapasiteit daarvan te verbeter, en sedert die riviernavorsingsprogram van die vyftiger en sestiger jare het die klem verskuif na navorsing op stilstaande waterliggame wat deur hierdie damme veroorsaak is. As gevolg hiervan het navorsing oor vloeiende waterekologie grootliks beperk gebly tot die entoesiasme en pogings van 'n paar individuele navorsers. 'n Aantal nuwe basiese idees is in ander dele van die wêreld ontwikkel, vernameklik in die Verenigde State van Amerika, en Suid-Afrikaanse navorsers moet nog die geleentheid kry om hierdie idees vir 'n beter begrip asook vir die instandhouding van plaaslike riversisteme te toets en toe te pas.

Hierdie verslag hersien die literatuur oor Suid-Afrikaanse rivierekologie, som die vlak van huidige beskikbare kennis op en maak aanbevelings oor navorsingsaanwysings en spesifieke projekte wat die meeste sal bydra tot ons vermoë om die belangrike funksies van ons riviere in die toekoms te handhaaf.

ACKNOWLEDGEMENTS

Valuable contributions and suggestions were made by the following reviewers, to whom I would like to extend my thanks: Dr J M King (University of Cape Town); Mr A H Coetzer (Cape Department of Nature Conservation); Dr P H Skelton (JLB Smith Institute of Ichthyology); Dr F M Chutter (National Institute for Water Research); and Dr C J Kleynhans (Transvaal Provincial Administration, Division of Nature Conservation).

I am very grateful to my wife Chloe and to Pat Rautenbach of the Institute for Freshwater Studies for typing the manuscript, and to Mrs L R van Niekerk of the Foundation for Research Development for proof-reading the final copy.

This report was compiled and written as part of a project funded by the Nature Conservation Research Division of the Foundation for Research Development, South African Council for Scientific and Industrial Research.

CONTENTS	Page
PREFACE	iii
ABSTRACT	v
SAMEVATTING	vi
ACKNOWLEDGEMENTS	vii
CHAPTER 1. INTRODUCTION	1
1.1 Background and aims	1
1.2 River ecosystem functioning, levels of research and conservation policy	4
1.3 A short history of ecological research in South African rivers since 1900	5
CHAPTER 2. SOME MAJOR HYDROBIOLOGICAL INVESTIGATIONS OF SOUTH AFRICAN RIVERS	8
2.1 The Great Berg River (south-western Cape)	8
2.2 The Tugela River system (Natal)	10
2.3 The Jukskei/Crocodile River system (Transvaal)	12
2.4 The Mgeni River (Natal)	14
2.5 The Vaal River (Transvaal and Orange Free State)	15
2.6 Major results and conclusions from the surveys of the Great Berg, Tugela, Jukskei/Crocodile, Mgeni and Vaal Rivers	18
2.6.1 Distribution of fauna	18
2.6.2 Classification of rivers	18
2.6.3 River zonation	19
2.6.4 Differences between South African rivers and those of the temperate Northern Hemisphere	19
2.6.5 Biotic indices of pollution	20
2.6.6 Changes in South African rivers	21
CHAPTER 3. OTHER RIVER ECOLOGY PROJECTS WITH AN EMPHASIS ON INVERTEBRATES AND DIATOMS	22
3.1 South African hydrobiological regions	22
3.2 The Swartkops River (eastern Cape)	25
3.3 The rivers of Natal	25
3.4 The Orange River	29
3.5 Mountain streams of the Barberton area (Queens, Hislops, Lomati Rivers of the Crocodile/Incomati system)	30

3.6	Diatom studies in Lesotho rivers	30
3.7	The Great Fish and Sundays Rivers (eastern Cape)	31
3.8	Streams of the Table Mountain (south-western Cape)	31
3.9	Invertebrate drift in the Mlaas (Mlazi) and Msunduze Rivers (Natal)	31
3.10	The Jukskei/Crocodile Rivers (Transvaal)	32
3.11	The Berg, Olifants, Breede and Black/Liesbeek Rivers (south-western Cape)	33
3.12	The Pongolo River (KwaZulu)	34
3.13	The Eerste River (south-western Cape)	36
3.14	The Olifants, Nwanedzi, Letaba and Sabie Rivers (eastern Transvaal)	37
3.15	The Vaal River (Transvaal and Orange Free State)	38
3.16	Snails of medical and veterinary importance	40
CHAPTER 4. FISH		42
4.1	Introduction	42
4.2	Taxonomy	42
4.3	Fish species distribution, introductions and biogeography	43
4.3.1	Introductions	46
4.3.2	Biogeography	47
4.4	Fish species studies	48
4.4.1	Cyprinidae	48
4.4.1.1	The genus <i>Barbus</i>	48
4.4.1.2	The genus <i>Labeo</i>	49
4.4.2	Cichlidae	49
4.4.3	Clariidae	50
4.4.4	Anguillidae (Eels)	51
4.4.5	The genus <i>Sandelia</i>	51
4.4.6	Other species and groups	51
4.5	Conclusions	52
CHAPTER 5. VERTEBRATES OTHER THAN FISH		53
5.1	Introduction	53
5.2	Mammals	53
5.3	Birds	54
5.4	Reptiles	55
5.5	Amphibians	55
5.6	Conclusions	57
CHAPTER 6. PLANTS		58
6.1	Introduction	58
6.1.1	The vegetation of the Pongolo floodplain	59
6.2	Catchment vegetation	59

6.3	Emergent vegetation	60
6.4	Aquatic macrophytes	61
6.4.1	Indigenous aquatic macrophytes	61
6.4.2	Invasive exotic macrophytes	62
6.4.2.1	Eichhornia crassipes	64
6.4.2.2	Myriophyllum aquaticum	64
6.4.2.3	Azolla filiculoides	65
6.4.2.4	Salvinia molesta	65
6.5	Aquatic microphytes	66
6.6	Conclusions	66
CHAPTER 7. THE CONSERVATION OF RIVERS		68
7.1	Integrated conservation	68
7.2	Environmental impact assessment and conservation plans for individual rivers	69
7.3	Conservation monitoring and the identification of threats	71
7.3.1	Fish	72
CHAPTER 8. SOME GENERAL CONCLUSIONS, WITH SPECIAL REFERENCE TO THE CONSERVATION OF RIVERS		75
8.1	An analysis of the literature	75
8.2	Conservation research	76
8.3	Research priorities	79
REFERENCES		82
RECENT TITLES IN THIS SERIES		120

CHAPTER 1 INTRODUCTION

1.1 Background and aims

South Africa is facing a water supply crisis caused by a combination of low rainfall (Figure 1), high evaporation rates, and a growing population whose geographical demands do not conform to the distribution of exploitable water supplies. This has led to the necessity for maximizing water storage, and transporting increasing quantities over longer and longer distances, with the result that there has been an increasing exploitation of freshwater resources for domestic, industrial and agricultural needs. The period of erecting large impoundments on major rivers, such as the H F Verwoerd and P K Le Roux dams on the Orange River, and the Pongolapoort dam on the Pongolo River, appears to have passed, mainly because most suitable sites and large rivers have been used up. Impoundment of smaller rivers, such as the Palmiet in the south-western Cape and the Kowie in the eastern Cape continues, and a series of major schemes to transfer water from high supply/low demand catchments to centres of high demand has been and continues to be effected. The Orange/Fish/Sundays scheme (Water Affairs, 1962) the Riviersonderend/Berg/Eerste scheme, (Water Affairs, 1968, 1973), the Komati/Usutu/Vaal scheme (Water Affairs, 1975, 1976a), the Tugela/Vaal link (Water Affairs, 1970), the Amatole scheme (Water Affairs, 1982) and the proposed Highlands water scheme, all involve transfers of water between major catchments. The impoundment, extraction and transfer of waters from South African rivers represent one form of exploitation. Domestic and industrial waste disposal, agricultural runoff, catchment degradation (through loss of vegetation and erosion), and the introduction of exotic species, are some of the other factors changing rivers in South Africa.

Research into, and conservation of rivers and streams has to be planned within the context of these pressures. Many of them are unavoidable, and the priority must be to understand their consequences, so as to minimize their effects.

The purpose of this document is to review the ecological work that has been done on South Africa's rivers, to provide a framework for future research planning and to expose areas in which more needs to be known. The review is confined to streams and rivers, and this excludes estuaries and impoundments which form fundamentally different ecological systems, to which the river provides input in the former case and input/output in the latter. Impoundments are relatively homogeneous environments in which the important processes take place in the water and the sediments. Processes tend to be cyclical with fairly well defined inputs and outputs, and the major heterogeneity consists of

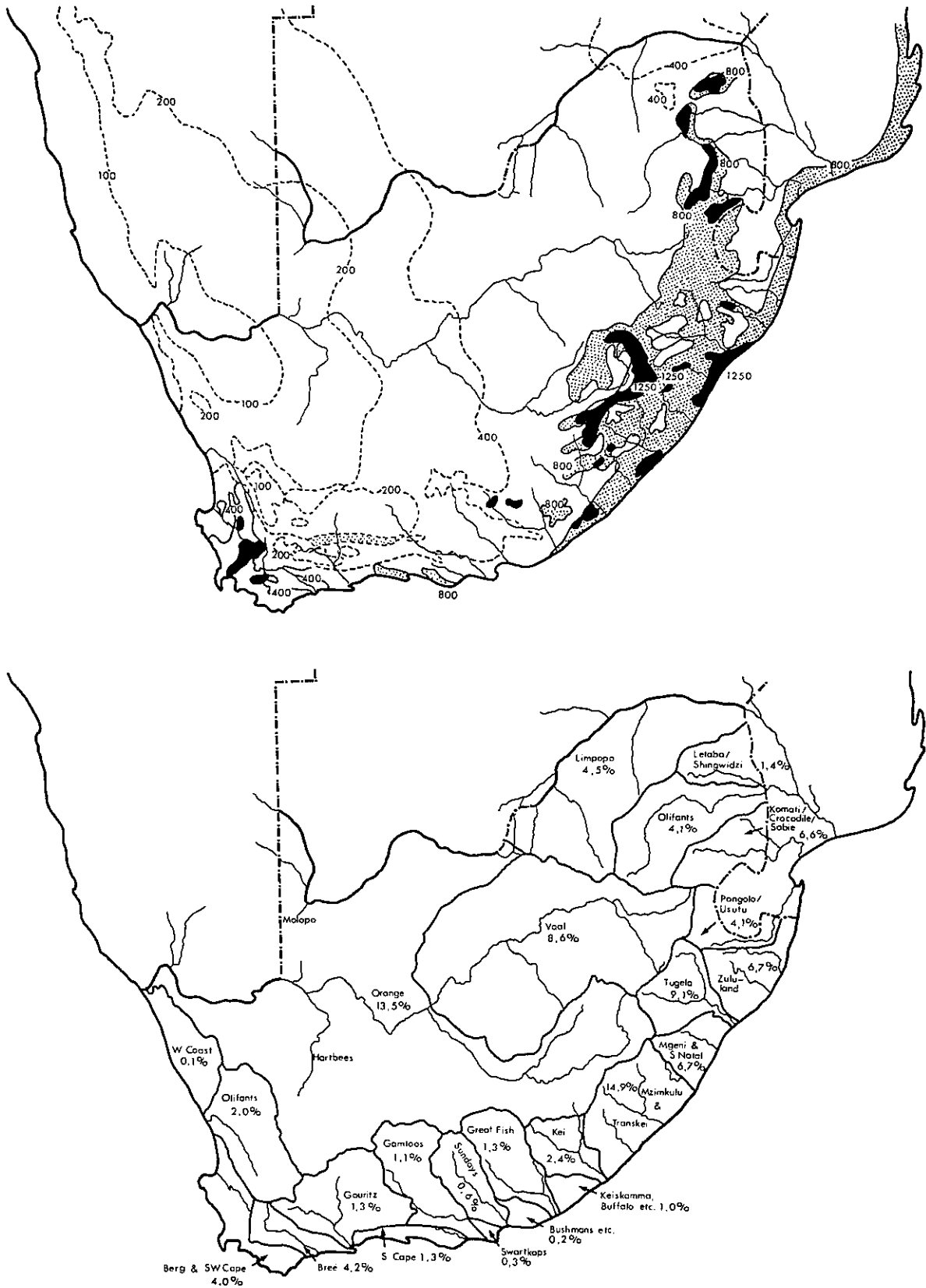


FIGURE 1. Top: Average annual rainfall (isohyets at 100 mm intervals).
Bottom: Principal drainage systems and their contribution to total mean annual runoff. (From Noble and Hemens, 1978).

thermally separated layers of water. In contrast, rivers are longitudinal systems of extreme heterogeneity, subject to stochastic catastrophic controlling events, in which catchment processes dominate, and processes in the water body and sediments are subsidiary. Inputs are often diffuse, and their effects are longitudinal downstream. With the exception of some fish, the biota of rivers is distinct from that of impoundments, the emphasis in the former being on benthic and riparian fauna and flora, and in the latter planktonic. The consequence of these differences is that the extensive research on still water limnology in South Africa has made little contribution to our understanding of flowing water ecology. A striking illustration of this is Hutchinson's (1957-1975) famous 'Treatise on Limnology', in which half a chapter (roughly 17 pages) out of 2 790 pages is devoted to rivers, the rest to lakes. There is, nevertheless, an extensive literature on the biology and ecology of South African rivers, and this is reviewed in the chapters which follow.

Two related subjects are not covered in this review. Papers, articles and books dealing exclusively with hydrology and/or water chemistry have not been included. These two subjects form major disciplines of their own, but are also obviously two of the fundamental underlying variables governing ecological conditions in rivers. All ecological studies take account of the hydrology and chemistry of the system, and in so far as they are included in these studies, they have been included here. Two very important sources of data on these subjects should be mentioned here. The Hydrological Research Unit of the University of the Witwatersrand have detailed the surface water resources of South Africa in six volumes of invaluable background hydrological data. Each volume deals with a separate drainage region.

Volume	Region	Authors
1	Limpopo/Olifants	Middleton, Pitman, Midgley, Robertson (1981)
2	Vaal	Middleton, Pitman, Midgley (1981)
3	Orange River and Namaqualand	Pitman, Middleton, Midgley, (1981a)
4	Western Cape	Pitman, Potgieter, Middleton, Midgley (1981)
5	Eastern Cape	Middleton, Lorentz, Pitman, Midgley (1981)
6	Eastern Escarpment	Pitman, Middleton, Midgley (1981b)

Each volume provides monthly rainfall and runoff figures for all large and medium sized river catchments in the region since records began (gaps and anomalies have been filled and corrected by careful analysis of comparable catchments). In addition, evaporation, geological, soil and land use information is included. The data is used to model potential water supplies and storage in the region. The second source of basic hydrological data is the Department of Water Affairs in Pretoria. The Department maintains a network of gauging stations on rivers throughout the country, and keeps computerized flow records dating back, in some cases, to the turn of the century. Water Affairs (1976b) details all gauging stations, giving coordinates, catchment area, date opened (and closed if applicable) and type of gauge. In addition the Department began an extensive series of water chemistry analyses in the 1970's. Most major rivers are now well covered, with complete analyses of inorganic ions, nutrients, pH and TDS, several

times per month. Both hydrological and chemical data are available as computer print outs from the Department in Pretoria.

1.2 River ecosystem functioning, levels of research and conservation policy

The management, research and conservation of rivers are all made more difficult by their heterogeneous longitudinal attributes referred to above. A large river typically flows through a number of different environmental zones, passes through the jurisdiction of numerous landowners and other authorities, and is affected by natural and artificial variables from many sources. Perhaps it is not surprising, therefore, that management policies and research concepts have lagged behind those in other fields.

There is at present no overall conservation management policy for rivers in South Africa. This is partly because of the limited powers of the conservation organisations with respect to rivers, partly because of the difficulties inherent in river management, (usually you cannot put a fence round a river and declare it a reserve), and partly because of the historical development of conservation bodies' responsibilities with respect to rivers. Originally the responsibilities of the provincial nature conservation organizations stemmed from the stocking and management of exotic fish species such as trout in rivers. This still forms a part of their responsibilities. The Cape Province has a written policy for departmental involvement in aquaculture, whose first objective is 'the conservation of indigenous species and unique aquatic ecosystems'. The Cape Province also has a management policy for freshwater fish, which includes a three part classification of rivers, mainly in terms of the desirability or otherwise of restocking with exotic species for angling purposes. The Natal Parks Board and Orange Free State Province also define their responsibilities chiefly in terms of the protection of fish in dams and rivers. The Transvaal Provincial Administration has a formal policy for the conservation of indigenous fish species and for the management of exotics. Individual conservation plans for each rare fish species are based on a study, from 1977 to 1982, of rare fishes of the Transvaal. The T.P.A. has also initiated a project to assess the conservation status of rivers in the province, taking account of river type, water quality, and catchment land use, as well as flora and fauna. All the provincial conservation bodies have statutory obligations with respect to the introduction of exotic species and pollution (eg Section 152 of the Natal Nature Conservation Ordinance 15/1974). The only stretches of river or stream which are protected in South Africa are those which are included in national or provincial nature reserves or state forests, and none of these (with the possible exception of the Blyde River Reserve in Transvaal) has been declared primarily for the sake of the river. It is therefore obvious that an urgent priority is to define a consistent policy embracing conservation objectives and management strategies for South African rivers. Such a policy is likely to have to adopt a holistic view of rivers in which nature conservation is part of a multiple use management plan aimed at conserving river functions within a framework of essential exploitation. Identifying and monitoring populations of indigenous species and investigating their biology is only a first step in such a strategy. To breed and reintroduce endemic fish into former habitats will only

work if the habitat can be returned to its former state. To advise on permissible levels of exploitation of rivers requires knowledge of the fundamental processes governing the functions of system.

The sequence of aims in ecological research on rivers should be:

1. Initially to locate and identify the types of organisms present.
2. To measure and describe the environmental conditions in different rivers.
3. To relate species and communities to environmental conditions.
4. To discover and quantify the important processes and interactions between the biotic and abiotic parts of the system.
5. To make accurate predictions about the effects of perturbations to the system.

Parts one and two consist of initial surveys and taxonomic work, which provide the fundamental framework for further research. Part three is a descriptive process which provides a monitoring capability. In other words, the flora and fauna in a river represents an integration of the biotic and abiotic processes of the catchment, and will change in response to environmental changes. The ability to interpret these changes will depend on an empirical understanding of correlations between biotic communities and environmental conditions. This kind of approach does not lead to an understanding of the processes governing the environmental conditions, nor to an ability to manage the system to meet conservation objectives. The level of knowledge necessary to achieve these objectives is embodied in aims four and five.

The following section outlines the progress and direction of river research in South Africa since the turn of the century, particularly in terms of the research levels summarized above.

1.3 A short history of ecological research in South African rivers since 1900

Between 1900 and 1930 the scientific literature on river organisms deals almost exclusively with taxonomic descriptions, and includes contributions by several eminent authors: Boulenger (1908) on fish, amphibians and reptiles, Hewitt (1911) on amphibians, Barnard (1914) on isopods, Sars (1916) on Cladocera. Some authors were also occupied with the biology of the species that they were describing: Rich (1918) examined the respiratory function of the rectum of a dragonfly nymph. Gilchrist and Thompson (1917) produced the first of a number of books (by different authors) on the theme 'the Freshwater Fish of South Africa'. Of thirty nine papers and books published on river fauna during this period, Algae, dragon flies, frogs and toads, crustaceans, tipulids and aquatic macrophytes received most attention, with some references to fish, caddis flies, hemipterans and freshwater sponges. One paper (Lansdell, 1925) noted the problems posed by water hyacinth (Eichhornia crassipes) in the Swartkops and Breede Rivers, described its propagation, and suggested mechanical removal.

From 1930 to 1950 taxonomic contributions continued, dealing with insect orders (Diptera, Plecoptera, Ephemeroptera, Odonata, Trichoptera), fish, amphibians, snails and algae. Particularly important contributions were made by Barnard (1932) and Crass (1947d) laying the foundations of

Ephemeropteran taxonomy. During this period K H Barnard examined and described an extraordinary variety of animals including fish (Barnard, 1938a,b; 1941a, 1943), Ephemeroptera (Barnard, 1932, 1941b), Odonata (Barnard 1933, 1937), Plecoptera (Barnard, 1934a), Trichoptera (Barnard, 1934b), Crustacea (Barnard, 1935, 1949a) Diptera (Barnard, 1947) and a medley of insect groups (Barnard, 1940). Fish studies dominate the literature during this period, providing nearly half of the published articles.

The early 1930's saw the publication of the first attempts to investigate aquatic ecology. These were related to the introduction and establishment of exotic angling species (salmon and trout) into Natal rivers. Day (1932a,b) discusses requirements in terms of temperature, altitude, food supply and migrations, for the successful establishment of trout and salmon. He made some interesting observations about the threat to trout from indigenous Barbus species which eat trout ova, and explained how the brown trout are better adapted to avoid such predation by spawning earlier, while indigenous species are still absent from their habitat. (Nowadays, the emphasis would be the other way around). Bush (1933a) identified similar environmental problems in the establishment of trout, and in addition concluded that the preservation of riverine and catchment vegetation is important for trout habitat, and that suitable insect species should be imported for trout food! Crass (1946, 1947b) investigated the feeding and growth rates of trout in Natal rivers, and concluded that their food supplies appeared to be adequate. Omer-Cooper (1949) introduced ecological investigation to invertebrate studies, suggesting that snail populations (and therefore bilharzia) might increase when the aquatic insect fauna is reduced or eliminated. Annecke and Peacock (1951) extended ecological work on bilharzia host snails in the Transvaal, concluding that molluscicides were the only effective means of controlling the disease.

The early 1950's saw the first official expressions of concern for the degradation of rivers and the deterioration of water quality (eg Stander, 1952). This resulted in the development of a coordinated programme of research in river hydrobiology by the National Institute for Water Research, which eventually covered the Great Berg, Tugela, Jukskei/Crocodile, Mgeni and Vaal Rivers. The protocol and results of this programme are covered in Chapter 2. The programme came to an end in the late 1960's, although surveys of Natal rivers continued into the 1970's. Separate hydrobiological projects have been carried out in the Eerste and Olifants Rivers of the Cape (among others), as well as further surveys of the Berg and Jukskei/Crocodile. These and other projects are reviewed in Chapter 3, including a multidisciplinary investigation of the functioning of the Pongolo floodplain.

The development of research into fish ecology in South African rivers has followed a course parallel to but separate from other aspects of river ecology. Since early investigations into the establishment of exotic species, the emphasis has changed to the identification and protection of the rarer indigenous species. Other priorities have been on species distribution surveys, life-history and autecological studies, fisheries assessment and development, and fish farming. These subjects are reviewed in Chapter 4.

Taxonomic studies have received less attention since the 1950's, notable exceptions being those on diatoms (B J Chohnoky, R E M Archibald, and F R Schoeman), molluscs (J A van Eeden's group at Potchefstroom), Trichoptera (K M F Scott), and fish (R A Jubb, P H Skelton and others). The lack of modern taxonomic work may be partly because some groups have been identified to a workable level, but the scarcity of routine and specialist identification facilities is a serious stumbling block in some areas of research.

This brief historical overview of South African river ecology shows that research has been concentrated on the achievement of aims 1 to 3 described earlier. Process-orientated research aimed at achieving a predictive understanding of the interactions between the biotic and abiotic components of rivers still remains to be tackled. The investigation of the Pongolo floodplain pans and the effects of the Pongolopoort dam has demonstrated the potential of this kind of approach. The Pongolo pans are influenced by hydrological processes controlled from the dam, and careful investigations of the effects of different flood levels have led to an understanding of the water requirements (amount and timing) necessary for the functioning of the flora and fauna in the pans. As a result it has been possible to develop a conservation plan to maintain the pans (Heeg and Breen, 1982). Paradoxically, however, investigations of the Pongolo system have concentrated almost exclusively on the pans, and the river itself has been largely ignored. Current research by B R Davies, J A Day and J M King on streams of the Jonkershoek Valley (south-western Cape) should provide valuable insights into the energy and nutrient pathways of mountain streams of the fynbos biome. These kinds of projects have a direct relevance to the management and conservation of river ecosystems, providing the knowledge to predict the consequences of natural and unnatural perturbations of the rivers and catchments, and to plan appropriate management strategies to cope with them.

