KUOPION YLIOPISTON JULKAISUJA C. LUONNONTIETEET JA YMPÄRISTÖTIETEET 236
KUOPIO UNIVERSITY PUBLICATIONS C. NATURAL AND ENVIRONMENTAL SCIENCES 236

HANNU MÖLSÄ

Management of Fisheries on Lake Tanganyika

Challenges for Research and the Community

Doctoral dissertation

To be presented by permission of the Faculty of Natural and Environmental Sciences
of the University of Kuopio for public examination in
Auditorium L22, Snellmania building, University of Kuopio
on Saturday, 13th September 2008, at 12 noon

Department of Biosciences
University of Kuopio

KUOPION YLIOPISTO

KUOPIO 2008

Distributor: Kuopio University Library
P.O. Box 1627
FI-70211 KUOPIO
FINLAND
Tel. +358 40 355 3430
Fax +358 17 163 410
http://www.uku.fi/kirjasto/julkaisutoiminta/julkmyyn.html

Series Editors: Professor Pertti Pasanen, Ph.D.
Department of Environmental Science

Professor Jari Kaipio, Ph.D.
Department of Applied Physics

Author's address: Department of Biosciences
Section of Applied Biotechnology
P.O. Box 1627
FI-70211 KUOPIO
FINLAND
Tel. +358 50 505 3145
Fax +358 17 163 752
E-mail: hannu.molsa@uku.fi

Supervisors: Professor Ossi V. Lindqvist, Ph.D.
University of Kuopio

Professor Jouko Sarvala, Ph.D.
University of Turku

Reviewers: Professor Jukka Salo, Ph.D.
University of Turku

Docent Heimo Mikkola, Ph.D.
University of Kuopio

Opponent: Associate Professor Jeppe Kolding, Ph.D.
Department of Biology
University of Bergen, Norway

ISBN 978-951-27-0974-8
ISBN 978-951-27-1089-8 (PDF)
ISSN 1235-0486

Kopijyvä
Kuopio 2008
Finland

Mölsä, Hannu. Management of Fisheries on Lake Tanganyika - Challenges for Research and the Community. Kuopio University Publications C. Natural and Environmental Sciences 236. 2008. 72 p.
ISBN 978-951-27-0974-8
ISBN 978-951-27-1089-8 (PDF)
ISSN 1235-0486

ABSTRACT

Lake Tanganyika fisheries resources play a vital role in the economy, peoples' wellbeing and nutrition in the four riparian countries, Burundi, Democratic Republic of Congo, Tanzania and Zambia. The fisheries provide a direct source of income and livelihood for more than 44,000 fishermen including a wide range of various operational groups, but the indirect influences of the lake fishery reach about ten million people in the catchment and trade area in Eastern Africa. Overall collapses in other food production sectors of agriculture due to civil unrest, social conflicts and environmental degradation in the region have clearly increased the pressure on the utilization of the fish resources in the lake.

The study outlines recent trends in fish catches and respective economic and social outputs in the sector. In the presence of weak managerial structures, poor monitoring and control capacity in the responsible institutes, and uncontrolled access to the lake fisheries, clear signs of over-exploitation and consequent changes in population structures are seen in the pelagic fish stocks. Fisheries have responded to these ecological changes with their behavior and investments to cope with the increasing uncertainties in livelihood. This includes shifting from industrial-scale operations into more cost-beneficial artisanal units, but also the traditional fishermen having deployed more efficient gear and motorized boats in order to secure their yields.

The study compiles the comprehensive hydrophysical, biological and fishery-related research conducted by an international intervention on the lake during 1992-2001. Conclusions are made on the utilization of the scientific knowledge in establishing a lake-wide fisheries management strategy that aims at ecological, economic, socio-economic and institutional sustainability in the development of the sector. It is recommended that the systematic monitoring of the environment, target fish populations and fisheries be combined with gathering informal information about the target societies, thus providing a multi-disciplinary reference basis for management decisions. Though ideal as the operational model, the management in partnership between the various stakeholder groups still requires substantial rethinking amongst the decision makers and reallocation of the resources in the institutions. Enhanced communication between the parties at the lake side, from the field to the central administration, and from the region to the international scientific community, is another challenge for making the scientific advice more useful in the process. Alternative measures are examined to promote good governance in fisheries management.

Universal Decimal Classification: 639.2(282.263.5), 799.1, 556.55, 574.62, 005.93, 658

CAB Thesaurus: Lake Tanganyika; fisheries; fishing; fishermen; management; fishery management; stocks; catch composition; ecosystems; assessment; research; environmental assessment; biodiversity; fishes; biology; limnology; sustainability; communication; administration; Burundi; Congo Democratic Republic; Tanzania; Zambia; Africa

ACKNOWLEDGEMENTS

This study was carried out in the Institute of Applied Biotechnology of the University of Kuopio and at Lake Tanganyika in the heart of East Africa. The core work was undertaken during the FAO-executed project 'Research for the Management of the Fisheries on Lake Tanganyika' (GCP/RAF/271/FIN) which was funded mainly by the Ministry for Foreign Affairs of Finland (MFA; the development agency was previously known as Finnida) and the Arab Gulf Programme for United Nations Development Organizations (AGFUND) in addition to the four lake-side nations, Burundi, D.R. Congo (former Zaïre), Tanzania and Zambia. This allocation for the fisheries research and development was exceptionally large and laid the ground for international networking between North and South and the establishment of a pool of expertise not only in Kuopio but also in several other universities and research institutes in Finland. The project in a way opened a new era for student and staff exchange in this field, and started conference services and scientific cooperation that are still continuing, which today have reached entirely new levels by using wireless communication .

The MFA named the project a model development project in 1993, Kuopio University awarded the research project with a prize in 1999, and the individual scientists in the project have received grants too numerous to be mentioned here.

First of all I wish to express my warmest thanks and appreciation to my supervisor, Professor Ossi V. Lindqvist, my dearest colleague and friend, for inviting me to the spectacular world of Africa and for the opportunities to work along with him throughout all these years in the fascinating circumstances and occasions on Lake Tanganyika. From the very beginning he introduced me to novel thoughts in fisheries science and also to the need for common sense and realism when dealing with an African context. I'll never forget the moments of excitement, fear, achievements and joy we have shared during the darkest nights at the lake or amongst the happiest, laughing African friends under the hot sun. Enjoying the best company and his intercultural, scientific and social skills, we started the world tour together, an endeavor that never has stopped.

My second scientific supervisor, Professor Jouko Sarvala, also my colleague and closest friend, has always kept me busy and updated with the latest scientific findings, many of which were completed by himself, and through his tireless, exact scientific work in limnology and fishery. There are many unforgettable moments, personal and cultural, that we still keep on compiling together in Africa or elsewhere, often through culinary fish experiences.

I belonged to the scientific advisory team of the Tanganyika project, which was a unique, international and multi-disciplinary intervention, which was practically executed by more than 120 scientists, technicians, administrators and supporting staff from 16 different nations. Therefore it is impossible to mention all these persons by name but I wish to acknowledge the local supervision of the demanding, tedious and often dangerous field work by Mr. S. Badende, Mr. D. Chitamwebwa, Mr. R. Kanyaru, Mr. N. Mulimbwa, Mr. L. Mwape and Mr. H. Phiri, the officers-in-charge of the four field stations. Without this continuous support and the technical assistance of your personnel, we never could have made this happen.

The Finnish scientific sub-component leaders, Dr. Jouko Sarvala, Dr. Timo Huttula, Dr. Kalevi Salonen, Dr. Eero Aro, Dr. Ilppo Vuorinen, Dr. Jussi Parkkinen, Dr. Liisa Kuusipalo, and the FAO field personnel, Mr. Eric Coenen, Dr. Piero Mannini, Dr. Pierre-Denis Plisnier and many others all conducted professionally their own particular field of research in the project. Mr. Pekka Kotilainen and Ms. Heini Kurki, Associate Professional Officers, were our reliable local Finnish counterparts and links to the field. They also were crucial in providing shelter and guidance when we took the Finnish university students to the limnology and fishery field courses to 'darkest Africa'.

Given the heavy administrative load of the project, the professional work done by Mr. Mike Mann, Mr. Mike Doeff, Mr. Dora Blessich, and many others at FAO/Head Quarters in Rome or in Accra was absolutely necessary and is also acknowledged. Exchanging views and opinions with Dr. Eric Reynolds at FAO became of vital importance when the work was reaching its final shape. Dr. Heimo Mikkola, FAO Res. rep., also joined me during the early phases of the project and showed me some unforgettable scenes on Lake Malawi.

Dr. George Hanek, the Project Coordinator, the famous character of FAO, kept the threads of the entire 'circus' (as you called it), often turbulent, impossible and stressing, in his strong hands, and guided it through years full of civil conflicts, unrest but also positive development in the region. We decided together to keep the project running while watching the fishermen in Bujumbura moving to their night work and turning their tillay lamps on at their lift-nets, hoping for food for their families, regardless of the violence and unrest around.

In Kuopio, a long way from the project field operations, the home office was efficiently run by Ms. Soile Nuutinen, Ms. Karin Koivisto and Ms. Marjut Hilska, who have also left their hearts in Africa – the club of savannah lovers is growing. I also appreciate the continuous support and understanding of the departmental personnel and colleagues, the late Prof. Mikko Harri, Prof. Atte von Wright, Ms. Anja Nuutinen and Ms. Marketta Lämsä, during these years, and during my occasional absences from teaching and administrative duties due to frequent travelling.

My sincerest and warmest thanks go to my family, Terttu my wife, and the children Matti, Reetta and Tiia-Mari (including the faithful dog 'Iisa') for their never-ending support of my long-term engagement in fisheries research in Africa. You never tried to prevent me from disappearing 'somewhere in the middle of nowhere' often for several weeks without any means of communicating. Your encouraging support in this long-term process was essential. I always carried your pictures with me and when returning tried to bring you a piece of my enormous experiences in the form of gifts and as endless stories.

Kuopio, September 2008

ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
AGFUND	Arab Gulf Programme for United Nations Development Organizations
CCRF	Code of Conduct for Responsible Fisheries
CIFA	Committee of Inland Fisheries of Africa
CPUE	Catch per Unit Effort
CRDFA	Fishermen Association at Central River Division
CTD	Conductivity Temperature Depth
DRC	Democratic Republic of Congo
FAO/UN	Food and Agriculture Organization/United Nations
FFMP	Framework for Fisheries Management Plan
LCFZ	Local Community Fisheries Zones
LFC	Local Fishery Council
LTBP	Lake Tanganyika Biodiversity Project
LME	Large Marine Ecosystem
LTA	Lake Tanganyika Authority
LTR	Lake Tanganyika Research
MPA	Marine Protected Area
MCS	Monitoring, Control and Surveillance
MSVPA	Multi-species Virtual Population Analysis
MSY	Maximum Sustainable Yield
PRODAP	Lake Tanganyika Integrated Regional Development Programme
TAC	Total Allowable Catch
VPA	Virtual Population Analysis
Y/R	Yield –per- recruitment

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following papers, referred to in the text by Roman numerals:

I Lindqvist, O.V. & H. Mölsä, 1992. Management of small-scale fisheries: is it possible? In: Tvedten, I. & B. Hersoug (eds.) Fishing for Development. The Scandinavian Institute of African Studies, 191- 207.

.**II** Mölsä, H., Reynolds, J.E., Coenen, E.J. & O.V. Lindqvist, 1999. Fisheries research towards resource management on Lake Tanganyika. *Hydrobiologia* 407: 1-24.

III Sarvala, J. Salonen, K., Järvinen M., Aro, E., Huttula, T., Kotilainen, P., Kurki, H., Langenberg, V., Mannini, P., Peltonen, A., Plisnier, P.-D., Vuorinen, I., Mölsä, H. & O.V. Lindqvist, 1999. Trophic structure of Lake Tanganyika: Carbon flows in the pelagic food web. *Hydrobiologia* 407: 149-173.

IV Sarvala, J., Tarvainen, M., Salonen K. & H. Mölsä, 2002. Pelagic food web as the basis of fisheries in Lake Tanganyika: a bioenergetic modeling analysis. *Aquatic Ecosystem Health & Management* 5: 283-292.

V Mölsä, H., Sarvala, J., Badende, S., Chitamwebwa, D., Kanyaru, R., Mulimbwa, N. & L. Mwape, 2002. Ecosystem monitoring in the development of sustainable fisheries in Lake Tanganyika. *Aquatic Ecosystem Health & Management* 5: 267-281.

VI Reynolds, E., Mölsä, H. & O.V. Lindqvist, 2002. A future fraught: precautionary, participatory, and regional outlooks for the fisheries of Lake Tanganyika. In: Keheb, K. & M-T. Sarch (eds.) On the management of the inland fisheries of Africa. Fountain Publishers, Heinemann & Currey. pp. 107-141.

1. INTRODUCTION....13
1.1 Setting the objectives 13
1.2 Materials and separate publications....16
2. FISHERIES CHARACTERISTICS....18
3. LAKE TANGANYIKA RESEARCH INITIATIVE....20
3.1 Background....20
3.2 Design and methodology of the LTR project....20
3.2 Project implementation....24
4. CHALLENGES FOR FISHERIES MANAGEMENT....26
5. RESEARCH TO PROMOTE FISHERIES MANAGEMENT....29
5.1 Trophic structure and ecosystem modelling....29
5.2 Catch trends....34
5.3 Protecting biodiversity....37
5.4 Socio-economic patterns....40
6. FORMULATION OF MANAGEMENT STRATEGY....44
6.1 Ecosystem management and measures....44
6.2 Management structures and operation models....47
6.3 Management by governmental authorities....48
6.4 Management in Partnership....52
7. CONCLUDING REMARKS....55
7.1 Adaptive strategies on Lake Tanganyika....55
7.2 Precautionary principle....56
7.3 Good governance in fisheries development....58
8. REFERENCES....60

APPENDIX: ORIGINAL PUBLICATIONS

1. INTRODUCTION

1.1 Setting the objectives

Lake Tanganyika resources play a vital role in the economy of East Africa and particularly in the four riparian countries, Burundi, Democratic Republic of Congo (former Zaïre), Tanzania and Zambia. More than 44,000 fishermen with about 19,000 operational fishing vessels are engaged directly in fishing, and about ten million people in the catchment and trade area utilise the fish products as their primary source of animal protein (Paffen *et al*., 1997). Annual catch varies in the range of 165,000 to 200,000 tonnes of fish, showing a slightly decreasing trend, whereas the human populations in the lake-side countries are clearly increasing, with an annual rate of 1.6 – 3.6% (estimated in 2007, CIA The World Fact Book). These opposite trends and the problems found in other food production sectors of agriculture due to civil unrest, social conflicts, and environmental degradation in the region have clearly increased the pressure on the fishery resources in the lake.

Since ancient times fishing activities have made a substantial contribution to peoples' food security, nutrition and family economy in the villages scattered along the coast line of the lake (Coulter, 1991). The lake itself, with its large dimensions (max. length 673 km; width 40 km; max. depth 1,470 km) is a crucial route of transportation for freight and people within and between the riparian countries.

The fishing communities around the lake include a large variety of cultural dimensions, national and regional features and local societies, which create a complex, dynamic entity. Today traditional units (gillnets, longlines and scoop nets) together with non-motorized artisanal units (liftnets and beach seines) supply more than 90% of the annual fish yields. Villages around almost 790 landing sites are far from the governmental social and health services due to the remote location and poor communication. In the course of modernisation since the 1950's, the so-called advanced artisanal fishermen, mostly lift-net fishers, have taken the leading role business-wise with more efficient gear and the use of engines. The average efficiency of a single artisanal unit increased drastically from 3 tonnes yr^{-1} up to an overall average of 14 tonnes yr^{-1} in the 1990's. This has also resulted in a wider coverage of the operations of these motorized groups than by the traditional groups. Thus bigger catches, usually as dried products (a sardine-type fish known locally as *kapenta*, *dagaa*), are taken in large quantities to distant major cities, which unites the lake-side communities with national and even international trade and commerce. This means one part of the fishermen societies has become better off compared with those doing fishing only for subsistence or people in other agriculture sectors.

Moving the industrial units, mostly purse seiners, from the Northern part of the Lake (Burundi, DRC) towards the South (Zambia), or the entire decommissioning of these groups, is another major change which has taken place in Lake Tanganyika. Consequently the contribution by artisanal units to the total production has increased drastically at the cost of both traditional and industrial sectors.

Despite their significant local social and economic importance, lake fisheries in general and those in remote Lake Tanganyika in particular are still secondary in executing the national policy of the four countries. For example, in Tanzania marine fisheries or Lake Victoria fisheries are considered to be more advantageous in terms of export potential and foreign earnings. Consequently, a chronic shortage of finance and personnel in responsible fisheries research and administrative bodies is apparent here and similarly in all four countries, which substantially affects the fisheries' management operations in this remote region.

Besides fisheries, Lake Tanganyika is also known for its vast biological diversity and endemic fauna, making the lake a world heritage. Therefore, ever increasing awareness is needed to address environmental threats and human-borne risks such as pollution, erosion, uncontrolled land use, over-exploitation of fish resources, and loss of biodiversity (Cohen, et al., 1993). Recently, climate change was claimed to have affected the lake productivity and thus also the fishery (O'Reilly *et al*., 2003).

This thesis outlines first the development that has taken place in the Lake Tanganyika fisheries during the 20th century and analyses the recent state of fisheries (fisheries sub-sectors, types, and yields are described in detail in publications II, V, VI).

The thesis deals particularly with the concept of fisheries management on Lake Tanganyika and surveys and evaluates the alternative methodologies of managing the fisheries resources and the entire fishery relying on these resources.

The current management challenges are outlined in detail in publications I, II, V, VI. When considering the targets for fisheries management, instead of merely the fish resources, the holistic ecosystem approach is emphasized and the complex dynamic linkages between the biological and human features are revealed.

The summary here regards insufficient management capacity, poor organisation and weak institutional processes as the primary managerial problems in fisheries on Lake Tanganyika. For these reasons, the open-access - common property paradigm is the prevailing basic feature and has resulted in ecological, economic and social conflicts in the sector.

Various stakeholder groups have different economic and socio-economic perceptions of future returns out of the fishing. Fishing for subsistence and for income generation may have different impacts on the stock and hence the needs for conservation and regulative measures also differ. Not only the need for management but also the capacity to get engaged in the management decision making varies a lot between the communities. The contribution in the process is a matter of capacity amongst the

fishermen groups and brings us to the question of poverty, ethics, democracy and rights of fishing, all of which are unevenly distributed.

The sustainable development of fisheries and viable operations are, however, common objectives to all fisher groups regardless of their level of investments and respective outputs. The concept of sustainability with all ecological, economic, social and institutional implications is discussed here. The four principal components of sustainability are distinguished (II, according to Charles, 1994), i.e. the ecological, socio-economic, community and institutional sustainability.

Similarly, when considering the management measures and attempts to promote the sustainable development of the fisheries, different capacities, cultures and community regulations need to be addressed.

The thesis pays special attention to the organisational structures and leadership in management, which may be either *authority driven* or *community driven*, or as is increasingly preferred today, a combination of the two, i.e. *Management in Partnership*. In the latter, each partner's role is defined and the responsibilities shared, making it both challenging and interesting.