CHAPTER 2 SOME MAJOR HYDROBIOLOGICAL INVESTIGATIONS OF SOUTH AFRICAN RIVERS

In the 1950's, in response to growing fears about pollution of limited water resources (Stander, 1952), the National Institute for Water Research of the CSIR initiated a series of detailed chemical and biological investigations of representative South African rivers. These projects used basically similar methods, and provided the major database and fundamental concepts for South African river biology. This section reviews these projects, and summarizes their major conclusions. Where subsequent resurveys have been carried out, these are reviewed in Chapter 3.

2.1 The Great Berg River (south-western Cape)

The first stage of the programme was an investigation of a clean river system, against which to judge the effects of pollution in more degraded systems. The Berg River was chosen, and methods were developed which became standard (with minor adjustments) for subsequent hydrobiological investigations. Biological observations were based on samples of the invertebrate fauna from: stones in current, stones in torrent, stones in backwaters/pools; sandy bottom, muddy bottom; marginal vegetation and stream bottom vegetation. Physical and chemical analyses consisted of pH, temperature, flow measurements, turbidity, colour, conductivity, dissolved oxygen, five day biochemical oxygen demand, chemical oxygen demand, and a suite of mineral and nutrient analyses.

Twenty-one sampling sites were selected from the headwaters above Franschhoek to the beginning of the estuary and including several tributaries. These were sampled monthly or bimonthly from 1951 to 1953. The results of the study were presented by Harrison and Elsworth (1958), Harrison (1958a), Scott (1958), (concentrating on the Chironomidae), and Harrison (1958b), which included an investigation of the polluted Krom River at Stellenbosch.

Among the major findings was the interpretation of the physical variables determining the characteristics of the river. The profile of the river, sloping steeply in the headwaters and flattening exponentially towards the mouth, gives rise to the main physical zones, and the faunal distribution was found to follow a similar pattern. A zonation scheme was erected consisting of:

		Altitude
Zone I	Source	(1500 - 1200 m)
Zone II	Mountain Torrent Zone	(1200 - 300 m)
Zone IIIA	Upper Foothill, Stony Run Zone	(300 - 150 m)
Zone IIIB	Lower Foothill Stony Run Zone	(150 - 90 m)
Zone IV	Foothill Soft Bottom Zone	(90 - >0m)
Zone V	Floodplain Zone	(Max 1-5m above sea level)

This zonation scheme was later compared with other European and South African schemes (Harrison, 1965a). The conclusion was that, although it is difficult to devise a system which is universally applicable, there are general elements of physical zonation which can usefully be applied to distinguish biotic communities.

Other physical characteristics of the river were found to be determined by geology, rainfall, silting and seasonal temperature variations. The geology of the Berg River is simple, the upper and middle reaches being underlain by Table Mountain Sandstone (TMS) giving rise to clear acid runoff, while the lower reaches flow over the more friable Malmesbury shales, giving rise to mineralized, turbid, alkaline waters. Later investigations demonstrated the region wide influences of TMS in the southern and south-western Cape (Harrison and Agnew, 1962; Harrison, 1964). All rivers flowing out of TMS catchments are acid, those of the south-western Cape (eg the Olifants, Berg, Breede) being clear, while those of the southern Cape (for reasons which remain obscure) are dark and humic stained (eg Groot, Storms, Keurbooms). The fauna of these acid streams was distinct from that of other parts of South Africa, with a degree of endemism (Harrison and Agnew, 1962).

The south-western Cape experiences a winter rainfall regime (April to November). This leads to alternate winter floods and summer low flows (or none). Harrison concluded that during floods the river bed was disturbed, during minimal flows the area of substratum under water was reduced, silting and scouring of the river bed was mediated by flow rates, and silting tended to increase downstream mainly as a result of geological changes. Seasonal temperature variations, from 30°C in the lower zones during summer, to 10°C in winter, were also a major determinant of the characteristics of the Berg River.

Harrison and Elsworth (1958) related these physical variables to the flora and fauna of the river. Plants were restricted in the upper zones to those able to attach to permanent surfaces (eg the moss Wardia hygrometrica, and Scirpus digitatus). River bed scouring and dessication, and silt deposition were felt to be the reasons for the lack of macrophytes and emergents in the lower reaches. For the invertebrate fauna, a succession of communities from zone to zone was described. The upper river communities (to Zone IIIB) were restricted from the lower reaches by rising temperatures and increasing silt loads. Seasonal changes were caused by winter floods and summer dessication, with concomitant changes in silt load, and by temperature changes. Winter floods had less effect on the fauna of the upper hard bottom zones than on the lower soft sediments.

In part 2 of the project report, (Harrison, 1958a), the fauna of sandy sediments in shallow pools and 'flats' and several of the tributaries of the Great Berg (Assegaibos, Kuils and Sout) were described. Part 3 (Scott, 1958) investigated the distribution and zonation of chironomids in the Berg River. Part 4 (Harrison, 1958b) described and discussed the effects of mild (in the Berg River and the Dwars tributary) and serious pollution (in the Krom River at Stellenbosch). In the former rivers, chemical methods were unable to detect any changes, except for five day BOD in the Berg River. Effects on invertebrate species varied, but some typical mountain stream species, especially Trichoptera disappeared, while Chironomidae, Baetis harrisoni, Simuliidae and Lymnaeidae increased, and Nais oligochaetes appeared. In seriously polluted stretches of the Krom River BOD increased dramatically and 'sewage fungus' appeared. Faunal effects included the appearance of Tubificidae, Lumbricidae, larvae of Psychoda alternata and Chironomus plumosus on stony runs. A comparison with conditions described from polluted European rivers found similar effects in the Berg River, with characteristic communities appearing in response to different levels of pollution. Harrison (1960) extended this discussion of the effects of pollution on faunal communities to include cases of mineral pollution in the Klip and Klipspruit Rivers (described in Harrison, 1958c) and organic pollution in an eutrophic stream - the Swartkops River (described in Harrison, 1959).

The zoogeographic aspects of river invertebrates in South Africa, which had become apparent in investigations of the Berg and Southern Cape rivers, are discussed in Harrison (1965b) and Harrison (1978). In these articles Harrison identifies two main groups:

1. An old element of cold stenothermal, mostly montane species, with Gondwanaland affinities. These were limited mainly to the southern Cape.
2. A pan-Ethiopian element of
 - a. Widespread tolerant species
 - b. Warm stenothermal, tropical species
 - c. Highveld climate species
 - d. Montane species and
 - e. Species of temporary mountain stream.

2.2 The Tugela River System (Natal)

The second major river system studied was the Tugela. The design of the project was modelled on the Berg River study, with monthly chemical and biological samples taken at a number of fixed points along the rivers. This project was conducted on a larger scale than that for the Berg River, with separate investigations of the main Tugela River (Oliff, 1960a), the Bushmans River with an emphasis on organic pollution (Oliff, 1960b), the Buffalo River (Oliff, 1963) and the Mooi River (Oliff and King, 1964).

The Tugela River flows through a complex of geological types including basalt and rhyolite lavas, Stormberg and Upper Beaufort beds, giving

rise to low dissolved and suspended material loads, followed by lower Beaufort and Ecca shales, providing higher loads of dissolved solids and more silt, and a rejuvenated steep gradient. The lower reaches are underlain by primitive granites and gneisses, and sandstone of the Natal group. Oliff (1960a) followed Harrison's zonation, with the exception of the lower depositional region, which was replaced by a torrential rejuvenated zone (in which, however, the biota did not revert to that of the upper torrential zones because of temperature differences). The zones were divided into climatic regions: the source, waterfall and torrential zones forming a temperate upland section; the foothill sand bed and rejuvenated zones forming a subtropical midland section and the lower valley sand bed zone forming a tropical lowland section. The fauna of the river could again be differentiated by zone, and distribution depended mainly on temperature, flowrate and altitude, with food availability, concentration of dissolved solids, silt loads and gradient as subsidiary determining factors. Once again seasonal flooding effects caused marked changes in the fauna, with summer spates reducing densities to 1/10th or 1/20th those of the dry winter season.

Invertebrate population densities in the Tugela were found to be inversely proportional to flow-rates, except in the upper river, implying that (as for the Berg River) floods caused less disturbance to the communities of the upper river hard substrate than to those further down. Densities were highest in August (dry winter month) and lowest in February (wet summer month).

Comparisons were made with other rivers and Oliff (1960a) concluded that there were many similarities between the Tugela and Vaal Rivers, and some Northern Hemisphere rivers. However, he defined some fundamental differences between the Tugela and Berg Rivers: The Tugela was subject to a summer rather than winter rainfall regime in which there was less variation in dissolved solids between wet and dry seasons; waters in the Tugela were alkaline rather than acid, primarily because of geological differences, and dissolved solids were mainly bicarbonates rather than chlorides. Oliff concluded that productivity (as measured by faunal density) seemed comparable to other river studies, and to the Berg River.

The second part of the Tugela study was concerned with organic pollution in the Bushmans tributary (Oliff, 1960b). The main sources of pollution were a board mill and milk-processing factory in Estcourt on the Little Bushmans River and a sewage farm on the main Bushmans River below the junction with the Little Bushmans.

The general effects of pollution at different distances from its source were examined. Light pollution caused an increase in the faunal density with no marked change in species composition, or an increase in density of normal fauna with the appearance of oligochaetes. Heavy pollution resulted in the appearance of 'sewage fungus' and a fauna dominated by oligochaetes and Entomostraca. Pollution levels were reflected by both the invertebrate biology and the biochemical oxygen demand. The ability of the river to 'self-purify' was measured as % reduction in five day BOD. Under aerobic conditions, self-purification was directly related to the density of the community. Different habitats in the same sampling site were found to show very

different degrees of pollution, emphasizing the need to examine all habitats across the width of the river when assessing pollution. Comparisons with features of organic pollution in other rivers indicated similar consequences in the Berg River, and it was concluded that pollution-indicating communities appeared similar to those in other parts of the world.

The Buffalo tributary system of the Tugela was investigated in the third part of the project (Oliff, 1963). Chemical and biological conditions, and zonation were similar to the main Tugela, although the uppermost zones, (the source and waterfall) were lacking. Some organic pollution was found, as was considerable mineral pollution from coal mines, particularly on the Dorps River at Utrecht, the Steenkool below Dundee, and in the Mzinyatshana River. The main identifiable effect of mineral pollution was to acidify the water. At a pH of five to seven the fauna became impoverished, and at 2,6 to 4 no fauna was found. In neutralized waters there was an increase in diatoms and filamentous algae, and in worms, ostracods and simuliids. As pH dropped ephemeropterans were reduced, and trichopterans initially increased but subsequently decreased. Following rains there was an initial decrease in pH and an increase in sulphates, as a result of leeching from the soils. The effects of mineral pollution were different from those found by Harrison (1958c) in the Klip River, where peat-bog conditions and a specialised fauna developed. In the Natal rivers, acid waters were quickly neutralised with the formation of iron oxide blanketing compounds.

The Mooi tributary of the Tugela was investigated in the final phase of the project (Oliff and King, 1964). Results confirmed findings summarized in previous sections. An interesting case of 'natural pollution' was described, caused by decomposing autumn leaves which produced a fauna dominated by Nais and Simulium species, and a reduced ephemeropteran community. A summary of faunal characteristics in response to pollution was given:

Gross organic pollution	- 'Sewage fungus', tubificid worms
Considerable sustained organic pollution	- Masses of Naididae and Chironomidae
Nutritive pollution	- Filamentous algae (especially <u>Spirogyra</u> and diatoms), normal fauna
Toxic pollution	- Total absence of fauna

Temperature was identified as the most important limiting factor for invertebrates in the Mooi River, but silt, current speed and substratum also determined species distribution.

2.3 The Jukskei/Crocodile River system (Transvaal)

Having looked at clean and moderately polluted rivers, an investigation of a seriously polluted system was identified as the next priority. The Crocodile/Jukskei system draining the north-western Witwatersrand provided highly polluted and clean streams in the same catchment. A three year hydrobiological study was carried out at 26 stations (Allanson, 1961) using methods similar to those of Harrison and Elsworth

(1958) and Oliff (1960a). The aims laid down by the CSIR-appointed steering committee were:

1. To determine present chemical and biological conditions of the river system.
2. To identify sources of pollution and effects on the biota.
3. To formulate biological indices of pollution.

Simultaneous studies of the diatom communities (Cholnoky, 1958a) and the microbiology (Keller, 1960) of the system were carried out.

The Jukskei/Crocodile flows in a summer rainfall catchment over complex geology, the main effect of which is to provide large sand and grit loads during floods. Its profile is shallow compared with the Berg and Tugela Rivers, and falls completely within Harrison and Elsworth's (1958) zones IIIa (upper) and IIIb (lower) foothill stony runs. Allanson (1961) found no further useful physiographic zonations, but divided the system into three reaches for convenience:

	Altitude
Upper Reach	1 600 - 1 450 m
Middle Reach	1 450 - 1 300 m
Lower Reach	1 300 - 1 150 m

Water temperatures varied from summer maxima between 17 and 25,5°C with some pools reaching 29,5°C, to winter minima down to freezing. Temperatures in the different reaches varied, with markedly higher winter temperatures in the lower reach.

Allanson (1961) concluded that parts of the Jukskei were more polluted by nitrogenous wastes than any other rivers investigated in South Africa. A careful analysis of water chemistry revealed that nitrification varied with current speed, and that the maintenance of aerobic conditions in the most polluted streams (the Sandfontein and Braamfontein) was partly due to the availability of oxygen from nitrates introduced in effluent discharges and by nitrification. In clean streams (eg the Blaauwbank) highest oxygen levels were identified in the mornings and the lowest levels were detected during the night. During rains the 'oxygen sag' disappeared in reaches with a steep profile, and was replaced by diurnal variation, leading to faster nutrient recycling, or purification over a shorter stretch of river. In the polluted upper reach of the main stream this diurnal variation was obscured by sudden flooding and variable water quality caused by peak discharges from the Bruma sewage works. Chemical analysis of the sediments showed no obvious differences between polluted and clean stretches of stream.

The plant communities were described, and the main observed perturbation was identified as the effects of urban erosion which reduced marginal vegetation in some areas. The invertebrate fauna was analysed in terms of 'commonness' of species. The most informative method of comparison of communities was found to be between moments (median and standard deviation) of the truncated log-normal species distribution, which retained the influence of more common species, without ignoring the implications of rarer components.

The interpretation of pollution effects on the fauna was complicated by multiple discharges of different types of effluent, but communities were categorized, (largely on their ability to withstand variable dissolved oxygen concentrations), as:

1. Pollution
2. Recovery with variable oxygen
3. Recovery with constant oxygen
4. Clean water
5. Ubiquitous

The diatom and microbiological information gathered by Cholnoky (1958b) and Keller (1960) respectively was found largely to corroborate the conclusions from chemical and macroinvertebrate studies. An interesting conclusion from Keller (1960) was that the self-purification capacity of the river (in terms of downstream reduction of faecal bacteria) was impaired in some places by discharges of industrial effluent. From Cholnoky's (1958b) data, based largely on the distribution of Nitzschia species, three categories of water were recognized by Allanson (1961):

1. Well oxygenated water with minimal nitrogen
2. Reasonably oxygenated water with variable chemical conditions
3. Reasonably oxygenated water with high nitrogen

Allanson concluded that algal and bacterial investigations provided a useful addition to faunal and chemical investigations, and that meaningful conclusions could be made through these methods. He pointed out that gross pollution is easily identified, but that more subtle pollution, which does not make obvious changes to the river, is potentially as dangerous, since impoundments such as that behind Hartbeespoort Dam have been converted from oligotrophic to eutrophic by such levels of pollution.

A comparison of the clean water fauna of the Jukskei/Crocodile with that of the Tugela and Great Berg revealed many more common species between the Jukskei/Crocodile and Tugela, than between either the Jukskei/Crocodile and the Berg, or the Tugela and the Berg.

2.4 The Mgeni River (Natal)

During the late 1950's a hydrobiological survey of the Mgeni River and its tributaries was carried out by Schoonbee (1963a,b,c), and Schoonbee and Kemp (1965). The objectives of the survey were in two parts:

- 1a. To map the urban, industrial, agricultural and recreation activities in the catchment, and identify sources of sewage disposal.
- b. To carry out a physical and chemical survey of the rivers to establish unpolluted conditions.
- c. To conduct an ecological investigation of the river in terms of the fauna.

2. To establish the faunal, bacterial and physiochemical conditions of polluted streams within the Mgeni catchment.

The same zonation scheme was adopted as that used by Oliff (1960a), but it was found that this distribution of faunal communities did not necessarily coincide with physical zones. Sediment loads were extremely variable, with the Msunduze tributary contributing a large proportion of sediment into the main river. Generally the chemical quality of the water was very good, but organic pollution was found in the Msunduze near Pietermaritzburg, in the Piesang, in the main Mgeni River below the Piesang inflow, and in the Palmiet River. In the latter case the Palmiet recovered its unpolluted water quality within 3,2 km of the furthest downstream effluent input (Schoonbee, 1963b).

The Ephemeroptera and Diptera dominated the fauna of the stony river bed, and ephemeropteran associations were recognized and described in detail. Comparisons of faunal communities with those in the Berg and Jukskei/Crocodile Rivers could not confidently be made, because of the limited taxonomic expertise available for identifying freshwater invertebrates at the time. Since the investigation of the Tugela system was carried out simultaneously with that on the Mgeni, identifications of animals in the two systems were cross-referenced, and were therefore comparable.

2.5 The Vaal River (Transvaal and Orange Free State)

An initial hydrobiological investigation of the Vaal River was undertaken in the middle reaches from the Vaal Dam to below the Vaal barrage. The influence of the two impoundments has been to stabilize the flow in this region, smoothing out flood variations. The first part of the investigation dealt with the water chemistry and invertebrate fauna of the river (other than muddy sediments) (Chutter, 1963). Seventeen stations were sampled over two-and-a-half years. Sources of pollution included sulphates from mine dump runoff in the Klip and Suikerbosrand streams, further mineral pollution from Houtkopspruit, and organic pollution from Vereeniging.

Some effects of the artificial stabilization of the river were observed. The marginal vegetation fauna was a mixture of species normally associated with lotic and lentic habitats. In the canalized zone algae and current speeds affected the fauna. Large populations of oligochaetes were found in the absence of organic pollution.

Mineral pollution caused flocculation of suspended sediments, and the impounded water of the Vaal Barrage was therefore clear. This allowed the build up of large populations of plankton. The release of water containing high zooplankton densities into the river below the barrage led to the development of large invertebrate populations (especially filter-feeding hydropsychid trichopteran).

Comparisons with the fauna from the Berg River revealed similarities between marginal vegetation faunas, but none between those of stones in

current. Chutter (1963) concluded that this was because the stony runs in this section of the Vaal were stable, allowing the development of populations with a restricted distribution, whereas marginal vegetation was a dynamic and variable habitat suitable for hardy widespread species.

A second aspect of this investigation was an investigation of the chemistry, bacteriology and invertebrates of the soft sediments (Harrison, et al, 1963). One of the effects of the stabilization of the river by the Vaal Barrage was the deposition of soft mud sediments in the reduced current speeds. The benthic fauna of the sediments was found to be generally poor, with local high densities of oligochaetes below the Suikerbosrand and Klip River inflows (presumably bringing suitable food into the main river), and of nematodes in a more sandy habitat. Chemical, bacterial and faunal correlations were unsuccessful, probably because interrelations were subtle and multivariate.

A second project on the Vaal River concentrated on sections of the river above the Vaal Dam and below the Vaal Haartz diversion weir (Chutter 1967a,b). The study was carried out in two parts:

a) A study of the fauna below the Vaal Hartz weir to elucidate the reasons for pest outbreaks of Simulium chutteri and to provide background information prior to control measures.

b) An investigation of the rivers of the Vaal Dam catchment to provide background data on water conditions.

The Simulium study concentrated mainly on the fauna of stones-in-current at eight sampling points between the diversion weir and Barkly West. The field work comprised four visits over one year, and developed a new method of sampling, based on the density of animals on individual stones.

Densities of Simulium chutteri were found to be highest where water fluctuations were greatest (due to a weekly flow cycle initiated by releases from the weir). S chutteri was found to invade newly inundated habitat rapidly, and thereby minimize competition and predation pressures mainly from hydropsychid trichopterans (which appeared to be more sedentary and unable to react so quickly) and from other species of simuliids. The availability of suitable substrate for S chutteri (semipermanent stony runs) had been artificially increased by alluvial diamond mining in the river bed. Some reduction of simuliid numbers was caused by parasitism by mermithid nematodes, which prevented the larvae from pupating.

Chutter's (1968a) discussion of this section included initial observations of feeding and behavioural adaptations of other invertebrate species. (eg the even distribution of Baetis glaucus in stony habitats may have been caused by its propensity to drift in the current). Chutter stressed the need for detailed autecological studies to understand faunal interrelationships.

The hydrobiological studies of the Vaal Dam catchment covered all the major tributaries as well as the main river, using 48 sample sites, most of which were sampled monthly over two years, and are reported in Chutter (1967a,b; 1969a,b; 1970, 1971a,b). Invertebrates were sampled from four biotopes (stones-in-current, marginal vegetation, stones-out-of-current, and sediments), and their distribution was correlated with chemical and physical attributes of the river.

The zonation system of Harrison and Elsworth (1958) was found to be of little use for the rivers of the Vaal Dam catchment. This was partly because all the streams are at high altitude, and partly because silt and sand loads rather than temperature changes were found to be the most significant characteristics of different parts of the rivers. A zonation scheme based on sediment characteristics was erected (Chutter, 1970):

1. An erosion zone characterized by hard river bed.
2. A stable depositing zone characterized by persistent emergent and macrophyte plant growth in stable sediments.
3. An unstable depositing zone characterized by a lack of plants, and by shifting sediments, and mediated by seasonal floods, high silt and sand loads, and erosion.

Faunal communities were correlated with these zones, and it was concluded that fauna of the higher erosion zone disappeared in depositing zones mainly due to their inability to withstand abrasion and respiratory interference by silt and sand, and because of alteration of food resources and the smothering of microhabitats. The animals of the depositing zone were restricted by food requirements, as in the case of filter-feeders, whose densities increased downstream with an increase in fine particulate organic matter (Chutter, 1969b).

Increased sediments found in the depositing zones were thought to have originated as a result of human influenced erosion rather than from material brought down the river from the upper zones. As the presence of the Vaal Dam caused deposition of sediments, the river downstream of the Dam has been artificially converted to a stable depositing zone.

The density of all groups of invertebrates was greatest in the dry early summer months. Since this was the season of lowest allochthonous input, the implication was that the fauna depended largely on autochthonous production in the river. This was supported by the absence of riverine forests (which would provide allochthonous input) in the Vaal Dam catchment. Instances of organic enrichment led to the production of dense populations of Cladocera and Copepoda. These were correlated with increases in populations of hydropsychid trichopteran which prey on the zooplankton. A secondary effect was the microhabitat modification caused by large numbers of hydropsychid cases built on and between stones-in-current (Chutter, 1971a).

Most of the streams of the Vaal Dam catchment were found to be of high chemical quality, but the Waterval River was becoming mineralized from gold mine runoff. These ions were not the type which are removed by biological activity and therefore the river purification processes associated with organic pollution did not apply.

A simultaneous investigation of the diatom flora of the Vaal Dam catchment was carried out by Archibald (1968). The findings of Cholnoky (1958a) in the Jukskei River were largely confirmed. Large densities of nitrogen heterotrophic Nitzschia were correlated with high nitrogen concentrations. Diatom associations indicated good water quality throughout the catchment, with the exception of the Waterval River.

2.6 Major results and conclusions from the surveys of the Great Berg, Tugela, Jukskei/Crocodile, Mgeni and Vaal Rivers

A number of fundamental concepts emerged from the above studies which have served to underpin subsequent research on river ecology in South Africa.

2.6.1. Distribution of fauna

These investigations constituted a comprehensive attempt to unravel the taxonomic difficulties of freshwater invertebrates in South Africa. Collections were despatched worldwide to the appropriate specialists, a solid taxonomic basis was laid down, and a start was also made on the study of individual species and community ecology. However, there remains an alarming array of taxonomic unknowns, and specialized identification facilities are probably more scarce now than when these projects were undertaken.