The basic question of the thesis is, what management measures are applicable to develop Lake Tanganyika fisheries when considering the management objectives and the management capacity available. Three organisational models that differ in their degree of participation are reviewed. The thesis makes reference to the Framework Fisheries Management Plan (hereafter FFMP, Reynolds *et al.,* 1999; II, V) as the ultimate outcome of the Lake Tanganyika Research Project (hereafter LTR, officially Research for the Management of the Fisheries on Lake Tanganyika, GCP/RAF/271/FIN; executed by the Food and Agriculture Organization (FAO) of the UN during 1992-2001 (II). An important contribution was also received from FAO FISHCODE project in preparing the FFMP.

The LTR Project aimed at providing a scientific basis to the regional management plan for the development of pelagic fisheries shared by four riparian countries. Therefore, a multipurpose Scientific Programme was designed and implemented in 1992-1999 in order to assess the physical and biological mechanisms that regulate and control the fish production of the Lake. I worked as the Deputy Scientific Coordinator of the project and contributed to the establishment of the management plan. The thesis summarises the findings of the Scientific Programme (Lindqvist *et al.*, 1999; II, III; VI) and in particular addresses the implications of the scientific research for the overall fisheries development strategy in the region. The work utilises the results of each project sub-work in limnology, fish biology, ecosystem modelling, catch statistics and socio-economics in the sense of assessing their value in designing the management options rather than using them as individual empirical studies.

The role of scientific advice in the management process has been intuitively understood, but the type of research found relevant has varied through the decades (Welcomme, 2001; Cunningham & Bostock, 2007). The evolution of management science is reviewed through examples of recent trials, successes or failures, in order to elaborate the experiences and intuitively circumstances on Lake Tanganyika which might share similarities and analogous features with other African Great Lakes.

As one of the starting points, the principle of the Code of Conduct for Responsible Fisheries (hereafter *Code*, FAO, 1995; 1996) will be discussed. This guideline emphasises the ecosystem perspective (Gislason *et al*., 2000; Rosenberg *et al*., 2000), precautionary principles (e.g. Lane & Stephenson, 1999; Weeks & Berkeley, 2000), and the stakeholders' own participation (co-management, participatory approach, community based arrangements, etc.) in the decision making in regard to resource conservation and management.

Thus, fisheries management on Lake Tanganyika is seen as a great challenge both for the research and for the fisheries communities themselves either as the target groups or as the key players.

1.2 Materials and separate publications

Original publications and personal contribution

I Lindqvist, O.V. & H. **Mölsä,** 1992. Management of small-scale fisheries: is it possible? In: Tvedten, I. & B. Hersoug (eds.) Fishing for Development. The Scandinavian Institute of African Studies, 191- 207.

Publication I (authors participated equally in the writing) discusses the possibilities of addressing the particular problems in small-scale fisheries which are dominant on Tanganyika. Special reference is made to capacity building through training, which was the main responsibility of the author. Publication I sets, through a historical view, the theoretical grounds for the problem setting and methodology in further studies.

II **Mölsä, H.**, Reynolds, J.E., Coenen, E.J. & O.V. Lindqvist, 1999. Fisheries research towards resource management on Lake Tanganyika. *Hydrobiologia* 407: 1-24.

Publication II (first author; wrote the first draft and introduced the core idea of alternative management regimes) summarises both the prevailing status of the fishery and the needs and opportunities for its management on Tanganyika. It makes reference to major scientific biological and limnological works and the socio-

economic surveys of the LTR project. It provides a thorough review of the management theory that reflects the entire conclusion of the thesis.

III Sarvala, J. Salonen, K., Järvinen M., Aro, E., Huttula, T., Kotilainen, P., Kurki, H., Langenberg, V., Mannini, P., Peltonen, A., Plisnier, P.-D., Vuorinen, I., **Mölsä, H. &** O.V. Lindqvist, 1999. Trophic structure of Lake Tanganyika: Carbon flows in the pelagic food web. *Hydrobiologia* 407: 149-173.

IV Sarvala, J., Tarvainen, M., Salonen K. & **H. Mölsä,** 2002. Pelagic food web as the basis of fisheries in Lake Tanganyika: a bioenergetic modeling analysis. *Aquatic Ecosystem Health & Management* 5: 283-292.

Publications III and IV (author as the deputy scientific coordinator; secured funding for the research; organised the field work; commented on the draft manuscripts) are examples of the reported ecosystem syntheses in the LTR project, given in order to outline the energy pathways and food-web interactions affecting the fish productivity. These models provide tools for understanding the ecological basis of the fish production of Tanganyika and they assess the possible impacts of environmental factors and human-borne operations on the lake productivity.

V **Mölsä, H.**, Sarvala, J., Badende, S., Chitamwebwa, D., Kanyaru, R., Mulimbwa, N. & L. Mwape, 2002. Ecosystem monitoring in the development of sustainable fisheries in Lake Tanganyika. *Aquatic Ecosystem Health & Management* 5: 267-281.

Publication V (first author; wrote the first draft manuscript; organised and managed the field monitoring and data collation) compiles the key statistics of the fisheries and trends including the results of national fisheries monitoring. It underlines the need for regular long-term data collection to provide fisheries authorities with facts about fish stocks, catch, and possible impacts of fishing on the resources.

VI Reynolds, E., **Mölsä, H.** & O.V. Lindqvist, 2002. A future fraught: precautionary, participatory, and regional outlooks for the fisheries of Lake Tanganyika. In: Keheb, K. & M-T. Sarch (eds.) On the management of the inland fisheries of Africa. Fountain Publishers, Heinemann & Currey. pp. 107-141

Publication VI (co-author for correspondence together with ER; wrote the first draft manuscript) is a comprehensive analysis of the precautionary, participatory and regional outlooks for the fisheries on Lake Tanganyika, with detailed comparison of the problems in particular fisheries sub-sectors and opportunities to address these problems.

2. FISHERIES CHARACTERISTICS

Fisheries on Lake Tanganyika are generally classified into three types according to their gear, equipment and economic scale: the 'traditional', 'artisanal' and 'industrial' sub-sectors, but today the definitions are becoming subjective because all groups are selling part of their catch if they obtain an excess for their subsistence and are using the income for their social and economic well-being (for detailed descriptions see II, V).

Lake Tanganyika resources, fish, water and route for transportation have been historically shared by village dwellers on the immediate lake basin in Burundi, Tanzania, Zambia and Democratic Republic of Congo (DRC). Since ancient times, fish from the lake has played a significant role in providing primarily livelihood and subsistence for these people. Fishing populations live in scattered villages or in temporary camps on the rather narrow piece of land between mountainous slopes and the lake shore. In many regions, fishing activities are performed seasonally and interrupted by farming activities, particularly during rainy seasons. Cash generation has been only a secondary aim but has developed into substantial commercial fishery in the last few decades (Coulter, 1991; Coenen, 1995; II, V).

The 'traditional' fishery was prosecuted in waters close to the shore. The canoes were small and the range of fishing covered only inshore, targeting the immature stocks of clupeids. This type of fishery has, historically, been based on the use of lusenga or scoop nets and light attraction (formerly with flares made of bundled cane, now with lamps) for the harvest of clupeids, and gillnets, long lines, hand lines, traps, spears, and poisons for the capture of demersal species (V).

The natural increase in fishing pressure and yield to respond to the increased need for fish as a stable food was followed by a rapid expansion of catches due to technological advances in gear design and efficiency in the 1950s-60s (Coulter, 1991; Coenen *et al*., 1998). That was the advent of 'artisanal' and 'industrial' fishery and the introduction of lift nets, purse seiners and long distance fleets to harvest the open water clupeid and *Lates* stocks that were seemingly under-exploited during that time.

The small-scale subsistence fishermen with their traditional gear had first to accept the arrival of the more efficient 'artisanal' units, e.g. beach seines, the catamaran-type lift nets, '*chiromila'* seines (ring nets) (Tanzania) and Apollo lift-nets (Burundi, Zaïre), which were able to produce increased amounts of fish for the markets. The artisanal fishery has grown immensely since the late 1950s, when the technique of liftnetting from catamaran rigs was first introduced in the northern portion of the lake. Liftnet units are equipped with 4 to 8 pressure lamps and operated by a four to six person team. The level of motorisation (outboard engines) for the overall fleet of

small craft on the lake remained low, at something less than 10%. The use of engines is restricted almost entirely to artisanal units (V).

'Industrial' fishing units consist of a large (16-20m) diesel-powered steel main vessel, a smaller net-setting vessel, and three or more light boats, all requiring a crew of 20 to 40 persons. The industrial fishery goes back to the mid-1950s, when Greek nationals introduced purse seining in Burundian waters. Purse seine units operated from larger ports throughout the lake in subsequent years, but are now concentrated in the southern portion due to excess capacity with regard to the yields and unit catches, as shown recently (II; V).

3. LAKE TANGANYIKA RESEARCH INITIATIVE

3.1 Background

After the termination of numerous national projects on Lake Tanganyika in the 1960-70s (mostly supported by the UN/FAO), only occasional efforts were made to compile statistical information in each country. Likewise, there were no straight-forward attempts to enhance the regional collaboration between the managerial bodies in the region, despite the many common problems. It became obvious that rapid changes in the abundance of pelagic stocks were due to extensive movements over the entire lake, which could not be effectively appraised by national projects confined to territorial waters, so a regional approach to resource assessment and management was required (Dunn & Hyytinen, 1987).

The four nations, Burundi, Tanzania, Zambia and Zaïre sharing the Lake Tanganyika territories and fishery resources, took the initiative to facilitate regional management plans as an international project to support fisheries development. Stagnating yields and declining unit catches in industrial fishery and the risk of over-exploitation caused common concern amongst the authorities and gave rise to these attempts. The first indications of environmental degradation and pollution were also seen, due to increased population size, intensified agriculture practices, and industrial and urban influences nearby the large towns. The first initiatives finally resulted in the Lake Tanganyika Research Project (GCP/RAF/271/FIN), funded by Finland and by Arab Gulf Programme for United Nations Development Organizations (AGFUND), and executed by the UN/FAO.

3.2 Design and methodology of the LTR project

Project objectives

The LTR project aimed at developing and testing a methodology for the scientific advice to promote fisheries development on Lake Tanganyika. Novel ideas in biological research and field methodology as well as in fisheries management were applied and are reported in this thesis. Rather than assessing merely the production level, the mechanisms of regulating the lake production dynamics were chosen primarily as the study objectives in the scientific programme. The role of physical and climatic factors, food web interactions, as well as the spatial and temporal fluctuations were of major concern in the plan that was designed to assess the current state of the pelagic fishery resources, their production dynamics and vulnerability to the fishing effort which was reported to be increasing. The programme was designed to provide the future regional fisheries management plan with an ecological basis and concrete answers to the questions where, when and by which

gear the pelagic fishery of Lake Tanganyika could be developed in a sustainable way (Lindqvist & Mikkola, 1989; Mikkola & Lindqvist, 1989; II).

The classic overview of the Lake Tanganyika ecosystem by Coulter (1991) and the respective summaries of geology, hydrodynamics, nutrient regime, pelagic ecosystem as well as fish and fisheries therein were used as primary sources of information and background for the scientific programme of the LTR. The early studies by Degens *et al*. (1971), Ferro (1975), Craig *et al*. (1974), Hecky & Kling (1981), and Coulter & Spigel (1991) had already shown the importance of large-scale climatic factors and hydrodynamic events in regulating and controlling the limnological phenomena and the subsequent biological production in the pelagic zone of the Lake Tanganyika. The major upwelling in Mpulungu area had been clearly reported.

The study was designed in the first place to shed light on the production patterns of the pelagic ecosystem where the role of physical forces, wind, upwelling and vertical mixing seemingly play a substantial role. Secondly, the studies of predator to prey relationships between planktivorous fish and zooplankton, and daily vertical migration of the prey community as the main antipredatory behavioural strategy were emphasised. Studies on population dynamics and life-histories of the dominant fish species were planned, and the possible discreteness of the sub-populations was to be assessed by population genetic studies. Assessment of biomass distribution and composition was to be made by lake-wide hydroacoustic and trawl surveys. The project also focused on collation of the fishery statistics and historical data, and harmonisation of the fishery statistics was one of the objectives (cf. Lindqvist & Mikkola, 1978, II; III).

Lake Tanganyika as a unit

The lake was considered as one integral unit where the fishery and other aquatic resources are shared by the four riparian nations. Therefore, the research was planned to serve the needs of establishing a common and lake-wide management policy and strategy for these countries. This was exceptional because all the earlier attempts to assess the fishery status, stock sizes or catch composition through hydroacoustic surveys or catch syrveys and the related studies on limnology and fish biology were conducted on a local basis although they were called regional projects (FAO projects in the 1960-70s in Zambia; in the 1970's in Burundi; since 1972 in Tanzania). Consequently, some biases have occurred in the overall picture of the ecosystem function and productivity of Tanganyika which also resulted in precautionary strategies within fisheries management (Coulter, 1991).

Increased pressure on fish stocks and the first signs of large *Lates* species becoming scarce in the catch had led to, in all riparian countries, the need to initiate lake-wise systematic studies of the target stocks, and of fish productivity, biomass, distribution, movements and dynamics (Coulter, 1991).

New approaches adopted

The objective setting in fisheries management took place in a novel way by choosing the multi-disciplinary development of the entire sector as the ultimate goal. Conventionally, the objective for fisheries management has been, as it was also on Lake Tanganyika, just to maintain the prevailing yield by preventing resource deterioration and decline (Walters, 1986). Concern for the state of the fish stocks led to the dominance in fishery management and administration of a great "conservation" attitude (Charles, 1992). This view of "balance of nature" and limited fish resources has, in a remarkable way, affected both the development of the managerial concept as a whole and the related research strategy. Therefore, the need to assess the current stock sizes and study the populations of the target species as the main part of management procedure has supported the dominant role of the biological scientists in the process, regardless of human-oriented fishery objectives in economic management (Charles, 1994).

As remarked by Allison (2002), sustainable development and therefore management for sustainability can be defined in numerous ways, with different emphases on economics, ecology, sociology and a composite of these. However, most management strategies are implicitly linked to the concept of a fixed stable environment-carrying capacity, an idea that is in itself problematic in both ecology and human demography (Pickett *et al*., 1997; Cohen, 1995).

The MSY (Maximum Sustainable Yield) and TAC (Total Allowable Catch) models are examples of the most static but also the most widely used applications. They rely largely on Beverton & Holt (1957), who introduced the yield-per-recruitment (Y/R) philosophy and the term of catch per unit effort (CPUE), as demonstrated with the data for North Sea haddock. The model has led to the concept of optimal 'eumetric' fishery management linked with virtual population analysis (VPA, e.g. Gulland, 1965), and catchability (e.g. Paloheimo and Dickie, 1964). Another type of yield model is the descriptive surplus-production model by Schaefer (1954).

With special reference to tropical conditions, Pauly (1998a) underlined the numerous problems in assessing the growth and mortality parameters in tropical fish populations as well as in gear selectivity, which are all key factors in the Y/R models. Also, he stated the necessity to extend the Y/R approach from its original single-species level to multi-species circumstances, and finally the ecosystem approach derived from the initial Beverton & Holt's work. In consequence, Pauly (1998a) together with Pauly (1998b) and Walters *et al*., (1997) introduced the so-called mass-balance trophic models of aquatic ecosystems, e.g. Ecopath (Christensen & Pauly, 1993). The models have proven their utility also in the tropics by including the possibility to apply multi-species virtual population analysis (MSVPA) as one of the key concepts of Beverton & Holt (1957).

When considering the management implications of the population models, Beverton (1998) still stressed the primary concern of regulation of fishing mortality rate, and hence, fishing effort, and underlined the control of effort as the ultimate objective of fishery management. This was, however, not what happened: the control of catches became a common goal, and consequently setting the catch quota, or total allowable catch quota (TAC), has been used as the primary goal in fishery development, both in short and long terms. Such a catch and stock-assessment driven approach has dominated the management of global fishery until today, regardless of numerous examples of consequent stock depletions, collapses, lost biodiversity and low economic returns (Rosenberg *et al.*, 1993; Roughgarden & Smith, 1999; Castilla & Defeo, 2005). Bundy *et al.*, (2008) have recently claimed the dismal state of the world's fisheries is due not to a lack of scientific information but to the way ecosystems are viewed. Regardless of encouraging shift toward multidisciplinary research, the ecosystem consists, according to the practical approach, of a biotic community (including humans) which interacts with the surrounding environment.

It has also been widely noted that the scientific advice has not been properly used in decision making due to weak links between the respective research and management bodies. The same situation has also prevailed on Lake Tanganyika. There, the overall lack of research and managerial resources has been severe in every riparian country. Academic fishery research has had practically no effect on the governmental fisheries administration, and mechanisms to transfer field observations or views to the central administration hardly exist in responsible institutes either. The complex nature and the dominant role of small-scale operators and traditional fishermen has made the management operations hard to perform, which is typical in most developing countries (I).

Conventional stock-assessment based studies were replaced with new approaches in the present study (II). Problem setting in fisheries studies and related limnology were exceptional when compared with many other cases world-wide, but was reasonable when developing tools for sound management practices (II, III, VI). The logistics and insufficient research capacities in the four riparian countries would have badly hampered the collection of data for the comprehensive stock size estimations. Also, the heterogeneity in the target fishing societies and the complicated biological dynamics were known, and therefore the traditional MSY and TAC models were not considered to be worth pursuing. These models were found to be non-practical and unsuitable for controlling or directing the current fishing effort. It was obvious that these models or related research would provide no concrete answers to any questions on the right moment or place of the fishing effort, nor help in forecasting the future.

The basic problem with the MSY concept is that it is a static one. Once the MSY level has been determined and the new fishing quota assessed, the fish population may have (and often has) shifted to another state, possibly resulting even in depensatory reactions and contributing to the gradual demise of the stock. The fishing effort itself often gives an on-time, though imperfect, indication of the state of the stock (cf. Lindqvist, 1977).

The models also neglect the significance of life-history adaptations and inter-specific relationships in multi-species stocks. One should note that the estimates of the standing stock or even production do not indicate directly the ecosystem's carrying capacity and resilience in the face of exploitation efforts. The real tolerance and vulnerability of fishing mortality is subject to the life-history characteristics of the fish populations and not just to the standing stock as such. The dominant pelagic fish species in Tanganyika (clupeids and *L. stappersii,* as distinct from the other *Lates* spp.) display the *r*-selected life-history strategy (Stearns, 1976) typified by features of high juvenile mortality, early maturity and recruitment to fishery, relatively short life cycle, and high turn-over rate. Such features are consistent with an adaptation towards non-predictable conditions and provide resistance to high fishing pressure (Adams 1980). High reproduction potential, multiple spawning, and migrations lead to regular recruitment and fast recovery after exposure to over-exploitation and highest actual yield and yield/ recruitment (Adams 1980; Armstrong & Shelton 1990; Fogerty *et al*. 1991; Jennings *et al*., 1998). Thus, the ecology of the dominant fish species on Lake Tanganyika today will bring to the system some additional 'resilience' to cope with varying fishing pressure, but needs to be quantified and regularly followed up.

3.2 Project implementation

To execute the scientific programme, substantial capacity building was necessary including upgrading/rebuilding a field station in each country. Stations were equipped with basic but modern limnology and fish biology devices (Uvira and Bujumbura stations partly shared these resources), and the research staff was trained to do the scientific work. More than 360 (including up to 70 local staff) researchers, technicians and administrators took part in these training occasions. The project built a research vessel (r/v *Tanganyika Explorer*) to conduct lake-wide hydroacoustic and midwater trawl surveys for fish stock assessment and limnology studies. A total of 20 surveys were conducted with integrated sampling of hydrodynamics, limnology, zooplankton, fish biology and fish genetics (Aro *&* Mannini, 1995; Mannini *et al*., 1996; Kurki *et al*., 1999; Szcucka, 1999; Kuusipalo, 1999). These studies also focused on seasonal and daily migrations, both horizontal and vertical, predator-prey relationships in pelagic communities, and overall distribution patterns and internal dynamics of food web components (Salonen *et al*., 1999; III).

Lake-wide modelling of hydrophysics was studied with data from automatic meteo-stations (onboard r/v Tanganyika *Explorer*, field stations), thermistor chains, water level recorders, and hydrodynamic measurements (ADCP current profilers, CTD sonde) during the cruises (Huttula, 1997; Podsetchine *et al*., 1999; Huttula *et al*., 2005). Satellite-borne remote sensing (NOAA AVHRR) was applied to measure the spatial and temporal variations of the surface water temperature (Tuomainen *et al*., 1998). Results were combined with the hydrodynamic modelling. Regular limnological studies covered the patterns of macronutrient and primary production dynamics and the physical phenomena (vertical mixing, upwelling, physical forcing) affecting the water chemistry and nutrient regime of the lake. In its areal and

seasonal coverage, the scientific programme was much more comprehensive than any of the earlier investigations. It was run entirely by the scientists and technicians of the four nations, led by the Project Coordinator in Bujumbura and other field personnel at the stations, and supervised by the Scientific Coordinator (University of Kuopio, Finland), and the sub-component leaders in Finland. The international Project Coordination Committee and the Scientific Coordination Committee took the overall responsibility for the project implementation and follow-up in each country.

The scientific programme of LTR had the following overall research objectives:

- To model the major hydrophysical and climatic factors that affect the functions, dynamics and production of the pelagic zone of Lake Tanganyika;
- To elucidate the trophic structure of the pelagic ecosystem to describe the nutrient and energy pathways to the pelagic fish community, trophic interactions within the food web, and horizontal and vertical movements of the pelagic communities including fish;
- To unravel the population biology and genetics of the three dominant target fish species in the pelagic fishery;
- To work out the development of the catch composition by nation, fishing type and gear, the trends in the unit catch, and dynamics of the dominant fish species.

The mid-term evaluation of the LTR Project (Roest & Salo, 1997) noted the success made in the physical and biological studies until then, but underlined the necessity of including socio-economic surveys in the programme to support the establishment of the regional Framework Fisheries Management Plan. In consequence, the following issues were included from 1997 onwards in the programme:

- Legal and institutional issues in the four riparian countries;
- Socio-economic surveys amongst the fishermen, fish processors and traders and assessment of the stake-holders' perceptions of fisheries problems and prospects, and their opinions of the proposed management measures, institutional set-ups and development attempts;
- Scientific reference basis for the Framework Fisheries Management Plan.

4. CHALLENGES FOR FISHERIES MANAGEMENT

The study aimed at providing the knowledge basis for the establishment of the Regional Fisheries Management Plan (II, III, VI; Reynolds, *et al.*, 1999). The main analysis of the present status of Lake Tanganyika fisheries is given, and the current problems and the respective fisheries-related effects are shown in table 1 (drawn mainly from VI and other LTR documentation). This assessment is then used as the reference when reviewing the main findings of the separate studies in hydro-physics, limnology, fish biology, catch statistics, and socio-economics, and evaluating their indicative value and implications for the fisheries management. Concluding remarks on the approach methodology and approach are then outlined in Chapter 5 of the thesis.

Publication VI summarizes the observations on the socio-economic and community welfare issues (Reynolds & Hanek, 1997; Reynolds, 1999 a; Magnet *et al.*, 2000; Meadows & Zwick, 2000; West, 2001) and describes the needs and challenges for the regional fisheries management, and are presented briefly as follows:

Fish supply and demand. The contribution of fish to the total animal protein supply within the four littoral states recently ranged from some 25% to 40% (Gréboval *et al.*, 1994), but the nutritional welfare role is becoming more and more difficult to sustain in the face of unremitting population growth across East-Central Africa (World Bank, 2008).

Resource access. The current open access regime is not sustainable in the long run because it leads to an increased pressure on the resource amounts.

Local empowerment. Although existing legislation in some cases provides for consultation between administrators and local representatives of fisher interests (Cacaud 1999), and although fisher committees exist at various landing sites (Reynolds & Hanek 1997), *de facto* local community participation in resource management decision-making and follow-up has been very minimal.

Equity. Prospects for developing modalities for sustainable management and conservation are clouded by widespread socio-economic inequalities. These include: a) relations between fishing unit owners and fish workers; b) gender-based differences; and c) relations between artisanal and traditional fishers on the one hand and the industrial fishing companies on the other.

Piracy. Incidents of piracy on the lake have increased alarmingly since the early 1990s, in association with political and economic chaos in the Congo, civil unrest in Burundi, population dislocations and refugee resettlement, and the widespread availability of sophisticated small arms obtained from war zones.

Further**,** the evaluation of the institutional and legal aspects of the Tanganyika fisheries summarised the major features and deficiencies (II):

Policy orientation. The four lacustrine states share a common policy orientation towards social welfare objectives, whilst recognising a requirement to secure sustainable resource use over the long term. At the same time, there is in all cases a basic lack of institutional means to achieve policy objectives.

Table 1. Causes and consequences of fisheries' development on pelagic fisheries of Lake Tanganyika since the 1950's (VI; data from various LTR and TREFIP documents).

Fisheries-related developments	**Fisheries-related effects**
Shift from traditional methods to artisanal lift netting and beach seining; industrial purse seining.	Overall average single unit efficiency increase from 3 to 14 t. yr^{-1} (Coenen, 1995).
Selective purse seining pressure on stocks of *L. mariae, L. microlepis,* and *L. angustifrons* (Coulter, 1970, 1991).	Stock reduction; simplified composition of commercial catch (two clupeids and *L. stappersii*) found today.
Retirement/withdrawal of industrial units from northern waters (competition from artisanal lift nets, civil strife, other factors). Migration to southern waters.	Zambian sector: 3 active units 15 years ago versus 30 now, almost exclusively targeting *L. stappersii* (Coenen *et al.*, 1998; Mannini, 1998).
Drop in CPUE (kg/boat/night), best documented for industrial operations during the early- to mid-1990s (Coenen *et al.*, 1998; van Zwieten *et al.*, 2002).	Burundi: from 166 kg to 111 kg; Zambia: 877 kg to 535 kg; DRC: from 780-950 kg (early 1990s) to 433 kg.
Increased duration of fishing trips for southern purse seiners (Coenen *et al.*, 1998; Mannini, 1998).	With progressive CPUE declines, indicates decrease of catchable stock, possible over-exploitation of *L. stappersii* owing to uncontrolled growth of the industrial fishery.
High juvenile content in northern catches of *L. stappersii*, lower proportions of *L. stappersii* in overall catches.	Signals possible excess fishing pressure on *L. stappersii* in north (Mannini, 1998).
High juvenile content in northern catches of *S. tanganicae*.	Signals possible over fishing of *S. tanganicae* stocks in north (Mannini, 1998; Mulimbwa, 2006).
Extensive use of unselective beach seines.	Destructive to juvenile *L. miodon* (shallow, inshore nursery grounds); also to cichlid community (Mannini, 1998).
General growth of small craft fleet from ca. 12,800 units in 1980s (Coulter, 1991) to ca. 18,000 units in 1990s (Paffen *et al.,* 1997). Increased effort directed at inshore demersal fishery, marked especially by extensive use of gillnets.	A collapse or serious decline of the inshore fishery would likely lead to transfer of effort to the pelagic fishery, and vice versa, with attendant complications (cf. Lindley, 2000).
High human population growth rates (2.5 – 4.3%) within the lake basin and expansion of land clearance for settlement and cultivation (World Bank, 2008; West, 2001).	Population doubling times of between 17 to 30 years; increased demand for fish, and recruitment of newcomers to employment in the harvest and post-harvest sectors; environmental degradation and fish habitat effects.
Increased demand for fuelwood supplies for fish smoking operations (Reynolds & Mölsä, 2000).	Environmental degradation; localised erosion and siltation of influent streams, near shore waters.

Budget shortfalls. Chronic under-funding seriously cripples the performance of national fisheries departments and research agencies. Departments are unable to provide adequate extension or monitoring, control, and surveillance (MCS) services. National fisheries researchers are hard-pressed to fulfil their roles as management and conservation technical advisers, and rely to a great extent on outside sources of funding.

Harmonisation of legislative frameworks. A consistent set of regulations needs to be developed for the management of stocks that are in reality unitary populations, not territorially divided sub-groups. Fisheries law derives from colonial-era decrees in some cases, and there is a general need for update and overhaul.

Regional management co-ordination. The CIFA Committee for Lake Tanganyika serves as a forum for technical discussions between the four states on the management of the fisheries. It is constituted as a consultative rather than executive body, however, and meets only once every two years. Although all four states are involved in the Committee, none of them provides legislative authority for participation in a fully-fledged regional management authority.

Enforcement and compliance. Regulations are widely ignored in practice, since they are either insufficiently enforced or not enforced at all. Co-management arrangements, through which local stakeholders would play an active role in regulatory decision-making and compliance assurance, have not been strong features of the 'top-down' institutional culture of national fisheries authorities.

Thus, the study deals with the concept of the sustainability on four levels as distinguished by Charles (1994):

- Ecological sustainability – maintenance of the resource base so as not to foreclose future options for its use;
- Socio-economic sustainability – the maintenance of livelihood-related benefits from the resource, for those who depend on it;
- Community sustainability – the ability of the groups of people to maintain social structures that enable equitable sharing of livelihood benefits from resource use;
- Institutional sustainability – the maintenance of suitable financial, administrative and organizational capability in the long term.

5. RESEARCH TO PROMOTE FISHERIES MANAGEMENT

5.1 Trophic structure and ecosystem modelling

Assumptions

According to the studies before the LTR Project, there has been some kind of discrepancy between the primary production and fish yields in the pelagial so that the observed yields were higher than expected (Hecky & Fee, 1981; Coulter, 1991). Therefore, it was supposed that the energy transfer through the pelagic food webs was more efficient than elsewhere, or alternative sources of energy would be available, e.g. through microbial loops which had not been studied before (Hecky, 1991).

A multi-disciplinary ecosystem analysis was made through a comprehensive co-ordinated scientific programme under an international supervision (II; III). The structure of the pelagic food-web was assessed not in order to estimate the catchable standing stock of fish but to analyse the mechanisms regulating the biological productivity, including fish. Thus, the ecosystem was studied in the widest sense, including hydro-physical regimes, energy pathways, food-web interactions and relationships between the biological community and human society. While underlining the dynamic patterns in the research, one assumed that the results would also best benefit the adaptive methodology and problem-oriented strategies in management of the fisheries, which were known to be complex and dynamic.

Studies and methodology

Data for the ecosystem assessments were collected by the intensive field sampling programme and on the multi-purpose cruises on r/v *Tanganyika Explorer* (III). The results were summarised as the scientific synthesis (Lindqvist *et al*., 1999) and in a large archive of sub-projects' reports and publications. (For the 100 technical documents, see http://www.fao.org/fi/ltr/index.htm). The project resulted in a hydrodynamic model of thermal regimes and flows (Huttula, 1997; Podsetchine *et al*., 1999, etc.), which provides a means of studying the water upwelling and mixing phenomena as well as the horizontal distribution of the biological components in the pelagic zone. Studies of primary production patterns (Salonen *et al*., 1999) and zooplankton communities shed light on their seasonality (Kurki, 1998), the bathymetric and areal movements (Kurki, 1998, Kurki *et al*., 1999; Vuorinen *et al*., 1999), and the production rate (III). Fish biology studies on two clupeids and *L. stappersii* revealed the population biology (Mannini, 1998), stock abundance and distribution (Szczucka, 1998), genetic discreteness (Kuusipalo, 1999), and finally the P/B ratios based on the trawl and hydroacoustic data (Mannini, 1998), and otolith readings (Ahonen, 2001). The final conclusions on the fish production potential and

in fact on the entire pelagic food web were based on the carbon-energy pathway calculation (III) that summarises to large extent the entire LTR biological data.

To complete the food web analyses, stable isotope analyses were initiated on Lake Tanganyika too (Sarvala *et al*., 2003). These studies reveal the food web structure in lake ecosystems in a dynamic way, because differences in the ratio of natural nitrogen and carbon isotopes ($\delta^{15}N$ and $\delta^{13}C$) between organisms indicate their feeding patterns and trophic relationships (Cabana & Rasmussen, 1996; Peterson & Fry, 1987). Pauly *et al*. (2000) studied trophic cascading effects in marine food webs. Bootsma *et al*., (1996) and Genner *et al*., (1999) studied the trophic dynamics in Lake Malawi, and O'Reilly *et al* (2002) the role of time averaging in food web studies also for Lake Tanganyika. For the most part, stable isotope studies only complement the more traditional data, but sometimes they can offer new insights, such as the prominent role of picoplankton in Tanganyika (Sarvala *et al*., 2003), supported later by direct measurements (Descy *et al*., 2005; de Wever *et al*., 2008).

Results and management implications

Firstly, the hydrodynamic studies showed the wind patterns and the ratio of the mixing layer depth to the productive layer depth, as well as the transport of the nutrients to the euphotic zone through turbulence, mixing and upwelling, all are of primary importance in adjusting the productivity levels, distribution and seasonality. Apart from the 'classic' SE wind-driven upwelling in the south, the areas of secondary upwelling, vertical mixing and horizontal transport were observed along the shallow shorelines and three main lake basins, where the land-based winds across the lake cause large-scale gyres *(*Huttula, 1997).

Later, Langenberg *et al*. (2002) further assessed the degrees of vertical mixing and turbulence which affect primary production in different parts of the lake. The observations underscored the consequences of hydrodynamic processes on biological productivity either by securing internal nutrients or by controlling the timing and magnitude of phytoplankton biomass production. Similarly, Langenberg *et al*. (2003) noted the influences of the strength in lake stratification and wind regimes on the intra- and inter-annual differences in upwelling and internal seiching.

Studies have shed light on the physical and biological mechanisms underlying and regulating directly the first levels in the food webs (III, Stenuite *et al*., 2007; Nahimana *et al*., 2008; De Wever *et al*., 2008) and increasingly also the implications for the secondary levels including fish populations, their distribution, dynamics and production (III, Sarvala *et al*.2006a, Sarvala *et al.* 2006 b). From the managerial point of view, it is important to distinguish between external factors, such as nutrient load, pollution, global changes, and internal fishery-related factors, such as fishing when considering the current status of the target stocks. Debate on these factors and their possible influences on fish catches have received a lot of publicity recently, indicating the substantial value of long-term data series as well as comparable methodology

and data processing when making final interpretations and conclusions (O'Reilly *et al*., 2003; Eschenbach, 2004; Verbourg *et al*., 2006; Sarvala *et al*., 2006 a, Sarvala et al., 2006 b, Nahimana *et al*., 2008).

Secondly, the studies of the biomass and production, and the relation between these, at each level of the food chain, made it possible to characterise the energy and nutrient flows between and within the trophic levels in a revised way (III; IV). The information compiled in these summaries is unique for its areal and seasonal coverage, and for the scientific accuracy, which takes advantage of the LTR Project's harmonised and intensive sampling programme on fixed sites, and the lake-wide multipurpose surveys to collect integrated samples of the ecosystem components. The results show that the trophic efficiency between zooplankton and phytoplankton is not exceptionally high, but the consumption of copepod zooplankton was considerably high in the northern and central part of the lake, where *Stolothrissa* was abundant, but smaller in the south. The consumption of shrimps, instead, was moderately low in the two northernmost zones, and was at its highest in the southern end, where *Lates stappersii* was dominant. The ecosystem studies (III) and the modelling (IV) both revealed that the Tanganyika ecosystem fall within the 'normal' range of deep tropical lakes, and no particular discrepancy between the trophic levels could be seen, in contrast to earlier suggestions.

The regional production estimates for each fish species allow comparisons with the catch statistics in each country. For *Stolothrissa*, the highest exploitation rates were found in Burundi and Zambia, and the lowest in Tanzania. For *Limnothrissa*, moderately low exploitation was found in Tanzania and Zambia, while the rates were high in Burundi and DRC. For *Lates stappersii*, in contrast, exploitation rates were extremely high in all countries, being lowest in Tanzania and highest in DRC. As for the whole-lake average, this figure was as high as 0.94 (IV). In conclusion, the clupeid stocks are seemingly less vulnerable to over-exploitation, whereas those of *Lates* are likely over-fished.

When considering the outcomes of these ecosystem studies and their use in formulating practical management actions (e.g. developed for marine fisheries by Murawski, 2000), one should ask how the conditions on Lake Tanganyika allow the achievement of biomass and production (surplus production), biodiversity, variability and finally, the social and economic benefits. For the Lake Tanganyika fishery there are great difficulties to quantify many, if not all, of these issues. The standing stock and biomass distribution of the pelagic fish were assessed in the LTR Project in hydro-acoustic surveys (Szczucka, 1998) and experimental trawling (Mannini 1998), although it is worth noting that the confidence belts around the whole-lake estimates were very wide. Using this basic information on stock size, trophic structure analysis (III), bio-energetic modelling (IV) as well as stable isotope analyses (Sarvala *et al*., 2003) were made to study carbon and energy pathways in the pelagic zone. The food-web analyses of the LTR Project also provided detailed information on the zooplankton, shrimp and fish species diversity in the pelagic zone, which is characterized by a moderately simple structure. Today the commercial fishery is targeted primarily on three species only, *S. tanganicae, L. miodon,* and *L. stappersii*.

The studies have given a moderately clear picture of the prevailing state of the stocks of these species, as well as of their trophic basis, i.e. food resources and possible vulnerability of the entire system to over-exploitation (fishing) or environmental disturbance (pollution, cascading trophic effects).

The lake-wide syntheses of the trophic structure (III) and assessments of the nutrient and energy flow in the pelagic food webs (IV) as completed with data from the monitoring phase (V), all together, showed that the current harvest rate of planktivorous fish was about 23% of total estimated fish production for the whole lake, and as high as 66% in the Burundi area. For piscivorous fish, the lakewide catch was about 70% of total estimated production. Even considering the uncertainties involved, the latter figure is quite high compared with average values elsewhere. Usually, commercial fisheries catch 20-25% of the production (Houde & Rutherford, 1993). The updated figures from the bioenergetic modelling (IV) confirmed these estimations, showing an even higher exploitation rate to production figures for the piscivorous *Lates stappersii*. From a lake-wide perspective, the annual fish yield relative to the number of fishermen per sq. km fits well with Bayley's (1988) data on other African lakes.

When evaluated by national areas, excess fishing capacity is suggested for the extreme Northern and Southern ends of the lake (IV). There are signs of excess fishing pressure of *S. tanganicae* stocks (high juvenile content and smaller mean length in catches) for the northern end of the lake, on both west and east coasts north of Karonda (Burundi coastline, about 75 km from the northern tip of the lake; the most recent development in the Congolese waters were documented by Mulimbwa, 2006). Furthermore, the highly unselective beach seine fishery, mostly prosecuted in Zambia, is heavily targeting juvenile *Limnothrissa miodon* in their shallow inshore nursery grounds (Mannini, 1998). The seines are also inflicting untold damage on the mainly cichlid coastal fish community.