Rivers throughout South Africa were found to be basically similar in terms of their fauna, with the possible exception of the rivers of the Table Mountain Sandstone formations of the southern and south-western Cape, which have endemic species, but in which the faunal communities are not fundamentally different. Chutter (1968b) identified three main faunal groups:

1. A group restricted to the acid streams of the south-western Cape.
2. A tropical group of species found mainly in the low-lying parts of Transvaal and in Zululand.
3. A more or less ubiquitous element found throughout southern Africa. (Possibly a temperate region element).

Harrison (1978) discussed the origins of southern African freshwater invertebrates and identified a number of groups:

1. Relic Gondwanaland forms. Cold-adapted and now confined to high altitude streams.
2. A pan-Ethiopian fauna comprising:
 - a) Widespread, hardy species
 - b) Tropical stenothermal species
 - c) Warm temperate species
 - d) Cold stenothermal species
 - e) Species of temporary mountain stream

2.6.2. Classification of rivers

Attempts have also been made to classify the rivers themselves.

Allanson (1965) commented that all South African rivers are geologically young, and could be assigned to one of the following categories:

1. Coastal rivers with mountain sources
2. Coastal rivers without mountain sources
3. Rivers of the elevated central plateau

Noble and Hemens (1978) have extended this to seven categories, combining geological, chemical and faunal characteristics:

1. Cape clear acid rivers (eg Olifants, Berg, Breede)
2. South Cape dark acid rivers (eg Kaaimans, Groot, Storms)
3. Southern Karoo turbid rivers (eg Gouritz, Gamtoos, Sundays, Great Fish)
4. Transkei and Natal degrading rivers (eg Buffalo, Great Kei, Mzimvubu, Mzimkulu, Mkomazi, Mgeni, Tugela)
5. Escarpment floodplain rivers (eg Crocodile/Limpopo, Letaba, Olifants, Sabie/Crocodile/Komati, Mfolosi, Mkuze, Pongolo/Usutu)
6. Vaal (catchment of the central Plateau)
7. Orange

2.6.3. River zonation

River zonation, either in the form suggested by Harrison and Elsworth (1958) or that of Chutter (1970), was accepted as a useful means of identifying more or less homogeneous stretches of river in terms of their physical and biotic components. However, zonation systems should not be too rigidly applied, and evidence from the Mgeni River indicates that the same system may not be applicable even in adjacent catchments. Rejuvenated sections of river in the Tugela and Vaal Rivers, representing physical zones similar to those of the upper catchment, did not support a fauna similar to that in the upper catchments.

Major factors limiting the distribution of the invertebrate fauna were identified as: temperature, suspended sediment, food requirements, and flow rate, (if gradient can be equated with flow rate and altitude with temperature). Different factors were limiting in different rivers, but this was largely a result of differences in scale and extremes of the variables in different systems.

2.6.4. Differences between South African rivers and those of the temperate Northern Hemisphere.

Some major differences were identified between the dominant processes in South African rivers, as compared with rivers of temperate Northern Hemisphere regions. These are important because a great deal of detailed research on rivers has been carried out in Europe and North America, and it is necessary to judge how far conclusions can be applied to South African rivers:

1. The rainfall/runoff regime, with more distinct seasonality and higher evaporation rates, leads to more violent flooding and drying events in South Africa. This has been exacerbated by erosion and destruction of catchment vegetation, which break down the storage

- and buffering capacity of the catchment, resulting in a more concentrated and shorter runoff reaction.
2. Most South African rivers are geologically young, and are therefore steeper, faster flowing and have less developed floodplains.
 3. In most South African rivers (with the exception of those flowing off TMS formations), turbidity and high silt loads are at least seasonally important.
 4. Chutter's investigation of the upper Vaal catchment led him to conclude that autochthonous production provided a larger proportion of the energy flow than in Northern Hemisphere temperate rivers, which tend to be dominated, at least in their upper catchments by allochthonous input from riverine forest. The upper Vaal has no riverine forest, and these conclusions remain to be confirmed for other South African rivers.

2.6.5 Biotic indices of pollution.

The response of invertebrate communities to different levels and types of pollution was particularly carefully examined. Organic pollution was found to create similar conditions to those in European rivers, and the response of the fauna was also similar. There were inevitable differences: for instance the plecopteran fauna, an important clean water group in Europe, is impoverished in South Africa. The potential for interpreting polluted conditions in rivers by an examination of the invertebrate fauna had been exploited in Europe for some time and various classifications had been proposed. There was also considerable opposition to the use of such systems, which were felt by Hynes (1964) to be too rigid. The advantages and disadvantages of a formal classification system, using invertebrate communities rather than indicator species, were discussed in Allanson (1960) and Chutter (1968b, 1972a). The result was the formulation of Chutter's biotic index of the quality of water in South African streams and rivers (Chutter, 1972a). A careful analysis of the distribution of species in all previous river surveys was used to identify those which are pollution tolerant, intolerant and ubiquitous. Scores from 0 to 10 were assigned to different groups, in which 0 indicates complete intolerance and 10 complete tolerance. Some groups, such as simuliids and chironomids, present taxonomic problems and contain both tolerant and intolerant species. To simplify identification and quantification of samples, these groups were considered at the family level or higher, and were given sliding scores which depended on the number and density of ephemeropteran species (and particularly baetids). The total additive score for a sample has to be calculated, and divided by the number of individuals in the sample to give a sample score between 0 to 10 in which scores represent the following conditions:

0-2	Clean unpolluted waters
2-4	Slightly enriched waters
4-7	Enriched waters
7-10	Polluted waters

Chutter (1972a) discussed the advantages and drawbacks of the system. Briefly, the index was intended only as a measure of organic pollution, and may give erroneous results in the event of either toxic pollution (from mine effluent, pesticides etc) or if a catastrophic event (floods

or drying out) has occurred in the recent past. Nevertheless, if it is applied for samples from different seasons and interpreted carefully, the index provides a consistent and conceptually simple integration of water quality. Its use, particularly in cases of mild to moderate pollution, appears to be more sensitive than chemical measures, which can in any case only measure instantaneous conditions at the moment that the sample was taken. Simultaneously, an examination of diatom communities in relation to water quality was carried out by Archibald (1972a). He concluded that species diversity was an inconsistent measure of pollution levels, since, although diversity was usually high in clean water and low in polluted water, it may be as high or as low at intermediate levels of pollution. He therefore suggested that the species composition and ecology are the most important criteria in assessing water quality.

2.6.6 Changes in South African rivers.

Chutter (1970) reviewed the effects of the past exploitation of South African rivers, in the light of information from previous surveys, and predicted likely future trends.

In many cases rivers have been converted from perennial to intermittent seasonal flows over the last 300 years. It has now been shown that rainfall has not decreased significantly over this time and therefore these changes must be ascribed to catchment mismanagement leading to erosion, siltation of rivers, with consequent turbidity, unstable riverbeds, loss of fauna, and possible changes in the water temperature regimes. Chutter also described the consequences of damming rivers: increased plankton production; downstream changes in fauna (large densities of *Hydra*, hydropsychids, and simuliids); precipitation of sediments in the impounded reservoirs; alteration of natural flow regimes according to supply needs; interference with fish migrations; water temperature and chemistry alterations; and channel erosion below the dam wall with subsequent riverbed armouring. The consequences of organic and mineral pollution were summarized, and it was suggested that increased irrigation will lead to mineralization of rivers from return flows. Introductions and dispersal of exotic fish and plant species have altered the biotic communities, as have the extermination of hippos and crocodiles in most rivers. Future increases in the human population can only lead to increased industrialization and urbanization, and the exploitation of marginal agricultural land, with concomitant increases in water extraction, mineralization and organic pollution. Finally, Chutter (1970) discussed the reasons for attempting to maintain rivers in a viable state, and concluded that, (apart from intrinsic values), recreation, aesthetics, the prevention of disease and pest species, and the protection of a river's ability to self purify were the main justifications.

CHAPTER 3 OTHER RIVER ECOLOGY PROJECTS WITH AN EMPHASIS ON INVERTEBRATES AND DIATOMS

The previous chapter reviewed some of the initial hydrobiological investigations which provided the first holistic view of South African rivers, and developed basic methods of investigation. This section attempts to gather the information from a number of simultaneous and subsequent research projects on river ecology, which varied markedly in scope, duration and intensity. Almost all owe something to the concepts and methods developed in the projects described earlier, and attempt to extend their findings geographically and/or conceptually. I have chosen to review the projects more or less by river system and chronologically, but related projects have been reviewed together.

3.1 South African Hydrobiological Regions

This was a project begun by J D Agnew and A D Harrison under the auspices of the CSIR, but never completed. The aim was to designate coherent hydrobiological regions for South Africa and attempt to identify a 'type river' for each region, which could then be investigated in detail as representative of all rivers in the region. A number of initial surveys were made and written up as reports for the National Institute for Water Research, CSIR. (Harrison, 1959; Agnew and Harrison 1960a,b,c,d). Results of a survey of the southern Cape rivers were published by Harrison and Agnew (1962). Harrison (1959) suggests the following river regions based on previous hydrobiological surveys:

- A. The Cape System Region
 - 1. Streams from Table Mountain Sandstone
 - a. Dark acid rivers
 - b. Clear acid rivers
 - 2. Streams from Bokkeveld and Witteberg series geology (eg the Hex River)
 - 3. Two large rivers, the Gouritz and the Gamtoos
 - 4. Streams from Malmesbury series geology
- B. Recent Limestone Region near Bredasdorp (southern Cape)
- C. Central Arid Region
- D. Eastern Cape Region
- E. South-east Coastal Region
 - 1. Streams originating in the Drakensberg Mountain region (F)

2. Streams originating in the foothills and outliers of the Drakensberg

- F. Drakensberg Mountain Region
- G. Highveld Region
- H. Eastern Escarpment Region
- J. Transvaal Mountain Region
- K. Lowveld Subtropical Region
- L. Middle Transvaal Veld Region (eg middle Olifants River)
- M. Tropical Arid Region (eg Palala River)

The Map in Figure 2 shows approximate boundaries of the regions.

An exploratory survey was made to the eastern and northern Transvaal (regions H,J,K,L and M) and single chemical and invertebrate samples (stones-in-current, marginal vegetation) were taken from 22 sites in the Sand (Limpopo), Letaba, Olifants, Sabie, Crocodile and Komati Rivers, (Agnew and Harrison, 1960a). A characteristic lowveld fauna was described. The rivers were typically neutral pH with low TDS, except for the Olifants and Limpopo which were more alkaline. A second visit to the Lowveld subtropical region (K) was used to sample the Sabie, Crocodile, Incomati, Limpopo, Usutu, Pongolo and Ingwavuma Rivers (Agnew and Harrison, 1960b). It was concluded that the Lower Sabie sample site represented an excellent type site for the area. No obvious faunal differences were found between the Limpopo/Incomati systems and those of Zululand, although the latter carried heavier silt loads. No typical floodplain species could be differentiated. The fauna of the lower reaches of the rivers showed marked similarities with that of the slow flowing middle Vaal, and of the lower Berg River in its floodplain.

A one day visit to the middle Transvaal veld region (L), covered the Magalakwena, Sterk and Palala Rivers (Agnew and Harrison, 1960c). The fauna was assessed as intermediate between the high and lowveld regions, and the Palala River was chosen as the type river for the region.

An exploratory survey of the rivers of the southern and southwestern Cape covered 26 stations in the Kruis, Kaaimans, Outeniqua Pass, Storms, Groot, Dorps, Krom, Assegaaibosch and van Staden streams (Agnew and Harrison, 1960d; Harrison and Agnew 1962). Two main objectives of the survey were to find out whether the characteristic fauna of the upper Berg River extended throughout the streams of TMS catchments to the limits near Port Elizabeth, and to see how closely the fauna is associated with low pH. Two faunal associations were identified:

1. A TMS acidobiontic association found in water with a pH less than 6. (Similar to the Upper Berg).
2. A temperate climate association best developed in alkaline streams.

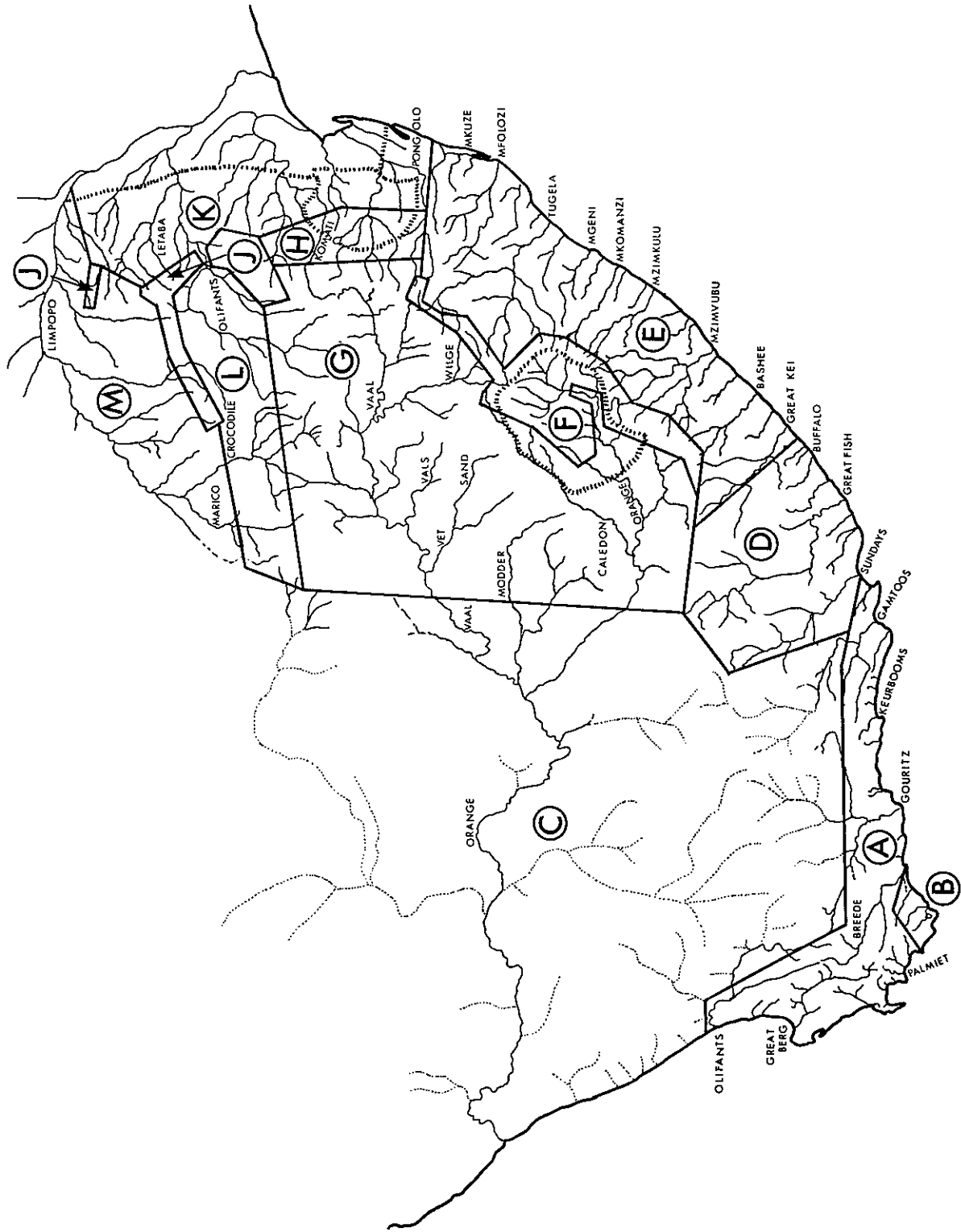


FIGURE 2. Hydrobiological regions defined by Harrison (1959).

The TMS association was found to extend to near the eastern limits of Table Mountain Sandstone, but the Swartkops River, and the van Staden's Pass stream had communities best described as depleted temperate fauna.

3.2 The Swartkops River (eastern Cape)

Harrison et al (1959) carried out two short surveys of the Swartkops River to investigate reports of organic pollution below Uitenhage, and to try to formulate effluent standards. Chemical, bacteriological, algal and invertebrate samples were taken, and indicated organic pollution from sewage effluent but little industrial pollution. River standards were recommended for chemical criteria.

3.3 The rivers of Natal

A series of hydrobiological investigations were carried out on Natal rivers in the 1960's and 1970's by the National Institute for Water Research, under the auspices of the Natal Town and Regional Planning Commission. A series of reports (Natal Town and Regional Planning Report, Volume 13, Parts I - VII) were prepared for different groups of rivers in Natal, including summaries of Oliff's Tugela survey, and Schoonbee's Mgeni survey (see previous chapter).

Because of the geographical scope of the project, many of the rivers were sampled at only a few points (and in some cases only one) and at only one time of the year. The project was therefore extensive rather than intensive in emphasis, when compared with those described in the previous chapter.

The first part of the report (Brand et al, 1967a) laid down the aims, methods and specifications for the investigations, which are largely based on the previous South African hydrobiological investigations, particularly those of the Tugela and Umgeni. The aims were summarized as being: "To assess the effects of changing industrial and agricultural conditions on water quality and thence to formulate standards for industrial wastes and effluents". Standard methods were described for chemical, bacteriological and faunal analyses, and their interpretation.

For inorganic results, it was suggested (Brand et al, 1967a) that, of the eight major inorganic solutes, only silica is relatively stable (between 10 and 25 ppm) in almost all rivers. The proportions of the remaining seven vary directly with TDS, in undisturbed rivers. An expected composition could therefore be calculated using means weighted according to the geological characteristics of the catchment. Departures from the expected proportions would indicate perturbation of the natural waters. Mean percentages for the seven solutes on different geological strata were given from undisturbed Natal streams. Means were also given for so-called 'sanitary' analysis (colour, turbidity, conductivity, pH, DO, BOD, nitrogen (all forms), phosphate, iron, free CO₂) and it was suggested that observed values greater than the mean \pm 2 standard deviations may be an indication of disturbance of the natural system.

Sampling of the invertebrates of marginal vegetation and sediments was discussed in the context of previous attempts to assess water quality

from the biological community. A table of invertebrates (Table 4, Brand et al 1967a) was presented, indicating the functional group (carnivore, herbivore, filter feeder, detritivore, omnivore) and pollution tolerance of each taxon. (Some of these classifications are criticized by Chutter, 1968b). An appendix gave a preliminary list of known invertebrate and vertebrate animals from Natal rivers. A biotic index was outlined for the classification of water quality, based on invertebrates from both marginal vegetation and sediments. The index was evaluated by a dichotomous key, leading through the presence/absence of the Baetidae (a clean water group) and the relative abundance of pollution tolerant and intolerant groups. Seven classes of communities were indicated:

- 0 Toxic disturbance
- 1 Heavy disturbance
- 2 Moderate/heavy disturbance
- 3 Moderate disturbance
- 4 Slight to heavy disturbance
- 5 Slight disturbance
- 6 Clean water

Bacterial criteria for water quality were examined in detail. Indicator organisms for faecal pollution were classified, and the significance of specific pathogens and other indicators is explained (eg bacteriophages such as Salmonella; 'sewage fungus'; and iron bacteria). The final section of Brand et al (1967a) summarized water quality criteria in terms of BOD, dissolved oxygen, pH, bacterial counts and appearance, and suggested six classes of water (see Table 1 for specific criteria).

The potential uses of the different classes can be summarized as follows (the classifications were intended to apply to the worst conditions in a river at any time, and were specific to Natal):

- Class 1. Suitable for all purposes after simple disinfection
- Class 2. Suitable for drinking water after conventional treatment
- Class 3. Not suitable for drinking or domestic use without special treatment
- Class 4. Mineralized water, not for domestic use, and probably not suitable for agricultural or industrial use
- Class 5. Only of possible use for irrigation, (usually faecally contaminated or organically enriched)
- Class 6. Foul water, usually a public nuisance or danger.

The first investigative report of the project concentrated on the Three Rivers Region between (but excluding) the Tugela and Mkomanzi Rivers (Brand et al, 1967b). Because of organic and faecal pollution, no class 1 waters were identified. Waters of class 2 predominated, except along the coastal belt where waters from class 3 to class 4 were found. The rivers for this and subsequent sections of the project are listed in Table 2. Part 3 of the report series (Brand et al, 1967c) is a recapitulation of Oliff's survey of the Tugela system (described in the previous chapter), interpreted in the context of the methods described in Brand et al (1967a). An additional bacteriological investigation

TABLE 1. Water quality classifications proposed by Brand et al (1967a) for South African rivers
(See text for further amplification)

Class	I	II	III	IV	V*	VI*
TDS, ppm	<100	<500	<1000	>1000	-	-
BOD, ppm	<1.5	<3	<5	<5	-	-
DO, % saturation	85 - 115	>60	>60	>20	>20	>20
pH value	6.9 - 8.5	6.0 - 9.5	6.0 - 9.5	-	-	-
Confirmed <u>E. coli</u> I per 100 ml.	<50**	<1500*	<50000**	-	-	-
Presumptive <u>E. coli</u> I per 100 ml.	<50**	<5000**	<50000**	-	-	-
Total plate count per ml (5 days 32°C)	<5000	-	-	-	-	-
Other bacteriological conditions	No <u>Salmonellae</u> , <u>Shigellae</u> , <u>Staph.</u> <u>aureus</u> , <u>Ps.aerugin.</u> nor sewage fungus	No sewage fungus	-	-	-	-
Appearance	Free from slicks, odours and suspended materials other than normal river silt	Free from slicks, odours and suspended materials other than normal river silt	Free from slicks, odours and suspended materials other than normal river silt	-	-	-

*Waters of this class may show virtually any values of the parameters not specifically tabulated.

**Not applicable to samples taken after recent rainfall.

TABLE 2. Natal rivers investigated during the 1950s, 1960s, and early 1970s by the National Institute for Water Research. (New names in brackets)

(Part numbers refer to Volume 13, Natal Town and Regional Planning Report)	
Part 2	Part 5
Sinkwazi	Umkomaas (Mkomanzi)
Nonoti	Amahlongwa
Umhlutuni	Umpambinyoni (Mpambanyoni)
Umvoti (Mvoti)	Umzinto (Mzinto)
Umhlali	Inkomba
Tongaat	Sezela
Umhloti (Mdloti)	Ifafa
Umhlanga (Mhlanga)	Mtwalume
Umgeni (Mgeni)	Umhlungwa (Umhlungwe)
Umbilo	Mhlabatshane
Umhlatuzana (Mhlatuzana)	Umzumbe (Mzumbe)
Umlaas (Mlazi)	Injambili (Ntshambili)
Isipingo	Indombe
Umbogintwini	Umtentweni (Mtentweni)
Amamzimtoti	Umzimkulu (Mzimkulu)
Little Amamzimtoti	Boboyi
Illovo (Lovu)	Zotsha
Umzimbasi (Mzimbasi)	Umhlangeni (Mhlangeni)
Umgababa	Uvongo (Vungu)
Ingane	Mbizane
	Mpenjati
	Mtamvuna
Part 3	Part 6
Tugela	Nonoti
Buffalo	
Sundays	
Bushmans	
Mooi	
	Part 7
Part 4	Buffalo
Amatikulu (Matigulu)	Ncandu
Umlalazi (Mlalazi)	Ngagane
Umhlatuzi (Mhlatuze)	Klip
Umfolozi (Mfolozi)	Ngogo
Nyalazi	Modderspruit
Hluhluwe	Sand
Umsinene	
Mkuze	
Pongolo	

and water chemical analyses were carried out in 1965 to assess changes in water quality since Oliff's survey. The water in most sites was of good quality conforming to class 1 or 2 criteria. There appeared to have been little deterioration in water quality over the twelve year period since Oliff's study, although pollution from coal mining had increased. The principal rivers of northern Natal and Zululand were investigated, and the results presented in Part 4 of the series (C G M Archibald et al, 1969). Analysis was predominantly chemical, with some bacteriological and hydrobiological studies, and algal species were recorded. Most of the waters were classified in class 2, but localized mineralization reduced some waters to class 3. Three major sources of pollution were identified: Drainage from coal mines, affecting the headwaters of the Mkuze and Black Mfolozi Rivers; organic pollution in the lower Mhlatuzi River; and organic pollution in the Pongolo River.