The suggested high exploitation rates are consistent with other indicators of fishing pressure, e.g. observed declines of catch per effort in the industrial purse seine fisheries, mainly harvesting *Lates stappersii*, both in the southern and northern ends of the lake (Coenen *et al*., 1998; V). The monitoring programme showed that the industrial fishery in Burundi has become even more negligible since 1995, the total catches being now less than 10% of the 1994 level. Also, the artisanal yields in Burundi and Uvira had by the early 2000s declined down to 50 or 10%, respectively, of the early 1990s amounts (Mulimbwa, 2006, S. Badende, pers. comm.). In the northern waters, in 1995 *L. stappersii* made up only around 20% of the commercial catch, with juveniles accounting for most of this contribution (Mannini, 1998). Later, this proportion slightly increased to 27% (S. Badende, pers. comm.). The increased duration of fishing trips in the industrial fishery in southern waters also indicates a decrease in the catchable stock and possible over-exploitation of *L. stappersii* (Mannini *et al*., 1996, Phiri, pers. comm.).

The present fishery and level of fishing effort seem to be approaching the limits of sustainability, especially in regard to the *Lates stappersii* and partly also *S. tanganicae*. If any uncontrolled increase of exploitation takes place, it means the ecosystem and fish production will become more susceptible to rapid environmental changes. Although these studies covered only a moderately short period of time and the project represented a period when the water level in the lake was exceptionally low, the project concluded that the lake falls into the average category of deep tropical lakes in regard to its productivity (III). Thus, the trophic studies on Lake Tanganyika suggest that one may apply the models of management developed for other large lakes or environments dominated by small pelagic species.

The models used have rather similar aims to those of the mass balance models such as Ecopath and its derivatives (Christensen & Pauly, 1993). They summarise the ecosystem in terms of the energy flows through the trophic levels. The Ecopath model describes trophic fluxes in mass-balance and trophic interactions varying with biomasses and harvest regimes. Ecopath software (EcoSim I) indicates likely directions of biomass change in various trophic groups under experimental conditions, and without requiring the users to engage in complex modelling or information gathering. It is therefore a valuable tool for designing ecosystem-scale adaptive management experiments (Walters *et al*., 1997). The second-generation software, Ecosim II, uses results from the Ecopath procedure for trophic mass-balance analysis to define biomass dynamics models for predicting temporal change in exploited ecosystems, and alterations in the life history of populations (Walters *et al*., 1999). Ecopath has been used globally to assess the production potential (Pauly & Christensen, 1995, etc.) or to study shifts in the trophic levels caused by harvesting (Pauly, 1995; Pauly, 1998 b). The Ecopath approach and related software has so far been applied in up to 130 fishery cases and watercourses all over the world (see http://www.ecopath.org/ for details of publications). Christensen & Pauly (1993) give a series of examples from tropical conditions too, with special emphasis on African Lakes (e.g. Chad, George, Kariba, Malawi, Turkana, Tanganyika).

Trophic food web models describe well the causal predator-prey relationships between the ecosystem parts. They enable comparison between changing states, the analysis of the ecological significance of any component of the food web, the identification of 'vacant feeding niches' and the prediction of impacts which change the balance of the system. Although reductionistic in their methodology (Larkin, 1996), they enhance understanding the current situation in the trophic structure. This may have implications while assessing the system resilience and vulnerability to environmental disturbances and harvesting. In this respect, ecosystem modelling may provide a means for the concept of ecosystem management too. But to help the managers to assess the production potential and related allowable catch in practice, there should be enough resources to compile, analyse and process the adequate data in a timely way. This may not be feasible in developing countries, where the research institutes suffer from a shortage of technical and human capacity. Management mechanisms in these conditions should be based on the data-poor or even data-less situations, rather than the precise empirical assessment of the fish resource size (Johannes, 1998). Therefore, studies that indicate the trends in catch

size and composition, or alternatively, occasional changes in the target stocks, are valuable predictors of the gross impacts of harvesting.

The models for describing the trophic dynamics and efficiency have provided valuable data bases to assess the current situation in the pelagic fishery resources on Tanganyika. Adoption of the precautionary approach as the starting point is viable and based on the observed indications of the depleted stocks, reduced catch per unit effort, and biological (recruitment) over exploitation. In concrete terms, limitations on industrial fishery in the south and beach seine fisheries along any coastal sites are justified (Reynolds *et al*., 1999). But then on the other hand, the study has indicated the real trophic relationships occurring in the ecosystem and estimated the actual yield/production rates which give some ground to plan future harvest rate and its areal and gear type-specific targeting. The long-term ecological assessments of fish stock dynamics in LTR are also consistent with the overall observations on the prevailing situation in the fishery, which can be noted through direct observations of fishermen behavior, economic improvements, and market situation (V; VI). The study has thus provided a scientific basis for an active fisheries development strategy which allows long-term social sustainability to emerge in a way that could not happen if a passive restriction-oriented strategy were chosen.

5.2 Catch trends

Assumptions

The fish yields in Lake Tanganyika kept increasing in line with the total harvest rate that was increasing due to new invaders in the fishing industry, and the technological development that could be seen everywhere in the world. The deployment of industrial gear and nylon nets in the 1950s was clearly seen in the evolution of the catches (Coenen *et al*., 1998). The fish markets were expanding, and dried clupeids ('ndagaa' in Burundi and Tanzania, 'kapenta' in Zambia and the DRC), sometimes also mixed with young *Lates stappersii*, were sold in large quantities to the industrial area of the Copperbelt in Zambia, some 1000 km distant, and in Bujumbura and to major towns in Tanzania. Traders collected dried fish sacks in every village all along the Tanzanian coast line, carried them onboard the passenger or cargo vessels to Mpulungu and sold the fish on long-distance markets in all these countries, including DRC (Coulter, 1991). The fish markets of Lake Tanganyika partly overlap with fish sales coming from L. Victoria, L. Malawi, and L. Kariba, thus creating a kind of 'common market' for post-harvest fish in Eastern Africa.

The first signs of depleted yields of the large *Lates* species (*L. mariae, L. microlepis, L. angustifrons)* were seen soon after the fishery expanded, and the two clupeids (*Limnothrissa* and *Stolothrissa*) and *L. stappersii*, the only one among the *Lates,* became dominant in the catch of all fishing groups. The loss of biodiversity raised some concern, and the simplified food web that was not known in detail was seen to

be more vulnerable to environmental disturbances and over-exploitation than before (Coulter, 1991).

The fishing industry of Lake Tanganyika faced new economic problems in the late 1980s, first due to contracting markets in mining regions of Zambia because of the collapsing industry there. Decreased catches, lower profitability and lost markets have forced the industrial sector in the northern parts of the lake to refrain from further investments or to partly stop operations; many sold their vessels and gear to the south (II).

During the 1990s the political problems (ethnic conflicts, civil war) in Zaïre, Burundi and Rwanda together with climatic disturbances (drought) resulted in local socio-political and economic collapses. This, in turn, ruined the food production potential also in other agricultural sectors and has contributed to poverty and hence lowered the purchasing capacity in rural areas. Together with growing population numbers, the demand for low-priced and dried fish, rich in proteins and minerals, led, however, to increased fishing pressure close to towns and other settlements. New invaders including many refugees entered the fishery, thus the ecological crisis in fishery resources led to socio-economic conflicts between local and migrant societies whose attitudes towards resource utilisation and conservation were likely very different. Thus, the era of interacting cultures and people with conflicting values, a situation which is even more pronounced in the 2000s, started already in the 1980s in the Lake Tanganyika fishery (VI).

Studies and methodology

Extensive studies on pelagic fish stocks (Szczucka, 1999), and fish population biology (Aro *et al*., 1998; Aro & Mannini, 1998; Mannini *et al*., 1998) were made regularly at the sub-stations and onboard the r/v Tanganyika Explorer. Catch statistics were collected and related frame surveys were conducted, resulting in summaries of catch composition and quantities by gear and fishing types (Coenen *et al*., 1998). Results of the monitoring in each country were compiled and reported partly in publication V, constituting an important source of information.

The value of long-term monitoring and data of time series in supporting managerial decisions is seen in the assessment of the possible impacts of climate change on hydrodynamics, limnology and related fishery yields (VI, Huttula *et al*., 2006; Sarvala *et al*., 2006 a, Sarvala *et al.,* 2006 b).

Results and management implications

As the first outcome, the main results are summarised in table 1 of the thesis, indicating both the changes in the catch, fishing operations, and fishery communities

as well as the implications for the fisheries management. Declining unit catches were best documented mainly in the industrial sector (V; Coenen *et al*., 1998; van Zwieten *et al*., 2002). These changes could directly indicate a decrease of catchable stock and possible over-exploitation of *L. stappersii* owing to uncontrolled growth of the fishing industry. Similarly, the high juvenile content of the *L. stappersii* and of *S. tanganyica*, particularly in the northern part of the lake, could directly indicate possible excess fishing pressure on *L. stappersii* and overfishing of *S. tanganyicae*, respectively (Mannini, 1998; Mulimbwa, 2006).

Kimirei *et al*. (2008) have reported similar phases specifically in the fishery in the Kigoma area, Tanzania. The traditional fishery period before 1975 was marked by low catches of *Lates* spp., and a dominance by clupeids, and was followed by a short industrial period (1975-78) marked by high catches of *Lates stappersii* and high total landings. This has changed since 1984, moving towards the artisanal period with relatively low catches and high dominance of *S. tanganicae*. Today the single-species fishery should be further managed, e.g. through spatial or temporal limitations, regulations and follow-up of minimum mesh sizes and minimum legal fish lengths, and through licensing mechanisms in order to meet the increased demand for fish as human food. In Tanzania, the increasing population size and growing numbers of refugees from DRC and Burundi are adding pressures on the management.

Such results give immediate data for taking decisions about restricting or redirecting the fishing effort and adopting areal and gear-wise limitations. Systematic compilation of such data through catch samples is also moderately simple to organise and can be harmonised in different countries (Coenen *et al*., 1998).

Secondly, the results of the fish biology studies and catch analyses also show that the current pelagic fish stocks on Lake Tanganyika are dominated by clupeids (*Stolothrissa tanganicae*, in particular) and by *L. stappersii*, which are all of the *r*-selected life-history type (in the case of *L. stappersii* it is compared with other *Lates* spp.). These characteristics indicate higher resistance to high fishing pressure, fast recovery capacity after exposure to over-exploitation (Adams, 1980; Armstrong and Shelton, 1990; Fogerty *et al*., 1991; Jennings *et al*., 1999) and thus additional resilience of the entire fishery in the course of recent years (Coulter, 1991). An interesting balance between the predatory *Lates* species and their clupeid preys were observed already by Coulter (1970) and later by other fishery investigations (e.g. Pearce, 1988; Coenen *et al*., 1998; Munyandorero, 2001; Munyandorero, 2002), indicating another level in population adaptation towards exploitation.

Such classifying life-history studies already provide a rough estimation of the population structure and indicate the respective carrying capacity to exploitation, but could be developed even further in an analysis of harvest-induced evolutionary impacts (see Jørgensen *et al*., 2007), which is a modern application of the population study as part of ecosystem management.

Further, Sarvala *et al*. (2006) report the very recent concern about the impact that the global climate change may have had on the biological productivity on Lake Tanganyika. There is an overall consensus about the recorded increase in the surface water temperature (Verbourg *et al*., 2003; O'Reilly *et al*., 2003) but the possible influences on biological productivity has been questioned (Sarvala *et al*., 2006 a, Sarvala *et al*., 2006 b). What is important from the managerial point of view is that no evidence has been produced of the reduced fish catches being affected by these physical phenomena (Sarvala *et al*., 2006 a, *Sarvala et al.,* 2006 b). On the contrary, publications II and V show the total catch increased up to 1995, and the regional declines in the industrial catches have been compensated for by lake-wide increase in artisanal catch. Mulimbwa (2006) has, however, shown that in the Uvira region of DRC, where the fishing pressure is highest, there have been later signs of depleting catches in places. To conclude, the changes in the catch levels and stock composition reflect more the changes in fishing intensity. Thus, the use of long-term statistics and monitoring data of the environment and catch were successfully used in making such conclusions. This brings us to the issue of fisheries research and the monitoring of catch trends as part of fisheries management. This is the field where one was able to apply the scientific advice most straightforwardly to support management decisions.

5.3 Protecting biodiversity

The magnificent biodiversity within the littoral-dwelling fish is, in principle, not an element of the immediate fishery management strategy itself, but more an issue in environmental management strategy (Strategic Action Plan, LTBP, 2001). As far as biodiversity in the pelagic fish is concerned, the ecosystem is simple and dominated by clupeids and *L. stappersii.* Three other centroptomid *Lates* spp. are caught in smaller quantities by purse seiners, lift-net units, and hook'n line fishermen. Being scarce and highly priced, these species are vulnerable to over-fishing.

The pollution control and other measures to protect biodiversity on Lake Tanganyika as a whole are of primary concern. Through these efforts, the term ecosystem management becomes broader, including the natural and human-borne factors affecting the environment in the lake and its watershed area (basin) too. In this respect, the question of biodiversity links fishery management to the overall holistic strategy on management of the lake resources on a sustainable basis (LTBP, 2001).

Management implications

Establishment of no take areas

Establishment of closed areas, 'no take' areas or protected areas (PAs) has increasingly become a practical tool and integral part of ecosystem management. The marine protected areas (MPAs) in which fishing is prohibited, have been proven successful in preserving faunal diversity and stock stability as part of large marine ecosystems (LMEs). Local experiences with MPAs show that leaving an area undisturbed long enough for stocks to rebuild can result in overall gains, more than compensating for the non-fishing in the MPAs (Russ & Alcaca, 1994).

Establishing and maintaining 'no take' areas is commonly applied as a routine approach in the developing countries due to their low costs, easy political acceptance and obvious biological advantages, although, on the other hand, critical scientific approval of them still remains widely controversial (Sale *et al.,* 2005). Little is known about the efficiency of such protected areas in supporting the production of the pelagic stocks. The interactive relationships between open area and shallow water ecosystems are key questions but are not yet fully understood in Lake Tanganyika. The main production of the three commercially important pelagic species takes place in open waters. Of the clupeids, however, *L. miodon* spawns and hatches on sandy substrates in waters less than 130 m deep (Matthes, 1967), and produces large schools of juveniles (15-40 mm long) that spend their first two months inshore (Pearce, 1985; Mannini, 1998). Thus, the establishment of PAs and particularly the banning of destructive gear such as dense beach seines may together have a slight impact on the local recruitment and population structure of *L. miodon* stocks.

Accordingly, Sanyanga *et al*., (1995) concluded that PAs have a fairly minor but positive impact on the local recruitment and population structure of *L. miodon* stocks in Lake Kariba. Recruitment of the more pelagic *S. tanganicae* is apparently less bound to the conditions in the littoral zone. The appearance of new cohorts in pelagic fishery follows, instead, peak abundance of pelagic zooplankton with a delay of 3-6 months, depending on the site (V). Thus the influence of the near-shore PAs on the recruitment and formation of ensembles of *S. tanganicae* cannot be proved.

Sustaining the stocks of the four *Lates* species is more subject to possible beneficial impacts of the PAs on the littoral-dwelling life stages (*L. angustifrons, L. mariae, L. microlepis* in particular) and appropriate regulations of fishing effort and gear. These three species seem to be particularly vulnerable to localised over-fishing which, in turn, reflects their less opportunistic types of life-history strategies and a habitat preference which is more sedentary than that of *L. stappersii* (see Adams, 1980; Jennings *et al*., 1999). Lindlay *et al*. (2000) have shown the importance of littoral-based traditional fishery, using more than 50 local gears which may quite selectively be targeted in the inshore areas, and therefore constitute a risk for the littoral-dwelling fish populations. This includes the cichlid species, the fishery of which stocks is inadequately reported in quantitative terms. Recently Sturmbauer (2008) has suggested a novel type of locally-administrated small-scale PAs to protect the cichlid biodiversity.

The effectiveness of even the best designed networks of PAs will depend on the conservation and fisheries efforts undertaken outside reserve boundaries (Murray *et al*., 1999). Individual reserves or reserve networks cannot alone produce the desired fishery and conservation outcomes (Roberts, 1998), and in any every case to become viable in practical management they require multi-level actions (Allison *et al*., 1998; Fogarty, 1999; Murray *et al*., 1999). In the context of the Lake Tanganyika region, this will include simultaneous managerial actions with respect to habitat protection, land-based operations, and monitoring and control of tourism and fishing activities. Disparities between national authorities often seriously hinder the initiating of such actions (Coulter, 1999). Given the highly fluctuating and unpredictable nature of the commercial fishery of Lake Tanganyika, the benefits in a pelagic ecosystem accruing from PAs will be difficult to ascertain.

Having the 'no take' areas in the pelagic area at distances that are beyond the operational capacity of most traditional fishermen or too far away for the artisanal units in economic terms, may be one additional option of management. This measure requires practically no efforts by the fishery authorities. These off-limit areas are kept in place by technical and economic means (e.g. as a result of steeply rising fuel prices) and in fact by the community's self-management strategy. Secondly, the establishment of 'protected areas' in the littoral areas or inshore waters may bring immediate benefits to the local benthic fish, such as cichlids or benthic stages of the pelagic species. Today there are no empirical data on the spawning or nursery grounds of these commercial species. But the lack of scientific results should not prevent the PA measure being applied if it is proven, by the experience of the authorities or the society itself, beneficial for reproduction, recruitment or production. Thus, PA could be an example of the 'precautionary principle' on the practical level, and be tested on a pilot scale (Reynolds & Mölsä, 2000; see also Sturmbauer, 2008).

Reserving some 'no take' or protection areas for stock recovery or maintenance can thus be implemented as part of ecosystem management. Success is not necessarily dependent on the fishery authorities' follow up and monitoring efforts or the capability to enforce the restrictions if the fishermen community itself supports the idea, and has experienced the net return of these areas. Stock protection may indirectly provide the fishermen with increased gains. But if compensations for lost catches become necessary, alternative gear may be supplied, credits may be provided to cover these investment costs, or other technical support may be distributed to the community to compensate for the economic losses. In the natural protection areas, rich in benthic fish, the PAs may serve as tourist attractions, and economic feasibility may be achieved by incorporating the fishermen into this business (VI).

Allison *et al*. (2000) considered three general conservation strategies on Lake Tanganyika: direct protection (lake reserves), economic substitution (promotion of alternative livelihood activities) and linked incentives (e.g. eco-tourism). Along the same lines, Coulter *et al*. (2006) suggested that setting aside core conservation areas of representative habitats with large fractions of biodiversity should be complemented with integrated Coastal Zone Management regimes outside these

reserves. This would allow the adoption of a wider development strategy including human-development needs.

5.4 Socio-economic patterns

Studies and methodology

The studies on fishery societies, their socio-economic status, and insights to the future of their livelihoods were included in the ecosystem analysis to complete the assessment of the bio-physical pathways in the pelagial of Lake Tanganyika (II). It was obvious that such information was needed to set a multidisciplinary ground for the management strategy (II; V). Therefore, the suggested management measures, e.g. areal and gear restrictions, development attempts, or restructuring the managerial organisations, were all introduced to the communities and representatives of fishery stakeholders in the community referenda (II; Reynolds & Hanek, 1997).

Results and implications for the management

There are nearly 800 fishing communities of various sizes distributed around the coastline of Lake Tanganyika. Members of these local communities represent the primary bloc of Tanganyika resource stakeholders, as the lake is their immediate source of livelihood and sustenance. Those most directly involved in the fisheries include harvest sector workers and owners of productive equipment (gear, canoes, etc.), post-harvest sector fish processors and traders, and providers of various support services (craft repair, spares, fuel, food stands, lodging, etc.). A far greater number of coastal people rely on the lake's resources as consumers for whom fish is a crucial source of animal protein food, and as family and household dependants of fisherfolk. Taking all these categories into account, it can be estimated that the welfare of some one million lake dwellers – perhaps one tenth of the entire Tanganyika basin population – is more or less directly tied to the fate of the fisheries (see Meadows & Zwick, 2000; Paffen *et al*., 1997; Reynolds & Hanek, 1997 for more detailed information).

The 1997 LTR sample survey data of lakeshore communities revealed an overall picture of poor physical infrastructure and a dearth of basic social services and amenities (Reynolds and Hanek, 1997). They also indicate that fishers in these communities live in relatively marginal conditions. For the most part, they command very limited resources in terms of formal education (completion of primary school), savings, earning power, and ownership of land, housing, and consumer goods, even as they strive to provide for family and household dependants. Lake Tanganyika's fishing communities thus share the wider regional conditions which, measured by

standard 'quality of life' indices, define East-Central African countries as amongst the world's most poverty-stricken and underdeveloped (cf. West, 2001). Nevertheless, fisheries remain a fairly attractive mode of employment for Tanganyika-basin inhabitants. Income prospects may not be spectacular, but they compare favourably with those that can be garnered in other sectors of the economy, especially in rural areas. This set of circumstances not only serves to keep people involved in fisheries work, but also acts to draw in others as well.

The more than 50% growth of small-scale fleet size since the 1980s indicates increased fishing effort at the inshore, demersal fishery (Lindley, 2000). As conditions of food and civil security became more difficult, more people were attracted to fishing for subsistence as well as a potential source of income. Traditional gear and equipment are usually cheaper to purchase and operate, and easier to repair or replace, than artisanal fishing tools (Lindley, 2000; West, 2001).

The role of new invaders from other areas (Northern parts) and from other sectors (mining industry, agriculture) and of refugees has increased, and in principle has resulted in a situation called Illegal, Unregulated, Unreported (IUU) fishing. There are weak links between the migratory groups and the local societies, and thus no community-based institutions with solid regulations or rules can be established. This could result in overall excess exploitation of near-shore stocks, and consequently in a transfer of effort to the pelagic fishery.

Retirement and withdrawal of industrial units from the North is another remarkable shift in the fishery structure, which indicates the industry's reactions to the alterations in the fishable stock and also to the financial situation, which has likely become less profitable (II, V, Table 1).

By emphasising the outputs of the traditional and small-scale sectors of fishery, the LTR project has shown a major concern for the economic and socio-economic sustainability of the poorest people in society. From the managerial point of view, this group is also the most difficult and challenging, because the operations cover a wide range of environments, technologies and cultures. Future project outlines (Magnet *et al.*, 2000; Reynolds & Mölsä, 2000) have, however, set increased local participation in management decision-making as one of the objectives. Although the present legislation in some cases provides means for consultation between administrators and local stakeholder groups, and some beach communities are reported to exist on some landing sites, the real local community participation in resource management decision-making and follow-up has been very minimal or not realised at all. The coming Framework Fisheries Management Plan will provide venues for improved social equity and democracy by the establishment of Local Fishery Councils (LFC) and Local Community Fisheries Zones (LCFZ) that will enhance the potential for community participation when put into place.

The 1998 LTR Community Referenda exercise indicated that women face disadvantages in the local decision-making processes concerning the resource use and in the overall social status and income level, compared with men. The future options in resource management will partly lessen such gender-based and social inequality.

Reducing poverty is the central objective of Finnish foreign aid. In the Lake Tanganyika region, the earnings of traditional fishermen typically are much lower than the regional per capita averages, whilst in the artisanal lift-net sector the earnings are higher than amongst the average working age population in these countries. The poverty of the traditional fishermen, who often are occupied in fishing part-time and only for subsistence, is a multi-dimensional economic and social matter.

Enhancing the harvest technology and post-harvest and marketing infrastructure will lead to higher economic returns amongst all the fishermen who are able to sell excess yields to local or distant markets. This means improvements in their earnings and hence in the general standard of living, including enhanced nutrition. Similar outputs are expected in the entire trade area through larger fish quantities and improved product quality.

Shifting from traditional and subsistence level fishery towards more advanced technology and increased capital intensity is regarded as a way to economic development. Technology enhancement is a two-sided affair that increases the production efficiency and welfare amongst the target group but also may create inequality and even social conflicts if the new techniques require more capital than before and the access to the technology or resources is distributed unevenly. It has been claimed that the efficient use of production factors such as labour, capital and resources leads to the economic optimum and even to the welfare maximum in a society (Clark, 1976).

As the other side of the coin, small-scale fisheries should be viewed as very economically viable and rational. Local gear and harvesting methods are socially and economically more efficient than large-scale technologies. They yield much greater tonnage of fish caught per unit of capital investment, and incur much lower capital cost per job created and much lower fuel consumption per tonne of fish caught (Thomson, 1980). Fisheries development today is analogous to rural development in general, which also underlines social equity, democracy, and equal access to the natural resources as key elements of sustainable development (Ministry for Foreign Affairs of Finland, 2007).

According to Bundy *et al*. (2008), Ecosystem Based Management, which aims at developing all sub-sectors of the fisheries, though regarded as the latest and most comprehensive conceptual approach, still fails to meet the needs of all groups evenly. To be successful, such management would call for corporate responsibility,

social justice and ethics, which means that the development of large-scale industrial fishing would not result in the taking over of resources from small-scale fishing, that the distribution of the benefits are equal, and that the inclusion of all stakeholders in the decision making is possible.

In conclusion, the management measures on Lake Tanganyika must address all the development challenges in the society including the immediate local needs of the poorest people and the economic expectations of the more advanced groups with linkages to the national trade and economy. These target groups also differ in terms of their ability to contribute to the management process or to bear any costs that arise. Thus, the management strategy needs to be formulated accordingly, and the operational models chosen with various degrees of participation.

6. FORMULATION OF MANAGEMENT STRATEGY

6.1 Ecosystem management and measures

Ecosystem management on Lake Tanganyika

In this chapter it is concluded that there are appropriate relevant measures to develop fisheries on Lake Tanganyika, although practical limitations and constraints make it very challenging (I). The present studies have shown that the multidisciplinary, ecosystem approach means, is a reasonable way of supporting development (II; VI). As part of ecosystem management, comprehensive systematic research efforts are justified (II, III, IV) in order to establish a scientific basis for the strategy. Research and monitoring can provide the fisheries authorities with important background information and current indications of the environment and fishery. The question of information collation and usage in decision making is discussed below. Also, the role of scientific data and advice is considered in various management structures, where the managerial duties are shared between the authorities and other stakeholders.

In the context of Lake Tanganyika, both the biotic ecosystem and human society are regarded as the 'ecosystem' and therefore ecosystem management includes the following issues:

- Direct measures to control and redirect the fishing effort in order to avoid continued over-exploitation of *Lates stappersii* and S. *tanganicae,* and to reduce the excess industrial fishing capacity in the Southern part of the lake
- Protection of biodiversity through fisheries management measures to conserve rare *Lates* species or littoral-dwelling cichlids
- Achievements in the fishery society in terms of reduced poverty, increased equity, access to decision making about the management, and conservation of the natural resources.

A combination of environmental concerns and fisheries management was also suggested by Nkotagu (2008): he suggested continuing international interventions as an ecosystem management strategy in line with the previous Lake Tanganyika Biodiversity Project (2001) and the Lake Tanganyika Research (LTR) project.

Definitions of ecosystem management

Ecosystem management is a way to put into practice more holistic approaches to resource management. It reflects the 'necessity of understanding multi-species interactions and questions of altered structure of the biological community (ecosystem stability)'. The management implications of the term 'ecosystem management' presume a reasonable understanding of the physical and chemical environment and the interactions between the species as well as between the organisms and the environment (ref. Larkin 1996).

The well-being of commercially harvested species and the associated fishing industry has been historically the ultimate goal of management. Now there are trends to reach broader ecosystem-oriented objectives as well (Sainsbury *et al*., 2000). In marine fishery, this may include recovery of endangered species, fishing-related effects on species and habitat, by-catch, and maintenance of biodiversity, ecosystem integrity and resilience (Larkin, 1998).

The broadest approach to ecosystem management today is included in high-level agreements, treaties, and policies that set out principles and objectives for the human use of biological resources (e.g. Law of the Sea Convention, UN Convention on the Environment and Development, Convention on Biological Diversity; Sainsbury *et al*., 2000). To reach that level from the present species-by-species management, a sequence of potentially complex actions has to be taken:

- the ecosystem must be defined;
- the resources within the ecosystem must be assessed;
- the interactions between the ecosystem components must be quantified;
- the human impact on the system and its components must be described.

The ecosystem approach means that the newly set focus in fisheries is no longer targeted on the sustainable yield of the target species itself: the impacts of fishing on the structure and function of the entire ecosystem have to be considered as well (Gislason *et al*., 2000). These views have been widely adopted in the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) and many related policy documents elsewhere. Examples of the empirical use of such analyses are seen in the trophic assessment of global fishery resources and their status (Pauly & Christensen, 1995; Pauly *et al*., 2000), amount of discarded catch (Alverson *et al*., 1994), and environmental disturbances (Blaber *et al*., 2000; Caddy, 2000).

Larkin (1998) has outlined the following three management components, initially for marine ecosystem management: the sustainable yield of products for human

consumption and animal foods, maintenance of biodiversity, and protection from the effects of pollution and habitat degradation.

Murawski (2000) has developed these goals by Larkin (1998) into practical management actions, the outcomes of which are measurable. Management programmes usually address some of the following considerations, but comprehensive management of the ecosystem must address them all.

Biomass and production of important system components, and assessment of the total system production available for harvest ('surplus production'). This can be made on the ecosystem or individual stock level;

Diversity – excessive exploitation can influence diversity at various levels or organization, owing to size and species selectivity of fisheries. Following such selective harvesting, species interactions such as predatory-prey relationships may alter with cascading effects through the food chain.

Variability – Several types of resource variability can be used as measures of sustainability. Highly perturbed systems tend to exhibit greater year-to-year variation in yields and recruitment.

Social and economic benefits – Ecosystem management, in the ideal form, will provide the entire society with the highest net benefit.

Lake Victoria is perhaps the most outstanding example of large-scale fisheries where alternative approaches have been introduced and applied to the management. The well-known phenomena in the lake environment, hydrography, and water quality associated with Nile perch introduction have set the basis for extensive studies of limnology and fish biology (e.g. Oguto-Ohwayo, 1990; Kitchell *et al*., 1997), biodiversity changes (e.g. Witte *et al*., 2007), and fisheries (Goudswaard *et al*., 2008). Vast investigations and project interventions have provided data on lake status and biological condition, but as Kolding *et al*., (2008) claim they have also resulted in rather static management strategies that are based on conventional stock models with no real solutions to the problems in either the environment or fishery (Kolding, 1994). They suggest the development of holistic monitoring systems for ecosystem-based management which emphasises choosing indicators of ecosystem drivers, stock states and fishing pressures (Jul-Larsen *et al*., 2003; Choi *et al*., 2005).

To make an ecosystem approach efficient, Bundy *et al*. (2008) still underline the importance of adopting conceptual governance, including strong regulatory measures by the society to influence human interventions, responsible use of power, and social justice, which, in turn, affect the natural resource base. Van der Knaap *et al*. (2007) and Geheb *et al*. (2007) claim, however, there are difficulties impeding effective

fisheries management on Lake Victoria, regardless of the established Beach Management Units who have power to enforce certain regulatory measures and well documented evidence of ecological disturbances. Establishing an adequate 'co-managerial' framework and implementing managerial action has not taken place yet, and a management structure based on three levels of administration is proposed, each level having at its core 'beach committees', serving as forums for negotiated managerial outcomes.

The present study on Lake Tanganyika showed that the ecosystem approach, which was applied from the very beginning, was reasonable and justified here too. Based on systematic multidisciplinary research and long time series of data, the internal mechanisms of the biological system were shown, and the direct measurements of the catch evolution were used to assess the implications for the society (II-V, Sarvala *et al*., 2006 a). The management strategy chosen is conceptualised to a large extent in line with the FAO Code of Conduct for Responsible Fisheries (FAO, 1995)., The alternative management structures with varying degrees of community participation are also drawn from the *Code* principles, and will be reviewed in the following section to elaborate the means of putting these strategies into place.

6.2 Management structures and operation models

Following the list of Hoggarth *et al*., (1999), a total of 15 various roles can be identified when the responsibilities between the institutions and authorities and other end-user groups in the fishery society are shared. The question of who is capable of taking responsibility and who has the incentive to take responsibility also needs to be considered. Welcomme (2001) has grouped the conditions for successful community-based management into the following main categories:

- participation must be rewarded by positive returns
- the unit of management is defined and reasonable
- resource side-rules and regulations are set and the communities are committed to following them
- institutional capacity to manage is defined, including experience, right to manage, leadership, communication and democracy
- monitoring of the fishery and resources is operational and useful to the community

This range of resource and community characteristics provides guidance on where the chances of success will be intrinsically higher and on what additional support by government or other organisations may be needed.

Which role carries out the information gathering in such a multi-purpose management regime where the responsibilities have been shared between various stake-holder groups? First, the stakeholder analysis includes identifying the key stakeholders, assessing stakeholder interests and the potential impact of fisheries management on these interests, assessing stakeholder influence and importance, power and status, and outlining the stakeholder participation strategy (Welcomme, 2001). The capacity of stakeholders to participate in the management process depends on includes human resources, skills and rights, as well as motivation (Hoggarth *et al.*, 1999).

Co-management arrangements result in outcomes that can be evaluated in terms of management efficiency (achieving an optimal rate of use of the fishery, income generation, management costs), equity (stakeholder representation, expectations met, process clarity, benefit distribution) and sustainability (system resilience, social commitments, governance) (see Sen & Raakjær Nielsen, 1996).

Sharing the responsibilities between the parties involves basically three distinct aspects if it is to be reasonable and efficient. First, the responsibilities, rights and relationships of different stakeholders with respect to the different management roles have to be made explicit and agreed. Secondly, a local capacity for fisheries management needs to be legitimated and developed where it exists, or created where it does not. Thirdly, overarching institutional structures, involving both representatives of local communities/ user groups and government, need to be created to mediate on wider issues, such as ecosystem impacts and the fishing regulations applicable to important shared stocks (Welcomme, 2001). The success of this option is subject to the institutional capacity and motivation of each stakeholder group to participate in the process. The degree of commitment may depend on rewards and incentives that make the management efforts reasonable and justified.

Thus, two alternative options of management organisations will be reviewed in the following:

'**Management by Government authorities'**: Management led and supervised by the fisheries authorities, including a major role by the Monitoring, Control and Surveillance (MCS) operations.

'**Management in Partnership'**: Responsibilities, duties and decision making shared between government and other stakeholders.

6.3 Management by governmental authorities

Role of fishery monitoring

It seems that environment and fishery monitoring will become the key element when the regional fishery management strategy is the institutional arrangement put into place on Lake Tanganyika. Monitoring will be an active measure that supports the

collection of information on the environmental conditions, fish resources and stakeholder groups. Through monitoring, it will be possible to follow up the impacts of the management measures taken and obtain a scientific basis for the decision making and for improving management performance. Monitoring may provide the two main principles of 'ecosystem management' and 'precautionary principle' with the core information, and is helpful in designing the actual measures, such as restrictions and limitations. But also, on the other hand, the results may shed light on the prevailing situation in regard to the resources and the communities, and provide advice on opportunities to develop the fishery in a sustainable way (V).

In practice, there are, however, several constraints for successful monitoring and institutional arrangements, which are related to the pile of uncertainty parameters discussed before. To establish a sufficient monitoring programme, decisions have to be taken about 1) what parameters are monitored and what is the value of the information; i.e. the degree of uncertainty accepted; 2) whether the institutional capacities in the four riparian countries are sufficient to carry out such monitoring; 3) who will use the monitoring results in the decision making, and how the information flows from monitoring to the end-users and finally results in the formulation of the management strategy. In addition, the function and methodology of the monitoring need to be addressed if community-based co-management will be paid increasing attention.

Choosing the monitoring parameters

Studying the food web structure, as was done in the LTR, cannot be continued as monitoring. Ecosystem analyses, linking together the hydrophysics, limnology and biological production, as well as the fish population studies, all serve as baseline information in understanding the trophic dynamics, nutrient and energy flows, species-to-species interactions, etc. of the target pelagic ecosystem. Assessing the current fish production level, or the production potential, is in this respect important when comparing Lake Tanganyika with other African lakes, or other related ecosystems, or fishery (III).

Through this information one can assess the general status, degree of disturbance, and vulnerability to additional environmental disturbances, or human-borne interventions. But continuously assessing the stock size is naturally not a reasonable way to monitor the resource levels. As stated before, there are important issues related to the necessity of assessing the standing stock to implement any managerial measures, i.e. the question of applying MSY, TAC or related models in practice. Second, there are numerous technical constraints in doing adequate sampling of the target stocks or population, i.e. the sources of errors due to sampling and uncertainties in data processing. Owing to the huge size of Lake Tanganyika, all estimates at the scale of the whole lake are bound to have wide confidence limits; on the other hand, local estimates, which could be more accurate, are not sufficient alone because of the openness of the system.

Appropriate monitoring variables should first describe the critical changes in the ecosystem or fishery, and second they should be relevant to the end-users (V). The staff in resource-poor institutions may consider obtaining data of the following variables on a regular basis:

- 'Early alarms' signalled by changes in hydrodynamic patterns;
- Density and distribution patterns in the meso- and macro-zooplankton communities that provide prey for planktivorous fish;
- CPUE and fish biology data for main target species;
- Continuities and changes in fishing communities (size, composition, and infrastructure) and the socio-economic circumstances of local harvest and post-harvest operators; and
- Continuities and changes in local views on trends in, problems with, and regulation of the fishery sector

The first three items have been studied in the recent study (V; Mannini *et al*., 1998), and included in the regular monitoring programme on Lake Tanganyika (Mannini, 1999). The other two, where the socio-economic parameters will be added, were planned in the extended operations of the Regional PRODAP programme (Reynolds & Mölsä, 2000). The hydrodynamic and limnological parameters may reflect the overall climatic, seasonal and occasional situation of the environment and factors controlling the biological production (Plisnier & Coenen, 1987; Langenberg *et al*., 2002). But, as discussed above, the predictive value of these primary factors in assessing the fish production or production potential are still far from complete (II; III; V). Using the CPUE data of liftnet or seine fisheries is the only practical way of obtaining information of catch development, but also some sort of bias may be expected due to light attraction during fishing. Catch composition is also specific to the gear used and to the exact fishing location (Coenen *et al*., 1998), which means that total catch records may not reliably reflect the true development of the fish stock.

The regular data sets in 1992-1999 and further monitoring data in 1999-2001 (V) already have proved the importance of long time series in indicating the changes, long-term trends and cycles better than single one-time values.

Though very laborious and resource demanding, comprehensive surveys of the whole ecosystem are likely needed periodically, particularly if new methodologies can be introduced and the understanding of the ecosystem functions improves. One good example was the study by Sarvala *et al*. (2003) who used the size-fractionated $\delta^{15}N$ and $\delta^{13}C$ isotope ratios as a tool of ecosystem study.