Part 5 of the report (Kemp et al 1976) dealt with the rivers of southern Natal. Most of the waters were of class 2, but the two major rivers (the Mzimkulu and Mkomanzi) contained class 3 water, due to mild organic enrichment, as did the smaller Amahlonga, Sezela, Mhlabatshane and Boboyi Rivers. The Mzinto River water was class 4, and that of the Inkomba and Mtentweni class 5. In this and subsequent parts of the project, Chutter's biotic index (Chutter, 1972a) was applied to the results of stones-in-current samples, and the index proposed by Brand et al (1967a) was modified slightly and used for samples from sediments and marginal vegetation.

Part 6 of the report describes the findings of a more intensive investigation of part of the Nonoti River below a sugar mill, which was monitored for a year. Chemistry, algology, bacteriology and oligochaete communities were studied in relation to pollution from the mill. Downstream recovery from mill effluent pollution was nearly complete after 3,2 km, but signs of disturbance were still evident after 8,4 km. Variable water flow prevented any application of oxygen sag theory, and may also have been responsible for a lack of correlation between chemical and other results. Attempts were made to characterize water quality using oligochaete biomass, and the occurrence of particular blue-green algae, but a chemical scheme (separate from that of Brand et al, 1967a) was eventually preferred.

The final part of the report (part 7, Fowles et al 1979) dealt with parts of the Buffalo River and its tributaries affected by the development of ISCOR steel works in Newcastle, and the Klip River tributary of the main Tugela, affected by large-scale industrial development at Ladysmith. The main aim was to collect background data against which the effects of developments could be assessed. Both areas had relatively clean water, but in Newcastle drainage from coal mines affected chemical quality, and other noticeable disturbances were related to urban effluents from Newcastle and Ladysmith.

3.4 The Orange River

Hydrobiological and invertebrate studies of the Orange River have been notably scarce, considering that this is the largest river in South Africa. Agnew (1965) described invertebrate samples from three

stations (Prieska, Upington and Onseepkans) collected from stones and marginal vegetation. Only limited conclusions could be drawn from such a superficial survey, but there appeared to be a distinctive element to the fauna when compared with stretches of the Tugela at the same altitude. Agnew (1965) pointed out that the impoundment of the river, (incomplete at the time of his survey), would probably make profound changes to the downstream fauna. Viljoen (1970) reports on aspects of the secondary production in the Orange/Caledon Rivers, upstream of the H F Verwoerd Dam. The energy and biomass of the zoobenthos was measured and described.

3.5 Mountain streams of the Barberton area (Queens, Hislops, Lomati Rivers of the Crocodile/Incomati system)

A two year investigation of streams in the Barberton area of eastern Transvaal was described by Hughes (1966a). The aims of the project were to add to the knowledge of faunal communities of the upper reach and describe their affinities with those of other rivers, and to collect background data in the light of plans to increase mining in these catchments. All the streams studied fell into the mountain torrent zone (II) and the foothill stony run zone (III) of Harrison and Elsworth (1958). Biotopes sampled were differentiated mainly in terms of current speed, as cascades, sprayed flanking regions, stickles, backwaters, and pools. The affinities of the ephemeropteran communities were examined and it was concluded that there were similarities with those of the Upper Tugela and the streams of the Vaal Dam catchment, but very few similarities with the Berg River. During the survey, it appeared that vegetation shading had an effect on the distribution of some species. Field studies (Hughes, 1966b) failed to show any significant effects on overall population density, or on any group or family, although certain species may have been influenced by light and shade. Laboratory experiments (Hughes 1965, 1966c,d) showed that mayfly nymphs were affected in their choice of habitat by light and shade. Tricorythus discolor depended on an interaction of light, current and thigmotaxis while Baetis harrisoni depended on light responses and current requirements.

3.6 Diatom studies in Lesotho Rivers

The systematics, taxonomy and autecology of the Diatomeae of Lesotho streams, rivers, dams, caves and bogs were described by Schoeman (1971, 1972, 1973). The study area included the upper streams of the Orange/Caledon system. The diatom associations from each sampling site were subjected to a statistical analysis in order to determine the relative densities of different species in the association. The water quality was assessed using diatom species as ecological indicators. The majority of Lesotho waters were found to be alkaline, and usually oxygen rich. However, water pollution by nitrogenous compounds was serious and was attributed to the densely populated rural areas, where there were large numbers of livestock.

3.7 The Great Fish and Sundays Rivers (eastern Cape)

Hydrobiological investigations of the Great Fish and Sundays Rivers were initiated as part of the Orange River Project, to provide a database against which to gauge the effects of the Orange/Fish/Sundays water transfer scheme, and to try to predict possible ecological consequences. Investigations covered the water chemistry and geology of the catchments (Forbes and Allanson, 1970a), and the biota, concentrating mainly on the Trichoptera (Scott, 1970), the Ephemeroptera (Forbes and Allanson, 1970b), the Simuliidae (Chutter 1972b,c), and diatom associations (Archibald, 1971). Scott, Allanson and Chutter (1972) summarize the results of the project. The main processes influencing water quality in the region were mineralization, siltation, low rainfall and the effects of highly saline groundwaters. The area is important for irrigated agriculture, and irrigation runoff compounded the mineralization problems. Drought during the period of the study restricted the general conclusions. Invertebrate populations were restricted in number and variety by mineralization, silting, and seasonal dessication. Organic pollution was not a problem, although mild enrichment was observed below Cradock and Cookhouse on the Great Fish River, and below Graaff Reinet on the Sundays River. The possibility of canalizing incoming Orange River water to prevent mineralization in existing river beds was discussed, and a warning was given about possible large increases in mammal-biting simuliids following the opening of the Orange/Fish tunnel. This prediction was borne out by the seasonal appearance of pest densities of Simulium chutteri in the lower Fish River since the flow has been made permanent by Orange River water transfer (Coetzee, 1982; O'Keefe, 1982).

3.8 Streams of Table Mountain (south-western Cape)

Dr K H Barnard carried out intensive sampling of a stream on Table Mountain (Platteklip Gorge) in all months of the year, during the years 1931 to 1935. These and supplementary records from other streams were analysed in Harrison and Barnard (1972). Most of the samples were taken from source zones (I) and mountain torrent zones (II), as defined by Harrison and Elsworth (1958). The fauna was relatively impoverished when compared with that of the mainland mountains. Reasons for this paucity may include local extinctions combined with low immigration rates because of the barrier of the Cape Flats. It is concluded that Table Mountain was a virtual island as far as mountain stream fauna is concerned.

3.9 Invertebrate drift in the Mlaas (Mlazi) and Msunduze Rivers (Natal)

A study to assess short-term variations in the drifting component of the invertebrate fauna is described by Chutter (1975). Samples were taken in the Mlazi River, 16 km below Shongweni Dam. A waterwheel drift sampler was used to filter known quantities of river water for 15 or 30 minute periods throughout the day and it is concluded that such measurements produced less variability than benthic sampling, and that the drift fauna could be adequately characterized with samples of as little as 350l taken over 15 minutes. Drift densities remained remarkably constant in a wide range of flows and for periods of over a week. It appeared for this single study that there would be useful

applications for investigating water quality using drift, but that tests in differing catchments would be needed to confirm this.

Chutter (1984) described a second attempt to correlate invertebrate drift with water quality, this time in the Msunduze River. In this case it was postulated that the production and density of benthic and drifting invertebrates would be increased by moderate organic and nutrient enrichment, and that drift density could therefore be used as an indication of organic pollution. Although drift density at one station was found to be significantly higher than elsewhere, there were no significant differences in the density at other sites. It was concluded that it would probably not be possible to relate drift density to water quality, because of the inherent variability in sampling, and because of complex environmental effects. However, Chutter felt that it might be possible to find relationships between drift and water quality in the abundance of components of the drift, as the number and types of chironomid pupal exuviae, for instance, showed obvious responses to changing water quality. Chutter (1984) also examined the relationship between his biotic index (Chutter, 1972) based on benthic invertebrates from stones-in-current, and chemical measures of water quality. Biotic index values correlated significantly with total Nitrogen and total Phosphorous concentrations, and with the five-day biochemical oxygen demand. The index was felt to be a useful measure of water quality.

3.10 The Jukskei/Crocodile Rivers (Transvaal)

A detailed two year resurvey of the Jukskei/Crocodile Rivers was carried out by Wilkinson (1976, 1979), based on water chemistry and analysis of the fauna of stones-in-current. A simultaneous analysis of diatom communities is reported by Schoeman (1976, 1979).

The aims of the project were to examine the value of the invertebrate fauna of stones-in-current in assessing water quality, and to describe changes in water quality since Cholnoky's (1958) and Allanson's (1961) investigations. Wilkinson (1976, 1979) used Chutter's (1972a) biotic index and computerized cluster analysis techniques to examine the faunal associations and changes in response to different water conditions. He defined three types of water quality environments:

1. Tributaries of the middle/lower reaches of the system, with agricultural catchments and no point sources of serious pollution.
2. The Modderfontein stream and the Jukskei below its junction with the Modderfontein - dominated by nitrogenous industrial effluent.
3. The middle/lower reaches of the main streams - dominated by phosphorus-rich sewage effluent.

The results from Chutter's biotic index reflected closely the effects of organic pollution, but in the Modderfontein stream, results were confused by toxic industrial wastes (probably heavy metals) which resulted in the absence of the community normally associated with organic pollution. Wilkinson concluded that the biota does reflect water quality, and even short-term and subtle changes which would be missed by 'snap' chemical analyses are shown up by analysis of faunal

communities. However, he stressed that the drawback of any rigid classification was that it might become misleading if interpreted literally by non-specialists. Cluster analysis showed that dominant and subsidiary faunal associations could be identified, and that these did not necessarily react in the same way to the same changes in water conditions. He concluded that all river systems have specific environmental effects which must be interpreted before meaningful conclusions can be made about artificial perturbations. Schoeman's (1976) simultaneous study on the diatom communities of the Jukskei/Crocodile largely confirmed Wilkinson's findings as to levels of pollution. Diatom species with similar ecological requirements were grouped and used as indicators of water conditions. Results were compared with chemical and algal growth potential data, and these suggested that diatom groups can serve as reliable indicators of water quality. It was concluded that the Modderfontein and Jukskei Rivers were considerably more eutrophic than the Hennops and Crocodile Rivers.

3.11 The Berg, Olifants, Breede and Black/Liesbeek Rivers (south-western Cape)

A number of surveys of rivers in the south-western Cape were carried out by A H Coetzer and reported between 1976 and 1982. A short study of the invertebrate fauna and algal growth potential of the Black/Liesbeek and Black/Vyekraal Rivers in Cape Town (Coetzer, 1976) provided values calculated for Chutter's biotic index. Values for sample sites above the Cape Town sewage outlet were between 5,7 and 7,1. Below the sewage outlet all values were between 9 and 10 (indicating gross organic pollution).

A similar survey of the Breede River (Coetzer, 1978a) covered 18 sampling points which were sampled during March in 1975 and 1976. Only the fauna of stones-in-current was collected, and values for Chutter's biotic index calculated. For both years index values were higher in the upper catchment (above Worcester) than in the middle reaches, as a result of agricultural effluents. Enriched water from the Kogmanskloof tributary raised the biotic index values some 35 km above Swellendam. Values remained high (indicating enrichment) at Swellendam, with anomalous low values at one site, for which no explanation could be given.

Coetzer (1978b) reported on a one year resurvey of the Berg River during which the invertebrate fauna at seven sites was sampled three times, to assess changes in water quality since Harrison and Elsworth's (1958) investigation. In the meantime a bacteriological and chemical study by Fourie and Steer (1970) had concluded that the Berg River above Paarl was unpolluted, that the Paarl/Wellington urban complex showed organic pollution, but that the river recovered below Wellington. Increased conductivity indicated mineralization below Wellington. Coetzer (1978b) sampled only the fauna of stones-in-current. Indications from increased numbers of coelenterates, decreased Plecoptera, and the absence of Megaloptera and some families of Trichoptera, Coleoptera and Diptera, compared with Harrison and Elsworth's (1958) samples, indicated that river conditions have deteriorated since the earlier survey. Biotic index values were

calculated and indicated slight enrichment in the upper reaches and moderate enrichment from Paarl downstream.

Coetzer (1982) reported a one year investigation of the Olifants/Doring River system, during which 22 sites were sampled monthly for invertebrates of stones-in-current, and for partial water chemistry analysis. Chutter's biotic index values were calculated, and in the main Olifants River, only one site (below Lutzville, towards the estuary) gave index values indicating any level of enrichment. In the Doring River, values for three sites showed mild or moderate enrichment at some time of the year. Index values could not be significantly related to physico-chemical parameters. Coetzer concluded that the Olifants is one of the less polluted of South Africa's rivers, and that the fauna is less abundant than indicated in published results for other rivers. The use of Strahler's river order system was preferred to the zonation systems proposed by Harrison and Elsworth (1958) or Chutter (1970).

3.12 The Pongolo River (KwaZulu)

The unique floodplain system of the Pongolo River downstream of Pongolapoort, and the changes to the floodplain threatened by the impoundment of the river at Jozini, have generated a different approach to research than that pursued in other river studies. Investigations of the river upstream of the dam have been notably scarce. C G M Archibald et al (1969) sampled invertebrates and water chemistry at half a dozen sites twice during one year, as part of the Natal rivers survey (see above). They found high quality water throughout the system, with some mineralization in the middle reaches, and localized organic pollution below Pongola town. This has been the only research concentrating on the river itself, the rest of the work reviewed here has concentrated on the functioning of the floodplain ecosystem, and particularly the seasonally inundated pans. A process orientated systems approach has been possible in the Pongolo floodplain investigations because of the conceptually simple hydrological processes which are fundamental to the functioning of the pans. A certain amount of floodwater is necessary to flush and fill the pans annually. The Pongolapoort Dam controls the downstream flow and must therefore be managed to provide the required levels of annual floods if the pans are to continue to provide livestock grazing and fish for the local people. The main thrust of research has been to unravel the nutrient and energy pathways in the pans, so as to predict the frequency, seasonality and duration of water releases which will maintain the pans for minimal water expenditure. This review describes the sequence of research leading to an understanding of floodplain pan function. Studies on the fish populations and fishery potential are reviewed in Chapter 4.

Coke (1970) described the pans at their lowest known levels, and recorded the lack of effect of a 28 cumec flood in filling them. He later monitored a larger water release which filled all but three pans (Coke, 1971) and because of fortuitous mid-summer timing, resulted in successful fish breeding. Coke and Pott (1970) and Phelines, Coke and Nichol (1973) produced a conservation plan for the floodplain, based on flood release planning, and recommended artificial barriers and feeder channels to maximize the use of water releases in filling pans.

Early studies of the aquatic macrophyte communities were carried out by Musil (1972), Musil et al (1973), and Musil et al (1976). Two groups were recognized, submerged macrophytes, and floating or rooted floating macrophytes. The distribution of the former was dictated by light availability, while the latter showed a preference for the protected eastern shores of pans. Correlations of distribution were also made with pH, oxygen and free carbon dioxide levels. Later vegetation analysis by K H Rogers (1980) identified six seasonally flooded and three aquatic communities. The seasonally flooded terrestrial communities provided important livestock grazing, while aquatic macrophyte growth and decomposition provided the basic food chain for fish production (K H Rogers 1978). F E J Rogers (1981) and K H Rogers and Breen (1981, 1982) investigated Potamogeton crispus as an important primary producer in the pans, restricted to winter growth. Long floods or the release of cold hypolimnial waters could adversely affect production. The epiphyton of P crispus played an important role in the decomposition processes of the macrophyte, providing a faster turnover of nutrients in the pans. Furness (1981) investigated the vegetation of seasonally flooded margins of the pans, and particularly Cynodon dactylon, the most important grazing plant. Highest productivity and greatest palatability of C dactylon occurred in winter, and fast decomposition rates after flooding ensured the speedy return of nutrients to the pans.

Heeg et al (1978) looked at levels of dissolved solids in the pans and concluded that high TDS values were a result of geologically mediated highly mineralized seepage waters. The importance of seasonal flooding to flush out the pans and reduce TDS was stressed. Breen et al (1978) conducted bathymetric studies of the pans, and showed that seasonal fluctuations in water level exposed marginal sediments that were important grazing areas.

Benthic invertebrate communities in the pans were investigated by Walley (1979). Different pans had different mid-pan sediment faunas, but marginal faunas were similar. High salinity was important in restricting the distribution of groups such as Lamellibranchs and oligochaetes. The productivity of two mussel species, an oligochaete and a chironomid was assessed. Pretorius et al (1975) surveyed the mollusc fauna of the pans and concluded that there was little difference between communities of deep and shallow pans. Bilharzia intermediate host snails were among the most successful species in the pans.

Heeg and Breen (1979, 1982) have drawn together much of the above research to form a holistic picture of the floodplain ecosystem, including its human inhabitants. Summarizing the hydrology, water quality, sociological impacts, and conservation of the system they pointed out that the values of the floodplain in providing a livelihood for the inhabitants were not taken into account when costing the Pongolapoort Dam and development of agriculture on the Makatini Flats surrounding the floodplain. A cost/benefit analysis showed that conservation of the floodplain, in terms of water allocation for the pans, could be justified for economic as well as intrinsic values. Among their recommendations was that the construction of inflatable weirs downstream of the dam should be considered, to maximize water use for flushing and filling the pans.

3.13 The Eerste River (south-western Cape)

A detailed study of invertebrate communities in the Eerste River was undertaken by King (1981, 1983). Monthly samples from eight sites were collected from the stony stream bed and marginal vegetation. Cluster analysis was used to identify faunal communities, and discriminant analysis to relate communities to the physico-chemical environment (King, 1981). Three zones were recognized in the stretch of river investigated: the mountain stream, the upper river and the lower river.

Results from the stony stream bed indicated six communities which could be separated either spatially or temporally:

- Winter Mountain Stream community
- Winter Upper River community
- Winter Lower River community
- Summer Upper River community
- Transitional (summer to winter) Lower River community
- Summer Lower River community

Characteristics were based on the species composition of the communities and in particular of the Ephemeroptera, the dominant insect group. Different species could be identified as typical of particular communities. Advantages of cluster analysis were that all component groups had an effect on community identification and that no prejudged classifications are necessary as the associations are identified objectively. Three communities (based on spatial separation) were recognized from the marginal vegetation, but these were not so clearly separated by cluster analysis as the stony bed communities. Discriminant analysis showed clear groupings of communities along environmental axes, of which dissolved oxygen, total alkalinity and pH were the most influential individual variables of those measured. King (1981) concluded that predictable communities occurred and could be identified by these methods. Stony bed fauna was found to be more sensitive to change than that of the marginal vegetation. There was a trend for winter communities to occupy stony bed habitats for longer, the nearer they were to the source of the stream; and the winter mountain stream community was present year round. The stream environment was more variable in summer than in winter and with increasing distance from the source. Dissolved oxygen level was the most important environmental variable limiting species distributions. The water of the mountain stream was pollution free, that of the upper river was 'reasonably clean', and that of the lower river was 'poor' in summer, due to low summer flows and effluents from Stellenbosch, but 'improved' in winter.

King (1983) examined invertebrate abundance, biomass and diversity in the Eerste River, based on the same fieldwork as King (1981). Abundance and biomass were found to increase downstream except where siltation from a dam construction site blanketed the substrate. Seasonal changes in abundance and biomass differed in the three zones, but all showed a peak in spring. Overall, the highest abundance and biomass was found in the lower river in summer, because of low flow and organic enrichment below Stellenbosch. The ephemeropteran fauna was

taken as representative of overall invertebrate diversity. In general, diversity decreased downstream, with major decreases below point sources of nutrient enrichment.

King et al (1979) reviewed the hydrology and hydrobiology of the fynbos biome in general, but with some specific references to the Eerste River. Less leaf litter falls from fynbos vegetation than from deciduous woodland, and fynbos leaves are tough and sclerophyllous. Therefore, decay takes place slowly, and most plant material is washed down stream before it can contribute to energy and nutrient turnover. This results in low productivity in fynbos catchment streams. The removal of fynbos and replacement with commercial timber crops reduces streamflow by increasing evapotranspiration, but removal or burning of fynbos initially increases streamflow. Streams in mountain fynbos yield high quality water and are heavily exploited for human use. Van der Zel and de Villiers (1975), in an evaluation of forestry in the Eerste River catchment, found that water use for forestry was comparable with that of the optimum mixed farming recommendation. They concluded that timber crops can be grown in the upper catchments of the south-western Cape without detrimentally influencing other land owners in, or the water yield from, such catchments.

3.14 The Olifants, Nwanedzi, Letaba and Sabie Rivers (eastern Transvaal)

The invertebrate ecology of the Mohlapiitse tributary of the Olifants River was studied by Masihleho (1981). The Trichoptera, Ephemeroptera and Simuliidae were numerically dominant, with a peak abundance in spring. Positive correlations were found between the following:

Current and	Ephemeroptera, Trichoptera, Odonata, Plecoptera, Coleoptera, Simuliidae;
Temperature and	Ephemeroptera, Coleoptera, Trichoptera, Simuliidae, Tabanidae, Tipulidae;
Turbidity and	Ephemeroptera, Trichoptera, Odonata, Plecoptera, Coleoptera, Simuliidae, Tabanidae, Tipulidae;
BOD, NH ₄ -N, NO ₃ -N and SO ₄ , NO ₂ -N and	Annelida, Gastropoda, Chironomidae Turbellaria.

Analyses of invertebrate drift showed that the Ephemeroptera, Odonata, Plecoptera, Coleoptera and Simuliidae were primarily nocturnal with respect to drift density, while Trichoptera were mainly diurnal. Drift densities were high in autumn and spring and generally low in winter.

Mokgalong (1981) describes aspects of the invertebrate ecology of the Nwanedzi tributary of the Limpopo River. In this case positive correlations were obtained between:

Current and	Trichoptera, Simuliidae;
Temperature and	Ephemeroptera, Tabanidae, Chironomidae;
Turbidity and	Ephemeroptera;
pH and	Ephemeroptera, Odonata, Tabanidae, Turbellaria;
Dissolved oxygen and	all invertebrate groups.

Samples were taken above and below the Luphephe-Nwanedzi twin impoundments. Above the dams the Simuliidae, Ephemeroptera and Chironomidae were dominant, indicating relatively unpolluted conditions. Below the dams high densities of Turbellaria and Trichoptera were taken as indications of organic enrichment. Invertebrate drift density was related to light intensity and water temperature fluctuations.

A short survey of the Sabie and Letaba Rivers within the Kruger Park was reported by O'Keeffe (1985a). Twenty stations were sampled for invertebrates and various attributes of the catchment described (geology, vegetation, bank stability etc) with the aim of assessing the conservation status of the two rivers. It was concluded that the Sabie River has been very little changed from its natural state, with a diverse fauna indicating clean water. The Letaba River was subject to much greater upstream perturbations, and has also been impounded in four places within the Kruger Park. The hydrological regime has been altered by water extraction and catchment degradation outside the Park, and by impoundments. Banks appeared unstable and the invertebrate fauna (dominated by simuliids) indicated mild enrichment. Natural differences between the two rivers were interpreted as the results of difference in stream gradient and rainfall.

3.15 The Vaal River (Transvaal and Orange Free State)

Ecological research in the Vaal River since Chutter's investigations (see previous chapter) has been concentrated in two fields of study: water pollution and the control of Simulium chutteri, a mammal-biting blackfly.

Pollution studies have tended to concentrate on physico-chemical indicators. Lenhard and du Plooy (1965) studied the bottom deposits of the river, analysing them for dehydrogenase activity, organic and inorganic carbon, nitrogen, humic acids, cation adsorption capacity and exchangeable bases. Sediment characteristics were compared with BOD of the flowing water. It was concluded that the sediments can provide a valuable index of the water quality. Van Hoven (1973) investigated the ecology of four aquatic oligochaetes in the Mooi, Vaal, Loopspruit and Droëspruit Rivers. It appeared that sediment texture and conductivity of the water were two of the most important factors governing the distribution of Limnodrilus hoffmeisteri. Grobler et al (1983) reported changes in turbidity as a result of mineralization in the lower Vaal River. Significant correlations were found between turbidity and conductivity and Sodium adsorption ratio. A predictive model relating photic depth to mineralization via turbidity was derived, and could be used to plan water quality management in the catchment.

In recent years two meetings have been held to discuss research needs for the Vaal River. 'Focus on the Vaal', a symposium, was reported in Henzen et al (1980). The emphasis was on improving water quality and increasing water supplies. Current and future research projects cover: river water quality (with emphasis on mineralization); impoundment water quality (with emphasis on eutrophication); irrigation, groundwater and industrial water usage; nutrient removal from effluents; water reclamation and desalination; rainfall stimulation; surface hydrology; flood occurrences and damage. A workshop on the Vaal River entitled

'An Assessment of Water-Related Problems of the Lower Vaal River', (Bruwer et al, 1985) was recently held. Main subjects discussed included: water quality in terms of TDS, trace elements, organic contaminants, nutrient status, temperature and dissolved oxygen levels, phytoplankton and zooplankton communities, aquatic macrophytes, and fish communities; water quality problems in terms of treatment to potable standards, irrigation and agricultural run-off; industrial considerations; recreational water use; and riverine ecology.

The second major subject of ecological research in the Vaal River, the control of Simulium chutteri, has been approached in a number of different ways. Chutter (1967a, 1968a) described the ecology of S chutteri larvae and ascribed increases in the population to changes in the water flow regime, and in the food supply of the larvae. Fluctuations in flow were related to irrigation needs, while the development of high densities of phytoplankton behind the Vaal Hartz weir provided an increase in food supplies for S chutteri larvae downstream of the weir.

Howell and Holmes (1969) described initial attempts to control S chutteri using DDT. These were successful in the short term, but rapid reinfestation occurred following increased flow after heavy rainfall. S chutteri's recolonization ability is ascribed to diapausing eggs in the river sediments. Begeman (1981) describes the bionomics of simuliids in the Vaal. The breeding cycle of several species is outlined and significant differences between species were noted. Eggs ascribed to S chutteri were found in Vaal River sediments, and were viable when removed, while other species deposited clusters of eggs on submerged stones. De Moor (1982a) carried out a three year study of Simulium ecology in the Vaal River near Warrenton. The aim was to identify factors influencing the abundance of simuliid larvae, and to devise control strategies. Careful analysis of larval development (de Moor, 1982b) and population dynamics of S chutteri revealed that the development of large larvae and pupae in winter led to more fecund adults in spring. This coincided with low predation pressure and could lead to rapid growth of blackfly populations in spring. Habitat preferences and seasonal abundance of all common simuliid species in the lower Vaal were described. Oviposition in open water and colonization and dispersal by drifting distinguished S chutteri from the other species. Interspecific competition was not intense, and fluctuating environmental conditions allowed seasonal increases in the various Simulium species. An empirical model was devised to predict the densities of adult S chutteri in spring from winter larval densities. It was suggested that flow manipulation (from the Vaal Hartz diversion weir) could be used to control S chutteri, as shutting off the river flow would lead to mass mortality of larvae and pupae. If this was done in winter, when the great majority of the population is in the aquatic stage, and when the overwintering large larvae are developing, maximum reduction of spring populations should be achieved.

Howell et al (1981) and Car (1983) described experimental manipulation of water flows in the Vaal and Orange River to control S chutteri. Substantial increases in larval drift as the flow was decreased, and a subsequent decrease in larval drift when flow was resumed, indicated

that considerable reduction in the larval populations had been achieved. Repeated flow manipulation centred around July, was found to be the most effective control strategy.

A further control method, using bacterial spores of Bacillus thuringiensis as a biocide, was described by Car and de Moor (1984) and Car (1984). In one trial, significant reductions in simuliid larval densities were achieved 70 m below the treatment point, but further downstream spores settled out of the water and became ineffective. Ambivalent results were achieved in a second trial. Larvae decreased at first, but subsequent upstream recolonization by small larvae caused increased densities. Apart from decreases in tanytarsine chironomids, no significant effects on non-target species were observed. Car (1984) described a control trial using B thuringiensis in the Pienaars River, a small heavily polluted river east of Pretoria. The efficacy of the biocide decreased by about ten times due to the high chloride and sewage content of the river.

3.16 Snails of medical and veterinary importance

Extensive research has been carried out on freshwater gastropods of the genera Bulinus and Biomphalaria, since many species act as intermediate hosts for schistosome trematodes which cause bilharzia. In addition much work has been done on the genus Lymnaea, species of which carry larval stages of liver flukes of the genus Fasciola. Although these investigations have been carried out from the specialized perspective of disease epidemiology, they have often contributed important information about the ecology of the aquatic habitat of these snails, which in many cases is the less turbulent parts of rivers.

Because their occurrence dictates the transmission of bilharzia and fascioliasis, the distribution of these host snails has been carefully surveyed, particularly by Professor van Eeden's group at Potchefstroom University. Van Eeden (1960) produced a key to freshwater and estuarine gastropods for South Africa. Van Eeden et al (1964) surveyed the distribution of Bulinus and Biomphalaria in and around Johannesburg, while van Eeden (1965a) discussed their distribution patterns throughout Transvaal, and van Eeden et al (1965) did the same for south-eastern Africa, including the distribution of Lymnaea. Van Eeden (1965b) described the distribution of Bulinus reticulatus in South Africa, and Brown (1966) investigated the taxonomy and distribution of Bulinus africanus and B globosus in south-eastern Africa. Van Eeden and Brown (1966) described the introduction and spread of the American snail Lymnaea columella, which has become an important host for fascioliasis in South Africa. Prinsloo and van Eeden (1973) mapped the distribution of freshwater molluscs in Lesotho, and discussed the importance of Lymnaea truncatula in the transmission of fascioliasis.

A number of researchers have attempted to define the environmental conditions necessary for the establishment of snail hosts of flukes. De Meillon et al (1958) and Schutte and Frank (1964) investigated aspects of water chemistry and their effect on snail distribution. Neither group could identify any significant simple correlation, although de Meillon et al (1958) found that current speed and turbidity could be important and that severe pollution had an adverse effect on

the snails. Schutte and Frank (1964) found some correlation between frequency of snail occurrence and hardness of the water, which was in turn correlated with altitude and temperature in the study area. They concluded that the habitat suitability is mediated by a complex of interrelated factors.

Combrinck (1968), Combrinck and van Eeden (1969), and Prinsloo and van Eeden (1969) reported on investigations into the influence of factors on the distribution of Bulinus tropicus and Lymnaea natalensis. Among their conclusions were that a muddy substratum with vegetative growth probably provides the best habitat for both species, but that they had different optimum temperature requirements. Jennings et al (1973) investigated the effect of TDS concentrations on Biomphalaria pfeifferi and found that a conductivity of between 350-400 μScm^{-1} was best suited for breeding. Jennings (1976) extended his investigations to include Bulinus tropicus and Lymnaea natalensis. The range of T.D.S. found in natural habitats was not sufficiently extreme to affect the distribution of Biomphalaria pfeifferi or Bulinus globosus but L. natalensis might be restricted at conductivities higher than 375 μScm^{-1} and Bulinus tropicus at those lower than 180 μScm^{-1} .

Appleton (1975; 1976a,b; 1977) and Appleton and Stiles (1976) investigated a number of abiotic influences of Biomphalaria pfeifferi, Bulinus globosus and Lymnaea natalensis, including geology, temperature and current speed. Changes in geology in the Gladdespruit stream, near Nelspruit, had effects on the channel morphology and water chemistry, and appeared to be the most influential feature governing snail distribution. Current velocity was also important, and high temperature limitation was noted for Biomphalaria pfeifferi. During his work on snails in the Gladdespruit stream, Appleton (1974) surveyed the invertebrate communities of the stream and listed species for four different zones.

CHAPTER 4 FISH

4.1 Introduction

Fish have received a great deal of attention in research on South African river ecology (almost a third of all books and articles on this subject deal primarily or exclusively with fish). The literature on fish research tends also to be self-contained, and separate from other facets of river ecology. The following review is organized by subject matter rather than by catchment, and covers the taxonomy, biology and ecology of fish in South African rivers. Two subjects on which there is an extensive literature have not been included. Articles entirely devoted to physiology were considered not to have a direct bearing on river ecology, although such studies often provide background information for ecological studies. The growing field of commercial fish farming for food has also been ignored, although aspects dealing with the rearing of indigenous species for reintroduction have been included.

4.2 Taxonomy

The taxonomy and systematics of fish have been more closely investigated than that of any other fresh water group, although new classifications and reviews of some groups are still necessary. General classification reviews and guides have been provided by Gilchrist and Thompson (1917), Crass (1956a, 1960, 1964) and Fowler (1934, 1935) for Natal, Barnard (1943) for the south-west Cape, Jubb (1961c) for the Limpopo and Zambesi, Jubb (1965) for the Cape, and Jubb (1967a) for all southern Africa, I G Gaigher (1969) and Le Roux and Steyn (1968) for Transvaal and Bruton et al (1982). Jackson (1975) has compiled a checklist of freshwater fish species for southern Africa and has suggested common names. Descriptions and reviews of the genus Barbus include Barnard (1938b) (descriptions of B hospes, B calidus, B phlegethon and B cernuus) Groenewald (1958), Jubb (1968a), Skelton (1974a, 1976); and Jubb (1966d) described B brevipinnis. The classification of the related rare cyprinid Oreodaimon quathlambae, found only in a few streams in the Drakensberg, has been discussed by Barnard (1938a), Jubb (1966a), Greenwood and Jubb (1967), Skelton (1974b), and Gephard (1978), with whom Skelton (1979) disagreed. Cichlid classification has been examined in Barnard (1949b), Jubb (1967b) (Serranochromis meridianus), Jubb (1968b) (Astatotilapia brevis), Voss (1972) (Tilapia sparrmani), Jubb (1973a) Oreochromis mossambicus, and Trewavas (1981) detailed the mouthbrooding differences between Sarotherodon (paternal or bi-paternal mouth-brooders) and Oreochromis (maternal mouth-brooders). Eels of the

genus Anguilla are discussed by Barnard (1957) and by Jubb (1957a), who recognized two species A mossambica and A marmorata. Jubb (1957b) recognized in addition A bicolor bicolor and A nebulosa labiata. Davies (1981) describes the separation of the four species at the glass eel stage. The genus Labeo in Transvaal has been revised by du Plessis (1963). Some of the small catfish species have been revised by Jubb and le Roux (1969) (Chiloglanis spp), Skelton (1981) described Austroglanis barnardi from the Olifants River in the south-western Cape, Skelton (1984) revised the genus Amphilius, and Skelton et al (1984) revised the generic identity of Gephyroglanis to Austroglanis. A revision of the genus Galaxias by Mcdowall (1973) concluded that all specimens in South Africa are from a single species Galaxias zebratus. Kok and Blaber (1977) described a new species of goby, Mugilogobius pongolensis from the Pongolo River floodplain.

4.3 Fish species distribution, introductions and biogeography

A number of studies and reviews have been devoted to surveys of fish species distribution in different parts of the country (Table 3). A number of studies on different aspects of fish biology have also contributed distribution information, and in addition, all four of the provincial nature conservation bodies hold large data bases on the distribution of indigenous and introduced species. Information about the presence and distribution of fish species is available for all large rivers, and for small streams and tributaries, either from the above sources, or from angling clubs.

Some specialized aspects of fish distribution and dispersal have also been investigated. I G Gaigher (1973) described the distribution of fish species in the Limpopo River, and noted the habitats in which different species occurred. As a result he was able to define five habitat types in the river, and described habitat preferences for each species. Crass (1969) outlined the distribution of indigenous and exotic fish species in Natal, and discussed the effects of land use. The main effect of agricultural land use was to increase erosion, leading to higher silt loads, which adversely affect both fish and their food organisms. A secondary effect was to decrease the catchment's buffer capacity to retain water, leading to more severe flash floods and reduced flows at other times. He concluded that catchment development was inevitable, but that the conservation of mountain catchments and the building of dams were likely to protect some of the more economically important species. Dam walls represented a barrier to fish dispersal and migrations, for which the answer may be the installation of fish ladders. Meyer (1972, 1974) has studied the use of fish ladders in Transvaal rivers, both in terms of their success in overcoming artificial barriers, and as a convenient collection point from which to monitor fish movements. The distribution and taxonomy of fish parasites and diseases in Transvaal have been investigated by Lombard (1968) who provided diagnostic descriptions of 22 diseases and parasites, and Prudhoe and Hussey (1977) who described a collection of monogenean, trematode, cestode and nematode worms from freshwater fish.

The distribution and ecology of fish in the Pongolo River has been intensively studied, both prior to and since the closure of the Pongolapoort Dam. Pott (1969) investigated fish populations in the

TABLE 3. A list of rivers and regions for which fish distributions have been published.

River or Region	Author	Date	Comments
Cape Province	Gaigher et al	1980b	Conservation status
Cape Province	Gaigher, I G	1978	Conservation status
Cape Province	Cape Department of Nature Conservation	1985	
Natal	Crass, R S	1960	Taxonomic
Natal	Crass, R S	1964	
Natal	Crass, R S	1966	
Maputaland	Bruton, M N	1980	Communities, conservation status, utilization
Kruger National Park	Pienaar, U de V	1978	
Buffalo River (E Cape)	Jackson, P B N	1982	Fishery potential
Caledon River	Marshall, R D	1972	
Great Fish River	Cambray, J A	1979	Introductions
Limpopo River	Gaigher, I G	1973	Habitat preferences
Limpopo River	Kleyhans, C J	1980	Crocodile, Matlabas, Mogol and Palala tributaries
Olifants River (S W Cape)	Jubb, R A	1983 1961a	
Olifants River (Transvaal)	Hecht, T and Mashego, S N	1981	Mohlaitse tributary only
Orange River	van Schoor, D J	1968	Aliwal North to Douglas
Orange River	Jubb, R A	1972a	Above H F Verwoerd Dam
Orange River	Jubb, R A	1972b	
Orange River	van Schoor, D J	1972	Upper River
Orange River	Cambray, J A	1976	H F Verwoerd Dam to P K le Roux Dam
Orange River	Cambray, J A	1977	Middle and Lower River
Orange River	Cambray, J A	1981a	Middle and Lower River
Orange River	Cambray, J A	1982	Middle and Lower River
Orange River	Cambray, J A	1984a	Middle and Lower River
Sak River (tributary of Orange River)	Hocutt, C H & Skelton P H	1983	
Pongolo River	Pott, R M	1969	Pre Pongolapoort Dam closure

river prior to the closure of the dam. Growth, density and dispersal patterns of some of the larger species, including Hydrocynus vittatus, Labeo rosae, and L. rubropunctatus were studied with a view to drawing up a management plan to maintain stocks after the closure of the dam. Pott (1968) had already pointed out the need for periodic water releases to maintain the floodplain pans below the dam, and Pott (1969) recommended that at least some of the pans must be preserved as holding habitat for H vittatus, L. rosae and Eutropius depressirostris from which the Pongolapoort reservoir could be stocked. The danger of population explosions of Oreochromis mossambicus and Tilapia rendalli in the absence of predators, was emphasized, and it was suggested that stocking with predators such as black bass and E depressirostris may also be necessary. Pott (1970) further recommended that tilapia populations in the reservoir should be reduced by selective trapping. Coke (1971) reported on some early flood releases from the dam, which raised the water level in some pans by as much as 5,5 m following a prolonged dry period. Collection of fish fry throughout the floodplain indicated that the flood had stimulated widespread spawning success, largely as a result of the flood timing (in mid-summer), which coincided with peak breeding condition in many fish species. Coke and Pott (1971) emphasized the importance of the floodplain pans as breeding habitat for many fish species, and outlined the natural hydrological regime (with floods of 85 cumecs occurring on average five times per year). Kok (1980) studied 13 fish species in the Pongolo floodplain pans, and described their life-history, feeding, and breeding in the context of the controlled flooding of the pans from the Pongolapoort dam. The permanent floodplain pans were found to be cichlid dominated, while the less stable, turbid pans were dominated by non-cichlid species.

A number of fish distribution studies have been carried out in order to monitor rare species, or to assess conservation status. These are also dealt with in Chapter 6 (on conservation), but should be mentioned here. The Olifants River system of the south-western Cape is well-known for its endemic fish fauna, comprising eight species. C M Gaigher (1973) outlines the shrinking distribution of some of these endemic species, and identifies introduced species, impoundment and increased sandy sedimentation as major threats. Skelton (1974a) described Barbus erubescens, newly identified from the Olifants system, and outlined characteristics of cyprinid breeding. Scott (1982) described the endemic fish fauna, and threats to their continued existence. A programme to rear Barbus capensis (a popular endemic angling fish) artificially for reintroduction is being carried out by the Cape Department of Nature Conservation. The importance of the Kruger National Park as a refuge area for eastern Transvaal fish species is emphasized by I G Gaigher (1978b). Of 60 species in eastern flowing Transvaal Rivers, 48 are found in the park. Skelton (1977) describes the country wide distribution and status of 28 threatened South African fish species in the Red Data Book - Fishes, of which an updated edition is in preparation. Cadieux (1980) attempted to quantify the environmental and economic impact of angling in the Transvaal, and discussed, inter alia, time spent fishing, the most favoured fish (carp, kurper and yellowfish) and total catch.

4.3.1 Introductions

South African rivers have been subjected to two kinds of fish introductions. The establishment of imported exotic fish either as angling species (trout, small and large-mouth bass, carp etc) or as food for angling species (bluegill sunfish) has affected most river systems. A second type of introduction is the dispersal of indigenous species into new catchments, usually by means of tunnels and canals for interbasin transfers. The effects of such introductions are still uncertain in many cases. This is partly because the spread of an introduced species has often coincided with catchment development, so that it has become difficult to disentangle the cause of an observed change in the resident fish population. In some parts of the Cape Olifants River system, the sharply discontinuous and adjacent distributions of small mouth bass and some of the endemic redbin (Barbus) species (eg above and below small cascades) provides strong circumstantial evidence that the bass are responsible for the absence of the redbins in stretches of stream (C M Gaigher, 1973). However, the introduced fish may often be the easiest target of suspicion which has not always been proved. The disappearance of Oreodaimon quathlambae from the Umkomazana River was initially thought to be connected to the introduction of trout (Jubb, 1966a), but Pike and Tedder (1973) found another population in the Tsoelikana River surviving with trout. They considered that artificial catchment degradation was the main threat to the survival of O quathlambae. The effects of indigenous species introduced into new catchments are even less well documented. Whenever fish are introduced into new areas there is a shift away from a natural pristine system, the effects of which may or may not be obvious for the fish fauna, but are almost impossible to gauge for the rest of the biota. The Cape Department of Nature Conservation has determined that bluegill sunfish (Lepomis macrochirus) and smallmouth bass (Micropterus dolomieu) have proven deleterious effects, may not be introduced into any waters in the province and surviving populations should be eradicated wherever possible. The Nature Conservation Division of the Transvaal Provincial Administration terminated breeding of M dolomieu in 1982.

The introduction of trout into Natal and early attempts to establish populations has been well documented by Day (1932b), Bush (1933a, 1933b) and Crass (1946). Crass (1956b) attempted to clarify the effects of trout on the local fauna. He concluded that they have no effect on invertebrate populations, but that local extinctions of small Barbus spp. may have resulted from their introduction. Crass (1964) attributes the disappearance of Amphilius natalensis to trout. The history of carp introductions is reviewed by Jubb (1973b). Carp (Cyprinus carpio) were first introduced in 1859 and are held to be a threat to indigenous Barbus species. The introduction of Gambusia, either for mosquito control or as fodder for bass is thought by Jubb (1964) to have been responsible for the disappearance of Poeciliopsis from the streams of the south-western Cape. It is also possible that Gambusia has been responsible for the disappearance of Aplocheilichthys katangae from the Apies River (C J Kleynhans, pers comm).

Of indigenous angling fishes, the Orange/Vaal yellowfish (Barbus aeneus)

has most often been introduced into new catchments. Jubb (1963) documents its introduction into the Kariega River, and Jubb (1966b) describes introductions for angling into the Gouritz, Olifants (Transvaal) and Great Kei Rivers. A close watch has been kept on the Great Fish River, where accidental introductions as a result of the Orange/Fish pipeline have been expected. Cambray and Jubb (1977a) found Labeo capensis, Labeo umbratus, Barbus aeneus, Clarias gariepinus and Cyprinus carpio at the tunnel outlet, and predicted the establishment of C gariepinus and B aeneus in the Fish and Sundays systems. Cambray and Jubb (1977b) detailed some of the problems encountered by fish on the way from the Orange to the Fish River, but noted that in spite of these seemingly fatal hazards, introductions have been effected. Cambray (1979) described the pre-tunnel fish fauna present in the Fish River before the tunnel was completed, and records that Barbus aeneus, Clarias gariepinus and Labeo capensis have so far been added from the Orange River. Laurenson and Hocutt (1984) recorded the addition of Austro sclateri to this list.

4.3.2 Biogeography

The distribution and affinities of fish species in southern Africa have often been used to provide evidence for links and discontinuities between river systems. The assumption has been that watersheds represent impenetrable barriers between catchments for fish. Jubb (1966c) commented that the popular theory that fish are transported between river systems by birds and animals, is not consistent with observed discontinuous distributions. He concludes that fish distributions appear to be consistent with geological and geomorphological events which isolate river catchments.

Crass (1962) suggested that fish colonization of Natal rivers was probably due to tectonic movements during the early pleistocene. Farquharson (1962) concluded from present day taxonomic groupings of cyprinids in southern Africa, that the region has been subject to a series of cyprinid invasions. He postulated that there were no environmental reasons for the absence of cyprinids from southern African rivers, and that therefore accessibility was the only possible reason preventing such colonization. He agreed with Crass (1962) that pleistocene upheavals were the main factors in dispersal. Jackson (1962) pointed out that ecological factors (such as specific habitat requirements) were likely to be as important as environmental factors (such as waterfalls) in governing fish distribution, and he gave examples of ecological tolerances operating both to extend or limit the distribution of various species.

A comparison of the indigenous fish fauna of the southern Cape and the Orange River led Jubb (1964a) to suggest that a substantial freshwater link must have existed between the two regions. The fish are mostly cyprinids, and therefore the link must have existed at a sufficiently distant time for their dispersal and divergent evolution, and during a much wetter period than the present. An extension of these ideas was presented by Jubb and Farquharson (1965) who suggested a freshwater link between the south-western Congo watershed and the Orange system during the late Tertiary. I G Gaigher and Pott (1973) use the affinities of the fish fauna to suggest the following links: A mid-

Pleiocene link between the Orange and Okavango Rivers; a Tertiary link between the Okavango/Upper Zambezi and the upper Limpopo Rivers; a Pleistocene link between the lower Limpopo and the lower Zambezi, and an Orange-Limpopo connection. (Netterberg (1973) quoted fossil mollusc evidence in support of the Okavango-Zambezi link, and against a Zambezi-Orange link). Skelton (1980) investigated the affinities of the redfin Barbus species of the southern and south-western Cape, and noted their similarity to Oreodaimon quathlambae which is confined to high altitude streams of the Drakensberg.

4.4 Fish species studies

A large proportion of research on riverine fish has been devoted to the biology or autecology of individual species or groups of fish. These are reviewed in the following section, organized by taxonomic group.

4.4.1 Cyprinidae

4.4.1.1 The genus Barbus contains many of the important indigenous angling species in South Africa, as well as a large number of the locally endemic species. The small redfins are an exceptionally interesting and vulnerable group of endemics of the genus Barbus.

General studies of groups of Barbus species have been made by du Plessis (1956), who described the mouth forms and related them to feeding adaptations and to different environments, and Skelton (1980), who looked at the systematics and biogeography of redfins in the streams of the southern and south-western Cape, and of the related Oreodaimon quathlambae in the Drakensberg.

Barbus capensis and B serra are the two large yellowfish endemic to the Olifants River system of the south-western Cape. Van Rensburg (1966) investigated the life history of these species, with particular emphasis on feeding, breeding and growth rates. Both species are omnivorous, feeding on algae, aquatic plants and insect larvae and adults, while B capensis stomachs also contained snails, and occasionally frogs, crabs and small fish. Growth rates were thought to be relatively slow and small specimens were rarely found in the same stretches of stream as bass. Mulder (1971, 1973a) contrasted the ecology of Barbus kimberleyensis and B aeneus in the Vaal River. Soil erosion and consequent increased turbidity appears to be restricting numbers of the former species. Angling pressures, combined with slow growth and late maturity, may cause a further decline in B kimberleyensis. B aeneus in contrast, is abundant in the Vaal, due to its omnivorous diet, greater tolerance to turbidity and earlier maturity. Wright and Coke (1975a,b) experimented with the artificial propagation of B natalensis in hatchery ponds. They achieved partial success, and emphasized the need for rigorous cleanliness, fungus control and an increased understanding of incubation and rearing techniques before bulk propagation could be advocated. A natural flood which resulted in siltation of hatchery spawning beds and a subsequent fish-kill had interesting implications for the survival of natural populations in increasingly eroded catchments.