Recent studies (VI; Sarvala *et al*., 2006 a, Sarvala *et al*., 2006 b) also show the value of direct catch statistics and monitoring in assessing the possible fishing-borne and climate-induced changes in fish yields.

Use and value of the monitoring results

The second condition for successful monitoring deals with the possibilities of utilising the obtained information in the decision making. This again is subject to the institutional capacities, physical and personnel structure of the responsible fishery and environmental bodies. On Tanganyika, the basic question has been how to share limited resources between national and international research and management programmes on other Great Lakes, inland and marine fisheries, or even between fisheries and other rural sectors. These choices reflect the priorities in the national policy, and emphasis placed on the lake fisheries in general. Regardless of the advantages shown in the fishery for the rural economy or international trade, such physical and technical contribution has remained rather limited in every country.

Critical parameters when planning the relevant monitoring programme include the size and education (training) of the personnel, motivation and attitude, and the finance of the respective authorities. This problem was addressed already before the project (I), and the personnel capacity was then enhanced through supervised field work and intensive training during the project (II; V). Technical assistance, researcher training, and international networking with colleagues overseas has allowed the local institutions to continue with the modest collection of hydrographic, biological and catch data to benefit scientific reporting and practical management (VI; Sarvala *et al*., 2006 a, Sarvala *et al.,* 2006 b).

The value of monitoring data correlates with their indicative value in providing relevant information for the decision making. Measurements of hydrophysical or limnology variables may be indirectly informative in assessing the environmental status, long-term or seasonal cycles, and primary factors controlling the secondary production in the pelagic zone, being thus not very practical tools in a resource-poor management system. The follow-up of the catch composition and sizes have been used directly, including more straightforward implications for fisheries (V; Kimirei *et al*., 2008). The weak communication links from the local level to the central administration have, however, reduced the influence the information might have on national level policy formulation.

The situation on Lake Malawi is quite similar to that on Tanganyika. The Malawian Department of Fisheries runs catch monitoring and CPUE analyses of industrial trawl fisheries, and small-scale fisheries on a regular basis, which results in vast quantities of data each year (Darwall & Allison, 2002). These results remain, however, sparsely analysed and processed due to lack of quality control and supervision for data collection and computer data logging; moreover, insufficient resources and logistical problems result in less than 10% of data collectors completing their assigned

program of monitoring (Turner *et al*., 1992). Effective management of the fisheries has, however, been extremely limited owing to a lack of finance and manpower for the enforcement of policies. Darwall & Allison (2002) have therefore suggested substantial alterations in the current stock-assessment-driven statistics and other structural changes in the monitoring regime of Lake Malawi to enhance the usage of the monitoring outcomes. A national management strategy with clearly defined objectives should, however, be first established, taking into account the development objectives of the various stake-holder groups, and sharing the responsibilities between these groups as part of co-management arrangements (Allison, 2002; Darwall & Allison, 2002).

6.4 Management in Partnership

The essential idea of co-management is the sharing of decision making and management functions between government and stakeholders in the fishery. More formally, co-management can be defined as the creation and implementation of suitable management arrangements with a set of agreed stakeholders, i.e. fishers and their organisations work jointly with government to develop and enforce fishery regulations and management measures (Charles, 2002). With almost similar phrasing, Sen & Nielsen (1996) defined co-management as an arrangement where responsibility for resource management is shared between the government and user groups. The concept focuses on the recognition that user groups have to be more actively involved in fisheries management if the regime is to be both effective and legitimate (Njaya, 2002). Following Campbell & Townsley (1996), community participation in fisheries management means that individual fishermen or fishermen groups that are actively involved in the management of the resources have evidence that regulations and control mechanisms are working in their best interests. Private advantages may be achieved on a short-term basis, or collective benefits are obtained in the society in the long run, once common decisions are taken and various stake-holder groups commit themselves to the community decisions. The 'co-management', 'management in partnership', 'participatory management,', or 'community-based management' policies may be implemented informally or by means of formal organisations, such as a committee or co-operative (Njaya, 2002).

The 'top-down' or 'command and control' management regimes, in addition to undervaluing the potential contributions of local knowledge systems and actors to the management process, often feature a heavy measure of state intervention. This may often result in an 'us versus them' response of disassociation amongst local fisherfolk, expressed in widespread indifference and even the deliberate violation of official regulations (II). Many examples from the African Great Lakes, as compiled by Geheb & Sarch (2002), show how inefficient the governmental regulations, gear restrictions, closed seasons or areas, etc. are in addressing the problem of over-exploitation or redirecting the fishing operations, even if they hav been shown to be ecologically justified (Njaya, 2002; Hara *et al*., 2002, Allison, 2002; Malasha, 2002; Wilson, 2002).

Njie and Mikkola (2002) in turn reported the establishment of a Fishermen Association at Central River Division (CRDFA) in 1993/94 as an encouraging initiative and later a successful institute to take over managerial responsibility in the riverine inland fisheries of Gambia. The association's efficacy in achieving positive results is, however, subject to the capacity of the government to contribute in the work as well, and therefore is a good example of a shared management model.

In CCRF language, '...the efficiency and implementability of...management measures are often highly dependent on the support gained from the interested parties' (FAO, 1997). Such support is most likely to exist where resource users can identify with specific measures because they have helped to craft them.

CCRF Technical Guidelines characterise 'management in partnership' as embracing '...the various arrangements which formally recognize the sharing of fisheries management responsibility and accountability between a fisheries management authority and institutions either public, such as a local government authority, or private, such as a group of interested parties' (FAO, 1997). Further points related to the rationale for such devolution of management authority and possible problems in its action are listed in the *Code*.

In terms of rights in a fishery system, the co-management arrangement provides the end users with a new type of right, 'management rights', in addition to the 'use rights' existing before. Management and use rights together belong to the broader concept of 'property rights'. If the community-based management system is inefficient and non-functional regarding the taking over of management responsibilities, the situation brings us closer to the issue of *open access* and *common property,* the two fundamental causes of the resource over-exploitation and resulting stock depletion (Charles, 2002). But if well organised, the community-driven management arrangement may enhance the use rights towards *controlled access* or *harvest rights*, and a *conservation ethic* as part of sustainability management.

In such a case, the entire fishery becomes self-regulated by the internal social and economic relationships. Ideally the communities' own regulative mechanisms are strong enough to ensure that real socio-economic sustainability be established but as the worst scenario, uneven harvest rights and capacities result in increased problems and finally in ecological collapses.

The role of scientific advice can be fundamental also in the model where the connections between governmental organisations and target societies are loose. Monitoring may provide essential indications of unfortunate trends, but to strengthen the institutional structures, participatory processes should be strengthened. On Lake Tanganyika only the artisanal groups and the industrial units can be reached through the fishermen assemblages, commercial networks or through the licensing procedures, which could be used also in information exchange. The present study (II; VI) proposes the establishment of Local Fishery Councils (LFC) and Local

Community Fisheries Zones (LCFZ) in order to enhance the potential for community participation and the necessary social equity and democracy. According to present plans such a scheme would cover 200 fishing villages (about 25% of the lake-wide total) which would be linked together through national Fisheries Councils and a Lake Tanganyika Regional Fisheries Council (called the Lake Tanganyika Authority). These community-based organisations would be, in partnership with the authorities, responsible for regulating the fishing effort, resource exploitation and post-harvest activities such as fish handling and processing, marketing channels and raising environment awareness amongst the population.

Should these managerial decisions require the replacement and abandoning of destructive gear and fishing practices, new techniques of fresh fish collection and preservation, improving of infrastructure and services, or other actions that would alter the income generation and distribution, loan assistance through LFC Micro-Credit Scheme will be arranged to compensate for economic losses (VI). Thus, it is most likely that the model of management in partnership can become operational only if such funding arrangements can be realised to encourage local participation.

7. CONCLUDING REMARKS

7.1 Adaptive strategies on Lake Tanganyika

It is concluded that the fisheries management strategy on Lake Tanganyika, as developed during the present study, has adopted to a modest extent the current approaches in fisheries management science. The lake fisheries and the conditions on the lake are full of extremes which affect the selection of strategies and practical measures: (1) high biological and hydro-physical dynamics which affect the production patterns and fish distributions; (2) strong annual and seasonal fluctuations of the pelagic stocks, which increase the unpredictability in economic planning; (3) long distances, remote conditions, poor communication, and weak infrastructure which reduce the capacity, efficiency and coverage of governmental and international (regional) managerial services; (4) poor institutional capacity and weak organisations of the fishery society due to the percentage of subsistence fishermen and the great variety of sub-cultures; and (5) overall social and economic problems, conflicts and disturbances in the region. All these characteristics greatly influence the strategy chosen, the possibilities to enforce the regulations, and the means to follow-up and monitor the impacts of the strategic decisions. Examples of successful indicators of the trends are given in the study (e.g. table 1), and the role of the research and monitoring was revealed (VI).

Given the highly fluctuating environment and unpredictable changes both in fish stocks and fisheries, no static measures are applicable and adaptive strategies are needed on Lake Tanganyika. This approach is in line with current ideas in fisheries science, but how to implement the strategy in practice remains open. Similarly, the fishermen do not react to greatly fluctuating fish resources at a static fixed effort level: they pay close attention to the extreme peaks and absence of yields, and regulate their fishing accordingly. Thus they adjust their catch rates not 'on the average' but according to fluctuations, to achieve sufficient profitability (Wilson, 2006).

The scientific methods for evaluating fishery-management strategies were advanced through two parallel initiatives: 'adaptive management' developed by Walters & Hilborn (1976), Walters (1986), and Ludwig & Walters (1989), and 'comprehensive assessment and management procedure evaluation', developed by the International Whaling Commission (Donovan, 1989; Magnusson and Stefansson, 1989).

In line with this, Lane & Stephenson (1999) stated that the basic difficulty for the fisheries management has been that systems are stochastic, uncertain and as a consequence, fundamentally difficult to control. Cochrane (1999) noted that dealing with uncertainties, such as those due to random variability in the dynamics of a stock and those in observations, are actually the major task that managers have to cope

with. Charles (1998) has also listed types of uncertainty, e.g. random fluctuations in target stocks, uncertainty in data parameters, and the structural uncertainty met there in the stake-holder groups (fishermen society, administrators, research bodies). These factors have in practice many implications for the actual management and its operational organisation and decision making. Recent developments in fishery science and management can be summarized as the recognition of the need for explicit attention to be paid to uncertainty, awareness that the major stakeholders must be involved in the decision making, the knowledge that open access fisheries will fail, and recognition that users must have a long-term stake in the fishery to secure their commitment to the sustainability of the fishery resource (Ludwig *et al*., 1993).

Adaptive management is now widely recognized as providing a successful and appropriate framework for scientific input to fishery management (Sainsbury, 1988). In Sainsbury *et al*., (2000) an ideal management includes the following preconditions:

- it reduces uncertainty of all types, where cost-effectively possible, and is robust to the remaining uncertainties, allowing the extraction of an appropriate proportion of the realizable yield, in accordance with the precautionary approach (FAO, 1996)
- it must be effective in multi-species fisheries where relevant
- it provides opportunities for the involvement of all stakeholders (addressing institutional and implementation uncertainty)

Additionally:

- measures must be feasible and cost-effective to monitor and enforce
- it should not introduce unnecessary social or economic distortions
- it should minimize the opportunity for an unsustainable increase in fishing mortality for short-term benefits
- it should minimize management costs and the need for frequent revision and adjustments in the resource of the fishery

The current study concluded that the future fisheries management on Lake Tanganyika can utilise all these principles, but to repeat, the practical implementation depends on the institutional capacity (including all stakeholders) to deal with such modern measures.

7.2 Precautionary principle

Charles (1988) added to the adaptive strategy the notion that comprehensive fishery management involves policy components that are robust and precautionary. These elements become more relevant if the degree of uncertainties grows bigger and the management has to cope with them all. If there are fundamental constraints in

obtaining reliable information about the resources, fish stocks or target populations, the precautionary management approach is likely to be adopted by responsible authorities. Also, if there is a gap between the actual field observations and official decision making, managers easily end up with restrictions and other conservative measures rather than in active means to pursue the industry and livelihood development as such. On the institutional level, precautionary management was introduced by the FAO (1995) as a risk-averse approach for decision-making when scientific understanding is lacking or incomplete (Weeks & Berkeley, 2000). The aspect takes into account uncertainties in stock assessments that would determine the target reference points (i.e. the 'positive' goal of optimum size), and at the same time the 'limit reference points (i.e. the negative goal of the lowest acceptable stock size) (MacGarvin, 2002). Richards & Maguire (1998) emphasised that the precautionary principles should not be applied only at the analytical phase but also during later implementation phases. The degree of caution is, however, negatively correlated with management performance. As a consequence, performance may continue to decline during the development of a management procedure if advisers are too conservative in their estimates of all the parameters that are needed for the model (Witting, 1999).

The precautionary principle was born in the fisheries policy and research in the riparian countries before the present study was started (Lindqvist & Mikkola, 1987). Later the study has concluded that the replacement of destructive gear and fishing methods (fine-mesh gill nets and dense beach seines) is ecologically justified. Such non-selective gear has been shown to carry the risk of local over-fishing and threaten breeding individuals and the recruitment of new cohorts of *Limnothrissa,* for example. For the same reasons the abandonment of fishing operations in breeding areas has to be encouraged, and the active driving of fish into net lines has to be forbidden.

There are indications that the kapenta in the Zambian part of the lake may be exposed to overfishing by too finely-meshed beach seines (Mannini 1998), with the consequence that a part of the production is lost. However, this 'lost' production, if it were saved by some management measures, may no longer be available to the same group of fishermen. Thus the traditional or artisanal fishermen may not have an interest in 'saving' the fish unless some other compensatory measures to their advantage are implemented at the same time (II).

Management in partnership may enhance the precautionary principles too if the stakeholders can agree on the common objectives, and the communities' social ruling is strong enough to support the conservation ethics. Hilborn (2007) states interestingly that if the prevention of overfishing is set as the management objective, the precautionary government-driven catch regulation is a typical measure. But if achieving wider economic success is aimed at, a much more systematic evaluation of the other aspects of fisheries performance is required, and therefore multidisciplinary participatory information collection is needed. In addition, an incentive structure is also necessary to support the participation of all parties. On Tanganyika and in the presence of extreme poverty amongst the subsistence and traditional fishermen, the

possible economic losses or alternative livelihoods may require external financial support through a LCF microcredit scheme.

7.3 Good governance in fisheries development

If the fisheries will be managed jointly by governmental interventions and community participation, there is still a risk that the links from the fisheries system to the central administration remain poor and that co-management is not actually realized, but the two levels remain separate and the system inefficient. In such a case the governmental party deals with administrative and regulatory measures, with no capacity of empowerment, and the fisheries system, on the other hand, deals with ecological issues (e.g. fish mortality) and the social system (e.g. economic and social values) with numerous complex internal forces (Nielsen & Holm, 2007). Given the lack of proper communication and information flow, the fishery remains self-managed or no-managed (Re: Jul-Larsen *et al*., 2003), bringing us back to the roots and open access regime.

The present study concludes, therefore, that successful management in partnership also requires a strong interactive relationship between the central authorities and the fisheries system. Through a systematic monitoring of the environment, target fish populations and fisheries combined with informal information about the target societies, a multi-disciplinary reference basis is created for governance and management decisions (Nielsen & Holm, 2007). The governing system is a broader concept than the management or any degrees of co-management, and it underlines the roles and capacity of each stakeholder group to supply information and be responsible for the decision making (Townsend *et al*., 2008).

Though ideal as an operational model, management in partnership between the various stakeholder groups still requires substantial rethinking amongst the decision makers and reallocation of the resources in the responsible institutions. Enhanced communication between the parties at the lake side and from the field to the central administration is needed before the socio-economic advantages of lake fisheries are approved and linked to national policy.

Challenges for successful governance in fisheries development are found also at the other end of stakeholder groups. Fishermen societies on Lake Tanganyika are diverse and scattered, thus any decentralized managerial models including shared responsibilities in the villages and communities require the establishment of local organizations, such as LFCs and LCFZs on Tanganyika. Initiating their operation also needs well organized financial support and assistance to cover the managerial costs. The present study shows, however, that the pelagic fisheries on Lake Tanganyika can be developed in a sustainable way, which means there are good grounds for maintaining self-sufficient economically sustainable fisheries that also have the capacity to bear the governing costs. Such capacity is, however, not the same in each fisher group but the advanced artisanal units that earn beyond the average

levels could contribute more than the traditional units fishing basically for subsistence. With reference to Sarch & Allison (2000) the marginal and less advanced fishermen are forced to adjust their operations in relation to environmental fluctuations and limited fishery resources and are thus less able to participate in the management operations or pay any additional costs. On Lake Tanganyika the highly fluctuating and migratory fish stocks bear as such a risk that limits the poorest groups to look for any sustainability and therefore they act with a short perspective for their own good.

In addition to local and national levels, linkages to international policy and trade are necessary, and they already resulted in the establishment of a regional administrative body, the Lake Tanganyika Authority, in 2008. Thus the final managerial structure on Lake Tanganyika could be very much similar to that suggested for Lake Victoria (Geheb *et al*., 2007), with three interactive levels of administration: a) Beach Committees that represent local stake holders, fishing communities, fish processing sector, and fisheries departments; b) District Committees to make decisions on fisheries matters of district-level concern; and c) a Regional Committee that provides the fishery with access to the international Lake Victoria Fisheries Organization. As Bundy *et al*. (2008) argue, all these three administrative levels and effective information flows between them are needed if we are to apply an ecosystem-based approach in implementing good ecosystem governance.

The coming years will show how management ideas can be transformed or converted into local and regional practices on Lake Tanganyika. Also, it remains to be seen which way the Lake Tanganyika Authority and other administrative structures will facilitate these practices to benefit the riparian states and their local inhabitants.

8. REFERENCES

Adams, P. B., 1980. Life history patterns in marine fishes and their consequences for fisheries management. Fish. Bull. 78:1–12.

Ahonen, H., 2001. Age and growth of the pelagic clupeids in Lake Tanganyika estimated by otolith microstructure analysis. MSc Thesis at University of Turku, Finland. 86 p.

Allison, E.H., 2002. Sustainable management of the African Great Lakes: Science for development. Aquatic Ecosystem Health & Management 5: 315- 327.

Allison, E.H., Paley R.G., Ntakimazi, G., Cowan, V. J. & K. West, 2000. Biodiversity assessment and conservation in Lake Tanganyika. BIOSS final technical report. Pollution control and other measures to protect biodiversity in Lake Tanganyika. RAF/92/G32, UNDP/GEF/LTBP Report for NRI, MRAG, IFE. 166 pp.

Allison, E.H., Mvula, P.M. & F. Ellis, 2002. Conflicting agendas inthe development and management of fisheries on Lake Malawi. In: Geheb, K. & M-T. Sarch (eds.) Africa's Inland Fisheries. The Management Challenge. Fountain Publishers, Heinemann & Currey. pp. 49-73.

Allison, G., Lubchenco, J. & M.H. Carr, 1998. Marine reserves are necessary but not sufficient for marine conservation. Ecological Applications 8(1) Supplement: S79-592

Armstrong, M.J. & P.A. Shelton, 1990. Clupeoid life-history styles in variable environments. Environmental Biology of Fishes 28: 77–85.