The ecology and life history of a number of the small redbfin species has also been described. Jackson (1973) gave accounts of the life cycles of Barbus anoplus and B asper. The early development and larval behaviour of B anoplus was described by Cambray (1983, 1984a). The wide distribution and colonizing potential of the species was attributed to developmental and early behavioural adaptations, as well as its tolerance to a wide range of temperatures. Barbus trevelyani is now restricted to a few rivers of the eastern Cape (the Buffalo, Tyume and Keiskamma). I G Gaigher (1975) discussed its ecology and life history and concluded that it is in danger of extinction because of habitat deterioration and the presence of introduced exotic species. Bok and Heard (1982) successfully carried out induced spawning of B trevelyani using pituitary extract from Labeo umbratus, and found that low water temperatures (below 18°C) appeared to have an inhibiting effect.

4.4.1.2 The genus Labeo is a large genus of freshwater fishes which feed on algae and detritus. Two species, Labeo capensis, the Orange River labeo, and Labeo umbratus, the moggel, have been particularly intensively studied. Baird (1971, 1976) and Baird and Fourie (1978) studied the feeding, growth and development of L capensis in the Caledon River system. Although both sexes had a similar growth rate, in large fish (over 35 cm) only 16% were males. Young fish were in better condition in summer than winter, but older (3+ years) fish were in better condition in winter. Fish attained maturity at 3+ years, and deposited large amounts of fat in winter, which was used for gonad development prior to spawning. Mulder (1973b) compared the ecology of Labeo capensis and L umbratus in the Vaal River. L capensis was numerically dominant in the river, while L umbratus was confined to lentic habitats. The success of the latter species in highveld impoundments was ascribed to its faster growth rate, early maturity and greater fecundity than L capensis. I G Gaigher et al (1980a) investigated the biased sex ratio of L capensis and concluded that sex ratios and spawning behaviour are an adaptation to ensure maximum population fecundity in an unfavourable environment for spawning, where there was high juvenile predation, and where there was high intraspecific competition during periods of low river flow. I G Gaigher (1984) successfully used scale readings to determine age in L capensis.

The ecology, reproduction and larval development of Labeo umbratus is described by Ntloko (1973) and I G Gaigher et al (1975). For this species the sex ratio remained 1:1, although females had a longer life-span than males. Jackson and Coetzee (1982) related observations of L umbratus spawning in a small irrigation ditch on an inundated floodplain. Spawning in vegetation is typical of Labeo species, and is contrasted with that of Barbus species, which tend to spawn on the gravelly substratum of main stream channels.

4.4.2 Cichlidae

Cichlids are a large family with extreme diversity of function. Perhaps the best-known species, Oreochromis mossambicus, has been introduced in many parts of the world as a food fish. An international literature exists on the fish-farming of cichlids, and on aspects of the biology of O mossambicus which is a favourite experimental species.

Only the studies of cichlids in South African rivers are reported here.

Le Roux (1956) investigated the feeding habits of the young of four cichlid species: Oreochromis mossambicus, Tilapia rendalli, T sparrmanii and T andersonii. Whilst less than 5 cm long, all species showed a preference for zooplankton. From 7,5 cm, O mossambicus and T andersonii take mainly phytoplankton, T rendalli feeds mainly on plant material, and T sparrmanii is an omnivore with a particular preference for bottom food. Du Plessis (1956) describes the status of Serranochromis thumbergii in Transvaal, and identifies its main food as chironomid larvae. Serranochromis meridianus is an endemic of the Incomati River system in eastern Transvaal. Pott and Le Roux (1968) described its breeding behaviour, including courtship, breeding colours, display, stimulation and oviposition. Ribbinck (1971) investigated the behaviour of Pseudocrenilabrus philander, with particular reference to breeding, and described its territories, courtship behaviour, fertilization and maternal care. He suggested that the facial pattern of the maternal fish facilitates the collection of the fry by dividing the brood into smaller groups. Potgieter (1974) studied the ecology of Oreochromis melanopleura in Transvaal in the context of its importance as an angling fish.

4.4.3 Clariidae

The Clariidae include some of the largest freshwater fish species in southern Africa, of which the best known and most widely studied is the sharptooth catfish Clarias gariepinus whose biology, including growth rates, breeding, feeding methods and preferences has been described by Bruton (1977). Groenewald (1964) discussed the feeding habits of C gariepinus, describing it as a general carnivore, mainly of fish, invertebrates, and zooplankton. It is also an opportunist feeder in emergencies and consumes large quantities of detritus probably incidentally. Van der Waal (1972, 1974) investigated aspects of the ecology, breeding and production of C gariepinus. Spawning was stimulated in aquaria by hormonal treatment. Courtship was described, eggs were distributed over a wide area (as in the field), and the final spawning stimulant was identified as Petrichor, a substance dissolved in flood waters that have run over dry ground. Donnelly (1973) observed the behaviour of C gariepinus in a mud pool while it was drying out. Branchial respiration ceased due to gill clogging, and was replaced by suprabranchial respiration and possibly some cutaneous exchange. No evidence of aestivation was found, and it was suggested that Clarias is only partially adapted to periods of dessication.

Bruton (1979) discussed adaptations to habitat dessication among clariids in general, and agreed that they are unable to survive in totally dry mud or sand, despite hearsay evidence to the contrary. Van der Waal and Schoonbee (1975) used pectoral spines to determine the growth of C gariepinus and concluded that the growth rate is maintained even after ten years. Bruton (1976) concluded from a study of past and present records that C gariepinus grows to a larger size than any other freshwater fish species in the Republic.

Mashego (1977) investigated ecto- and endoparasites of C gariepinus in Lebowa, finding seven helminth parasites, including one species with a

virtual 100% incidence. Mashego and Saayman (1981) detailed the nematode parasites of C gariepinus. Hecht et al (1982) experimented with various hormonal spawning inducers and concluded that catfish PGE alone was most effective.

4.4.4 Anguillidae (Eels)

Five species of eel have been identified from South African rivers: Anguilla mossambica, A nebulosa labiata, A obscura, A marmorata and A bicolor bicolor. There has been much speculation about the whereabouts of marine breeding grounds (eg Jubb, 1964b, 1970), and of the ability of eels to surmount obstacles and cross catchments in their upstream migrations (eg Jubb, 1959). Harrison (1953) discussed the use of scales in aging eels, but pointed out that there was no information as to how long eels had spent in a marine environment. Jubb (1970) described eel growth rates and morphological changes, Jackson (1973) also described the life-cycle of eels and Tarr (1977) and Tarr and Hill (1978) measured several aspects of the energetics of eels, including feeding assimilation efficiency and the energy value of elvers. A project to assess the possibility of a commercial eel fishery in the eastern Cape and Transkei was summarized in reports by Bok (1974) for the Kowie and Fish Rivers, Butler (1974), Kretzmann and Davies (1976) and Davies (1979) for the Keiskamma River, Stobbs (1974, 1975) Stobbs and Bok (1974), for the Mtata River, and Maceoghegan and Davies (1977) for the Swartkops and Sundays Rivers. Natural stocks were felt to be insufficient and yield per unit effort too expensive to maintain a commercial fishery. Davies (1982) concluded that it might be possible to culture juveniles economically, but culture from the glass eel or elver stage would not be economic.

4.4.5 The genus Sandelia

Two species of Sandelia are found in South Africa: S capensis is widely distributed in the southern coastal Cape Province, but S bainsii is confined to an area from the Kowie to the Buffalo Rivers in the eastern Cape. Jubb (1971) described the biology of both species, and compared them with other species of anabantid fish, particularly in terms of their auxiliary breathing organ which allows limited migration across damp ground. Jackson (1973) described the life cycle of Sandelia bainsii. Cambray (1981b) summarized the distribution of S bainsii and described a number of structural adaptations which indicate a more strictly aquatic existence, compared to some amphibious tropical relatives. He concluded that the major threats to the limited distribution of S bainsii were weir building, pollution and predatory exotic fish.

4.4.6 Other species and groups

Bok (1976, 1979, 1980) made a comparative study of the mullet Myxus capensis and Mugil cephalus in the freshwaters of some eastern Cape rivers. M capensis is found further upstream than M cephalus. He stressed that the construction of weirs was a major threat to such species, since they migrate between the sea and freshwater. A weir planned for the Kowie River is to be bypassed by a fish-ladder. Kneria auriculata, a cold stenothermal species, preferring stretches of stream

containing calm pools, was studied by Kleynhans (1979) in the upper reaches of the Crocodile River (eastern Transvaal). He described five isolated populations all of which are threatened by exotic predators, catchment degradation, and dam building. The ecology, breeding, growth and feeding habits of the tiger fish (Hydrocynus vittatus) was investigated by I G Gaigher (1970) in the Incomati River system. Food changed from Entomostraca to insects and finally to fish as individuals grow and seasonal migrations downstream after the first floods and back upstream at the end of the rainy season were linked to prey movements. Spawning took place after the downstream migration, among aquatic vegetation on flooded river banks and in lakes. The species' range was considerably reduced by the construction of weirs which prevented upstream movement.

4.5 Conclusions

Fish occupy a unique position among riverine biota, because they are the largest and most noticeable of the ubiquitous river fauna, and because they represent the most important component of the system for recreation (angling). For these reasons they are often perceived as the most important component for conservation, and a great deal of research emphasis has accordingly been placed on fish.

The majority of articles identified in this review have concentrated on autecological studies of single species, and there has been very little research to establish either the importance of fish populations in the functioning of river ecosystems, or to quantify the effects of catchment and river changes on fish populations. Because most fish species are carnivores or omnivores, they are operating at the higher trophic levels and are therefore likely to be vulnerable to disturbances at all lower levels, including those caused by physical catchment changes. The maintenance of fish populations and the conservation of threatened fish species requires not only an understanding of their individual species biology, but the identification of critical components of their habitat, and the capacity to predict how perturbations will affect them.

CHAPTER 5 VERTEBRATES OTHER THAN FISH

5.1 Introduction

This chapter is something of a 'catch-all' intended to summarize the often fragmentary research on mammals, birds, reptiles and amphibians associated with rivers. The extent and depth of research on these vertebrate groups does not approach that for fish, and this is a function of the resources devoted to these aspects of river ecology, rather than any reflection of the quality of work done by individuals.

The best known large vertebrates - the crocodile and hippopotamus, have been extensively investigated. Other species and groups are less well known, at least in relation to rivers. A problem in compiling this review has been that many vertebrates are partly but not exclusively associated with rivers, and there is therefore no obvious decision as to how extensive coverage should be. As a general rule, only those species which could be described as riverine are included, and even for these species, studies in other habitats have not been covered.

5.2 Mammals

Truly riverine mammals in South Africa are confined to the hippopotamus, the Cape clawless otter (*Aonyx capensis*), the spotted-necked otter (*Lutra maculicollis*), and the water mongoose (*Atilax paludinosus*).

Hippo distribution is now largely confined to northern Natal and the eastern Transvaal. Tinley (1958, 1976) detailed the distribution and density of hippos on the Pongolo and Mkuze floodplains, and in the Kosi Lake system, while Scotcher (1974, 1978) concentrated on hippo populations in Ndumu Game Reserve on the Pongolo floodplain. He related hippo movements to the floodplain hydrological cycle, concluding that hippos move into the floodplain pans during periods of high water level, but back into the river during low flows. He also investigated feeding preferences, and showed that hippos are area rather than species selective grazers. Scotcher et al (1978) extended these findings, concluding that the condition of grass species influenced the seasonal movements of hippos, which prefer to graze open short green grass areas.

In the Transvaal, Pienaar (1966) reported an experimental cropping of hippos in the Letaba River of the Kruger Park. He identified lack of adequate habitat rather than food as the limiting factor for hippo populations, and set quotas for the Letaba, Olifants and Crocodile Rivers, but not for the Levubu and Sabie Rivers. Viljoen (1980)

surveyed the hippo populations in the Olifants and Blyde Rivers where he found densities of 2,7 and 0,7 hippos per kilometre respectively.

Two species of otter occur naturally in South Africa - the Cape clawless otter (Aonyx capensis) and the spotted-necked otter (Lutra maculicollis). Both are rare, but Rowe-Rowe (1978) considered that this is a function of their restricted niches, and that neither species is endangered. Rowe-Rowe (1975, 1977a,b) investigated the distribution and ecology of both species, especially in Natal. Feeding preferences, prey capture and behaviour were all studied and Rowe-Rowe concluded that their effects on game-birds, waterfowl and sport-fish were negligible. Van der Zee (1979, 1981a,b) also concentrated on studies of the prey and diet of the Cape clawless otter, this time in the Tsitsikamma National Park. This population is concentrated along the coastal strip, where a density of one otter per two kilometres was recorded. Diet preferences reflected the marine environment, with marine crabs, octopus and suckerfish forming more than 80% of the recognizable prey remains in faeces. Taylor (1970) described the habits and distribution of the Cape clawless otter in the Port Elizabeth area, and concluded that numbers have declined recently, probably as a result of disturbance and habitat degradation. Information about the other riverine mammal, the water mongoose (Atilax paludinosus) is extremely sparse. A short article by Crawford (1982) records the capture of two water mongoose in Tsitsikamma Park.

5.3 Birds

Although a large number of birds are associated with water, standing water is the preferred habitat of most species of waterfowl, and very few can be considered to be primarily riverine species.

The African black duck (Anas sparsa) is an exception which has been intensively studied in the Eerste River by I J Ball, P G H Frost, W R Siegfried and F McKinney. McKinney et al (1978) defined behavioural specialization of the African black duck for river life. A variety of behavioural adaptations, including year-round territoriality, cooperation by both sexes in territorial defence, elimination of rape, the strong development of mate-testing, mate-stealing and mate-holding, and reduced social courtship, were all interpreted in terms of river specialization. Ball et al (1978) also concentrated on territorial behaviour of the African black duck, and noted that very few territorial paired birds were found on dam reservoirs, although non-territorial birds often are. Frost et al (1978) reported on sex-ratios (which did not differ significantly from parity), morphology and growth of African black ducks. The Eerste River also provided the site for a study of feeding and breeding behaviour of the giant kingfisher by Arkell (1978). The main prey species was found to be the Cape river crab (Potamon perlatus), whose diurnal activity pattern was correlated with that of the giant kingfisher.

On the Orange River, Cambray (1985) recorded numbers of piscivorous birds (particularly grey heron, Ardea cinera, and whitebreasted cormorant, Phalacrocorax carbo) below the P K Le Roux Dam wall. Since water releases are dependent on remote electricity generation demand, direct sampling of fish movements in the river were hazardous, and the

number of birds was used as an indication of densities of fish such as Barbus aeneus, B kimberleyensis, B anoplus, Labeo capensis and Clarias gariepinus, as they congregated below the dam wall, unable to move further upstream. Minimum numbers of birds were observed from April/May to August, with maximum numbers from September to December.

5.4 Reptiles

The focus of attention on riverine reptiles has been the crocodile, which has been extensively investigated by A C Pooley. Apart from the crocodile, Raw (1973) has reviewed the taxonomy of the dusky-bellied water snake (Lycodonomorphus laevissimus), and Jubb (1979a) has described the feeding and breeding habits of the water leguaan (Varanus niloticus).

In Zululand, the crocodile breeding season commenced after the onset of summer rains, and hatching occurred when rains were at their peak (Pooley, 1969a). Breeding success was highly variable, depending largely on egg predation and flooding, which could wash away all the eggs. Incubation rates depended on the position of an egg in a clutch, and on temperature, humidity and rainfall, (Pooley, 1969a). Once hatched, the adult female transported the young to water, and thereafter both parents shared guard duties for six to eight weeks until the hatchlings dispersed (Pooley, 1974a,b, 1977; Pooley and Gans, 1976). Small crocodiles have been observed to construct burrows to escape cold weather, while larger individuals have been known to dig pools for water collection during droughts (Pooley, 1969b).

Much of Pooley's research has been concerned with the conservation status of crocodiles and with management methods for their conservation. A survey of crocodile numbers throughout Africa (Pooley, 1972, 1973) identified a decline in numbers everywhere. Pooley concluded that viable crocodile farms established in Zimbabwe have been unable to meet the demand for hides, that legislation has been inadequate to protect wild populations, and that crocodile farms should be strictly controlled. Management requirements include population surveys to determine breeding stocks and recruitment rates, and an overhaul of legislation. Pooley (1980) concentrated on the status of the remaining crocodile populations in Mafutaland, now confined to the Ndumu Reserve, Lake Sibaya and Lake St Lucia, where the Natal Parks Board has initiated a conservation programme which includes monitoring wild populations and rearing and restocking young in depleted habitats.

Jubb (1979b) commented on the probable original distribution of crocodiles in South Africa, citing a skull found in Uitenhage to show that crocodiles once inhabited at least as far south as the Keiskamma River. Jacobsen (1984) investigated crocodile populations in the Transvaal outside the Kruger Park where he found remnant populations, mainly of young crocodiles (less than three metres long) in sections of seven rivers, with probable breeding populations in six rivers.

5.5 Amphibians

Although almost all frogs and toads require an aquatic (or at least wet) habitat for the juvenile stage of their life cycle, only a few can be

described as closely connected to rivers. Most of these are species in the genera Xenopus, Rana, Heleophryne, Hyperolius and Bufo.

Extensive early research was devoted to the taxonomy of amphibians. Sclater (1899), Boulenger (1908), Hewitt (1911, 1913, 1925, 1926, 1932) Fitzsimons (1946, 1947, 1948), van Dijk (1966), and Grieg et al (1979) all include descriptions or redescriptions of species. A number of checklists and field guides have also been produced, including one by the Albany Museum (1937) for reptiles, amphibians and fish of the eastern Cape, a checklist for all these groups in the Kruger Park by Pienaar (1961), a field guide to reptiles and amphibians of southern Africa by Rose (1962), an account of the frogs of South Africa by Wager (1965), and the excellent guide by Passmore and Carruthers (1980), which has been lavishly illustrated, includes notes on the ecology and distribution of species and provides detailed explanations and sonagrams of frog calls, which are useful diagnostic aids.

The distribution and zoogeography of amphibians in southern Africa has been investigated by J C Poynton and D E van Dijk. Poynton (1964) identified two major faunal types: a north-eastern tropical fauna, and a south-western Cape fauna, with intermediate types between. Poynton (1982) presented evidence for sympatric hybridization, in which species pairs of amphibians were identified, with one of each pair being 'non tropical'. Altitude- and latitude-mediated temperature differences defined species' ranges. In Poynton and Bass (1970) and Poynton (1980), the distribution of amphibians in northern Natal was described, with a transition between the tropical and non-tropical fauna explained in terms of temperature and optimal number of breeding nights. Van Dijk (1971a, 1982) examined the distribution of amphibians in relation to physical and climatic variables, but concluded that more detailed information and mapping was necessary for resolving different habitats. Van Dijk (1971b, 1977) used studies of locomotion, feeding, predator avoidance and oviposition to explain amphibian distribution in terms of habitat.

Investigations of breeding adaptations of frogs have stimulated some interesting results. Savage (1965) found that spawning of Xenopus laevis was correlated with weed growth, rather than expected cues such as climate or illumination, and field studies on Rana temporaria suggested that spawning was controlled by an algal metabolite (Savage, 1971). Further laboratory experiments on Xenopus laevis were carried out by Savage (1971), who found that a variety of algal cultures and extracts would induce spawning. Picker (1980) investigated the mating calls and behaviour of X laevis and concluded that calls consisted of complex frequency structures, with individual frogs accentuating different bands. The idea that females choose conspecific mates of maximum fitness has considerable support among evolutionary biologists, but little data has been collected to test this hypothesis. This idea has not found support from results by Passmore and Telford (1983) who have shown that female Hyperolius marmoratus frogs do not mate selectively with males on the basis of size or age. Mating call intensity and spectral structure were correlated with body size, but mating was also random in this respect.

5.6 Conclusions

Pooley's (1974a,b) investigations of parental care in crocodiles, McKinney et al's (1978) interpretations of African black duck behaviour, and Passmore and Telford's (1983) work on sexual selection (or its absence) in frogs are all examples of imaginative research leading to important insights into individual species or biological problems. They do, however, highlight the emphasis on individual species studies which has so far dominated research on riverine vertebrates. There is an urgent need to relate species ecology to river ecosystem functioning, if we are to be able to make useful management decisions to maintain existing vertebrate populations. As with fish population management, there is a general realization (eg Pienaar, 1966) that habitat maintenance is the important criterion for species conservation, but at present there has been little research to quantify habitat requirements, or to investigate the important ecological processes necessary for habitat maintenance.

CHAPTER 6 PLANTS

6.1 Introduction

There are several types of plant communities which have an important influence on the hydrology and biota of rivers. The first of these is the catchment vegetation which affects the evaporative loss from the catchment and therefore the runoff to the river. The vegetation influences both the amount of water that will reach the river, and the frequency and duration of floods and dry periods. As Chutter (1973) has pointed out, the hydrological regimes of many South African rivers have been changed from perennial to intermittent flow over the past 300 years, due to the removal of the natural vegetation cover and the consequent destruction of the buffering capacity of the catchment. Catchment vegetation also affects the chemical constituents of the runoff, the type and amount of allochthonous input to the river, and, because it binds and stabilizes the soil, the amount of silt reaching the river. The catchment vegetation therefore affects the hydrology, water chemistry, turbidity and suspended sediment load of a river, as well as dictating to a large extent the energy and nutrient inputs to the system. It is therefore a major determinant of the characteristics of a river, and changes in catchment land use will lead to fundamental changes in the ecology of a river system. The riparian or river bank vegetation has an important role in the stabilization of river banks, as well as being the immediate source of allochthonous energy and nutrient input to the river.

The second plant community that influences rivers is the emergent semi-aquatic vegetation. This also has a role to play in the flood buffering capacity of a river, especially where extensive marshy areas provide an absorbent overflow area. The experience in the Hout Bay stream, near Cape Town (Beaumont, 1981; Grindley, 1984) provides convincing evidence of the importance of emergent plants in riverside marshes. Clearance and drainage of the lower Hout Bay palmiet marshes for residential development has led to a dramatic downcutting of the river bed as floodwaters are funnelled through the remaining channel. Attempts to halt the channel cutback by installing a concrete weir have resulted in the river diverting from its normal channel during floods, and flowing through the foundation of riverside houses. Emergent plants also contribute to nutrient and energy cycling, provide a separate habitat for river fauna and algal aufwuchs, and may change open waters to marshes by trapping silt.

The third plant community comprises the aquatic macrophytes. These

again play a role in the flow of energy and nutrients through rivers, and provide additional habitat and food for the biota. Perhaps the greatest attention in South Africa has been focused on introduced macrophytes, whose explosive powers of colonization have caused considerable economic problems.

Aquatic microphytes, algae and in particular diatoms and phytoplankton, form an extremely important part of the production of a river. Many stream animals, particularly invertebrate filter-feeders and scraper-feeders, rely on microphytic growth. The algal community is sensitive to levels of nutrient input, and can be used to gauge water quality.

6.1.1 The vegetation of the Pongolo floodplain

The vegetation of the Pongolo floodplain below the Pongolapoort Dam has been intensively studied as part of the investigation of the functioning of the floodplain pans. Plant communities (macrophyte and seasonally inundated), growth, production, decomposition and rôle in the energy/nutrient budgets of the pans have been described in Furness (1978, 1981), Furness and Breen (1980), Musil (1972), Musil et al (1973, 1976) and K H Rogers and Breen (1981, 1982). These studies are reviewed and discussed together with other investigations of the Pongolo River system in Chapter 3. The results have provided an integrated view of the functioning of the floodplain ecosystem, which is summarized by Heeg and Breen (1982). They have been able to propose a realistic plan for the management of water releases from the dam to provide for agricultural needs with minimal disruption of the floodplain ecology.