Aro, E. & P. Mannini, 1995. Results of fish population biology studies on Lake Tanganyika during July 1993–June 1994. FAO/FINNIDA Research for the Management of the Fisheries. GCP/RAF/271/FIN–TD/38 (En): 113 pp.

Bayley, P.B., 1998. Accounting for effort when comparing tropical fisheries in lakes, river flood plains, and lagoons. Limnology and Oceanography 33: 963-972.

Berverton, R., 1998. Fish, fact and fantasy: a long view. Reviews in Fish Biology and Fisheries 8: 229-249.

Beverton, R.J.H. & S.J. Holt, 1957. On the dynamics of exploited fish populations. Fishery Investigations 2: 1-533.

Bootsma, H.A., Hecky, R.E., Hesslein, R.H. & G.F. Turner, 1996. Food partitioning among Lake Malawi nearshore fishes as revealed by stable isotope analyses. Ecology 77: 97-101.

Bundy, A., Chuenpagdee, R., Jentoft, S. & R. Mahon, 2008. If science is not the answer, what is? An alternative governance model for the world's fisheries. Front Ecol. Environment 6: 152-155.

Cabana, G. & J.B. Rasmussen, 1996. Comparison of aquatic food chains using nitrogen isotopes. Proc. Natl. Acad. Sci. USA. Ecology 93: 10844–10847.

Cacaud, P., 1999. Review of a monitoring, control and surveillance system for lake Tanganyika Fisheries. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika GCP/RAF/271/FIN-TD/96 (En): 21 pp

Campbell, J. & P. Townsley, 1996. Participatory and integrated policy: a framework for small-scale fisheries in Sub-Saharan Africa. Integrated Marine Management, United Kingdom.

Castilla, J.C. & O. Defeo, 2005. Paradig shifts needed for world fisheries. Science 26: 1324-1325.

Charles, A.T, 1988. Fishery socioeconomics: A survey. Land Economics 68: 276-295.

Charles, A.T., 1992. Fishery conflicts: A unified framework. Marine Policy 16: 379-393.

Charles, A.T., 1994. Towards sustainability: The fishery experience. Ecological Economics 11:201-211.

Charles, A.T., 1998. Living with uncertainty in fisheries. Analytical methods, management priorities and the Canadian groundfishery experience. Fisheries Research 37: 37-50.

Charles, A.T., 2001. Sustainable fishery systems. Blackwell Science, Oxford.

Charles, A.T., 2002. The Precautionary Approach and 'Burden of Proof' Challenges in Fishery Management. Bulletin of Marine Science 70(2): 683-694.

Choi, J.S., Frank, K.T., Petrie, B.D. & W.C. Leggett, 2005. Integrated assessment of a large marine ecosystem: a case study of the devolution of the eastern Scotian shelf, Canada. Oceanography and Marine Biology: an annual review 43:47-67.

Christensen, V. and D. Pauly (eds). 1993. Trophic models of aquatic ecosystems. ICLARM Conference Proceedings No. 26, 390 p.

Coenen, E. J. (ed.), 1995. LTR's fisheries statistics subcomponent: March 1995 update of results for Lake Tanganyika. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika GCP/RAF/271/FIN/TD/32 (En): 45 pp.

Coenen, E.J., Paffen, P. & E. Nikomeze, 1998. Catch per unit of effort (CPUE) study for different areas and fishing gears of Lake Tanganyika. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika GCP/RAF/271/FIN-TD/80 (En): 92 pp.

Cohen, A., 1995. Paleoecological approaches to the conservation biology of benthos in ancient lakes: a case study from Lake Tanganyika. Journal of the North American Benthological Society 14: 654-668.

Cohen, A.S., R. Bills, C.Z. Cocquyt, and A.G. Caljon, 1993. Impact of Sediment Pollution on Biodiversity in Lake Tanganyika. Conservation Biology 7(3): 667-677.

Clark, C.W., 1976. Mathematical Bioeconomics. New York: Wiley

Cochrane, K.L., 1999. Complexity in fisheries and limitations in the increasing complexity of fisheries management. ICES Journal of Marine Science 56: 917-926.

Coulter, G.W., 1970. Population changes within a group of fish species in Lake Tanganyika following their exploitation. Journal Fish Biology 2: 329-353.

Coulter GW (ed.), 1991. Lake Tanganyika and its Life. British Museum (Natural History) and Oxford University Press, Oxford, 354 pp.

Coulter, G.W., 1999. Sustaining both biodiversity and fisheries in ancient lakes. In: H. Kawanabe, G.W. Coulter, A.C. Roosevelt (Eds.) Ancient Lakes: Their Cultural and Biological Diversity. pp. 177-187. Kenobi Productions, Belgium.

Coulter, G.W., Langenberg, V., Lowe-McConnell, R., Riedel, F., Roest, F., Sarvala, J. & O. Timoshkin, 2006. The problems confronting survival of biodiversity in ancient lakes. Verh. Int. Verein. Limnol 29: 1178-1181.

Coulter, G.W. & R.H. Spigel, 1991. Hydrodynamics. In: Lake Tanganyika and its Life (Ed. G.W. Coulter), pp. 49–75. Oxford University Press, London.

Craig, H., Dixon, F., Craig, V., Edmond, J. & G.W., Coulter, 1974. Lake Tanganyika geochemical and hydrographic study: 1973 expedition. Publication Scripps Institution of Oceanography Series, 75–5, 1–83.

Cunningham, S. & T. Bostock (eds), 2007. Successful fisheries management: issues, case studies, perspectives. Eburon. 240pp.

Darwall, W.R.T. & E.H. Allison, 2002. Monitoring, assessing, and managing fish stocks in Lake Malawi/Nyassa: Current approaches and future possibilities. Aquatic Ecosystem Health & Management 5(3): 293-306.

Degens, E.T., von Herzen, R.P. & H.-K. Wong, 1971. Lake Tanganyika: water chemistry, seciments, geological structure. Naturwissenschaften 58: 229-241.

Descy, J.-P., Hardy, M-A., Sténuite, S., Pirlot, S., Leporcq, B., Kimirei, I., Sekadende, B., Mwaitega, S.R. & D. Sinyenza, 2005. Phytoplankton pigments and community composition in Lake Tanganyika. Freshwater Biology 50: 668-684.

De Wever, A., Muylaert, K., Langlet, D., Alleman, L., Descy , J-P., Andre, L. , Cocquyt, C. & W. Vyverman, 2008. Differential response of phytoplankton to additions of nitrogen, phosphorus and iron in Lake Tanganyika. Freshwater Biology 53: 264–277

Donovan, G. P., 1989. Preface. The Comprehensive Assessment of Whale Stocks: the early years. (Special Issue 11 of Report of the International Whaling Commission (ed. G. P. Donovan).

Dunn. I.G. & L. Hyytinen, 1987. Report on a Project Identification Mission, GCP/RAF/229/FIN, FAO, Rome, 59 pp.

Eschenbach, W.W., 2004. Climate-change effect on Lake Tanganyika? – Nature 15 July 2004. www.nature.com/nature. doi: 10.1038/nature02689.

FAO, 1995. Code of Conduct for Responsible Fisheries, Rome, FAO, 41 pp.

FAO, 1996. Precautionary approach to capture fisheries and species introductions. Rome: FAO, FAO Technical Guidelines for Responsible Fisheries. 2, 54 pp.

FAO, 1997. Technical guidelines for responsible fisheries, No. 4: Fisheries Management. FAO, Rome.

FAO, 2003.The ecosystem approach to fisheries.FAO Technical Guidelines for Responsible Fisheries. No. 4, Suppl. 2. Rome, FAO. 112 p.

Ferro, W., 1975. Observations limnologique dans le nord du Lac Tanganyika. FAO report FI:DP/BDI/73/020/7. 29p.

Fogerty, M.J., 1999. Essential habitat, marine reserves fishery management. Trends in Ecology and Evolution 14: 133-134.

Fogerty, M.J., Sissenwine, M.P. & E.B. Cohen, 1991. Recruitment variability and the dynamics of exploited marine populations. Trends in Ecology and Evolution 6: 241–246.

Geheb, K. & M-T. Sarch (eds.), 2002. Africa's Inland Fisheries. The Management Challenge. Fountain Publishers, Heinemann & Currey.

Geheb, K., Modesta Medard, M., Mercy Kyangwa, M. & C. Lwenya, 2007. The future of change: roles, dynamics and functions for fishing communities in the management of Lake Victoria's fisheries. Aquatic Ecosystem Health & Management 10: 467-480.

Genner, M.J., Turner, G.F. & S.J. Hawkins, 1999. Resource control by territorial male cichlid fish in Lake Malawi. Journal of Animal Ecology 68: 522-529.

Gislason, H., Sinclair, M., Sainsbury, K. & R. O'Boyle, 2000. Symposium overview: incorporating ecosystem objectives within fisheries management. ICES Journal of Marine Science 57: 468-475.

Goudswaard, P.C., Witte, F. & E. F. B. Katunzi, 2008. The invasion of an introduced predator, Nile perch (*Lates niloticus*, L.) in Lake Victoria (East Africa): chronology and causes. Environmental Biology of Fishes 81:127–139

Gréboval, D., Bellemans, M. & M. Fryd, 1994. Fisheries characteristics of the shared lakes of the East African Rift. CIFA Technical Paper 21, FAO, Rome.

Gulland, J.A., 1965. Estimation of mortality rates. Annex to Arctic fisheries working group report ICES C.M./1965/D:3. (mimeo). Reprinted as p. 231-241. In P.H. Cushing (ed). Key papers on fish populations. Oxford. IRL Press. 1983.

Hanek, G., Everett, G., Mölsä, H. & O.V. Lindqvist, 1996. Developing and sustaining world fisheries resources: The state of science and management; 2nd World Fisheries Congress Proceedings, 1996, 334-338. CSIRO Publishing, Collingworth, Australia.

Hara, M., Donda, S. & F.J. Njaya, 2002. Lessons from Malawi's experience with fisheries co-management initiatives. In: Geheb, K. & M-T. Sarch (eds.) Africa's Inland Fisheries. The Management Challenge. Fountain Publishers, Heinemann & Currey. pp. 31- 48.

Hecky, R. E., 1991. The pelagic ecosystem. In G. W. Coulter, (ed.), Lake Tanganyika and Its Life. Oxford University Press, Oxford: 90–110.

Hecky, R. E. & E. J. Fee, 1981. Primary production and rates of algal growth in Lake Tanganyika. Limnology and Oceanography 26: 532–547.

Hecky, R.E. & H.J. Kling, 1981.The phytoplankton and protozooplankton of the euphotic zone of Lake Tanganyika: species composition, biomass, chlorophyll content, and spatio-temporal distribution. – Limnology and Oceanography 26: 548-564.

Hilborn, R., 2007. Managing fisheries is managing people: what has been learned? Fish and Fisheries 8 (4): 285–296

Hoggarth, D.D., Cowan, V.J. Halls, A.S. et al., 1999. Management guidelines for Asian floodplain river fisheries. FAO Fisheries Technical Paper 348/1, 348/2, FAO, Rome.

Houde, E. D. & E. S. Rutherford, 1993. Recent trends in estuarine fisheries: predictions of fish production and yield. Estuaries 16: 161–176.

Huttula, T. (Ed.), 1997: Flow, Thermal, Regime and Sediment Transport Studies and Lake Tanganyika – Kuopio University Publications C., Natural and environmental Sciences 73. ISBN 951-781-711-8. ISSN 1235-0486. 173p.

Huttula, T., Huttunen, O., Podsetchine, V., Peltonen, A., Kotilainen, P. & H. Mölsä, 2006. Hydrodynamics and thermal regime of Lake Tanganyika. Verh. Internat. Verein. Limnol. 29: 1174-1177.

Jennings, S., Reynolds, J.D. & S. C. Mills, 1998. Life history correlates of responses to fisheries exploitation. Proceedings B Royal Society of London 265: 333 - 339

Johannes, R.E., 1998. The case for data-less marine resource management: examples from tropical nearshore fisheries. Trends in Ecology and Evolution 13: 243-246.

Jørgensen,C., Enberg,K., Dunlop, E.S., Arlinghaus, R. S., Boukal, D.S., Brander,K., Ernande,B., Gårdmark, A., Johnston,F., Matsumura, S., Pardoe, H., Raab, K., Silva, A., Vainikka, A., Dieckmann, U., Heino, M. & A. D. Rijnsdorp, 2007. Managing evolving fish stocks. Science 318: 1247-1248.

Jul-Larsen, E., Kolding, J., Nielsen, J.R., Overa, R. & P.A.M. van Zwieten, 2003. Management, co-management or no management? Major dilemmas in southern African freshwater fisheries. Part 1: Synthesis Report. FAO Fisheries Technical Paper 426/1. FAO, Rome.

Kimirei, I.A., Mgaya, Y. D. & A. I. Chande, 2008. Changes in species composition and abundance of commercially important pelagic fish species in Kigoma area, Lake Tanganyika, Tanzania. Aquatic Ecosystem Health & Management 11:29-35.

Kitchell, J. F., Schindler, D. E., Ogutu-Ohwayo, R. & P.N. Reinthal, 1997. The Nile perch in Lake Victoria: interactions between predation and fisheries. Ecological Applications 7:653-664.

Kolding, J. 1994. Plus ça change, plus c'est la même chose. On the ecology and exploitation of fish in fluctuating tropical freshwater systems. Dr. Scient. thesis, Department of Fisheries and Marine Biology, University of Bergen, ISBN 82-7744-011-1. 197 pp.

Kolding, J., van Zwieten, P., Mkumbo, O., Silsbe, G. & R. Hecky, 2008. Are the Lake Victoria fisheries threatened by exploitation or eutrophication? Towards an ecosystem based approach to management (in press).

Kurki, H., 1998. Results of plankton net and torpedo sampling during cruises on board R/V Tanganyika Explorer. GCP/RAF/271/FIN-TD/85.

Kurki, H., Mannini P., Vuorinen, I., Aro, E., Mölsä, H. & O.V. Lindqvist, 1999. Macrozooplankton communities in Lake Tanganyika indicate food chain differences between the northern part and the main basins. Hydrobiologia 407: 123-129.

Kuusipalo, L., 1999. Genetic differentiation of endemic nile perch, *Lates stappersii* (Centropomidae, Pisces) populations in Lake Tanganyika suggested by RAPD markers. Hydrobiologia 407: 141-148.

Lake Tanganyika Biodiversity Project, 2001. Lake Tanganyika: Results and Experiences of the UNDP/GEF Conservation Initiative (RAF/92/G32) in Burundi, D.R. Congo, Tanzania, and Zambia.Strategic Action Programme. (West, K. ed.) http://www.ltbp.org/FTP/FINLT.PDF

Lane, D.E. & R.L. Stephenson, 1999. Fisheries management science: a framework for the implementation of fisheries-management systems. ICES J. Mar. Sci. 56, 1059-1066.

Langenberg, V.T., Mwape, L.M., Tshibangu. K., Tumba, X.V., Koelmans, A.A., Roijackers, R., Salonen, K., Sarvala, J. & H. Mölsä, 2002. Comparison of thermal stratification, light attenuation and chlorophyll-a dynamics between the ends of Lake Tanganyika. Aquatic Ecosystem Health & Management 5: 255-265.

Langenberg, V. T., Sarvala, J. & R. Roijackers, 2003. Effect of wind induced water movements on nutrients, chlorophyll-a, and primary production in Lake Tanganyika. Aquatic Ecosystem Health & Management, 6: 279-288.

Larkin, P.A., 1996. Concepts and issues in marine ecosystem management. Rev. Fish Biol. Fisheries 6: 136-164.

Larkin, P. 1988. Comments on the Workshop Presentations. p.287-289. In Wooster, W.S. (ed.) Fishery Science and Management: Objectives and Limitations. Lecture Notes on Coastal and Estuarine Studies. 28. Springer-Verlag, New York.

Lindley, R., 2000. Lake Tanganyika Biodiversity Project Fishing Practices Special Study. UNDP/GEF/RAF/92/G32.

Lindqvist, O.V., 1977. On the principles of management strategies of crayfish and fish populations. Freshwater crayfish 3:249-261.

Lindqvist, O.V. & H. Mikkola, 1989. Lake Tanganyika: review of limnology, stock assessment, biology of fishes and fisheries. Prepared for the Regional Project for the Management of Fisheries, Lake Tanganyika. Rome, FAO, GCP/RAF/229/FIN: 51 pp

Lindqvist, O.V., Mölsä, H. & J. Sarvala (eds.), 1999a. Lake Tanganyika Research: Summary of the Scientific Programme 1992-1998. FAO/FINNIDA Research

for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN/94 (En): 102 p.

Lindqvist, O.V., Mölsä, H., Salonen, K. & J. Sarvala (eds.), 1999b. From Limnology to Fisheries: Lake Tanganyika and Other Large Lakes. Kluwer Acad. Publ. 218 pp.

Ludwig, D. & C.J. Walters, 1989. A robust method for parameter estimation from catch and effort data. Can. J. Fisheries Aquatic Sci. 46: 137-144.

Ludwig, D., Hilborn, R. & C. Walters, 1993. Uncertainty, resource exploitation, and conservation. Science 260: 17-36.

MacGarvin, M., 2002. Fisheries: taking stock. In: Gee et al. (Eds.) Late lessons from early warnings: the precautionary principle 1896-2000. European Environment Agency, Environmental issue report 22.

Magnet C., Reynolds, R. E. & H. Bru, 2000. Lake Tanganyika Regional Fisheries Programme: A proposal for the implementation of the Lake Tanganyika Regional Framework Fisheries Management Plan. FAO/FISHCODE; GCP/INT/648/NOR, Field Report F-14 (En): 128 p. Rome, FAO.

Magnusson, K. G. & G. Stefansson, 1989. A feedback strategy to regulate catches from a whale stock, The Comprehensive Assessment of Whale Stocks: The Early Years (Special Issue 11 of Report of the International Whaling Commission (ed. G. P. Donovan)), 171–190.

Malasha, I., 2002. The outcome of a co-managerial arrangement in an inland fishery: The case of Lake Kariba (Zambia). In: Geheb, K. & M-T. Sarch (eds.) Africa's Inland Fisheries. The Management Challenge. Fountain Publishers, Heinemann & Currey. pp. 89- 106.

Mannini,P., 1998. Geographical distribution patterns of pelagic fish and macrozooplankton in Lake Tanganyika. GCP/RAF/271/FIN-TD83 (En): 1-125.

Mannini, P., Aro, E., Katonda, I., Kissaka, B., Mambona, C., Milindi, G., Paffen, P. & P. Verburg, 1996. Pelagic fish stocks of Lake Tanganyika: biology and exploitation. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN-TD/53 (En): 85 pp.

Mannini, P., 1999. Lake Tanganyika Fisheries Monitoring Programme. GCP/RAF/271/FIN-TD/90 (En): 1-65.

Matthes, H. 1967. Preliminary investigations into the biology of the Lake Tanganyika Clupeidae. Fisheries Research Bulletin of Zambia 4: 39-45.

McClanahan, T. & J.C. Castilla (eds), 2007. Fisheries management. Progress toward sustainability. Blackwell Publishers. 344pp.

Meadows, K. & K. Zwick, 2000. Socio-economic special study: final report. UNDP/GEF/RAF/92/G32. 55 p.

Mikkola, H. & O.V. Lindqvist, 1989. Report on a Project Mobilization Mission. Lake Tanganyika Regional Fisheries Research Project.GCP/RAF/229/FIN, Rome, Italy.