6.2 Catchment vegetation

The experimental manipulation of catchment vegetation has been a major area of research for the South African Directorate of Forestry. The Mountain Catchment Areas Act of 1970 requires the supply of silt-free water from mountain catchments (Ackerman, 1976), and considerable research has been directed to this objective. Nanni (1963, 1972) investigated the effects of indigenous scrub vegetation and pine forests on water runoff in catchments in Jonkershoek and the Drakensberg Mountains. He found that daily runoff increased by about 12 l for every metre of streambank vegetation removed, and that dry weather streamflow dropped by about 1700 l.ha⁻¹.day⁻¹ in catchments planted with pines for forestry. Van der Zel (1970) detailed the changes in water flow after thinning of pine forest. Removal of 33% of the trees caused a 50% increase in flow. This effect was maintained for at least three years after the thinning process. Wicht (1971) reviewed worldwide studies indicating that afforestation may increase evapotranspiration by between 34 to 450 mm per year, and reported that experimental afforestation of a fynbos catchment resulted in a streamflow decrease of 51%. Systems analysis is a useful tool in catchment hydrology, and was used by Van der Zel (1975) to investigate development plans within the Umgeni catchment. A similar approach for the Crocodile River catchment (eastern Transvaal) was used to identify the option of managing up to 77% of veld for optimum water yield purposes, as financed by prospective water users (van der Zel, 1977).

Van der Zel (1980, 1981a,b) and van der Zel and de Villiers (1975) discussed optimum mountain catchment management in South Africa. Catchment models were developed to identify the most satisfactory mixture of emphasis on wood production and water supply. Evaluations showed that water use on a forestry farm does not differ from that of an optimum mixed farming recommendation.

Bosch (1981) reviewed worldwide paired catchment experiments to show that reduction of forest cover increased water yield, that forest establishment on sparsely vegetated land decreased water yield and that response to treatments was highly variable. Bosch and Hewlett (1982) used these conclusions predictively. Pine and eucalypt forest caused an average 40 mm change in water yield per 10% change in cover, while deciduous hardwood and scrub caused 325 mm and 10 mm change respectively. King et al (1979) have summarized available information on the effects of fynbos vegetation on rivers, and the effects of replacing the shrub-like fynbos with trees. They emphasized the paucity of knowledge, and among recommendations for future research were: tracing surface and groundwater movements and determining how they are affected by vegetation, soil types and geology; examining interrelations between nutrient cycles of the soil, water and fynbos; determining the relationship between pH, colour and humic acids, and how geology, soil and vegetation affect them; and identifying the extent to which the vegetation can be manipulated to increase water yield, without destroying the integrity of the fynbos.

Several general surveys of riverine and catchment vegetation have been undertaken in South Africa. Acocks (1976) has investigated the natural riverine vegetation types of semi-arid and arid regions. One hundred and seventeen grass and sedge species and 212 other plants were identified as relics of the original extensive riverine flora. The importance of riverine vegetation in preventing erosion, especially in arid regions subject to violent climatic events, was stressed. Jacot Guillarmod (1973) described the characteristic vegetation of the Fish River: a lack of grass, many short spiny succulents; even height canopy; rigidity even in high winds; and adapted to a dry environment with extreme temperatures. As part of an environmental investigation for the preparation of a development plan of the Swartkops River basin, Jacot Guillarmod (1974) investigated the vegetation in the catchment. Cultivated and degraded areas were described, as well as coastal floodplain, river terraces, and the vegetation of higher ground. Historical changes in the vegetation were analysed.

6.3 Emergent vegetation

Very little research into emergent plants has been carried out in South Africa. Gordon-Gray and Ward (1971) investigated the taxonomy and ecology of Phragmites in Natal and described the morphological and genetic differences between P australis and P mauritanus. Distribution patterns of the two species were found to be significant in relation to ecological changes, in swamps and estuaries, particularly with regard to siltation. Greyvenstein and de Villiers (1975) describe the uses of Phragmites australis in soil conservation. The reed is a valuable soil reclamation plant because it is indigenous to South Africa, and therefore establishes permanently and spreads easily without posing a

threat to the natural biota. It thrives in watercourses, decreasing water flow rate and increasing sediment deposition, and it will grow through after being covered in sediment from floods.

Although their studies were predominantly concerned with the fauna of the river, Harrison and Elsworth (1958) noted the distribution of aquatic plants in the various zones of the Berg River. Characteristic emergent species were Scirpus digitatus in the upper zones, palmiet (Prionium serratum) and the grass Paspalum vaginatum in the middle zones, and Cyperus spp and Phragmites australis in the more slowly flowing lower zones. Oliff (1960) noted a similar pattern in the Tugela, with little vegetation in the upper reaches, Cyperus marginatus in the foothill zones, supplemented by Phragmites australis and Polygonum setulosum in the lower reaches. Allanson (1961) noted the replacement of Polygonum lapathifolium and P salicifolium by P clandestinum in polluted sections of the Jukskei system. He also noted that diversity was greater among fringing plant species in unpolluted sections.

Some of the studies on aquatic macrophytes (reviewed below), also deal with emergent plant communities.

6.4 Aquatic macrophytes

Introduced aquatic plants seem to have the ability for explosive colonization and therefore present two separate problems. Like any other introduced plant, they distort the natural biotic community, making it difficult to judge what natural conditions should be, but in addition, a number of species are so prolific that they cause economic problems by clogging waterways, increasing evapotranspiration water loss, destroying the recreation amenities of waterways, and interfering with piped water supplies. The potential for increase of these plants is often linked to artificial eutrophication, providing an excess of normally limiting nutrients. However, it is not clear whether this is always the case, or whether the plants will colonize undisturbed systems to the same extent. This section deals with macrophytes in two parts: natural plant communities; and invasive exotic species.

6.4.1 Indigenous aquatic macrophytes

Two bibliographies are available for aquatic plants in Southern Africa. Gibbs Russell (1975) provides a comprehensive taxonomic bibliography, which includes all mentions of vascular aquatic plants (including emergent species). Howard-Williams (1979) has produced a selected bibliography on the ecology of aquatic macrophytes. This specifically excludes purely taxonomic references. Mitchell (1978) provided a review of research into freshwater plants in southern Africa. He noted that riverine macrophytes have to cope with seasonal dessication and floods which cause physical damage, and reduce light penetration to plants through turbid water. The flora of unregulated rivers tends to be of low diversity and biomass as a result. The general effect of dams has been to increase the amount and diversity of aquatic flora below the dam, both because of higher nutrient concentrations in water released from the reservoir and because of flow regulation. Mauve (1965) reviewed the genus Potamogeton, providing a description of

generic characters and a key to species.

One of the earliest surveys of aquatic vegetation was carried out in the south-western Cape by Stephens (1929). He described the plant communities of different freshwater types, including, in a section on streams, the Black/Liesbeek and Hout Bay Rivers. A survey of the upper Orange and Caledon River systems was described by Edwards and Nel (1972) and Edwards (1974). Macrophytes were recorded in 11% of 1 813 sites inspected but none were found in either of the two main rivers. Generally, they were confined to quieter pools and dams, and to the smaller tributaries.

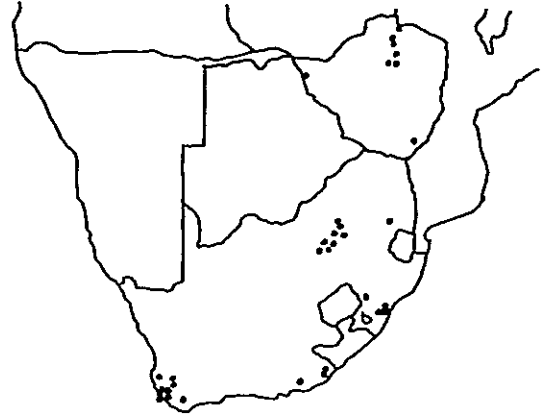
The bogs and vleis of the high altitude regions of the Drakensberg form the source of many of South Africa's rivers. The vegetation of the bogs is a complex of communities containing tussock grasses, sedges, and mosses. Associated pools contain Crassula inanis, Lagarosiphon muscoides and Limosella capensis among other macrophytes. Van Zinderen Bakker (1955) described the vegetation of the bogs, using pollen analyses to diagnose formerly wetter conditions in the Drakensberg range. The bogs form natural sponges regulating the largest watershed in South Africa, but have been threatened by erosion, resulting from intensive summer grazing. Van Zinderen Bakker and Werger (1974) described the phytosociology of the bogs, vleis and surrounding areas. They reiterated the importance of the bogs in regulating stream headwaters. Both grazing and trampling damaged the bogs by increasing erosion. Jacot Guillarmod (1962, 1963, 1969) describes the vegetation of the margins and banks of Lesotho's highland and lowland rivers, as well as the mountain peat bogs and sponges, including detailed studies of the Tipperary bog which supported the conclusions of van Zinderen Bakker. She identified the increased density of permanent inhabitants in the region, and diamond mining as being ultimately responsible for the habitat degradation. Jacot Guillarmod (1970a, 1972) described the role of the bogs in filtering stream water, and documented the deterioration of flow and water quality downstream in the Orange River.

6.4.2 Invasive exotic macrophytes

The introduced aquatic macrophytes which have so far caused most problems in South Africa are: Eichhornia crassipes (water hyacinth), Myriophyllum aquaticum (parrot's feather), Azolla filiculoides and Salvinia molesta (Kariba weed). Their distribution in South Africa is shown in Figure 3. Jacot Guillarmod (1970b, 1978a, 1979a) traced the systematics of aquatic problem plants, suggesting that they are able to spread much faster than terrestrial plants. Steyn et al (1979) provided a guide to the use of herbicides for aquatic weed control, and described the limnological considerations and statutory requirements that must be considered. The available compounds and different methods and strategies of spraying were outlined. Suggestions were made for detailed monitoring of results and subsequent water analyses. Shillingshaw (1981) has pointed out that attempts to control water weeds have been hampered because there has been no overall controlling body for South African rivers.



EICHHORNIA CRASSIPES



MYRIOPHYLLUM AQUATICUM



SALVINIA MOLESTA



AZOLLA FILICULOIDES

FIGURE 3. The distribution of the main aquatic problem plants in southern Africa. (After Jacot Guillarmod, 1979 and Ashton and Walmsley, 1984).

6.4.2.1 Eichhornia crassipes was first introduced into South Africa from South America as an ornamental plant in 1884, and is now well established in all four provinces. The plant may be either free-floating or rooted, has an enormous capacity for vegetative reproduction, and submerged seeds are known to remain viable for 15 years (Kluge, 1978). Dense mats disrupt navigation, fishing and other recreational activities. They may also reduce or clog water flow, and increase evapotranspiration. Effects on the aquatic environment include cutting out light, reducing oxygen, increasing acidity of the water, and providing habitat for mosquito breeding.

The first published account of water weed problems was written by Lansdell (1925), who described serious infestations in the Swartkops and Breede Rivers, and suggested mechanical removal as a possible control or eradication measure, because the weed was not widespread at that time. Edwards and Musil (1975) reviewed the worldwide distribution of E crassipes and described its economic impact, while Jacot Guillarmod (1977a) described its distribution in South Africa. Until fairly recently, water hyacinth had been thought to spread in South Africa by vegetative propagation alone, but Jacot Guillarmod and Allanson (1978) reported the setting of seed by experimental stands of the plant. They pointed out that a seed reservoir in the marginal sediments of water bodies would not be affected by herbicides. Kluge and Annecke (1972) outlined the prospects for biological control of water hyacinth. Under experimental conditions Gerber (1979) showed that E crassipes increased evaporation by 30%. Goodman (1981) outlined the past history and present status of water hyacinth in the Ndumu Game Reserve. Schafer (1977) has suggested that water hyacinth could be used as a substrate for the production of biogas, as fertilizer, or as an organic medium for sewage purification.

6.4.2.2 Myriophyllum aquaticum (Parrott's feather) is a rooted water plant, native to South America, which was first recorded in South Africa in 1921, but may have been introduced some years previously. Only female plants are found in South Africa and therefore vegetative propagation is the only means of reproduction. However, a portion only a few millimetres long is sufficient to start growth. Foci of infestation appear to be in the south-western Cape, the East London area and the middle Vaal River, but the plant is now widely established throughout South Africa (Jacot Guillarmod, 1978b).

Piaget and Schliemann (1973) described M aquaticum, as firmly established in the Berg, Krom, Eerste and Dwars Rivers. They concluded that chemical analyses failed to link the distribution of the plant with sewage enrichment, and that mechanical removal was the only available control method. A study of the taxonomy and autecology of M aquaticum was carried out by Flach (1977). He examined the morphology of M aquaticum and compared it to the indigenous M spicatum which is not a problem plant. He also investigated the distribution, vegetative propagation, shade tolerance, drought resistance, nitrogen utilization, evapotranspiration, salinity tolerance and chemical composition of M aquaticum. Jacot Guillarmod (1976, 1977b) summarized the problems associated with M aquaticum, distinguished between the introduced and natural species, and commented on the inadequacy of present legislation in preventing the spread of aquatic weeds. Jacot

Guillarmod (1979b) observed that Myriophyllum was rarely reported until the 1970's, (although it had by then been in the country for 50 years). She felt that the dramatic spread since the 1970's was evidence that widening distribution of the plant was exponential, with a long initial phase of relatively slow dispersal, followed by a sharp increase in the rate of spreading.

6.4.2.3 Azolla filiculoides is a small aquatic heterosporous fern, first recorded in South Africa in the late 1940's (Oosthuizen and Walters, 1961). The plant occurs both free-floating in water and rooted on land. Although reproduction by spores has been shown (Jacot Guillarmod, 1979a), vegetative increase is probably more common. It also is a native of South America.

Oosthuizen and Walters (1961) reported a serious infestation of Azolla in the Oorlogspoort River near Colesberg, but stated that control by diesel oil was effective in tests. Subsequently, Jacot Guillarmod (1979a), noted that the rising cost of fuel and the ineffectiveness of this control method have caused this practice to be abandoned. Ashton (1974) investigated the growth rate and nitrogenase activity of A filiculoides in a wide range of light and temperature regimes, and found that both vary with the pH of the nutrient solution used. The degree of cold tolerance of the plant varied with its size and the pH of the solution. Ashton predicted that A filiculoides was unlikely to colonize the open waters of the Hendrik Verwoerd Dam. He later extended autecological studies of A filiculoides in the catchment area of the dam (Ashton, 1982). Jacot Guillarmod (1978c) summarized the history of A filiculoides in South Africa and illustrated its distribution. Two indigenous species of Azolla, A pinnata and A nilotica were distinguished from A filiculoides by Ashton and Walmsley (1984) and the distribution of all three species is illustrated. It was suggested that the minute spores of A filiculoides might easily have been carried to South Africa by storm blown waterfowl from America. The distribution of the plant is limited to quiet pools and backwaters, where it is protected from wind and turbulence.

6.4.2.4 Salvinia molesta (Kariba weed) is a sterile hybrid free-floating fern, probably formed from a cross between S auriculata and S herzogii in a botanical garden in Brazil. It therefore depends entirely on vegetative reproduction (Jacot Guillarmod, 1978d). Its most notorious colonization was that of Lake Kariba, where it covered only 20 ha in 1959, but increased to cover 40 000 ha by 1961 (Jacot Guillarmod, 1978). It was probably brought into the Zambezi area before 1948, as an ornamental plant for ponds or fish tanks (Jacot Guillarmod, 1979a). It has now spread into the Transvaal, Natal and the Cape, but there is no indication of how it has been introduced. The streams leading into Swartvlei (southern Cape) are infested and Jubb (1961b) reports its occurrence in the Baakens River, near Port Elizabeth. Several isolated occurrences, such as the Kruger Park, and a small farm dam near Doveton, Natal, are difficult to explain since there appear to be no obvious connections to other infestations (Jacot Guillarmod, 1979a). Keulder (1982) has described a method of measuring standing crop using leaf area, which correlated with pigment extractions and fresh and dry weight under experimental conditions.

6.5 Aquatic microphytes

A considerable literature has been built up on algal taxonomy, dominated by work on diatoms. Table 4 summarizes these reports and articles by major algal group, listing author, date and main locality. The preponderance of work on diatoms may be partly explained by the intrinsic fascination which diatoms have traditionally held for algologists, but they are also often the dominant algal species in streams and rivers.

Diatoms have been extensively used as indicators of nutrient enrichment and water quality, and studies such as Cholnoky (1958a) in the Jukskei/Crocodile River, Archibald (1968) in the Vaal, Archibald (1971) in the Sundays and Great Fish Rivers, Schoeman (1971, 1972, 1973, 1976) in Lesotho, and Schoeman (1979) in the Hennops River have been reviewed in Chapters 2 and 3. Hancock (1973a,b) also used diatom associations to interpret pollution effects, and changes in pH, nitrogen content, dissolved oxygen, alkalinity, and light in the Klip River in Transvaal which received mineral and acid runoff from gold mine dumps. Barlow and Lee (1974) sampled the phytoplankton standing crop in the Jukskei River system, and revealed that the principle source of eutrophication came from the Modderfontein stream.

The role of epiphytic algae and bacteria in the decomposition of Potamogeton crispus in Pongolo floodplain pans has been investigated by F E J Rogers (1981) and K H Rogers and Breen (1981). P. crispus production and decomposition played an important role in energy and nutrient transfer in the pans, and it was concluded that the ephyton made a significant contribution to turnover rates.

6.6 Conclusions

The research emphasis on different plant communities associated with rivers has been very varied. Catchment vegetation has been looked at mainly from the point of view of hydrological changes caused by vegetation changes, while the emphasis in macrophyte studies has been on introduced pest species and their colonization ability. Algal studies have concentrated on the elucidation of very complex taxonomic problems, and on the use of diatoms in monitoring water quality. Perhaps the most productive approach has been that taken in the Pongolo system in which the various components of terrestrial and aquatic vegetation have been looked at from the point of view of energy and nutrient flux through the system. This concept has led to a good understanding of the relative importance of each component to the functioning of the system, and their reaction to perturbations.

TABLE 4. Taxonomic references for riverine algae

Taxon	Author	Date	Area/River
Cyanophyta	Welsh, H	1962	Swaziland
Cyanophyta	Welsh, H	1964	South Africa
Cyanophyta	Claus, G	1964	Buffalo River
Cyanophyta	Welsh, H	1966	Kowie River
Cyanophyta	Archibald, C G M	1966	Kowie River
Cyanophyta	Archibald, C G M	1967	Kowie River
Cyanophyta	Cholnoky-Pfannkuche, K	1968	Kowie River
Chlorophyta	Pocock, M A	1937	South Africa
Chlorophyta	Pocock, M A	1959	South Africa
Chlorophyta	Claassen, M I	1977	Transvaal
Diatomaceae	Grove, E	1894	Mtwalume River
Diatomaceae	Fritsch, F E, Rich, F	1929	Griqualand West
Diatomaceae	Cholnoky, B J	1953	Hennops River
Diatomaceae	Cholnoky, B J	1954a	Africa
Diatomaceae	Cholnoky, B J	1957	Tugela River
Diatomaceae	Cholnoky, B J	1958b	South Africa
Diatomaceae	Cholnoky, B J	1959	Cape Province
Diatomaceae	Cholnoky, B J	1960a	Natal
Diatomaceae	Cholnoky, B J	1960b	Swartkops River
Diatomaceae	Cholnoky, B J	1962a	Eastern Transvaal
Diatomaceae	Cholnoky, B J	1962b	Cape Province
Diatomaceae	Cholnoky, B J	1962c	Swaziland
Diatomaceae	Giffen, M H	1966a	Hogsback
Diatomaceae	Giffen, M H	1966b	South Africa
Diatomaceae	Cholnoky-Pfannkuche, K	1966	South Africa
Diatomaceae	Archibald, R E M	1966a	Vaal River
Diatomaceae	Archibald, R E M	1966b	Vaal River
Diatomaceae	Schoeman, F R	1969	Lesotho
Diatomaceae	Schoeman, F R	1970	Lesotho
Diatomaceae	Cholnoky, B J	1970	Nonoti River
Diatomaceae	Schoeman, F R	1972	South Africa
Diatomaceae	Archibald, R E M	1972b	South Africa
Diatomaceae	Schoeman, F R, Archibald, R E M	1974	South Africa
Diatomaceae	Schoeman, F R, Archibald, R E M Barlow D J	1976	South Africa
Diatomaceae	Schoeman, F R, Meaton, V H	1981	South Africa
Diatomaceae	Schoeman, F R, Meaton, V H	1982	Africa
Diatomaceae	Schoeman, F R	1982	Jukskei River
Diatomaceae	Archibald, R E M	1982	Sundays River
Diatomaceae	Archibald, R E M	1983a	South Africa
Diatomaceae	Archibald, R E M	1983b	Sundays/Fish River
Diatomaceae	Archibald, R E M, Schoeman, F R	1984	South Africa
General	Fritsch, F E	1918	Cape
General	Fritsch, F E, Rich, F	1924	Natal
General	Cholnoky, B J	1954b	Mogol River
General	Claassen, M I	1961	Transvaal

CHAPTER 7 THE CONSERVATION OF RIVERS

The introductory chapter contains a discussion of conservation policy in South Africa, and the concluding chapter attempts to draw some general conclusions about the priorities and possible directions for river research within the context of conservation. The function of this chapter is to review those articles in the South African literature which have made a contribution to the conservation of rivers and their biota, or have discussed river conservation.

The subjects covered in the literature include a holistic view of conservation, aimed at the exploitation of rivers for multiple purposes within renewable limits; conservation plans aimed at minimizing the effects of development on the natural system; the identification and monitoring of conservation threats to specific biota; and reports of isolated instances of habitat degradation and species loss.

7.1 Integrated conservation

Conservation of rivers within the context of the critical water supply shortage in South Africa is the theme of O'Keeffe (1985b). Because most rivers have already been exploited, and because water supply priorities are bound to prevail, conservation objectives have to be tailored within a multiple-use doctrine for rivers. Rivers perform numerous important functions both for the natural biota and for human purposes, and it is important to emphasize the benefits of conserving these functions for all users.

This holistic view of conservation was espoused by Phillips (1965), in a commentary on the approach to the planning of large scale river developments such as the Orange River scheme. The ramifications of this scheme were bound to be widespread, and Phillips felt that a direct assessment of the economic costs and benefits is too narrow a basis on which to justify the scheme. He advocated a holistic ecological approach in which aspects of land-use suitability, erosion potential, and disruption of the natural ecosystem were taken into account, as well as the social implications of providing large quantities of water to formerly arid areas. He also felt that the development of new industries and relocation of large numbers of people to exploit the opportunities offered by the water supply, required increased levels of personnel training.

Roberts (1981) discussed the environmental considerations of water development projects from the point of view of the Department of Water

Affairs. Although the Commission of Enquiry of 1970 made no recommendation regarding the desirability of undertaking environmental impact assessments for water projects, environmental considerations usually play an important role during the planning, construction and operation of water projects. Recently there has been a growing awareness of environmental considerations, and although no legislation has been passed, voluntary cooperation by planners in assessing environmental impact has been advocated by the government. Roberts (1981) outlined procedures for environmental impact assessment which may be handled either by an environmental committee, appointed by the Minister for Environmental Affairs, or by an internal assessment within the Department of Water Affairs. He stated that all impacts of a scheme are considered, including beneficial ones such as increased food production; and cited case studies demonstrating environmental impact assessment procedures. These included the Mfolozi River impoundment scheme (which is described more fully below); dams in the western Cape where sand is blown from the reservoir onto valuable land; several assessments of the impact of dams on estuaries (eg the proposed dam on the Palmiet River, which could affect rare and endangered species of Cape flora); deterioration of grazing in the Vet River catchment; and effects of the pumped storage scheme of the Drakensberg project.

Roberts (1983) discussed environmental constraints on the development of water resources.

He acknowledged the urgent need for exploitation of available water supplies, but also identified a new and essential water demand - that required for environmental management. He suggested that the objective of environmental management is to gain the maximum net benefit from all available natural resources. Environmental demands were estimated for estuaries and lakes, and nature reserves, and amounted to approximately 11% of total demand. Roberts pointed out that this is a simplistic model which required further calibration, but underlined the necessity for incorporating environmental considerations into project planning at every stage. He recommended that adequate allowance should be made for environmental studies that can be integrated into the initial specifications of a project.

Allanson and Rabie (1983) reviewed the environmental aspects of freshwater systems in South Africa, and examined the nature and extent of surface freshwater resources. They outlined environmental problems and the relevant legislation associated with water resources (soil erosion, impoundment, eutrophication, mineralization etc), and described the public bodies responsible for controlling freshwater resources, and their powers. The provisions and requirements of the Water Act of 1956 were described, and some of its shortcomings highlighted. The article ended with a criticism of the lack of a holistic systems approach to water supply and freshwater problems. The necessity for a defined policy for river management, and the inclusion of environmental safeguards was stressed.