Ministry for Foreign Affairs of Finland, 2007. Development Policy Programme - Towards a Sustainable and Just World Community. Development Policy Information Unit, Helsinki. 40 p.

Mulimbwa, N., 2006. Assessment of the commercial artisanal fishing impact on three endemic pelagic fish stocks of *Stolothrissa tanganicae, Limnothrissa miodon* and *Lates stappersii* in Bujumbura and Kigoma subbasins of Lake Tanganyika. Verh. Internat. Verein. Limnol. 29: 1189-1193.

Munyandorero, J., 2001. Length-based Beverton and Holt spawning stock biomass per-recruit-models, with application to the *Lates stappersii* (Boulenger) stock in Lake Tanganyika. Fisheries Management and Ecology 8: 1–14.

Munyandorero, J., 2002. The Lake Tanganyika clupeid and latid fishery system: indicators and problems inherent in assessments and management. African Study Monographs 23: 117-145.

Murawski S.A., 2000. Definitions of overfishing from an ecosystem perspective. ICES Journal of Marine Science 57:649–658.

Murray, S.N., Ambrose, R.F., Bohnsack, J.A., Botsford, L.V., Carr, M.H., Davis, G.E., Dayton, P.K., Gotshall, D., Gunderson, D.R., Hixon, M.A., Lubchenco, J., Mangel, M., MacCall, A., McArdle, D.A., Ogden, J.C., Roughgarden, J., Starr, R.M., Tegner, M.J. & M.M. Yoklavich, 1999. No-take reserve networks: sustaining fishery populations and marine ecosystems. Fisheries, Nov: 11-25.

Mölsä, H., Reynolds, J.E., Coenen, E.J. & O.V., Lindqvist, 1999. Fisheries research towards resource management on Lake Tanganyika. Hydrobiologia 407: 1-24.

Mölsä, H., Sarvala, J., Badende, S., Chitamwebwa, D., Kanyaru, R., Mulimbwa, M. & L. Mwape, 2002. Ecosystem monitoring in the development of sustainable fisheries in Lake Tanganyika. Aquatic Ecosystem Health & Management 5(3): 267-281.

Nahimana, D., Brion, N., Baeyens, W. & G. Ntakimazi, 2008. General nutrient distribution in the water column of Northern Lake Tanganyika. Aquatic Ecosystem Health & Management 11(1): 8–15.

Nielsen, K.N. & P. Holm, 2007. A brief catalogue of failures: Framing evaluation and learning in fisheries resource management. Marine Policy 31: 669-680.

Njaya, F.J., 2002. Fisheries co-management in Malawi: Implementation arrangements for Lakes Malombe, Chilwa and Chiura. In: Geheb, K. & M-T. Sharch (eds.) Africa's Inland Fisheries. The Management Challenge. Fountain Publishers, Heinemann & Currey. pp. 9- 30.

Njie, M & H. Mikkola, 2002. Management and development of the Gambia river fisheries: a case for the co-management of inland fisheries resources. In: Geheb, K. & M-T. Sharch (eds.) Africa's Inland Fisheries. The Management Challenge. Fountain Publishers, Heinemann & Currey. pp. 228-239.

Nkotagu, H.H., 2008. Lake Tanganyika ecosystem management strategies. Aquatic Ecosystem Health & Management 11: 36-41.

Ogutu-Ohwayo, R., 1990. The decline of the native fishes of Lake Victoria and Kyoga (East Africa) and the impact of introduced species, especially the Nile perch, Lates niloticus and the Nile tilapia, Oreochromis niloticus. Environmental Biology Fishes 27: 81-96.

O'Reilly, C.M., R. E., Hecky, A. S., Cohen & P.-D. Plisnier, 2002. Interpreting stable isotopes in food webs: Recognizing the role of time averaging at different trophic levels. Limnology and Oceanography 47(1): 306–309

O'Reilly, C.M., Alin, S.R., Plisnier, P.D., Cohen, A.S. & B.A. McKee, 2003. Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. Nature 424: 766-768.

Paffen, P., Coenen, E., Banmbara, S., Wa Bazolana, M., Lyimo, E. & C. Lukwesa, 1997. Synthesis of the 1995 simultaneous frame survey of Lake Tanganyika Fisheries. GCP/RAF/271/FIN-TD 60 (En.) 1-35.

Paloheimo, J.E. & L.M. Dickie, 1964. Abundance and fishing success. Rapp. P.-C. Reun. Cons. Perm. Int. Explor. Mer. 155 (28):152-163.

Pauly, D., 1995. Anecdotes and shifting baseline syndrome of fisheries. Trends in Ecology and Evolution 10(10): 430.

Pauly. D., 1998 a. Beyond our original horizons: the tropicalization of Beferton and Holt. Reviews in Fish Biology and Fisheries 8(3): 307-334.

Pauly. D. (ed.), 1998 b. Use of Ecopath with Ecosim to evaluate strategies for sustainable exploitation of multi-species resources. Fisheries Centre Research Reports 6(2). 49 p.

Pauly, D. & V. Christensen, 1995. Primary production required to sustain global fisheries. Nature 374: 255-257.

Pauly D., Christensen V. & C. Walters, 2000. Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. ICES Journal of Marine Science 57:697–706.

Pearce, M., 1988. Some effects of *Lates* species on pelagic and demersal fish in Zambian waters of Lake Tanganyika. FAO, CIFA Occasional Paper 15: 69-87.

Peterson, B. J. & B. Fry, 1987. Stable isotopes in ecosystem studies. Annual Review of Ecology and Systematics 18; 293-320.

Pickett, S.T.A., Ostfeld, R.S. Schackak, M. & G.E. Likens (Eds.), 1997. The Ecological Basis of Conservation: Heterogeneity, Ecosystems and Biodiversity. Chapman and Hall and International Thompson Publishing, New York.

Podsetchine, V., Huttula, T. & H. Savijärvi, 1999. A three dimensional-circulation model of Lake Tanganyika. Hydrobiologia 407: 25-35.

Reynolds, J.E., Hanek, G., Mölsä, H. & O.V. Lindqvist, 1999. Lake Tanganyika Framework Fisheries Management Plan: Background, policy considerations, and main elements. FAO/FINNIDA Research for the Management of the Fisheries on Lake Tanganyika. GCP/RAF/271/FIN/97 (En): 52 p.

Reynolds, J.E. & G. Hanek, 1997. Tanganyika fisheries and local stakeholders. An Overview of the LTR Lakewide Socio-economic Survey, 1997. FAO/FINNIDA Research for the Management of the Fisheries of LakeTanganyika. GCP/RAF/271/FIN-TD/71 (En): 72p.

Reynolds, J. E. & H. Mölsä, 2000. Environmental Impact Assessment Report. Lake Tanganyika Regional Fisheries Programme (TREFIP). African Development Bank. FAO/UN, Rome, Italy, 91 pp.

Reynolds, J.E., H. Mölsä & O.V. Lindqvist, 2002. A future fraught: precautionary, participatory, and regional outlooks for the fisheries of Lake Tanganyika. In: Geheb, K. & M-T. Sarch (eds.) Africa's Inland Fisheries. The Management Challenge. Fountain Publishers, Heinemann & Currey. pp. 107-141.

Richards, L. J. & J-J. Maquire, 1998. Recent international agreements and the precautionary approach: new directions for fisheries management science. Can. J. Fish. Aquat. Sci.55: 1545-1552.

Roest, F. & J. Salo, 1997. Mid-term Review. Research Project for the Management of the Fisheries in Lake Tanganyika. Ministry for Foreign Affairs of Finland, Helsinki, Blue series 7: 1-46.

Rosenberg, A. A., Fogarty, M. J., Sissenwine, M. P., Beddington, J. R. & J.B. Shepherd, 1993. Achieving sustainable use of renewable resources. Science (Washington, D.C.), 262: 828-829.

Rosenberg A., Bigford, T.E., Leathery, S., Hill, R.L. & K. Bickers, 2000. Ecosystem approaches to fishery management through essential fish habitat. Bulletin of Marine Science 66:535–543.

Roughgarden, J. & F. Smith, 1996. Why fisheries collapse and what to do about it. Proc. Natl. Acad. Sci. USA, Vol. 93: 5078-5083.

Sainsbury, K. J.,1988. The ecological basis of multispecies fisheries, and management of a demersal fishery in tropical Australia. In: Gulland, J. A. (Ed.), Fish population dynamics, (2nd ed.), Chapter 14, pp.349-82, John Wiley & Sons Ltd.

Sainsbury, K.J., Punt, A.E. & A.D.M. Smith, 2000. Design of operational management strategies for achieving fishery ecosystem objectives. – ICES Journal of Marine Science, 57: 731–741.

Sale P. F., Cowen, R.K., Danilowicz, B.S., Jones, G.P., Kritzer, J.P., Lindeman, K.C., Planes, S., Polunin, N.V.C., Russ, G.R., Sadovy, Y.J. & R.S. Steneck, 2005. Critical science gaps impede use of no-take fishery reserves. Trends in Ecology and Evolution 20 (2): 74-80.

Salonen K., Sarvala, J., Järvinen, M., Langenberg, V., Nuottajärvi, M., Vuorio, K. & D. Chitamwebwa, 1999. Phytoplankton in Lake Tanganyika – vertical and horizontal distribution of *in vivo* fluorescence. Hydrobiologia 407: 89-103.

Sanyanga, R., Machena, C. & N. Kautsky, 1995. Abundance and distribution of inshore fish in fished and protected areas in Lake Kariba, Zimbabwe. Hydrobiologia 306:67-78.

Sarch, M.-T. & E. H. Allison, 2000. Fluctuating fisheries in Africa's inland waters: well adapted livelihoods, maladapted management. *Proceedings of the*

conference "Microbehavior, Macroresutls ad Externalities: Conceptual Issues". July 9-14th 2000. Corvallis, Oregon: International Institute of Fisheries Economics and Trade (IIFET). http://oregonstate.edu/dept/IIFET/2000/papers/sarch.pdf

Sarvala J., Salonen, K., Järvinen, M., Aro E., Huttula, T., Kotilainen, P., Kurki, H., Langenberg, V., Mannini, P., Peltonen, A., Plisnier, P-D., Vuorinen, I., Mölsä, H. & O.V. Lindqvist, 1999. Trophic structure of Lake Tanganyika: Carbon flows in the pelagic food web. Hydrobiologia 407: 149-173.

Sarvala, J., Tarvainen, M., Salonen, K. & H. Mölsä, 2002. Pelagic food web as the basis of fisheries in Lake Tanganyika: a bioenergetic modeling analysis. Aquatic Ecosystem Health & Management 5: 283-292.

Sarvala, J., Badende, S., Chitamwebwa, D., Juvonen, P., Mwape, L., Mölsä, H., Mulimbwa, N., Salonen, K., Tarvainen, M. & K. Vuorio, 2003. Size-fractionated $\delta^{15}N$ and $\delta^{13}C$ isotope ratios elucidate the role of the microbial food web in the pelagial of Lake Tanganyika. Aquatic Ecosystem Health & Management 6: 241-250.

Sarvala, J., Langenberg, V.T., Salonen, K., Chitamwebwa, D., Coulter, G.W., Huttula, T., Kanyaru, R., Kotilainen, P., Makasa, L., Mulimbwa, N. & H. Mölsä, 2006 a. Fish catches from Lake Tanganyika mainly reflect changes in fishery practices, not climate. Verh. Internat. Verein. Limnol. 29: 1182-1188.

Sarvala, J., Langenberg, V.T., Salonen. K., Chitamwebwa, D., Coulter, G.W., Huttula , T., Kotilainen,P., Mulimbwa, N. & H. Mölsä, 2006 b. Changes in dissolved silica and transparency are not sufficient evidence for decreased primary productivity due to climate warming in Lake Tanganyika. Reply to comment by Verburg, Hecky and Kling. Verh. Internat. Verein. Limnol. 29: 2339-2342.

Schaefer, M., 1954. Some aspects of the dynamics of populations important to to the management of commercial marine fisheries. Bull. 1-ATTC/ Bol. CIAT, 1(2):27-56.

Schramm, H.L. & W.A. Hubert, 1996. Ecosystem management: implications for fisheries management. Fisheries 21(12): 6-11.

Sen, S. & J. Raakjær Nielsen, 1996. Fisheries co-management: a comparative analysis. Marine Policy 20: 410-418.

Stearns, S.C. 1976. Life history tactics: A review of the ideas. Quarterly Review of Biology 51: 3-47.

Stenuite, S., Pirlot, S., Hardy, M-A., Sarmento, H., Tarbe, A-L., Leporck, B. & J-P. Descy, 2007. Phytoplankton production and growth rate in Lake Tanganyika: evidence of a decline in primary productivity in recent decades. Freshwater Biology 52: 2226–2239.

Sturmbauer, C., 2008.The Great Lakes in East Africa – conservation biological considerations for species flocks. Hydrobiologia (SIAL meetings 2006, Special issue, in print)

Szczucka, J., 1998. Acoustic estimation of fish abundance and their spatial distributions in Lake Tanganyika. FAO/FINNIDA Research for the

Management of the Fisheries of Lake Tanganyika. GCP/RAF/271/FIN-TD/84 (En): 63 pp.

Thomson, D., 1980 Conflict within the fishing industry. ICLARM Newsletters 3(3): 3–4.

Townsend, R., Shotton, S. & H. Uchida, 2008. Case studies in fisheries self-governance. FAO Fisheries Technical Paper 504: 451 pp.

Tuomainen, V., Mölsä, H., Parkkinen, J. Patomäki, L. & O.V. Lindqvist, 1997. The NOAA Series' AVHRR Radiometer's capability of revealing water features in Lake Tanganyika. FAO/FINNIDA GCP/RAF/271/FIN/77 (En) 28 p.

Turner, G.F., Seisay, M.B.D. & N.P. van Zalinge, 1992. An evaluation of the Malawi Catch Assessment Survey of Traditional Fisheries. FAO tech. Rep.

Van der Knaap, M., Roest, F.C. & M. Munawar, 2007. Great Lake Victoria Fisheries: Changes, Sustainability, and Building Blocks for Management. Aquatic Ecosystem Health & Management 10: 481–483.

Van Zwieten, P.A.M., Roest, F.C., Machiels, M.A.M. & W.L.T. van Densen, 2002. Effects of inter-annual variability, seasonality and persistence on the perception of long-term trends in catch rates of the industrial pelagic purse-seine fishery of northern Lake Tanganyika (Burundi). Fisheries Research *54*: 329-348.

Verburg, P., Hecky, R.E. & H. Kling, 2003. Ecological consequences of a century of warming in Lake Tanganyika. Science 301: 505-507.

Verburg, P., Hecky, R.E. & H. Kling, 2006. Climate warming decreased primary productivity in Lake Tanganyika, inferred from accumulation of dissolved silica and increased transparency. Verh. Internat. Verein. Limnol. 29: 2335-2338.

Vuorinen, I., Kurki, H., Bosma, E., Kalangali, A., Mölsä, H. & O.V. Lindqvist , 1999. Vertical distribution and migration of pelagic Copepoda in Lake Tanganyika. Hydrobiologia 407: 115-121.

Walters, C.J., 1986. Adaptive Management of Renewable Resources. MacMillan, New York.

Walters C.J. & R. Hilborn, 1976. Adaptive control of fishing systems. Journal Fisheries Research Board of Canada 33: 145-159.

Walters, C., Christensen, V. & D. Pauly, 1997. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. Reviews in Fish Biology and Fisheries 7:139-172.

Walters, C.J., Pauly, D., Christensen, V. & J. Kitchell, 1999. Representing density dependent consequences of life history strategies in aquatic ecosystems: Ecosim II. Ecosystems 3: 70-83.

Weeks, H. & S. Berkeley, 2000. Uncertainty and precautionary management of marine fisheries: can the old methods fit the new mandates? Fisheries 25: 6-15.

Welcomme, R.L., 2001. Inland Fisheries. Ecology and Management. Fishing News Books, 358 pp.

West. K., 2001. Lake Tanganyika: Results and experiences of the UNDP/GEF Conservation Initiative. UNDP/GEF/RAF/92/G32, 138 p.

Wilson, D.C., 2002. Lake Victoria fisheries' attitudes towards management and co-management. In: Geheb, K. & M-T. Sarch (eds.) Africa's Inland Fisheries. The Management Challenge. Fountain Publishers, Heinemann & Currey. pp. 174-194.

Wilson, J. A., 2006. Matching social and ecological systems in complex ocean fisheries. Ecology and Society 11: 9. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art9/

Witte, F., Wanink, J.H. & M. Kishe-Machumu, 2007. Species distinction and the biodiversity crisis in Lake Victoria. Trans. Am. Fish. Soc. 136: 1146-1159.

Witting, L., 1999. Optimization of management procedures with control on uncertainty risk. ICES Journal of Marine Science 56: 876-883.

World Bank, 2008. Country profiles (Burundi, Democratic Republic of Congo, Tanzania, Zambia). Web page: http://www.worldbank.org/ (30.07.2008)

Kuopio University Publications C. Natural and Environmental Sciences

C 213. Georgiadis, Stefanos. State-Space Modeling and Bayesian Methods for Evoked Potential Estimation.
2007. 179 p. Acad. Diss.

C 214. Sierpowska, Joanna. Electrical and dielectric characterization of trabecular bone quality.
2007. 92 p. Acad. Diss.

C 215. Koivunen, Jari. Effects of conventional treatment, tertiary treatment and disinfection processes on hygienic and physico-chemical quality of municipal wastewaters.
2007. 80 p. Acad. Diss.

C 216. Lammentausta, Eveliina. Structural and mechanical characterization of articular cartilage and trabecular bone with quantitative NMR .
2007. 89 p. Acad. Diss.

C 217. Veijalainen, Anna-Maria. Sustainable organic waste management in tree-seedling production.
2007. 114 p. Acad. Diss.

C 218. Madetoja, Elina. Novel process line approach for model-based optimization in papermaking.
2007. 125 p. Acad. Diss.

C 219. Hyttinen, Marko. Formation of organic compounds and subsequent emissions from ventilation filters.
2007. 80 p. Acad. Diss.

C 220. Plumed-Ferrer, Carmen. Lactobacillus plantarum: from application to protein expression.
2007. 60 p. Acad. Diss.

C 221. Saavalainen, Katri. Evaluation of the mechanisms of gene regulation on the chromatin level at the example of human hyaluronan synthase 2 and cyclin C genes.
2007. 102 p. Acad. Diss.

C 222. Koponen, Hannu T. Production of nitrous oxide (N_2O) and nitric oxide (NO) in boreal agricultural soils at low temperature.
2007. 102 p. Acad. Diss.

C 223. Korkea-aho, Tiina. Epidermal papillomatosis in roach (Rutilus rutilus) as an indicator of environmental stressors.
2007. 53 p. Acad. Diss.

C 224. Räisänen, Jouni. Fourier transform infrared (FTIR) spectroscopy for monitoring of solvent emission rates from industrial processes.
2007. 75 p. Acad. Diss.

C 225. Nissinen, Anne. Towards ecological control of carrot psyllid (Trioza apicalis).
2008. 128 p. Acad. Diss.

C 226. Huttunen, Janne. Approximation and modellingerrors in nonstationary inverse problems.
2008. 56 p. Acad. Diss.

C 227. Freiwald, Vera. Does elevated ozone predispose northern deciduous tree species to abiotic and biotic stresses?
2008. 109 p. Acad. Diss.