7.2 Environmental impact assessment, and conservation plans for individual rivers

A significant advance for environmental impact assessment was taken in

1976 with the appointment of a committee of enquiry into the ecological aspects of a dam in the Mfolozi River basin. This appears to have been the first time that an environmental study was undertaken before any detailed planning of a project with potential ecological impact (Porter, 1977). Thirteen possible dam sites were identified by the Department of Water Affairs, and the probable impacts of each were assessed by a multidisciplinary team, using a matrix approach. Thirty different engineering actions and 36 environmental variables were considered, giving a total of 1 080 possible interactions according to Porter (1978) who presented an example of the method, using a hypothetical impoundment within the Mfolozi Reserve. A further example, using the proposed Klipfontein site, was detailed by Porter (1981). Results of the assessments identified the Mfolozi Game Reserve as the most valuable conservation resource in the catchment, but found that the Onrust, Doornkop or Ulundi sites would cause fewest disruptions and would have advantages in terms of recreation and increased aquatic habitat (Porter, 1982).

Conservation plans for the Pongolo floodplain have been mentioned in previous sections. These emanated from studies undertaken after the construction of the Pongolapoort Dam, and were carried out largely independently of the planning and construction of the dam. An initial plan for the conservation of the floodplain pans was produced by Coke and Pott (1970), mainly to maintain fish stocks and breeding habitat. They discussed artificial floods from the dam, localized raising of river water levels by artificial barriers, the excavation of feeder-channels to some pans, and the use of canalized or pumped water. They calculated a water budget and estimated that 305,000 m³ p.a. of water was lost from pans through evaporation. Consequently, they recommended that 1 000 000 m³ of water should be made available annually from the dam for the conservation of the pans. In addition, plans were proposed for the conservation of the larger pans as food-fish resources, angling and hunting reserves, and as nature reserves. It was suggested that fishing by Bantu in the area could be formed into an intensive industry. Heeg and Breen (1982) have tentatively estimated the water requirements of the floodplain as 42 000 000 m³ p.a. if inflatable weirs were installed to maximize water use. Regarding this water requirement as an agricultural loss, they produced a cost benefit analysis to show that the gain in terms of local fisheries, subsistence agriculture and tourist potential should more than offset the loss in irrigated agricultural production. Their analysis relied purely on economics, without taking account of the intrinsic conservation values of the floodplain.

Noble (1974) produced an evaluation of the conservation status of aquatic biotopes as part of Project Aqua in South Africa. Project Aqua was an international undertaking of the Freshwater Productivity Section of the International Biological Programme. The aims of the project were to list and describe aquatic sites of scientific importance and to propose their conservation. A classification and definitions of different aquatic biotopes was presented. Recommendations were made for the conservation of additional sites not in existing conservation areas, a preliminary list of South African Project Aqua sites was proposed, and included the rivers listed in the following paragraph.

The section of Noble (1974) dealing with rivers and streams identified the Storms, Touws and Groot (Nature's Valley) catchments as being entirely within conserved areas. These are all situated in the southern Cape Province. In addition, the following headwater streams were listed as being situated within conserved areas: the upper Jonkershoek-Eerste River catchment (south-western Cape); the Holsloot River catchment (Breede River system, western Cape); the Buffalo River catchment (eastern Cape); the Mlanbonjwa River catchment (Tugela River system, Natal); the Houtbosloop catchment (Crocodile-Incomati River system, eastern Transvaal); the Debegeni River catchment (Groot Letaba-Olifants-Limpopo River system, eastern Transvaal); and the Mooi River catchment (Tugela River system, Natal).

Small scale conservation efforts involving non-specialists and volunteers have not been a conspicuous part of the South African conservation scene. An exception is described in Anon. (1977). This describes the campaign to clean up the Jukskei River by Mrs Wendy Bodman, retired nurse and liaison officer for the South African Council for Conservation and Anti-pollution. By taking photographs of obvious pollution, litter, and degradation, and presenting slide shows to officers of seven municipalities with areas bordering the Jukskei, Mrs Bodman mobilized forces to reduce industrial effluent, remove litter and prevent illegal dumping. She was also instrumental in the clearing of riverside paths for recreation. McVeigh (1981a) described a similar campaign relating to the Lourens River in Somerset West. A locally-formed conservation group caused the council to reconsider a plan to canalize and divert the river to allow road widening, and has organized clearance of exotic trees and shrubs from the banks.

7.3 Conservation monitoring and the identification of threats

A large number of studies have diagnosed and monitored conservation threats to particular habitats or species. Many of these have already been described in previous sections and need only be mentioned briefly here. Jacot Guillarmod (1969, 1970a,c) and van Zinderen Bakker (1955, 1974) identified the mountain bogs and vleis of Lesotho as essential regulating features of many South African rivers (see Chapter 5).

McVeigh (1981b,c) identified the problem of riverbed bulldozing, and discussed the ecological implications. Twenty kilometres of the Berg River were bulldozed in 1979 and 1980 to allow unimpeded water flow for flood prevention. This has reduced the habitat diversity of this stretch of river to a flat, wide bed of rocks, and increased downstream silting (McVeigh, 1981b). He also described bulldozing of four to five kilometres of the floodplain at the source of the Holsloot stream (a tributary of the Breede River), in order to provide material for heightening a dam wall. As a result the natural river course has disappeared, leaving a bare flat sandy plain (McVeigh, 1981c).

The conservation status, and management of vertebrates other than fish has received considerable attention. Details of Rowe-Rowe's (1975, 1977a,b; 1978) work on the two species of otter native to South Africa, and Pooley's (1972, 1973, 1980) work on crocodiles are contained in Chapter 5.

The Nile crocodile is one of the 10 species listed as vulnerable in the South African Red Data Book - Reptiles and Amphibians (McLachlan, 1978). Forty-six threatened species are listed, of which two are endangered, 10 are vulnerable (including the crocodile, water monitor, and rain frog), 21 are rare, 12 are peripherally rare and one is of unknown status.

7.3.1 Fish

The South African Red Data Book - Fishes (Skelton, 1977) listed 28 species. Barbus trevelyani, B phlegethon, B treurensis, Oreodaimon quathlambae and Clarias cavernicola were listed as endangered, Sarotherodon placidus as endangered in South Africa, Hippocampus capensis and Barbus erubescens as vulnerable, and Nothobranchius orthonotus and N rachovii as vulnerable in South Africa. In addition 15 species were listed as rare, and three as rare in South Africa.

The identification of threatened fish populations and attempts to diagnose reasons for their decline have received considerable attention. Increased erosion, sedimentation and siltation have been suggested as a threat to the endemic species (especially small redfin Barbus spp.) in the Olifants River (C M Gaigher, 1973), to Barbus trevelyani in the eastern Cape (I G Gaigher, 1979), to Kneria auriculata in the Crocodile River (eastern Transvaal) (Kleynhans, 1980), to Oreodaimon quathlambae in the Tsoelikana River (Pike and Tedder, 1973), and to five threatened Cape species, (including some of the above mentioned) (Skelton 1977). Introduced species (particularly trout and bass) are also implicated in the decline of Olifants River endemics (C M Gaigher, 1973, 1979; Scott, 1982); Barbus trevelyani (I G Gaigher 1979), Oreodaimon quathlambae in the upper Umkomazana River (Jubb, 1966a); Kneria auriculata in the Transvaal (Kleynhans, 1980); and of nine threatened Cape species (Skelton, 1977). Impoundments preventing migrations are blamed for population or range reduction of Olifants River endemics (C M Gaigher, 1979; Scott 1982); Kneria auriculata (Kleynhans, 1980); Mugil cephalus and Myxus capensis in the eastern Cape (Bok, 1976); and Hydrocynus vittatus in the Incomati system (I G Gaigher, 1970). I G Gaigher et al (1980b) however, doubted whether this factor alone has threatened the survival of any freshwater species. In addition I G Gaigher (1979) blamed lowered water levels (due to extraction for agriculture) as well as the above problems, as a threat to Barbus trevelyani. Skelton (1977) cited water extraction as a cause of decline for six threatened Cape species.

Skelton (1983) reviewed the conservation of threatened fishes in southern Africa. He pointed out that the number of fish species declined from north to south and that both tropical and non-tropical species reached the margins of their distribution in southern Africa. They are therefore particularly vulnerable. Skelton summarized the major threats to vertebrate species, identified by the IUCN (Percentages indicate the proportion of species affected).

1. Habitat degradation (67%)
2. Over exploitation (37%)
3. Effects of introduced species (19%)
4. Loss of food supply (4%)
5. Killing for farming or prey protection (3%)
6. Incidental take (2%)

Of these, habitat destruction and the effects of exotic species were identified as the most important threats to fish in South Africa. I G Gaigher et al (1980b) described the distribution and conservation status of indigenous freshwater fish in the Cape Province. They identified and discussed a number of factors affecting the survival of threatened fish populations, and pointed out that the Cape's long history of European settlement has meant that more changes to rivers have been made than in other areas of South Africa. The acid oligotrophic nature of the rivers of the western and southern Cape dictate a natural scarcity of species and numbers. South Africa has amongst the highest rates of soil erosion in the world and farming and related land use can cause erosion leading to siltation, sand deposition and increased turbidity. Summarizing the effects of erosion, I G Gaigher et al (1980b) pointed out that changes in the river substratum, macrophytes and invertebrates will be reflected in fish populations, and that silt deposition also covered breeding sites and turbidity might cause water temperature changes. Water extraction represents another threat, reducing aquatic habitat, changing temperature regimes and possibly increasing the effects of pollution by concentrating pollutants.

They cited mineralization and eutrophication as serious problems in the Berg and Breede Rivers, where hardy exotics such as blue gill sunfish and carp may increase at the expense of less tolerant indigenous species. Pesticides and herbicides tended to have localized effects but might threaten very rare species. Removal of riverine vegetation might seriously affect the detritus food chain which was likely to be the main energy source in the oligotrophic acid rivers. Introduced species could threaten indigenous populations by predation, competition and genetic swamping (where hybridization occurred); and the smallmouth bass, which has been introduced to almost all Cape rivers, has been the most destructive predator. Predation effects might be increased by habitat degradation removing prey refuges. Fertile hybridization has been demonstrated between some yellowfish species, posing a further threat from possible introductions via intercatchment water transfer schemes.

I G Gaigher et al (1980b) also described the effects of mining, industrial development and human settlement, leading to chemical, organic and thermal pollution, watershed connections, canalization and diversions. Dams and weirs acted as barriers to migration, drowned breeding/feeding grounds, changed flow regimes (which may be crucial for breeding cycles), established habitat for undesirable species, and created new thermal and chemical states for downstream flows. They might also affect the genetics of indigenous populations by creating different environmental pressures which would select different gene combinations.

Of these threats, I G Gaigher et al (1980b) identified overgrazing, ploughing, water extraction and introductions of exotic fish as probably the most destructive for indigenous Cape fish species. They summarized a management policy of the Cape Department of Nature and Environmental Conservation for freshwater, in which rivers and streams have been divided into three categories:

1. Important for the conservation of indigenous fauna and flora or unique ecosystems.
No introductions will be permitted, and every effort should be made to monitor and protect these rivers.
2. Not of prime importance for conservation.
These will be managed for angling or commercial utilization and may be stocked with exotics.
3. Waters which have become unsuitable for fish and other organisms.
Management will be aimed at rehabilitation.

I G Gaigher et al (1980b) also suggested a number of conservation aims. These were briefly:

1. Public education.
2. Attempts to foster better understanding between ecologists and developers.
3. Improved soil and water conservation.
4. Careful screening of fish translocations.
5. Establishment of whole catchment fish sanctuaries for threatened species.
6. Management based on well-defined policies, including a management plan for each river system.

CHAPTER 8 SOME GENERAL CONCLUSIONS, WITH SPECIAL REFERENCE TO THE CONSERVATION OF RIVERS

8.1 An analysis of the literature

The preceding review has been based on information collected for a bibliography of ecological research on South African rivers (O'Keefe and O'Keefe, 1986, in press). The bibliography is intended to cover publications and unpublished reports exhaustively for this topic. Of the 1 200 references in the bibliography, 78% are published in some form, 3% are theses, and 19% are unpublished reports for government agencies, conservation bodies, university departments or research institutes. It is uncertain whether the bibliography provides a comprehensive coverage of unpublished reports but, from the frequency with which hitherto unsuspected sources came to light during compilation, it is possible that there are many reports missing. Two conclusions can be drawn from these observations. A large proportion of the knowledge and experience gained about South African rivers is contained in unpublished reports which are not generally available, and secondly, there may be considerably more information which is not available at all (since it is not contained in any reference list). The quality of the analysis and deductions from unpublished sources is extremely hard to gauge, but the raw data is nevertheless invaluable in contributing to basic information about South African rivers.

A superficial analysis of the South African literature provides some idea of where the main research emphasis has been concentrated. Table 5 lists percentages of all books and articles by main subject and by main taxonomic group with 'Rivers' referring to articles on the ecology of all aspects of a river. 'Descriptive' refers to articles describing general aspects of research findings, or specific incidents (usually in trade or semi-popular journals). 'Biological' distinguishes articles which deal with aspects of a species without reference to its environment, and is an incomplete section, since purely anatomical or physiological studies have not been included.

It is immediately obvious that a large proportion of research effort has been devoted to the autecology of individual species, and particularly to invertebrates and fish. This has been partly a consequence of the necessary emphasis on taxonomy during the formative years of river research, partly of the distribution of individual enthusiasms, and partly of the financial and logistical difficulty of mounting holistic or multidisciplinary research projects on even small parts of river systems. Notable exceptions to these trends have been the hydrobiological investigations described in Chapters 2 and 3. Some

TABLE 5. A breakdown of literature on the ecology of running waters in South Africa. The categories are defined from 1 100 books, conference papers and articles in scientific and semiscientific journals. Further explanation of some of the categories is given in the text

Type of Article	%	Main Group	%
Ecological	44	Invertebrates	34
Taxonomic	26	Fish	29
Descriptive	13	Rivers	25
Biological	8	Plants	7
Review	8	Amphibians	4

current projects are also demonstrating that system studies are possible with limited resources. J M King, Day and Davies at the University of Cape Town, by limiting the study area to small streams in the Jonkershoek catchment, have been able to devise methods to investigate energy and nutrient budgets, so as to identify the important processes governing stream functions. C J Kleynhans and J Engelbrecht at the Nature Conservation Division of the Transvaal Provincial Administration have developed methods for overview regional surveys of many aspects of rivers, to provide an initial database for the conservation assessment of Transvaal rivers. K C D Hamman and A H Coetzer at the Cape Department of Nature Conservation have begun a multidisciplinary project aimed at identifying habitat requirements for endemic fish in the Olifants River system. R N Porter, of the Natal Parks Board, has developed a protocol for environmental impact assessment of the Mfolozi River. These are all attempts to provide an integrated understanding of river ecology, often improvising methods to circumvent the problems of limited resources.

8.2 Conservation research

A preliminary discussion in the introductory chapter identified the lack of an overall conservation policy for rivers in South Africa. The importance of such a policy has been underlined by I G Gaigher et al (1980b) and by Allanson and Rabie (1983). The development of such a consensus policy must therefore be a major priority, since the directions for future research will depend crucially on the careful definition of conservation aims for rivers.

Articles reviewed in Chapter 6 have shown that there are two approaches to conservation in rivers. The first is concerned with nature conservation, and deals with the desirability of maintaining pristine systems in which the following criteria (modified from Newbold et al,

1983) are of greatest importance:

- Naturalness
- Representativeness
- Diversity
- Rarity
- Fragility
- Geographical position
- Size

'Naturalness' implies the extent to which a system has been altered from its state before the arrival of industrial man, and applies well to rivers. A river whose catchment has been least affected by artificial perturbations will represent a coherent system containing a more or less adapted community. It also acts as a baseline against which to compare the level of degradation in other systems.

'Representativeness' identifies the desirability of conserving typical examples of all different kinds of systems. In South Africa seven groups of rivers have been identified at the regional level by Noble and Hemens (1978), but obviously different or higher resolution groupings may become appropriate.

'Diversity' is an uncomfortable criterion for rivers. Many of South Africa's streams and rivers flow very infrequently and contain a sparse but specialized biota. Regulation by means of dams or inter-basin water transfers has changed many seasonal rivers into constant flows, and may well have increased the biotic diversity, but without adding to the conservation value. Perhaps 'natural diversity' is a better criterion.

'Rarity' of species or habitats must be taken into account, in terms of the intrinsic interest in rarities, their use as first indicators of degradation, and their contribution to the 'fragility' of a system.

'Fragility' indicates both the resilience of a system to interference, and the level of threat of further interference. 'Geographical position' is important because it may affect the status of a system with regard to future threats. (For instance, a river near a major urban/industrial area is very likely to be disturbed). 'Geographical position' is also important because it is desirable to conserve systems in different geographical positions.

'Size' with respect to rivers, is some combination of length, runoff, catchment area and stream order. Size is important because of the implications of 'a viable unit', and habitat diversity, but also because there is a clear distinction between the threat status and management possibilities for large and small rivers in South Africa. Small rivers and streams are less likely to be economically important, already exploited, or subject to major development. They are more likely to be under the jurisdiction of a single owner or government agency, and may therefore be more easily managed. Small streams form the upper catchments of large rivers, which are therefore the recipients of the cumulative effects of upstream perturbations. Large rivers, without exception, are important parts of the economic infrastructure, and have

been, and will continue to be, managed primarily for water supply and effluent disposal.

'Nature conservation' is applicable to natural or little-altered systems in which a high degree of protection may be possible (eg in a nature reserve). In South Africa, this option is restricted to small streams and tributaries, normally in the upper catchments where no uncontrolled exploitation from upstream can affect the protected reaches. Research potential and management options in these situations are restricted only by available manpower, financial resources and the constitution of the controlling body.

The second approach to conservation has been termed a holistic view. In this case, the underlying criteria are often the same, but the other perspectives and demands on rivers systems are acknowledged and accepted. The river is viewed as a renewable resource which can be exploited for multiple uses, the overall aim being to maximize its uses with minimal detriment to its essential functions. Examples of some of the main uses and functions of rivers are listed below:

River Functions

Landscape drainage
Water supply
Sediment transport
Nutrient transport
Water transport
Water purification
Nutrient recycling
Biotic dispersal
Vegetation maintenance
Biotic habitats
Groundwater recharge

River Uses

Domestic
Industrial
Agricultural
Forestry
Fisheries
Recreational
Conservation
Scientific

In all large rivers and most small rivers in South Africa, this kind of multiple use is already a fact of life, and conservation priorities have to be integrated with those of other users. Conservation, however, while receiving considerable lip service, has traditionally been ranked very low down the scale of user priorities. This has often been the fault of the conservationists who have been unable, 1) to define clearly and precisely their aims, 2) to offer clear predictive conclusions about the consequences of river developments at the planning stage. This inability to offer constructive advice has often been because the planning authorities have not included ecological expertise at the planning stage. Phillips (1965) pointed out that ecological aspects must not be tacked onto development projects, but must be an integral part of them. The conservation community for its part, must be able to make a professional contribution. This requires an understanding of rivers as integrated systems, and the ways in which different perturbations will affect different processes. To summarize this view of conservation, the emphasis is not: "No effluent must be allowed in

this river", but "How much of a particular effluent can be disposed of in this river without seriously affecting the biota, and breaking down the self purification capacity of the system".

At present, there is a reasonable understanding, in the specific case cited above, of the effects of effluents in rivers, but very little predictive capacity. Similarly, if an impoundment is planned for a river, some of the general consequences can be described, but the severity and persistence of the effects cannot be accurately predicted or quantified.

8.3 Research priorities

There are two major impediments to effective research on rivers in South Africa. Rivers are longitudinal, dendritic, unpredictable, with diffuse inputs, and dependent on catchment processes, and these are all attributes which cause problems in the planning and logistics of river research. However, recent conceptual models of river ecosystem functioning, developed in the United States of America, have made a considerable contribution to overcoming these problems. The river continuum concept, suggested by Vannote et al (1980) is an attempt to provide a unifying concept of ecological processes in rivers. They suggested that plant and animal communities adjust to spatial resource gradients imposed by downstream changes in environmental conditions (Ward et al, 1984). One of the most important implications is that biological adjustments are evident as changes in the ratio of production to respiration, which represents the 'trophic status' of a particular stretch of river. Another helpful aspect is the classification of the fauna in functional, rather than taxonomic groups, according to feeding adaptations. Thus a community dominated by 'shredders' is seen as yielding to one dominated by 'grazers' and 'collectors' as the coarse particulate organic input to the headwater streams is comminuted to fine particles and augmented by epilithic algal production further downstream. The river continuum concept, and the serial discontinuity concept of Ward and Stanford (1983) which applies the format to predicting downstream effects and 'reset distances' of impoundments in rivers, both identify important research priorities which have so far not been addressed in South African rivers.

The second impediment to river research is a critical shortage of resources, and particularly of trained manpower. This has probably been a result of the emphasis on lake and reservoir research in the last twenty years, which has channelled limnologists away from the study of running water ecology. However, the shortage of skilled manpower is common to many industries and professions in South Africa, and is unlikely to be remedied in the near future.

The following suggestions for research priorities have therefore been classified according to the levels of training necessary for their accomplishment.

Noble and Hemens (1978) and Ward et al (1984) have previously identified priorities for research into river ecology, and some of their suggestions have been included here. Projects have been assigned to one of three categories, and are listed in order of importance:

Category 1:

Specialized ecological research which requires highly trained manpower, although it is not necessarily expensive to do. These projects are aimed at providing a basis of understanding of ecological processes in rivers, from which management decisions may be made.

Category 2:

Monitoring and conservation management projects. This kind of research is often expensive in terms of the number of personnel and amount of travelling required, but methods can be refined to be within the capability of less specialized people than 1 above.

Category 3:

Information gathering and 'clean-up' projects. These exercises require only good organizational ability and enthusiasm. Local conservation groups and angling interests are ideal targets for this kind of operation.

1. Specialized ecological research.

- a. Downstream effects of impoundments, particularly in terms of reset distances required for physical and biological parameters to return to nonimpounded conditions.
- b. The measurement of trophic status in rivers using production/respiration ratios, as an integrated measure of biological activity, and calibration of changes in the ratio in response to different perturbations in the river.
- c. Functional classification of river fauna. At present very little is known about the feeding methods and preferences of most riverine species, and these must be understood before functional changes in communities can be related to river processes.
- d. The role of rivers in nutrient recycling and absorption. The ability of rivers to act as 'nutrient buffers' preventing eutrophication of recipient water bodies, and the length of river required to 'self-purify' after effluent input are both important aspects of nutrient cycling in rivers.
- e. Quantification of the relationships between time scales associated with hydrological processes and those of the biota.
- f. Effects of inter-basin water transfers.
- g. Effects of fish populations on energy flow and nutrient cycling in rivers.
- h. Environmental effects of dam construction projects.

2. Monitoring and conservation management projects.

- a. Drawing up a consensus policy of conservation aims and criteria for South African rivers.
- b. Development of a protocol for research into river development projects at the planning stage.
- c. Preparation of a field guide to freshwater invertebrates. (At present this important group is often ignored because of the difficulties of identification).
- d. Development of methods for the consistent evaluation of the conservation status of rivers.
- e. Ordination analysis of existing data (especially on invertebrates), to identify comparable rivers/stretchers of river.
- f. Resurveys of selected rivers to evaluate changes over time.
- g. Evaluation of changes in river and catchment conditions by:
 - i. Water temperature changes.
 - ii. Palaeoecological methods such as pollen analysis, diatom frustules, mollusc shells, and fishbone middens.
 - iii. Fixed point photography (and the comparison of historic photographs).

3. Information gathering and clean-up projects.

These would include such projects as the efforts of Mrs W Bodman to clean up parts of the Jukskei River (Anon, 1977) and the organization of angling competitions to gain information about fish stocks and to provide a platform for education about the harmful effects of exotic species. The present need is for an evaluation of the potential for these projects and the development of the methods and infrastructure to make them happen.

Without the more fundamental river process investigations it will be difficult to provide the level of input to development planning necessary for ecological aspects to be taken seriously. However, it has to be recognized that rivers are going to be developed anyway, and that best use has to be made of the present limited knowledge and resources to prevent overexploitation. The less specialized projects are aimed at achieving this, but they are not a substitute for fundamental research.

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